Dear Editor,

Please find enclosed our response to the reviewer 1's comments regarding the manuscript entitled, "Morphological Response of Vegetated and Urbanized Barrier Islands to Hurricane Ian" for publication in Natural Hazards and Earth System Sciences (NHESS).

We appreciate the constructive comments on our manuscript. We will adopt most of their suggestions, but we also have identified some suggestions that we do not agree with. In those cases, we have tried to be very clear about why we differ from the reviewer's opinion and we have made an effort to clarify our writing and explanations. In the following paragraphs we detail our rebuttal (in blue) regarding the modifications we made to the manuscript to the reviewers' comments (in black).

General Comments from Reviewer #1:

Reviewer's Comment: This manuscript describes the morphologic responses of two barrier islands to the extreme conditions produced by Hurricane Ian. This manuscript uses a combination of multiple scenarios that incorporate different landcover classifications to determine which of the modeled scenarios most accurately replicates the observed morphological responses.The manuscript makes a couple of important points. First, spatially variable bed roughness elements are important to include to best simulate the morphodynamic response of barrier islands during large storm events. Second, increased secondary vegetation densities can reduce erosion along dune environments.However, this manuscript is limited in that it focuses only on dune response, instead of incorporating multiple morphological responses (i.e., changes in shoreline position, beach volume, beach slope, barrier-island interior volume, etc.) within the analyses. This study would benefit by incorporating more details about the total morphologic changes, instead of only focusing on impacts to dune crest height and dune crest cross-shore position.

Authors' Response: We thank the reviewer for their positive assessment of the manuscript. We agree that incorporating additional morphological metrics (e.g., shoreline position, beach volume, and beach slope) would provide a more complete assessment of storm-driven coastal change. However, shoreline-position analysis was not included because XBeach is not specifically designed or commonly used for robust shoreline change analysis. Following the reviewer's suggestion provided later in the specific comments, we will revise the section headings to explicitly reflect a focus on dune responses rather than expanding the scope of the manuscript. Accordingly, Section 4.1 will be renamed to Storm-Induced Dune Morphodynamics at Lovers Key, and Section 4.2 will be renamed to Storm-Induced Dune Morphodynamics at Fort Myers Beach.

Reviewer's Comment: Additionally, this manuscript fails to contextualize the results within the body of existing literature in the discussion. The discussion section could benefit by adding two different sections:

1. How the modeled results presented in this manuscript compare to existing interpretations of the morphologic responses of Lovers Key and Fort Myers Beach resulting from Hurricane Ian (e.g., Wang et al., 2024; McCormick et al., 2025; Hauptman et al., 2024).

2. How the modeled results presented in this manuscript compare to the existing body of literature that modeled the morphological responses of previous large storm events that have impacted developed barrier islands such as Hurricanes Michael and Sandy (e.g., Ma et al., 2024; Smallegan et al., 2016)

Authors' Response: We agree with the reviewer that the Discussion section benefits from contextualization within existing literature. In response, we will revise the Discussion section to explicitly include the comparison of the modelled dune responses presented in this manuscript with published field-based interpretations of Hurricane Ian impacts at Lovers Key and Fort Myers Beach (e.g., Wang et al., 2024; McCormick et al., 2025; Hauptman et al., 2024), focusing on similarities and differences in dune erosion patterns and spatial variability and results within the broader context of previous XBeach-based modeling studies of large storm events impacting barrier islands, including Hurricanes Michael and Sandy (e.g., Ma et al., 2024; Smallegan et al., 2016), which is presented below.

Proposed New Text: The modelled morphologic responses presented here indicate that dune crest lowering and landward crest migration were dominant responses at Lovers Key, with spatial variability influenced by vegetation cover, consistent with post-storm LiDAR-based interpretations of widespread beach–dune erosion under an inundation-dominated regime during Ian (Wang et al., 2024).At Fort Myers Beach, the modeled response exhibits pronounced alongshore variability that corresponds to the built environment, in agreement with observations from developed Estero Island showing spatially heterogeneous erosion and overwash, with landward sediment transport pathways enhanced along roads and between anthropogenic structures (McCormick et al., 2025). While these observational studies quantify measured post-storm change, the present framework reproduces the primary spatial patterns of dune response, supporting an inundation-dominated interpretation of storm impacts. XBeach simulations of Hurricane Sandy at Bay Head, New Jersey, further demonstrate that hard structures (a buried seawall) can materially alter modeled dune erosion and island response relative to an unarmored case (Smallegan et al., 2016), providing a relevant analogue for interpreting how development can modulate storm-driven morphodynamics.

In contrast, the study by Ma et al. (2024) is useful primarily for methodological context (e.g., motivation for using non-hydrostatic XBeach for storm conditions such as Hurricane Michael) rather than as a direct analogue to our land-cover/structure-focused analysis, as its emphasis is on hydrodynamic representation and broader model capability rather than isolating the role of urban roughness elements or engineered features in controlling alongshore variability; therefore, it has not been included in our detailed discussion. Similarly, Hauptman et al. (2024) provides valuable post-storm, remote-sensing–based documentation of elevation-change patterns and damage hotspots on Estero Island, but it is not included as a primary model–data comparison framework here because its analysis focuses on event-scale damage assessment rather than process-based morphodynamic metrics.

Specific Comments from Reviewer #1:

Authors' Response:

For the specific comments (*), each has been addressed by first restating the reviewer's comment, followed by the original text from the manuscript and the corresponding revised text, as presented below.

[40-45] * – There is a lot of information on global mean sea level, which is not carried through the rest of the manuscript. I would suggest either limiting the amount of info about sea level, or carry it throughout the rest of the manuscript.

Existing Text [40-45]: Barrier islands are becoming increasingly vulnerable not only as human occupation intensifies, but also as extreme events become more frequent and sea level rise accelerates (IPCC, 2018; Jiménez et al., 2011). During the latter half of the 20th century, global mean sea level rose at about 2.5 mm/year and in recent decades has accelerated to about 3.9 mm/year (Brooks et al., 2017; IPCC, 2021). Projections for the coming decades indicate that even modest increases in sea level will amplify storm impacts, leading to extensive inundation and substantial morphological alterations of low-lying coastal landscapes and sandy barrier systems (FitzGerald et al., 2008; Tebaldi et al., 2012).

Proposed Revised Text: Barrier islands are becoming increasingly vulnerable as human occupation intensifies and extreme storm events become more frequent (IPCC, 2018; Jiménez et al., 2011). This vulnerability is further exacerbated by sea-level rise, as even modest increases in mean sea level are projected to amplify storm impacts (FitzGerald et al., 2008; Tebaldi et al., 2012).

[70–71] * – There should be more information about measured (or modeled) conditions produced by Hurricane Ian, including storm track, duration, wind speeds, water levels, etc. These conditions are published and available through Bucci et al. (2022) but should be included to provide context for the storm.

Existing Text [70–71]: Hurricane Ian originated from a tropical wave that emerged off the west coast of Africa. It intensified over the Gulf of Mexico and made landfall as Category 4 in Lee County, Florida on 28 September 2022.

Proposed Revised Text: Hurricane Ian originated from a tropical wave that emerged off the west coast of Africa. It intensified over the Gulf of Mexico and made landfall as Category 4 in Lee County, Florida on 28 September 2022. The storm followed a northward track across southwest Florida produced prolonged extreme forcing, with maximum sustained winds of ~65–70 m s^{-1}, minimum central pressure of ~941 mb, and storm surge exceeding 3–4 m above mean sea level, resulting in widespread inundation of barrier islands including Fort Myers Beach and Lovers Key (Bucci et al., 2022)

[80–99]* – There are a lot of different data sources that were used for the "observed changes" resulting from Hurricane Ian. These datasets are presented here but there are no specific details or information about the spatial uncertainties (both horizontal and vertical) of the different datasets, and the specific methodologies used to collect those data. For example, the authors discuss "LiDAR surveys" accessed by NOAA's Digital Coast and different LiDAR surveys provided by Florida Gulf Coast University. Were these surveys collected using the same methods? Do they have the same uncertainties? Clarification and increased specificity for each of the datasets is needed here. Additionally, CEC transects extend up to 1km into the nearshore, were those collected by a total station, as noted in the manuscript, or was it done using bathymetric surveying (i.e., single beam sonar)?

Authors' Response: We thank the reviewer for highlighting the need for greater clarity regarding the data sources; this information will be added to Section 2, Study Area and Data Availability.

Proposed New Text: The Hurricane Ian topo-bathymetric LiDAR datasets from NOAA's Digital Coast were collected using airborne LiDAR systems under standardized USACE–NOAA protocols, have 1 m horizontal resolution, are referenced to NAVD88, and report a vertical accuracy of ~19.6 cm (95% confidence) for topographic data, with depth-dependent accuracy for bathymetric returns (OCM Partners, 2025a,b). The CEC transects were surveyed using RTK GPS across the subaerial beach and into the surf zone (to approximately −4 m NAVD88), with deeper nearshore bathymetry collected using single-beam sonar and ~6 m overlap between RTK GPS and sonar measurements to ensure continuity (M. Poff, CEC, pers. comm.). The FGCU post-storm LiDAR data were collected using a UAV-mounted Velodyne HDL-32 sensor flown at ~50 m altitude with ~60 m swath width and ~20 m overlap between adjacent flight lines; vertical accuracy assessments indicate ~5 cm accuracy, and the dataset is referenced to NAVD88 (C. Daly, FGCU, pers. comm.; see also Bhatta et al., 2023).

[116] * – The continuously updated digital elevation model that is cited through the NOAA (2018) reference is a 1/9 arc second DEM, which has a 3m pixel resolution.

Existing Text [116] - The bathymetry was generated by combining the NOAA Pre-Ian DEM, which extends to depths of up to 7 meters, with the 1-meter-resolution Continuously Updated Digital Elevation Model (CUDEM) dataset (NOAA, 2018) to provide coverage of deeper waters.

Proposed Revised Text: The bathymetry was generated by combining the NOAA Pre-Ian DEM, which extends to depths of up to 7 meters, with the 3-meters-resolution Continuously Updated Digital Elevation Model (CUDEM) dataset (NOAA, 2018) to provide coverage of deeper waters.

[121] * – How do the modeled wave and water levels compare to the measured total water levels during Hurricane Ian on Fort Myers Beach and Lovers Key? I think this should be addressed to validate the modeled water levels during the storm. These are accessible through the USGS Flood Event Viewer (https://apps.usgs.gov/fev/event/2022-ian)

Authors' Response: We thank the reviewer for this important suggestion. We agree that validation of the modelled hydrodynamic conditions against measured total water levels strengthens the study. Accordingly, we will include a comparison between modelled and observed water levels obtained from the USGS Flood Event Viewer in the revised manuscript to demonstrate the consistency of the hydrodynamic forcing during Hurricane Ian.

[150–152] * – Can the authors speculate as to why there were differences in the land cover classifications? Was it the result of differences in cell size or a different reason?

Existing text [150–152]: For Lovers Key, several patches of primary vegetation along the back-barrier and foredune zones are classified as secondary vegetation in Scenario 3, highlighting differences in vegetation classification between the two datasets.

Proposed Revised Text: For Lovers Key, several patches of primary vegetation along the back-barrier and foredune zones are classified as secondary vegetation in Scenario 3, highlighting differences between the two land-cover datasets. These differences are related to variations in source data resolution, classification methodology, and preprocessing approaches, rather than representing actual changes in vegetation condition.

[167–170] * – How did the authors differentiate beach berm crests from primary dune crests in Equation 3 at locations where beach berms (or berm ridges associated with ridge and runnel morphologies) existed following the storm?

Existing [167–170]: For Lovers Key, the change in dune crest elevation was evaluated by plotting transects perpendicular to the coastline, extending approximately 200 meters inland to intersect the primary dune. The dune crest is defined as the first maximum elevation along each transect (Equation 3), and crest shift is defined as the horizontal displacement of the dune crest relative to its initial position, as predicted or observed (Equation 4): $zcrest = max(zb\ (x,y))$

Proposed Revised Text: For Lovers Key, changes in dune crest elevation were evaluated using shore-normal transects extending approximately 200 m landward from the shoreline, a distance selected to ensure intersection with the primary dune. Along each transect, the dune crest was defined as the maximum elevation associated with the primary dune, thereby excluding lower-elevation berm crests that may exist seaward before or following the storm (Equation 3). The dune crest location was identified along each transect, and post-storm crest elevation was evaluated at the same location. Crest shift was defined as the horizontal displacement of this primary dune crest relative to its pre-storm position (Equation 4).

[175–225]* – This whole section does a nice job of comparing the modeled outputs to the observed changes but only considers dune crest height and dune position as "morphological responses". With many other morphologic responses (including changes in shoreline position, beach volume, beach slope, barrier-island interior volumes, etc.) excluded from this section (and excluded from the entire manuscript), this section should either be renamed to be focused only on dune responses, or expand it significantly to encapsulate more of the morphologic responses resulting from Hurricane Ian.

Authors' Response: We agree with the reviewer that this section focuses specifically on dune-related metrics. We have revised the section headings to emphasize dune morphodynamics rather than implying a broader assessment of coastal morphology. Accordingly, Section 4.1 will be renamed to Storm-Induced Dune Morphodynamics at Lovers Key (instead of Morphological Response of Lovers Key), and Section 4.2 will be similarly revised for Fort Myers Beach.

[Figure 6] *– Why are the observed Pre- and Post-storm profiles labeled as NOAA+CEC? I thought those were two different datasets, with varying spatial scales and data collection methods (i.e., one is LiDAR and one is a total station survey)?

Authors' Response: We will clarify this in the text as follows: The profiles are labeled as NOAA+CEC because the two datasets were merged to construct continuous cross-shore profiles extending from the subaerial beach and dune into deeper nearshore waters. NOAA LiDAR provides high-resolution coverage of the subaerial and shallow nearshore regions but does not reliably capture deeper bathymetry, whereas the CEC surveys extend offshore beyond the LiDAR coverage. Both datasets are referenced to NAVD88 and were spatially aligned prior to merging, resulting in a continuous profile with consistent vertical referencing. We will clarify this in the text.

[230–275]* – See above comment ([175–225]) about morphological responses. Additionally, there is no section here about lateral or vertical changes in dune crest. Was this section excluded due to a lack of prominent primary dunes on Fort Myers Beach, or a different reason? A short explanation for why this was excluded from the Fort Myers Beach section should be included.

Authors' Response: Section 4.2 will be revised to Storm-Induced Dune Morphodynamics at Fort Myers Beach to reflect the dune-focused scope of the analysis. Yes, dune crest changes were not evaluated at Fort Myers Beach due to the absence of well-defined, continuous primary dunes and the strong influence of urban development, which makes consistent crest identification difficult.

[261–263] * – The observed deposition within the nearshore was a trend found in other field-based studies on Hurricane Ian (cited in the general comments section and next comment). Could you provide hypotheses as to why this is not seen in the modeled output of this study?

Existing [261–263]: In Transect 13 (Fig. 8a), the post-storm profile shows offshore sand accumulation between x = 400–600 m, which is not captured in any of the modelled scenarios.

Authors' Response: We will clarify this in the text as follows: The absence of this offshore accumulation in the modeled results is likely related to localized alongshore gradients in sediment redistribution that may not be fully captured by the cross-shore transects. Additionally, the parameterization of XBeach during storm events can favor onshore-directed sediment transport when wave skewness- and asymmetry-driven processes dominate, which may limit the representation of offshore deposition. These factors could contribute to the differences between the observed and simulated nearshore sediment accumulation.

[278–282]* – How do your results fit into the bigger context of the growing body of literature already published on Hurricane Ian, as well as the modeled results from other previous large storm events from around the US and the World? The sensitivity analyses should still be a part of the discussion section, but the authors do not address how their work fits into the existing body of literature. For example, the authors could compare the modeled water levels from Hurricane Ian to the findings of McCann et al. (2024) and the modeled morphologic changes to the results of McCormick et al. (2025), Hauptman et al. (2024), and Wang et al. (2024). Additionally, the authors could provide more context for how their approach to incorporating variable bed roughness values for vegetation and built environments could have improved the results of previous studies that focused on other large storm events that impacted developed islands, such as Hurricane Michael or Sandy.

Authors' Response: We thank the reviewer for this valuable suggestion. In response, we will revise the Discussion section to compare our modeled morphodynamic results with published studies, as presented above in the general comments section

[294–303] * – Are these examples of available datasets collected frequently enough, or at a fine enough resolution, to be useful for coastal managers?

Existing text[294–303]: The modelling approach applied in this study for South-West Florida is transferable to barrier-island locations worldwide. This study has shown that the critical input and forcing data required to obtain meaningful results are high-resolution topo bathymetric data, land-use land-cover (LULC) data, and water levels. The availability of these input data may vary. Other U.S. locations can use the same NOAA sources of input and forcing data sets used here. For other locations, the availability and quality of the input and forcing data may vary, although it is improving. Data for European locations are available through Copernicus databases such as the Copernicus DEM (GLO-30, GLO-90 and EU-DEM) (ESA, 2025) and products such as DeltaDTM (Pronk et al., 2024) which provide high-resolution topographic and bathymetric data. In addition, global bare-earth elevation data can be obtained from FABDEM, global bare-earth DEM derived from Copernicus GLO-30 (Meadows et al., 2024).

Authors' Response: We will clarify this in the text as follows: These datasets generally provide sufficient spatial resolution for storm-impact assessment and scenario-based modeling, which are commonly used by coastal managers. However, their update frequency varies by region and dataset, and they may not be collected frequently enough to support continuous monitoring or rapid-response management applications in all locations.

[303–305] * – This claim seems to be a bit of a stretch for the scope of this manuscript. Also, "vegetation restoration" is a little ambiguous and could use some clarification.

Existing text [303–305] With these inputs and the approach presented here, coastal managers can assess coastal hazards related to erosion and flooding under current conditions on urbanized and natural barrier islands and evaluate mitigation measures such as vegetation restoration. The sensitivity study may also provide guidance on the interpretation of results in cases where the input and forcing data are of lower than desired quality.

Proposed Revised Text: With these inputs and modelling approach presented here, coastal managers can assess storm-driven erosion and flooding hazards on urbanized and natural barrier islands under current conditions. The framework may also be used to explore the relative influence of land-cover characteristics, such as the presence or absence of vegetated dune areas, on modelled morphologic response. The sensitivity study may also provide guidance on the interpretation of results in cases where the input and forcing data are of lower than desired quality.

[308–309] *– This statement is not well supported in this context. This paper shows that the XBeach model can "reasonably" approximate the results of the inundation regime during

Hurricane Ian and does not provide citations to support that the model can accurately approximate the three other regimes. Please provide citations of other studies that have successfully replicated the three other impact regimes.

Existing text [308–309] The results of this study add to the evidence base showing that it is now possible to predict morphological changes across all Sallenger (2000) regimes with a single numerical model. For instance, Van der Lugt et al. (2019) showed good skill for cases of barrier-island breaching on Fire Island (New York, USA) and Matanzas Inlet (Florida, USA) but also highlighted that variations in boundary water levels and wave characteristics influenced breach formation and dune response.

Proposed Revised Text: The results of this study add to the evidence base showing that it is now possible to predict morphological changes across all Sallenger (2000) regimes with a single numerical model. In this paper we show that the model can reasonably approximate the behavior in the Inundation Regime, while Van der Lugt et al. (2019) showed skill in simulating collision- and overwash-dominated responses, including cases of barrier-island breaching such as those documented for Fire Island (New York, USA) and Matanzas Inlet (Florida, USA), but also highlighted that variations in boundary water levels and wave characteristics influenced breach formation and dune response.

[320–334] – This section would be better suited in the results section, as it is presenting new results relating to a different land cover scenario. The results of this then could be elaborated on within the discussion and include appropriate references that corroborate the results.

Authors' Response: Yes, we will move that section to results.

Technical Corrections:

[75] – "Lovers Key State Park comprises…"

This will be changed as suggested.

[141] – Incorrect citation; should be "Salgano (2023)"

This will be changed as suggested.

[Figure 3] – Need scale bars and North arrows on both sets of maps with different spatial extents and different rotations; maps of Fort Myers Beach are too small to determine the differences in land cover classification

Figure 3 will be updated as suggested.

[194–195] – Elevations should include the vertical datum (NAVD88?)

All elevations reported in the manuscript and figures are referenced to NAVD88, as indicated on the y-axes of the relevant figures. To avoid unnecessary repetition, the vertical datum is not restated for every elevation value mentioned in the text.

[203] – What do you mean by “waning flows”? Decreased flow velocities or ebbing flows, or both?

This will be revised as “ebbing flows”.

[Figure 5] – Dashed lines and shading are difficult to distinguish in greyscale, you may want to consider making these colored lines (in addition to the different dash types) to make them more distinguishable; may want to put orientation indicator to show which direction is North/South along the x-axis to orient reader.

The figure originally used colored lines; however, these were revised to greyscale following recommendations from the editorial support team to ensure accessibility for readers with color-vision deficiencies, based on guidance from the Coblis – Color Blindness Simulator.

[212–213] – Elevations should include the vertical datum (NAVD88?)

All elevations reported in the manuscript and figures are referenced to NAVD88, as indicated on the y-axes of the relevant figures. To avoid unnecessary repetition, the vertical datum is not restated for every elevation value mentioned in the text.

[230] – “Hurricane Ian”

This will be changed as suggested.

[241–244] – “A noticeable effect…”: This sentence is awkwardly worded and redundant, and should be revised.

Existing: A noticeable effect of urbanization was the formation of overwash with reduced deposition immediately landward of buildings or roads and the accumulation of sand on their seaward side, with urbanized areas also experiencing overwash deposits and local scouring, highlighting how built environment influences flow and sediment deposition (Hapke et al., 2015; Houser et al., 2008).

Proposed Revised Text: Urbanization influenced overwash patterns by limiting landward sediment deposition behind buildings and roads while promoting sand accumulation on their seaward sides; urbanized areas also exhibited localized overwash deposits and scouring, reflecting the role of built structures in modifying flow pathways and sediment redistribution (Hapke et al., 2015; Houser et al., 2008).

[259] – “4.2.1 Model Versus…”

This will be changed as suggested.

[324] – Elevations should include the vertical datum (NAVD88?)

All elevations reported in the manuscript and figures are referenced to NAVD88, as indicated on the y-axes of the relevant figures. To avoid unnecessary repetition, the vertical datum is not restated for every elevation value mentioned in the text.

[350–353] – "Three model scenarios… Scenario 2 is based on…": Need to reword these two sentences as there are typos and could be combined into one sentence.

Existing: Three model scenarios were developed: In Scenario 1, the baseline sandy-bed case, in which vegetation and built environments are not taken into account. Scenario 2 is based on NOPP Land Use and Land Cover (LULC) data, and Scenario 3 uses NOAA LULC data; both incorporate vegetation and built environments.

Proposed Revised Text: Three model scenarios were developed: Scenario 1 represents a baseline sandy-bed case that does not account for vegetation or the built environment, while Scenarios 2 and 3 incorporate vegetation and built environments using NOPP and NOAA land use landcover (LULC) datasets, respectively.

[364] – "(waves and surge)"

This will be changed as suggested.

References:

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