HOW RELEVANT ARE UNCERTAINTIES IN GLOBAL MODELS FOR ASSESSING STORM EROSION ON BARRIER ISLANDS?

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INTRODUCTION

Coastal storms can promote damaging impacts on barrier islands, induced by coastal flooding and beach erosion (Leaman et al., 2021). Process-based morphodynamic models, implemented with high-resolution topo-bathymetric and oceanographic data, enable the assessment of these coastal hazards at regional and local scales and the development of early warning systems. The advent of global models to characterise wave forcing (global wave reanalyses) and topo-bathymetry (global digital elevation models, DEM) allows the quantification of storm impacts to be extended to larger scales and data-poor areas. However, the uncertainties and limitations associated with the use of input conditions from low-resolution global models must be comprehensively addressed, as they can lead to errors in the subsequent model outputs. This work explores the uncertainties in global models and in the resulting quantification of storm impacts.

METHODS

To investigate the uncertainties in storm induced erosion as a function of the variability of existing global models, a 50-year return period storm was simulated using XBeach, with varying conditions reflecting the uncertainty of global topo-bathymetric DEMs and global wave reanalysis models. The results from the application of global models were compared with a baseline output derived from a simulation performed with high-resolution morphological and oceanographic data (Figure 1). Following Fanti et al. (2023a), the topo-bathymetric profile of the barrier island was obtained by merging the TanDEM-X global DEM (12 m resolution) and the ETOPO 2022 global bathymetry. Cross-shore profiles were extracted in a morphologically homogeneous sector of the barrier island, aligned at the dune top and averaged to obtain a synthetic profile representative of the area. Due to data gaps and the inaccuracy of space-borne global datasets in the shallow coastal areas, the Dean equilibrium profile (Dean 1991) was adopted to merge the barrier topography with the nearshore bathymetry, from the mean sea level to the depth of closure. The global DEM profile was compared with a profile derived from high-resolution LiDAR. The hydrodynamic forcing (significant wave height, peak wave period and wave direction) obtained from 26 years of WAVERYS global wave reanalysis data (22 km resolution), was calibrated with a global equation to improve the representation of extreme wave conditions (Fanti et al., 2023b). The tide and surge were extracted from the Global Tide and Surge Model (GTSM 2.5 km resolution). A synthetic storm shape was derived by averaging storm events with >2-year return period wave height, centred on the peak and scaled to obtain the 50-year return period wave height. To simulate the sediment transport and barrier island erosion induced by the synthetic storm, XBeach was used in 1D hydrostatic mode (surfbeat) and coupled to SWAN at 30 m depth for propagating the offshore wave forcing. The methodology was tested on a natural sector of the Outer Banks barrier island system in the USA. The baseline barrier profile was derived from the USACE 2019 LiDAR-derived DEM (1 m resolution) and the CUDEM regional bathymetric model (3 m resolution). The storm hydrodynamic data were obtained from NOAA's Virginia wave buoy and the Duck tide gauge. To quantify the uncertainty in the post-storm morphodynamic response of the barrier island, the variability in global models was considered through the incorporation of error ranges associated with the topo-bathymetric profile (±0.56 m, Root Mean Square Error derived from the comparison with the high-resolution topo-bathymetric profile), and with the 50-year return period wave height (±0.71 m, 50% confidence interval). Nine XBeach runs were performed with a combination of hydrodynamic inputs and topo-bathymetric profiles with associated uncertainties (Figure 1). The results were compared to the high-resolution baseline scenario run implemented with the LiDAR-derived synthetic profile and hydrodynamic input from the local buoy and tide gauge data. The eroded volume, horizontal beach and dune face retreat and the storm impact regime (Sallenger 2000) were evaluated.

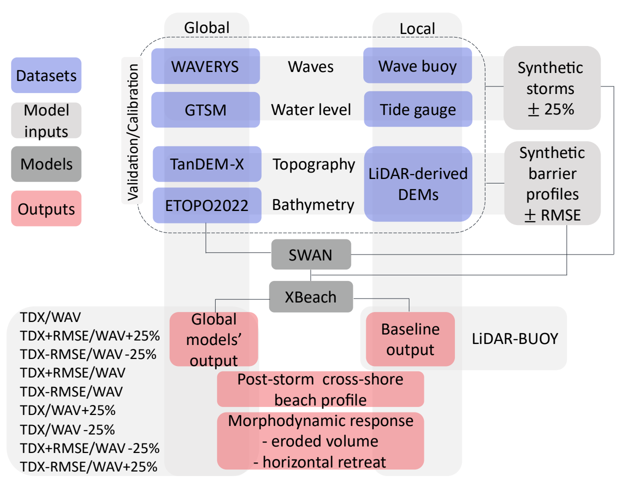

Figure 1 - Data sources used and modelling workflow

RESULTS AND DISCUSSION

The input conditions derived from the global models present relevant differences in relation to those derived from the local high-resolution datasets for the baseline run. In terms of hydrodynamics, the global models underestimate the storm forcing, leading to lower total water levels during the storm (Figure 2). For the morphology, the bathymetry was overestimated (bias of 1.17 m), while the dune top was underestimated by 1.87 m. As a result, while the erosional response in terms of post-storm horizontal retreat was properly captured for the lower dune face (below 3 m, Figure 3), it was underestimated for the upper dune face (above 3 m), and none of the global models runs reproduced the landward retreat of the dune crest simulated in the baseline scenario. However, the retreat between 1.5 m and 3 m averaged across the global model runs was 16.3 m, comparing very well with an average retreat of 16.2 m in the baseline run. The dune was impacted during high water levels in all simulations, and the average storm impact regime ranged from swash (dune not impacted) during 68% of the storm duration to collision during 32%, in perfect agreement with the baseline run. The subaerial eroded volume was underestimated in the global runs, differing on average by 55% from the baseline simulation, with the TDX-RMSE and WAV+25% combination yielding the best result (76.9 m^3/m compared to 98.9 m^3/m for the baseline run). When considering the sources of uncertainty, topo-bathymetric accuracy dominated the variability of the erosional response compared to the uncertainty in the total water level (Figure 3). This is partly because WAVERYS was previously calibrated, but mainly due to the coarse resolution of openly available global DEMs, which prevents the accurate representation of the beach morphology, particularly the dune crest height and local bathymetric features. Despite these uncertainties, the storm regime was well captured in all global model runs, and the total maximum water level exceeded the dune toe elevation (collision regime), resulting in dune retreat and erosion. Identification of the coastal erosion and flooding hazard category is a key aspect in early warning systems (Leaman et al., 2021; Stockdon et al., 2023), meaning that despite the level of uncertainty associated with global models, they can still be useful as a baseline for global-scale assessments of storm impacts.

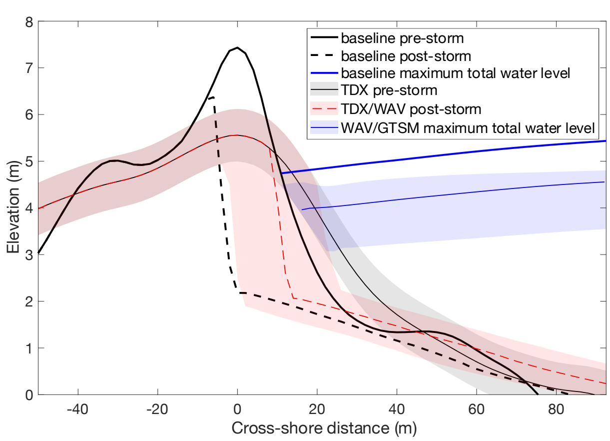

Figure 2 – Pre (continuous lines) and post (dotted lines) storm profiles simulated with XBeach. The uncertainty bounds are reported for the global models

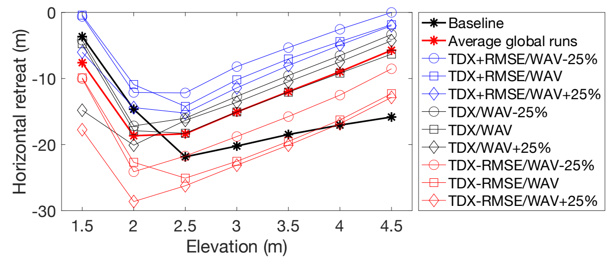

Figure 3 – Horizontal retreat (difference between pre-storm profile and post-storm profile) from baseline run, average of global model runs and varying boundary conditions from global models. Colours are associated with the topo-bathymetric input, symbols with the wave input

CONCLUSION

The quantification of uncertainties in global models and their impact on the erosional response was performed with encouraging results for the case study of the Outer Banks. Despite the intrinsic uncertainties, all global model combinations were able to reproduce the storm impact regimes compared to the baseline run, as well as the horizontal retreat of the dune, with some underestimation at the dune crest. Extending the methodology to a wider range of barrier islands and storm scenarios will better constrain the potential and range of applicability of global models to quantify the impacts of coastal storms. This can help to identify areas at risk and implement adaptation strategies in many areas of the global coast where accurate high-resolution data are lacking.

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