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Storm Impact Assessment for Scotland's Wave-Dominated Sedimentary Coasts

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Abstract. Along wave-dominated sedimentary coasts, risks posed by chronic coastal erosion and rising sea levels during this century have received much attention. However, extreme wave runup during large storms are still poorly characterised at large spatial scales, and can contribute significantly to coastal flooding and erosion. This creates an important challenge for coastal management and adaptation planning. This work presents a national-scale storm impact assessment for Scotland's wave-dominated sand and gravel coasts. It uses readily available national and European datasets to model extreme total water levels that include storm wave runup, tides, storm surge and changes in mean sea level. Future impacts are assessed by integrating likely climate-driven changes to storm forcing and coastal morphology. Outputs estimate the likely storm impact regime at 50 m alongshore transects in Scotland's natural sand and gravel coasts for the present day, 2050 and 2100, considering climate change scenarios RCP4.5 and RCP8.5. Results indicate 65%, 11% and 4% of transects currently experience collision, overwash and inundation as the most severe storm impact. Towards 2100, transects in overwash and inundation increase to 20% (22%) for RCP4.5 (RCP8.5), but local increases vary considerably between coastal cells. This study contributes to a strategic, national scale understanding of coastal risk that supports the spatial prioritisation of areas in need of proactive adaptation solutions.

Keywords: Coastal Adaptation · Flooding · Erosion · Wave Runup

1 Introduction

Coastal zones are dynamic interfaces between the sea and land, and are exposed to hazards that include coastal erosion and flooding due to extreme water levels from tides, storm surge and waves. Despite these risks, coasts are economically and socially

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important and globally an estimated 898 million people currently live in the low-elevation coastal zone, with numbers projected to increase this century under all shared socio-economic pathways [1].

To assess the potential risk to coastal communities, significant effort has been made to characterise coastal change [2] and extreme water levels [e.g. 3] and how it may evolve this century. These studies model extreme water levels at the global scale as the combined effect of tides, storm surge and wave setup, but exclude wave-induced swash. This omission is necessary due to the absence of detailed topographic data, specifically beach slope, which is not available at sufficient resolution in global datasets. In Scotland, wave contributions to extreme water levels are considered for limited sections of the coastline, but whole coast assessments currently only include sea level rise (SLR), tide and storm surge contributions [4]. At the national scale, there is thus a lack of understanding of storm-induced wave runup, which can make a significant contribution to total water levels along exposed coasts and drive substantial morphological changes to the beaches and dunes [5]. This leaves a critical gap in the current understanding of storm-driven coastal risk, which hampers adaptation planning, especially along non-urban coasts, where coastal communities and infrastructure are often located directly behind sand or shingle barriers that act as the first line of defense during storms.

This work presents a national-scale storm impact assessment for Scotland's wave-dominated sand and gravel coasts. By modelling extreme total water levels that include storm wave runup, the objectives are to understand a) where natural sand and shingle barriers are vulnerable (resilient) to present-day storm impacts, b) where coastal assets behind natural barriers are most at risk of storm-driven flooding, and c) how these risks may change towards 2050 and 2100. This improved understanding of coastal storm impacts and the role of natural barriers in coastal protection can then highlight areas where proactive adaptation planning should be prioritised.

2 Study Area and Methods

Scotland's coastline is highly complex and varied, with a heavily indented configuration on the Atlantic coast versus more linear stretches on the North Sea coast. Sediment ranges from fine sand to cobbles, with sandy barrier systems, mixed and composite sand-gravel beaches, and pure gravel beaches. Storm exposure also varies significantly, as the west coast and islands face extreme Atlantic storm systems, while adjacent coastlines on the Irish Sea are more sheltered. The wave climate on the east coast of Scotland tends to be less extreme than in the west, but extratropical cyclones over the North Sea can cause extreme storm surges and coastal flooding when coincident with high tides.

The storm impact assessment was performed for the entire coast of Scotland and included open coastlines with sand or gravel barriers, where wave action (as opposed to tidal inundation) is the predominant hydrodynamic driver of beach morphology. Sedimentary accumulations on rocky and highly engineered coasts were excluded from the assessment, as runup on these beaches fall outside the scope of the models used.

To provide a conceptual understanding of potential storm impacts at the national scale, the storm impact scale framework of Sallenger [6] was used to identify the storm impact regimes of swash, collision, overwash or inundation. The assessment was implemented within a geospatial framework, where each stretch of coastline was populated with shore-normal transects, spaced 50 m apart. Along each transect, the local topography profile was extracted, extreme total water levels were computed, and compared with the toe and crest elevations of the most seaward coastal barrier to estimate the transect's storm regime (Fig. 1). The study comprised of 12,798 transects, equivalent to 640 km (~3.6%) of Scotland's coastline.

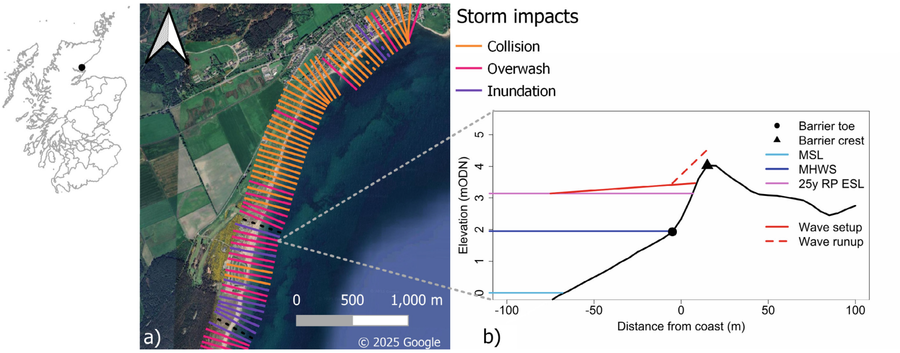

Fig. 1. a) Present day storm regimes for Golspie, Highland b) Transect beach-barrier morphology and water levels, predicting overwash. Map produced in QGIS 3.26 (www.qgis.org). Map data: Google © 2025. Administrative boundaries (level 3) from the GADM database (gadm.org, v3.6).

Extreme total water levels (TWL) were computed as the sum of extreme still water levels (ESL) and extreme wave runup, and this was done for the present day and climate scenarios RCP4.5 and RCP8.5 in 2050 and 2100. ESL comprised of tides and storm surge, uplifted by 95th percentile projected SLR (Table 1). To build a synthetic storm, the 25-year return period ESL was chosen to represent a large but likely storm. For storm wave conditions, the 99th percentile deepwater significant wave height and peak period were used. Using wave and beach slope data, the 2% exceedance of extreme wave runup ($R_{2\%}$) on sandy, composite and mixed sand/gravel beaches was modelled with the empirical parameterisation of Stockdon et al. [7], while $R_{2\%}$ on pure gravel beaches was modelled with a gravel-specific parameterisation by Poate et al. [8].

To assess potential storm impacts for mid- and end of century, future extreme TWL were compared with future barrier morphology, adjusted for SLR with a conceptual model that used historic coastal change as a first-order indicator of sediment budget.

Table 1. Primary data sources for storm impact assessment.

Data	Description	Source
Extreme still water levels	25-year return levels of tide and storm surge, base year 2017	Met Office Hadley Centre
Mean sea level	95th percentile SLR for RCP4.5 and RCP8.5 in 2020, 2050 and 2100	Met Office Hadley Centre
Wave climate	99th percentile H_s and T_p for the present day, mid-century and end-century	Copernicus Climate Change Service
Elevation	National digital terrain model, 5 m resolution	Ordnance Survey
Assets	Roads, railway lines and property	Ordnance Survey

3 Results and Discussion

Along Scotland's wave-dominated sedimentary coasts, 65%, 11% and 4% of coastal transects are modelled to experience collision, overwash and inundation as the most severe present-day impact regime. Towards 2100, transects in overwash and inundation are modelled to increase to 20% (22%) for RCP4.5 (RCP8.5), which suggests storm impacts will intensify towards the end of the century, regardless of emissions scenario.

Given the complexity of the Scottish coastline, storm impacts vary considerably around the coast (Fig. 2). For example, cells 3 and 11 are projected to experience the largest proportions of overwash and inundation for the present day (24% and 40%, respectively), while cell 2 shows the greatest present-day resilience to storm impacts, with 85% of transects in collision and only 8% in overwash or inundation. All cells show an increase in overwash and inundation towards the end of the century, under RCP4.5 and RCP8.5. Under RCP8.5, cells 3, 6 and 7 are predicted to have proportionately the largest increases in more severe impact regimes (Fig. 2).

Areas of overlap between low-lying areas of high asset density and overwash or inundation regimes indicate hotspots of greatest storm-related coastal flood risk (Fig. 3). Locations of regime upshift, where the modelled storm regime for RCP8.5 in 2100 is more severe than for the present day, suggest that for many currently high-risk asset areas, storm impacts are expected to increase towards the end of the century (Fig. 3). At the national scale, these high-risk areas represent 808 transects (~40 km of coastline) and provide a strategic understanding of where to target further local-scale assessments.

While these results provide a first order indication of hotspots in need of coastal adaptation, there are a range of limitations when working at large spatial scales, mainly related to input data and methodology. By using national elevation data, the analysis uses a single snapshot of barrier morphology that varies in acquisition date around the coast. Furthermore, medium horizontal resolution and accuracy of the national DTM adds uncertainty to extracted barrier toe and crest elevations.

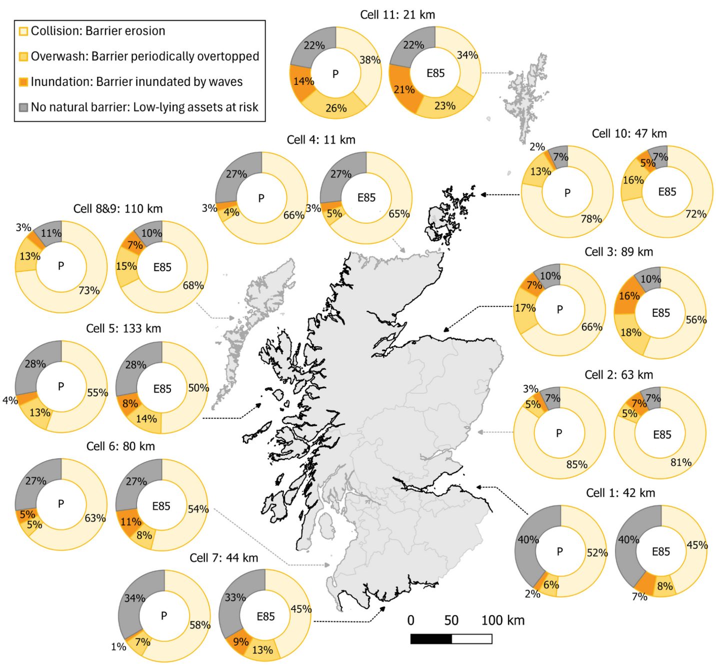

Fig. 2. Percentage of transects in each storm regime per coastal cell (alternating black/grey sections of coastline). Length of coastline studied/cell. P = present day, E85 = end-century RCP8.5. Map produced in QGIS 3.26 (www.qgis.org). Administrative boundaries (level 3) from the GADM database (gadm.org, v3.6).

Extreme still water levels combining tide and storm surge are provided at 2 km spacing around the coast from state-of-the-art national models. By using a 25-year return period ESL, the model uncertainty is small (order of ±10 cm), and thus does not contribute significantly to analysis uncertainty. However, there is large uncertainty regarding the amount of SLR that will happen this century, with the difference between modelled 5th to 95th percentile SLR in 2100 in the order of 0.5 m for Scotland. Therefore, the choice of SLR percentile has a large bearing on total water levels and storm impact regime predictions. Here, we only consider 95th percentile projected SLR in each climate scenario, as a precautionary high-impact estimate of TWL.

Finally, there is still large uncertainty regarding the future changes in the storm wave climate for the North Atlantic. An increase in winter-mean wave height, variability (larger extremes) and periodicity has been observed over the last 70 years, but it is not yet clear if this can be attributed to climatic change [9]. Most existing climate models, including the regional climate model used to produce the wave data used in this study, do not predict a notable increase in wind speed (and in turn wave height) for the North Atlantic in the XXI century [9, 10]. However, if the observed trend of increasing wave height continues in the next decades, wave climate projections used in this analysis likely underestimate wave contributions to future TWL.

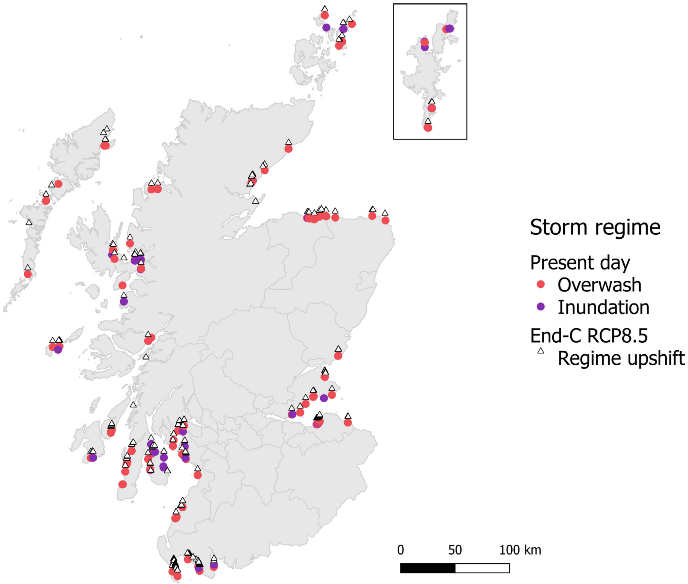

Fig. 3. Areas with low-lying assets and high impact storm regimes. Map produced in QGIS 3.26 (www.qgis.org). Administrative boundaries (level 3) from the GADM database (gadm.org, v3.6).

4 Conclusion

This study presents the first national storm impact assessment for Scotland that includes storm wave runup. It outlines areas of increasing coastal risk for this century, with large increases in high impact storm regimes predicted for sectors of the Scottish coast. The study identifies where natural barriers fronting coastal assets are currently vulnerable to storm-driven flooding, and where impacts are likely to increase in the future. This contributes to a strategic understanding of coastal hazards and supports the spatial prioritization of areas in need of further local assessment and adaptation planning.

References

1. Reimann L, Vafeidis AT, Honsel LE (2023) Population development as a driver of coastal risk: current trends and future pathways. Cambridge Prisms Coast. Futures 1:e14
2. Mentaschi L, Vousdoukas MI, Pekel JF et al (2018) Global long-term observations of coastal erosion and accretion. Sci Rep 8(1):12876
3. Jevrejeva S, Williams J, Vousdoukas MI et al (2023) Future sea level rise dominates changes in worst case extreme sea levels along the global coastline by 2100. Environ Res Lett 18(2):024037
4. SEPA (2023) Coastal Flooding Summary: Methodology and Mapping, pp 1–29
5. Stockdon HF, Long JW, Palmsten ML et al (2023) Operational forecasts of wave-driven water levels and coastal hazards for US Gulf and Atlantic coasts. Commun Earth Environ 4(1):169
6. Sallenger AH (2000) Storm impact scale for barrier islands. J Coastal Res 16(3):890–895

7. Stockdon HF, Holman RA, Howd PA et al (2006) Empirical parameterization of setup, swash, and runup. Coast Eng 53(7):573–588
8. Poate TG, McCall RT, Masselink G (2016) A new parameterisation for runup on gravel beaches. Coast Eng 117:176–190
9. Castelle B, Dodet G, Masselink G et al (2018) Increased winter-mean wave height, variability, and periodicity in the Northeast Atlantic over 1949–2017. Geophys Res Lett 45(8):3586–3596
10. Tobin I, Jerez S, Vautard R et al (2016) Climate change impacts on the power generation potential of a European mid-century wind farms scenario. Environ Res Lett 11(3):034013

Parameterised Barrier Morphological Evolution for Future Storm Impact Assessment

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Abstract. Coastal storm impacts are mainly determined by the interaction of extreme water levels with barrier morphology, particularly the height of the foredune. While future projections of storm hydrodynamic forcing, integrating sea level rise, tides, waves and storm surges, are readily available, predicting future barrier morphology at a decadal scale remains a challenge due to uncertainties in modeling morphodynamic processes. This study proposes a simplified model to predict future foredune morphology at decadal scale and determine storm impacts on coastal barriers, focusing on the critical role of foredune morphology. The model identifies three morphological behavior modes based on the nature of the sediment budget and associated shoreline dynamics, distinguishing between: "keep-up mode" for accreting barriers, "catch-up mode" for stable to mildly accreting barriers, and "give-up mode" for eroding barriers. Application to the Portuguese coast, specifically the eroding barrier of Torrão do Lameiro, demonstrates that even with rising sea level and higher total water levels, storm impacts remain within the same regime by 2050. This simplified model offers a practical approach for considering an evolving foredune morphology, which can support first-order assessments of future storm impacts in changing climate.

Keywords: Barrier Morphology · Foredune · Sediment Budget · Storm Impacts · Coastal Behaviour Modelling

1 Introduction

The impacts of storms on coastal barriers are largely determined by the interaction of extreme water levels with the morphological characteristics of the beach-dune system [1]. The storm-induced extreme water levels determine the severity of the forcing, while the morphology of the beach and, more importantly the dune, regulates the ability of barriers to withstand erosion and prevent flooding. This interdependency of hydrodynamic forcing and morphological setting is thus fundamental for categorising and predicting storm impacts [2].

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When considering future storm impacts in a changing climate, predictions of hydrodynamic forcing integrating sea level rise (SLR), tides, storm surge and waves are nowadays readily available from individual or ensemble climate projections e.g. [3]. These are increasingly used to determine changes in extreme water levels and estimate flooding extents at local to global scales [4, 5]. However, predictions of future barrier morphology remain elusive, as morphodynamic linkages in beach-dune systems across scales are still poorly resolved, particularly when scaling from process observations to decadal morphological changes [6]. For storm impact assessments, this results in an incomplete, but often applied approach, where future extreme sea levels are only compared to present day barrier morphology [4, 7].

Predicting future dune morphology, particularly the height of foredunes, is fundamental for assessing future storm vulnerability in coastal barriers [8]. However, despite recent advances in coastal dune morphological models, both process-based or data-driven, there are still many uncertainties in the numerical modelling of long-term (decadal) coupled beach and dune morphodynamic processes [9]. Therefore, simplified models that describe key evolutionary modes, integrating empirical observations or parameterising observed barrier change behaviours, remain a useful solution for predicting coastal morphological change. The reduced complexity in terms of processes and data used, alongside the low computational requirements make such models particularly useful for long-term and large-scale application, and potentially useful for integration in climate change impact assessments. Aiming to evaluate future storm impacts in coastal barriers, this work proposes a parameterised morphological behaviour model of barrier evolution, exploring its application to the Portuguese coast.

2 Model Framework

For first-order assessment of storm impacts on coastal barriers, such as the well-established Storm Impact Scale outlined by Sallenger [1], the elevation of the foredune toe (D_{low}) and crest (D_{high}) are critical morphological parameters. While these two variables simplify barrier morphology, they represent the key vertical dimensions and are commonly incorporated in simplified or idealized coastal behaviour models. Considering this, to parameterise barrier evolution the proposed modelling framework considers exclusively changes to the height of the toe and the crest of the foredune.

Foredune evolution depends primarily on wind, vegetation and sediment supply [10]. At decadal timescales, and assuming quasi-stationary wave and wind regimes, while excluding human impacts and changes in vegetation cover, the elevation of foredunes is mainly controlled by sediment budget, shoreline change and beach morphodynamic type [11]. Although morphodynamic beach type is variable around a modal state, it can be assumed stable at decadal scales if there are no changes to sediment type. This leaves sediment budget and associated shoreline change as key controls of decadal foredune morphological evolution. Different foredune evolutionary behaviour modes can then be considered for accreting, stable and eroding barriers [11]. Taking a sediment budget conceptual approach to foredune evolution [10] and focussing exclusively on the decadal change of the foredune toe and crest elevation in a context of rising sea levels, three morphological behaviour modes are proposed (Fig. 1). In moderately to highly accreting barriers, indicative of a strongly positive sediment budget, foredunes can keep pace with rising sea levels, increasing their toe and crest elevations at the rate of SLR as the shoreline progrades (*keep-up mode*). In stable to mildly accreting barriers, where a slightly positive sediment budget is necessary to maintain the shoreline position with rising sea level, the foredune toe elevation increases at the rate of SLR, but the foredune crest remains at the same elevation (*catch-up mode*). In this mode, most of the sediment is used to aggrade the beach and also prograde the stoss slope of the foredune, limiting the sediment availability for vertical foredune growth. Finally, in eroding barriers the sediment budget is negative, and the foredune retreats landward, with the crest elevation determined by the topography of the landward dune ridges (*give-up mode*). In this mode, the toe elevation continues to increase at the rate of SLR, as sediment is supplied to the beach from the eroding dunes.

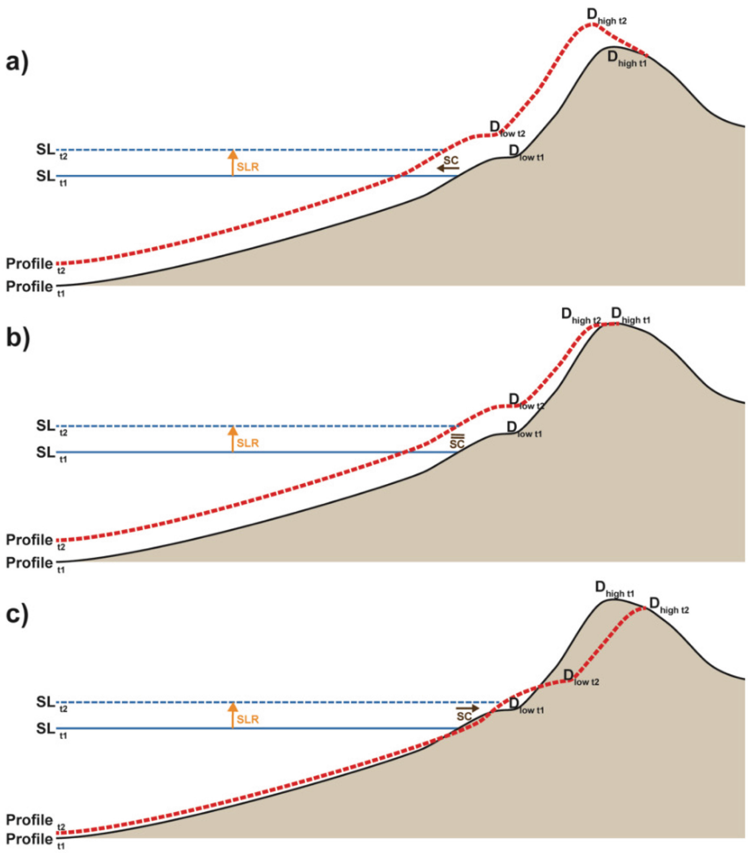

Fig. 1. Schematic overview of change in foredune morphological parameters (D_{low} and D_{high}) in relation to shoreline change (SC) and sea level rise (SLR). a) keep-up mode, b) catch-up mode and c) give-up mode.

Across the three behaviour modes the elevation of the foredune toe increases at the rate of SLR, as the beach profile adjusts vertically to maintain morphodynamic equilibrium with mean sea level [12]. This reflects the fact that, at decadal scales, water levels will be permanently raised by the amount of SLR, but only episodically raised by the storm-induced surge and runup, and foredune toe reflects only the permanent increase in water levels. If the wave regime is not quasi-stationary, changes in the modal wave climate should be incorporated in the trajectory of the foredune toe elevation.

3 Application to the Portuguese Coast

The morphological behaviour model was applied to sandy barriers along the Portuguese coast, using high-resolution LiDAR data of beach and dune systems collected in 2011, combined with multidecadal shoreline change rates from 1958 to 2010 determined by Lira et al. [13]. Storm impact regimes were determined following Sallenger [1] for the present and in 2050 considering the RCP8.5 climate change scenario. Extreme water levels, specifically total water level (R_{high}) and maximum still water levels (R_{low}), were computed for the 100-year return period storm using wave and storm-surge projections from the Copernicus Climate Change Service for the European coastline, alongside the regional IPCC AR6 median sea level projection and considering a mean high tide level.

Considering the example of Torrão do Lameiro barrier, located in the exposed NW coast of Portugal and experiencing a shoreline change rate of −0.5 m/yr, applying the give-up mode to project the 2050 dune toe and crest elevations results in a D_{low} of 7.6 m and D_{high} of 12.6 m, respectively (Fig. 2). The exact crest location is adjusted from the stoss slope to the adjacent peak to better align with dune crest morphology. In this case, even with a projected increase in R_{high} of 1 m and R_{low} of 0.6 m, the total water level remains under the dune crest elevation estimated for 2050, as the retreating shoreline will reach a higher dune ridge located landward of the current foredune. As such, a collision storm impact regime is maintained between the present and 2050, despite the rise in sea level and the increased severity of storm forcing.

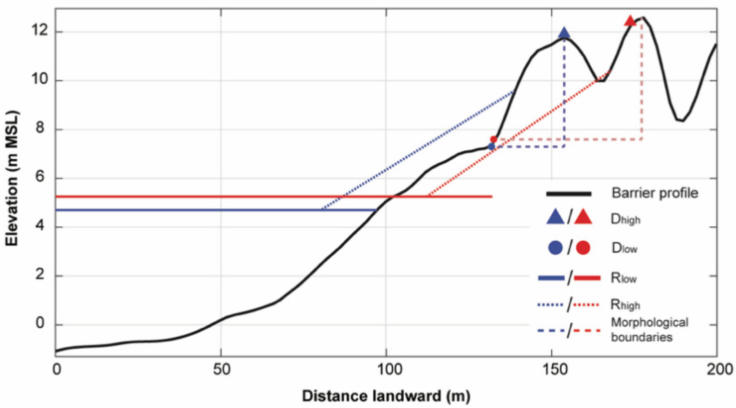

Fig. 2. Overview of present (blue) and RCP8.5 2050 projection (red) of foredune morphological parameters (D_{high} and D_{low}) and and extreme water levels (R_{high} and R_{low}) for Torrão do Lameiro.

4 Discussion

Sandy barriers are highly variable in form and setting, which results in a range of morphological responses to SLR that depend on a variety of processes and variables that cannot be meaningfully captured by a single model [14]. However, at decadal to centennial scales, the nature of the overall sediment budget and associated shoreline change can be used to infer generic barrier and foredune morphological change patterns under positive, neutral and negative sediment budgets [12]. The parameterised morphological behaviour model of barrier evolution proposed in this work incorporates simplified relationships between shoreline and foredune morphological change under rising sea levels, which although not universally valid, attempt to distinguish between common behaviour modes. The reliance on shoreline change and barrier topography metrics makes this approach widely applicable, particularly given the increasing availability of medium resolution global datasets that can be used to obtain, even if with limitations e.g. [15], all the hydrodynamic and morphological parameters considered in the model.

Although the use of on invariant coastal morphology is commonly recognised as a key limitation for assessments of future storm impacts [4, 7], very few studies have incorporated changes to future barrier morphology when modelling the potential impacts of storm events in a changing climate e.g. [16]. As first-order storm impacts in coastal barriers are largely controlled by foredune height [1, 8], predicting the entire barrier profile is not essential. Foredune toe and particularly crest, i.e. D_{high}, are the fundamental variables that must be considered for more confidently determining if future storms are likely to lead to increased collision, overwash and inundation of coastal barriers. Applying the parameterised model to Torrão do Lameiro, a coastal barrier under significant erosion and exposed to more extreme total water levels, indicates that storm impacts will remain within the same regime towards the mid-century. This is due to the presence of a second, inland-located, dune ridge, which highlights the critical importance of landward morphology when evaluating storm impacts in retreating coastal barriers under the give-up mode.

5 Conclusion

This work proposes a new simplified morphological behaviour model to estimate future foredune morphological parameters required for first-order assessments of storm impacts in coastal barriers. This model can be applied with limited information, but addresses a critical limitation in storm impact assessments in a changing climate, which typically evaluate future extreme water levels but do not consider the expected multi-decadal variation in barrier morphology. The application to Torrão do Lameiro in the NW coast of Portugal demonstrates that, despite the increase in total water levels, future storm impacts remain in the collision regime, even for extreme 100-year return period storm conditions.

References

1. Sallenger A (2016) Storm impact scale for barrier islands. J Coast Res 16(3):890–895

2. Leaman C, Harley M, Splinter K, Thran M, Kinsela M, Turner I (2021) A storm hazard matrix combining coastal flooding and beach erosion. Coast Eng 170:104001
3. Jevrejeva S, Williams J, Vousdoukas M, Jackson L (2023) Future sea level rise dominates changes in worst case extreme sea levels along the global coastline by 2100. Environ Res Lett 18(2):024037
4. Thomas J et al (2024) The projected exposure and response of a natural barrier island system to climate-driven coastal hazards. Sci Rep 14:25814
5. Kirezci E et al (2020) Projections of global-scale extreme sea levels and resulting episodic coastal flooding over the 21st Century. Sci Rep 10(1):11629
6. Walker IJ et al (2017) Scale-dependent perspectives on the geomorphology and evolution of beach-dune systems. Earth-Sci Rev 171:220–253
7. Passeri D, Bilskie M, Plant N, Long J, Hagen S (2018) Dynamic modelling of barrier island response to hurricane storm surge under sea level rise. Clim Change 149:413–425
8. Plant N, Thieler R, Passeri D (2016) Coupling centennial-scale shoreline change to seal-level rise and coastal morphology in the gulf of Mexico using a Bayesian network. Earth's Futur 4:143–158
9. Kombiadou K, Costas S, Roelvink D (2023) Exploring controls on coastal dune growth through a simplified model. J Geophys Res Earth Surf 128:e2023JF007080
10. Davidson-Arnott R et al (2018) Sediment budget controls on foredune height: comparing simulation model results with field data. Earth Surf Proc Landf 43:1798–1810
11. Doyle TB, Hesp P, Woodroffe CD (2024) Foredune morphology: regional patter and surfzone-beach-dune interactions along the New South Wales coast. Earth Surf Proc Landf 49:3115–3138
12. Davidson-Arnott R, Bauer B (2021) Controls on the geomorphic response of beach-dune systems to water level rise. J Great Lakes Res 47:1594–1612
13. Lira C, Silva A, Taborda R, Andrade C (2016) Coastline evolution of Portuguese low-lying coast in the last 50 years: an integrated approach. Earth Syst Sci Data 8:165–278
14. Cooper J et al (2020) Sandy beaches can survive sea level rise. Nat Clim Chang 10:993–995
15. Fanti V, Ferreira Ó, Kümmerer V, Loureiro C (2023) Improved estimates of extreme wave conditions in coastal areas from calibrated global reanalyses. Commun Earth Environ 4(1):151
16. Passeri D, et al (2020) The roles of storminess and sea level rise in decadal barrier island evolution. Geophys Res Lett 47:e2020GL089370