

CONTRASTING SHORELINE DYNAMICS IN GEOLOGICALLY CONTROLLED BARRIERS

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INTRODUCTION

Quantifying and understanding coastal geomorphological change are of paramount importance for coastal management and policy making (Boak & Turner, 2005). For wave-dominated coastal barriers, contemporary morphological change is mainly determined by hydrodynamic forcing conditions and antecedent beach morphology (e.g., Burvingt & Castelle, 2023). However, in geologically controlled barriers, beach morphodynamic processes and responses are additionally influenced by the pre-existing geological framework (Robinet et al., 2020). These geological controls are rarely considered in shoreline change assessments, despite being essential for predicting future coastal change at the management scales (Cooper et al., 2018). This work examines the influence of foreshore configuration with varying degrees of geological control on shoreline evolution using seven years of satellite derived shoreline data from three beaches in the Outer Hebrides barriers (NW Scotland).

METHODS

Satellite Derived Vegetation Lines (SDVL), which represent the seaward edge of dune vegetation (Boak & Turner, 2005), were extracted from Planet Scope imagery as a shoreline position indicator between December 2016 and May 2023. The pre-processing of the satellite imagery was performed using the open source CoastSat.PlanetScope python toolkit (Doherty et al., 2022), including image filtering, co-registration, and merging. After pre-processing, the Normalised Difference Vegetation Index (NDVI) was calculated for each image and for distinct beach sections defined based on differences in vegetation cover and water table. These sections were spatially restricted to a small alongshore band covering the vegetated dune and upper beach, allowing the use of automatic image thresholding based on Otsu's method. The SDVL position was extracted as the NDVI contour determined with a spatially variable Otsu threshold. The automated approach was then validated by visual inspection of each SDVL to remove misinterpreted shorelines due to poor image quality or interference from seaweed deposits near the dune. Shoreline changes were determined from the intersection of the valid SDVLs with shore-perpendicular transects with a 25 m spacing.

The positional accuracy of SDVLs was evaluated against Measured Vegetation Lines (MVL) obtained from RTK-DGNSS field surveys during the 2022-23 winter season. After validation, the dune-based shorelines were averaged to monthly SDVL positions and shoreline change was analysed as the deviation from the mean SDVL position during the monitoring period. The SDVL changes were also spatially averaged to obtain the mean shoreline change in each site.

To analyse the influence of geological control on shoreline changes, the beaches were divided into rocky and sandy sectors according to the foreshore configuration. Rocky sectors are dominated by outcropping rock features, whereas sandy sectors have no visible rocky surfaces and are predominantly sandy.

RESULTS

According to the comparison with the temporally closest MVL, the SDVL are in very good agreement, demonstrated by a strong positive correlation ($R > 0.99$) and a RMSE of 2.57 m, which corresponds to sub-pixel error given the 3.7 m spatial resolution of the Planet Scope images.

Site-averaged monthly mean SDVLs positions show clear seasonal variability over the last 7 years, with shoreline retreat occurring in winter and shoreline advance in summer (Figure 1). However, there are differences in the shoreline variability between sites. Gualan shows muted shoreline variability when compared to the other two beaches. In addition, Howmore and Ormiclate show statistically significant trends of shoreline advance, superimposed on the seasonal variation of the shoreline position.

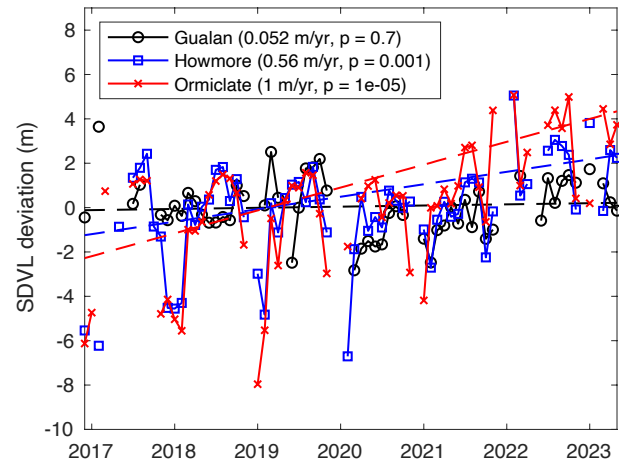


Figure 1 - Site-averaged monthly mean SDVL position (lines with symbols) relative to the mean for the whole period analysed and multiannual trends (dashed lines). The dots represent data points for each month and the connecting line is interrupted where data gaps are longer than one month.

At the finer spatial scale of individual beaches, distinct intra-site shoreline behaviour can be observed, with varying shoreline changes between beach sectors with different types of foreshore configuration (Figure 2). Beach sectors fronted by a sandy foreshore show a consistently higher variability in shoreline position than sections fronted by a rocky foreshore. This shoreline behaviour pattern is consistent across all three beaches.

DISCUSSION

Shoreline change derived from satellite imagery is commonly assessed using the wet/dry line shoreline position (McAllister et al., 2022). However, this indicator has significant limitations in coastlines characterised by gentle shoreface slopes, large tidal variation, and high cloud cover (Konstantinou et al., 2023). The combination of the vegetation line as a shoreline indicator as proposed here with the higher spatial and temporal resolution of Planet Scope imagery prevents the errors induced by tidal and swash driven aliasing and improves the usability of satellite imagery on these coastlines.

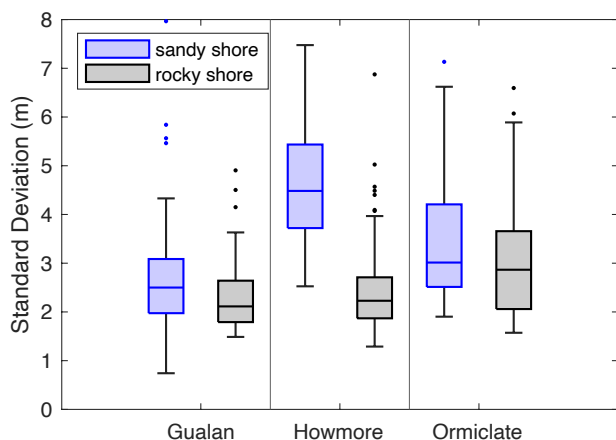


Figure 2 - Standard deviations of monthly SDVL position grouped by beach and foreshore configuration.

The geomorphological variability of the Hebridean barrier system is mediated by the topography of the frequently exposed underlying bedrock surfaces and limited sediment supply (Pile et al., 2019). The control exerted by the bedrock topography is also evident in the contemporary shoreline dynamics. Despite similar shoreline orientation, and hence wave exposure, there are differences in shoreline variability between sites, and lower shoreline variability is observed in beach sections fronted by rocky foreshores, when compared to sandy foreshores. Geological controls on contemporary shoreline dynamics have also been identified in south-east Australian barriers, where the pre-existent geological framework modulates the spatial variability of shoreline change (Robinet et al., 2020). One hypothesis is that the sediment-starved foreshore of these beach sections limits cross-shore sediment transport, and the non-erodible surface consistently dissipates wave energy, resulting in limited morphological change.

While geological variables influence the shoreline dynamics, changes in shoreline position are driven by hydrodynamic forcing. The seasonality of the beach-averaged shoreline positions is related to the strong seasonality of the wave power in the NE Atlantic. The advancing trend in shoreline position may be associated with a long-term (years) recovery phase from energetic winters that occurred prior to the monitoring period. This long-term beach recovery trend is observed in several beaches along the Atlantic coast of Europe and was

initiated after the extreme storm conditions recorded in the winter of 2013/14 (Burvingt & Castelle, 2023).

CONCLUSION

The analysis of SDVL change in 3 barriers in NW Scotland over the last 7 years indicates that, in addition to hydrodynamic forcing, the alongshore varying geological configuration results in distinct inter- and intra-site shoreline change behaviour. These findings demonstrate that the inclusion of geological controls in shoreline change assessments improves the understanding of shoreline change along coastal barriers. However, additional field and modelling efforts are required to disentangle the influence of the pre-existing geological framework on nearshore morphodynamic processes. The semi-automated shoreline change approach presented in this work is a robust tool for assessing monthly to multi-annual morphological change in coastal areas with a well-marked transition between the beach and the vegetated dune, regardless of beach and shoreface slope and tidal range.

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REFERENCES

- Boak & Turner (2005): Shoreline Definition and Detection: A Review. *Journal of Coastal Research*, 214, 688-703.
- Burvingt & Castelle (2023): Storm response and multi-annual recovery of eight coastal dunes spread along the Atlantic coast of Europe. *Geomorphology*, 435, 108735.
- Cooper, Green & Loureiro (2018). Geological constraints on mesoscale coastal barrier behaviour. *Global and Planetary Change*, 168, 15-34.
- Doherty, Harley, Vos, & Splinter (2022): A Python toolkit to monitor sandy shoreline change using high-resolution PlanetScope cubesats. *Environmental Modelling & Software*, 157, 105512.
- Konstantinou, Scott, Masselink, Stokes, Conley & Castelle (2023): Satellite-based shoreline detection along high-energy macrotidal coasts and influence of beach state. *Marine Geology*, 462, 107082.
- McAllister Payo, Novellino, Dolphin & Medina-Lopez (2022): Multispectral satellite imagery and machine learning for the extraction of shoreline indicators. *Coastal Engineering*, 174, 104102.
- Pile, Cooper & Jackson (2019). Stratigraphy and internal structure of wind-dominated barrier islands (dune and machair) of the Outer Hebrides, Scotland. *Earth Surface Processes and Landforms*, 44(7), 1482-1493.
- Robinet, Castelle, Idier, Harley & Splinter (2020): Controls of local geology and cross-shore/longshore processes on embayed beach shoreline variability. *Marine Geology*, 422, 106118.