Quantifying the Role of Offshore Bar Morphology on Runup and Dune Erosion

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INTRODUCTION

Runup is the wave-driven component of the total water level and is a critical metric for characterizing exposure to coastal hazards (Sallenger, 2000; Stockdon et al., 2006). The vertical extent of wave runup is typically parameterized as a function of offshore wave characteristics and beach slope (e.g., Stockdon et al., 2006). Recent research has considered the role of nearshore bars in regulating wave breaking and found that the depth of the bar regulates the elevation of runup at the shoreline (e.g., Cohn et al., 2014). However, the relationship between the morphology of the bar and the various hydrodynamic components related to runup (i.e., swash and setup) has not been explored. Further, the relationship between the bar morphology and the style of dune erosion has not been analyzed. In this study we use the numerical model XBeach (XB; Roelvink et al., 2009) to reproduce a flume experiment performed at the University of New South Wales (UNSW) Sydney Water Research Laboratory (Conti et al., 2023). We then synthesize and modify the bar in the profile to explore how the bar crest depth, bar trough depth and bar distance from the shoreline can affect runup and resulting dune erosion. Note that we use the Conti et al. (2023) study to define initial conditions for XBeach and validate the model setup but not to compare results as that study was ultimately focused on the role of moisture content in the dune on erosion.

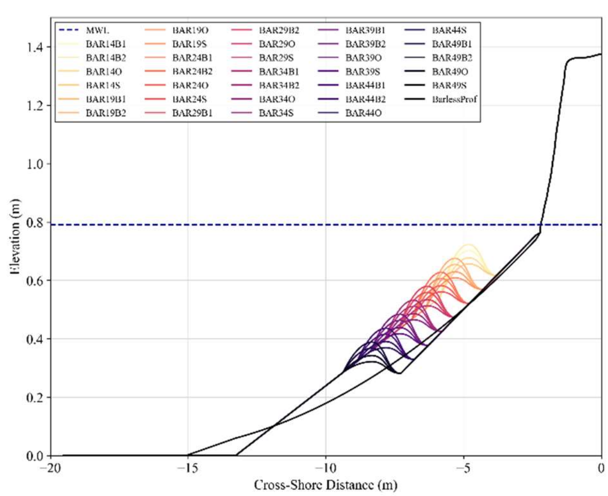

Figure 1 – Synthetic cross-shore profiles derived from the original flume profile in (Conti et al., 2023) with systematic adjustments to the bar depth and location following Stephens et al., (2011).

METHODS

The XBeach simulations were forced with a JONSWAP spectrum with a significant wave height (*Hs*) Hs = 0.25 m and peak wave period (*Tp*) Tp = 1.52 s for a total of 4,000 waves (approx. 75 minutes; Conti et al., 2023). The mean water level (MWL) in the flume was 0.79 m. The runup characteristics have been normalized by the wave height to present non-dimensional results for comparison to field observations as part of the ongoing work, this work will also involve comparisons between the barred and barless profiles to identify the role of the bar more precisely.

XBeach-Surfbeat (XB-SB) was used to reproduce the observed erosion and XB-Non-Hydrostatic (XB-NH) to reproduce the observed hydrodynamics from the flume experiment as XB-NH is not recommended for erosional studies. A series of calibration simulations were run to validate the erosion observed in XB-SB and observed wave probe data in XB-NH.

XBeach-Surfbeat was calibrated to replicate the dune erosion and runup observed from the flume experiment by varying three key input parameters (*facsk, facas, form)*. Modeled profiles were output at 15-minute intervals and compared with measured profiles from the experiment. The simulations ran for 75 minutes. The best-fit hindcast had an average RMSE between modelled and measured beach profiles of 0.04 m. A virtual runup gauge was implemented in XB to track the runup level with a 25 Hz frequency to match the flume data from the physical experiment. Runup was replicated modestly well, with an error in the 2% percent runup exceedance elevation ($R_{2\%}$) values between the model and experiment of 7.5%.

XB-Non-Hydrostatic was calibrated to replicate hydrodynamics from the experiment. The wave tank modes and peak frequency of the wave conditions were well replicated, whilst some high frequency energy above 1 Hz was not captured. Comparing *Hs* values from the three probe array and XB output shows almost identical wave condition with an error of 0.6%. The calibrated XBeach models were then used to simulate the same experiments but with the bar on the profile systematically modified following the methodology of Stephens et al. (2011) (Figure 1). The modeled bar morphology was then compared to the modeled runup to quantify the role of the bar morphology (i.e., bar crest depth, bar trough depth, bar location) in determining wave runup and dune face erosion.

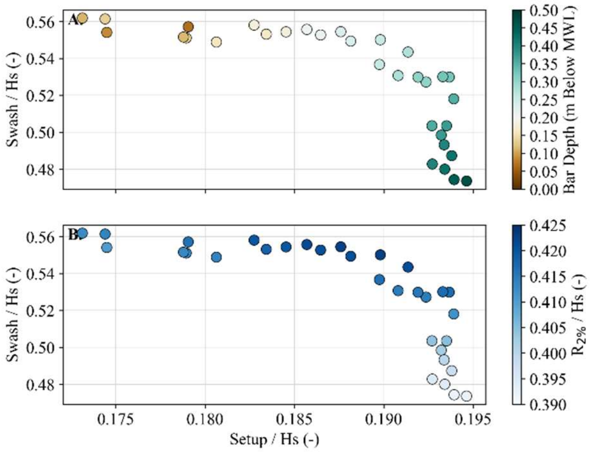

Figure 2 - Swash versus setup colored by A) bar depth below MWL and B) $R_{2\%}$. The colors in A are centered such that a bar depth of 0.20 m (equal to the breaker depth) is white.

RESULTS

Results from the synthetic simulations show that the bar morphology regulates the maximum runup elevation at the shoreline, however there is an optimum range wherein the runup is maximized that is related to the breaker depth (0.20 m, Figure 2A). As the bar depth increases below MWL, the maximum runup elevation increases linearly with wave setup while the swash remains constant (Figure 2B). However, once the bar depth is below the breaker depth the swash component of the runup sharply decrease while the setup remains constant resulting in an equally sharp decrease in runup.

DISCUSSION

Initial results confirm that the presence of a bar is predicted to regulate the runup level at the shoreline. However, further investigation into the various components of the bar morphology demonstrate that a primary influence on the runup level comes from the depth of the bar below the mean water level. When the bar is shallow, waves break on the bar and there is little variation in the swash component of the runup. As the bar is made deeper, but still shallow enough to induce wave breaking, less energy is dissipated at the bar and a greater setup is experienced at the shoreline. We note that in this experimental setup, there is a relationship between the depth of the bar and the distance from the shoreline (Figure 1). Controlling for surf zone width here would introduce variations in foreshore steepness that would affect runup on the shoreline as well as place a greater number of synthetic bars below wave base.

CONCLUSION

A series of XBeach simulations were run (surfbeat and non-hydrostatic) to reproduce the results of a flume experiment by Conti et al. (2023). XB-Surfbeat was calibrated to hindcast dune erosion and runup values - obtaining an RMSE on the beach profile of 0.04 m, and percentage error on modelled $R_{2\%}$ value of 7.5%. XB-Non-Hydrostatic was calibrated to replicate the experiment hydrodynamics, obtaining near identical onshore incident wave conditions with an error in modelled Hs of 0.6%. Upon calibrating the model to the experiment, the offshore bar was modified in XBeach to systematically explore how the morphology of the bar affected runup and dune erosion. Initial results show that the depth of the bar appears to be the primary control on both runup and setup with both increasing as the bar shallows, up to a threshold minimum water depth beyond which point the runup decreases significantly.

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