FIELD OBSERVATIONS AND NUMERICAL MODELLING OF HEADLAND BYPASSING IN A HIGH-ENERGY COMPLEX COASTAL ENVIRONMENT

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INTRODUCTION

Understanding and being able to model nearshore sediment transport processes is important for the development of coastal protection and management strategies. To date, most formulations for longshore sediment transport and associated shoreline change have been developed for idealized alongshore uniform sandy beaches. However, many coastlines are far more complex, such as those featuring headlands, which may considerably alter longshore transport processes (Ab Razak, 2015). Headlands can (partially) obstruct longshore transport, thus affecting the sediment balance and, as a result, complicate predictions of shoreline change compared to the case of an alongshore uniform beach. Quantitative expressions to estimate sediment bypass rates around headlands are rare (McCarroll, 2021), especially for large headlands with complex shape. This is primarily due to substantial spatio-temporal variations in sediment transport that can occur in such complex environments and the difficulty of conducting field measurements in high-energy headland environments (McCarroll, 2018), which are critical for developing and validating (empirical) sediment transport formulas. This study adopts a novel field set-up to explore headland bypassing in the high-energy environment around Robe, South Australia, by measuring sediment concentrations and flow velocities around a large and complex headland. The field data is then used to validate a numerical model.

FIELD SITE

The township Robe is located at the northern side of the Robe headland on the south-eastern coast of South Australia (Figure 1).

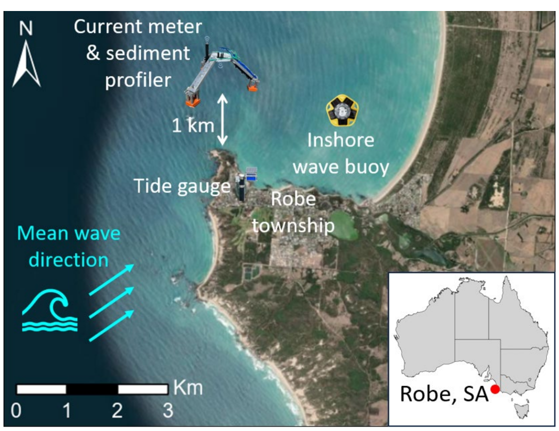

Figure 1 - Location of the study area Robe on the south-eastern coast of South Australia with location of the deployed instruments and the mean wave direction.

The coast around Robe provides an excellent case study to investigate hydrodynamic and morphological coastal processes in high-energy complex coastal environments. This is due to its geomorphological history resulting in the formation of headlands, sandy beaches, cliffs, islands, rock platforms, and reefs (Murray-Wallace, 1999), and its exposure to some of the world's largest swell waves generated by Southern Ocean extra-tropical storms (Hemer, 2010). Waves approach the coast mainly from the south-westerly direction with deep-water wave heights usually exceeding 5 m, and commonly exceeding 10 m (Short, 1988).

Robe's main beaches are located on the leeward side of the headland, sheltered from the large south-westerly swell waves.

METHODS

A novel field set-up to investigate headland bypassing is adopted by using a co-located acoustic current meter and sediment profiler at about 1 km north of the tip of the Robe headland (Figure 1). The instruments were deployed for two 8-week periods in summer (19/12/2022 - 11/02/2023) and winter (20/06/2023 - 21/08/2023). Both devices are attached to a metal mooring frame with sinking weights, which was deployed at a depth of 10 m. The current meter is facing upwards, measuring 3D current velocities at a single point approximately 1 m from the bed, while the sediment profiler is facing downwards, measuring sediment concentration at 1 cm increments covering an 80 cm vertical column above the sea floor.

To relate the findings of these instruments to other environmental conditions, wave characteristics were measured at a frequency of 2.5 Hz using 2 Spotter wave buoys (1 at a location 8 km offshore and 1 at a location 1 km inshore, Figure 1). Water levels were obtained every 5 min from a permanent tide gauge located in the Robe marina (Figure 1) and is operated by the South Australian Department for Environment and Water.

The data collected was then used to validate a numerical model (Delft3D), which simulates the coupled effects of waves and flow, allowing for the investigation of different scenarios regarding headland bypassing and its influence on sediment budgets. The bathymetric data used for the process-based model consist of high resolution (5 m) LiDAR data from 2022 in the nearshore and coarser resolution multi-beam (250 m) data, released by Geoscience Australia in 2023, further offshore. The model is forced with 2D wave spectra timeseries obtained from the offshore wave buoy and tidal constituents obtained from the TPXO 7.2 model (Egbert, 2002).

PRELIMINARY FINDINGS

The study's findings reveal critical insights into sediment transport patterns around the Robe headland. The measurements show substantial differences in sediment transport between the summer and winter seasons. During the stormier winter season, relatively high sediment concentrations and increased current velocities (and consequently high sediment transport rates) were observed (Figure 2). During summer (moderate) conditions, sediment is mainly transported in a south-east direction towards Robe's sheltered beaches, thereby supplementing their sediment budgets. On the other hand, during winter (energetic) conditions, when sediment concentrations are high, sediment that passes the headland is mainly transported in a north-east direction and is unlikely to reach Robe's beaches.

During storm events, the highest sediment concentrations are found when the wave heights are peaking and the gradients in current speed are highest. Highest current speeds occur about 12 hours after the peak in wave heights and sediment concentrations (Figure 2).

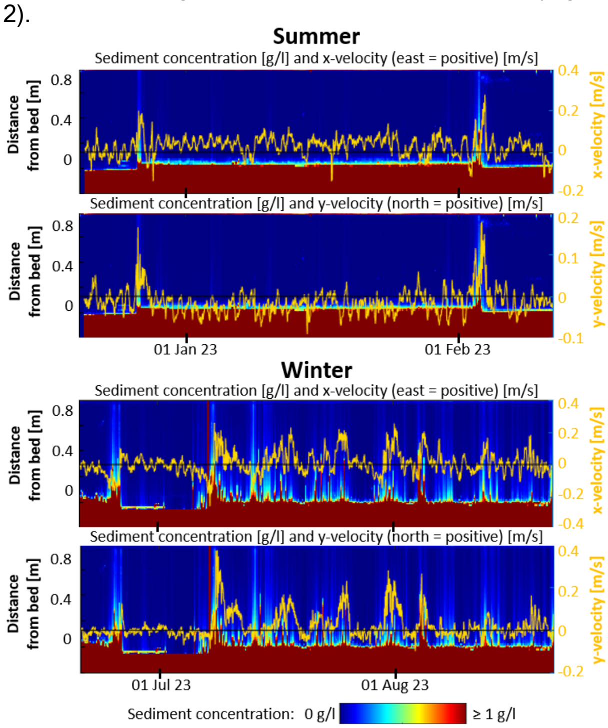

Figure 2 – Sediment concentrations in an 80 cm vertical column above the seabed and current velocities in x- and y-direction over time for summer (19 Dec 22 – 11 Feb 23, top panels) and winter (20 Jun 23 – 21 Aug 23, bottom panels) seasons in 10 m deep water about 1 km north of the tip of the Robe headland.

The coupled wave-flow model results were compared with measured wave- and current characteristics as well as sediment transport rates derived from measurements of sediment concentrations and current speeds. The model represents the measured data well near the headland and near the beaches. We found that the modeled wave heights were relatively sensitive to the headland geometry. Thus, achieving an accurate representation of wave heights at the inshore wave buoy location within the model requires a high-resolution depiction of headland geometry.

The model scenario runs show different headland bypassing mechanisms for moderate and energetic conditions, which are in line with the measured observations. Sediment is transported around the headland towards the beaches sheltered by the headland during moderate conditions. For energetic conditions, sediment is transported away from the sheltered beaches and embayment circulation occurs.

The novel field set-up of combining sediment profiling and current measurements overcomes the limitations of assessing sediment transport rates with high temporal frequency in a high-energy wave environment. The field data is extremely valuable for the validation of numerical models to improve our understanding of headland bypassing patterns and mechanisms for different environmental conditions.

CONCLUSIONS

This study significantly contributes to our understanding of sediment transport around headlands in high-energy environments. The data collected and the coupled wave-flow numerical model offer valuable tools for predicting how headland bypassing influences sediment budgets and shoreline changes. While the study's primary focus is on Robe, South Australia, its findings have broader implications for other complex coastlines featuring headlands.

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