Delft University of Technology

Document Version
Final published version

Licence
CC BY

Citation (APA)
Abdulsalam, M. B., Jaramillo, C., de Freitas, L., González, M., & Antolínez, J. A. A. (2026). Predicting Shoreline Orientation on Diverse Coastal Environments. In C. Coelho, C. Hallin, F. Sancho, & P. A. Silva (Eds.), *Coastal Dynamics 2025: Volume 2* (pp. 693-698). (Coastal Research Library; Vol. 42). Springer. https://doi.org/10.1007/978-3-032-15477-4_104

Important note
To cite this publication, please use the final published version (if applicable).
Please check the document version above.

Copyright
In case the licence states "Dutch Copyright Act (Article 25fa)", this publication was made available Green Open Access via the TU Delft Institutional Repository pursuant to Dutch Copyright Act (Article 25fa, the Taverne amendment). This provision does not affect copyright ownership.
Unless copyright is transferred by contract or statute, it remains with the copyright holder.

Sharing and reuse
Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy
Please contact us and provide details if you believe this document breaches copyrights.
We will remove access to the work immediately and investigate your claim.

This work is downloaded from Delft University of Technology.

Predicting Shoreline Orientation on Diverse Coastal Environments

Mayowa Basit Abdulsalam[1(✉)], Camilo Jaramillo[1], Lucas de Freitas[1], Mauricio González[1], and José A. A. Antolínez[2]

[1] IHCantabria- Environmental Hydraulics Institute, Universidad de Cantabria, Santander, Spain
mayowa-basit.abdulsalam@alumnos.unican.es

[2] Department of Hydraulic Engineering, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands

Abstract. Coastal zones are highly dynamic environments shaped by various environmental forcing agents such as waves and nearshore currents operating across diverse spatio-temporal scales. For effective decision-making, coastal managers require simplified, computationally efficient models to predict future shoreline morphodynamics. Among the models developed over the years, equilibrium-based shoreline evolution models (EBSEMs) have garnered significant attention for their computational efficiency. However, their application has mainly been limited to microtidal sandy beaches when simulating shoreline orientation, necessitating further evaluation across broader coastal settings.

This study investigates the applicability of EBSEMs in predicting shoreline rotational variability at two morphologically distinct sites: Narrabeen Beach, Australia, and Moncofa Beach, Spain. These sites differ in sediment size, tidal regimes, data sources, observation periods, and monitoring frequencies, providing a robust framework for model evaluation. Results demonstrate that the EBSEM successfully replicates the general trends of shoreline orientation variability on both sites, qualitatively and quantitatively. Seasonal rotation trends were accurately captured, emphasizing the model's capability to operate across varying spatial and temporal scales. These findings further reinforced the capabilities of EBSEMs as practical tools for coastal management, particularly for predicting shoreline orientation changes under diverse environmental conditions.

Keywords: Shoreline orientation · Shoreline variability · Equilibrium-based shoreline evolution models · Beach rotation

1 Introduction

To properly assess and quantify shoreline evolution, the scientific community has formulated various methods to predict shoreline variability over medium to long-term scales. These methods include 3D, multiline, one-line, combined, and equilibrium-based shoreline evolution models (EBSEMs). Among these, EBSEMs stand out for their simplicity in setup and calibration, computational efficiency, and ability to forecast daily and long-term morphological changes in diverse coastal settings [1]. Despite their advantages,

© The Author(s) 2026
C. Coelho et al. (Eds.): CD 2025, COASTALRL 42, pp. 693–698, 2026.
https://doi.org/10.1007/978-3-032-15477-4_104

EBSEMs for rotational movement have been limitedly applied, primarily focusing on microtidal sandy beaches [1–3]. Therefore, further assessment of their performance across broader coastal settings is essential.

This study evaluates EBSEMs' ability to predict shoreline rotation variability across different coastal environments globally, varying in sediment size, tidal ranges, observation periods, data sources, and frequency, using the model developed by [1], hereafter referred to as JA21 for modelling shoreline orientation. Such analyses would enable the implementation of more data-driven, targeted, suitable, and economically efficient management strategies and actions for developing and monitoring the coastal environment.

2 Equilibrium-Based Shoreline Evolution Model (EBSEM)

In this study, the model proposed by JA21 was used to reproduce the shoreline orientation evolution. This model is based on an equilibrium condition and assumes that beach rotation is induced by the power and direction of the incoming waves as follows:

$$\frac{d\alpha_s(t)}{dt} = L^{\pm} P \Delta\alpha_s(\theta) \tag{1}$$

where $\alpha_s(t)$ denotes the shoreline orientation (°) at a given time 't', with $L^{\pm}$ representing the proportionality constants ($m^{-2}h^{-2}$) for the clockwise (L^{+}) and counterclockwise (L^{-}) shoreline rotation rates. Incident wave power, P (m^2s), serves as the model weighting factor, calculated from the squared significant wave height, Hs^2 (m^2) and the peak period, Tp (s). The shoreline orientation disequilibrium, $\alpha_s(\theta)$, , is the difference between the shoreline orientation (α_s) and the equilibrium shoreline orientation (α_{seq}). The α_{seq}, , defined as a linear function of the incident wave direction (θ), can be expressed as $\alpha_{seq} = (\theta - b)/a$, where 'a' and 'b' are empirical calibration parameters.

In this study, the model's performance was assessed using metrics including root-mean-square error (RMSE), the Nash-Sutcliffe efficiency coefficient (NSE), and the Mielke Skill Score (λ), based on observational data from each case study.

3 Study Site

This section presents the morphological characterisation of study sites for this research (Fig. 1), the wave characterisation, which is the main driving force of the selected equilibrium-based shoreline evolution model, and the corresponding derived shoreline orientation datasets.

3.1 Narrabeen Beach

Narrabeen Beach (Fig. 1a), located 20 km north of Sydney Harbour, is a 3.6 km embayed beach system bordered by Narrabeen Headland to the north and Long Reef Point to the south. It has two beaches—Narrabeen Beach in the north and Collaroy Beach in the south—and a small intermittently open lagoon at its northern end [4]. The site is a microtidal beach, characterised by homogeneous fine-to-medium quartz sand (median grain size ~ 0.3 mm) with ~ 30% carbonate content, forming a largely closed sedimentary system [5]. Shoreline data were collected through the Narrabeen-Collaroy monitoring program monthly (1976–2019), evolving from traditional methods to RTK-GPS surveys in 2004, with beach profiles measured at five cross-shore locations (PF1, PF2, PF4, PF6, and PF8). Wave climate data (1979–2019) using wave roses (Fig. 2), indicate that Hs range from 0.4–9.0 m, predominantly from the South-Southeast. Seasonal variability shows east-northeast waves dominate in summer, shifting to southward waves in winter.

3.2 Moncofa Beach

Moncofa Beach (Fig. 1b), an urbanised microtidal coastline between the ports of Castellón and Sagunto on the Spanish Mediterranean coast, consists of artificially embayed beaches separated by groins. Sediment sizes vary from fine sand to pebbles, reflecting the system's constructed nature [6]. The shoreline orientation data were derived from Landsat 5, Landsat 8, and Sentinel-2 images from April 2017 to January 2020 [6]. Wave climate data (1979–2020) using wave roses (Fig. 2), indicate a bimodal seasonal pattern, with storm waves frequently arriving from the East-Northeast and eastward swells dominating the summer. Hs range from 0.03–4.0 m, with Tp spanning 0.5–11.5 s.

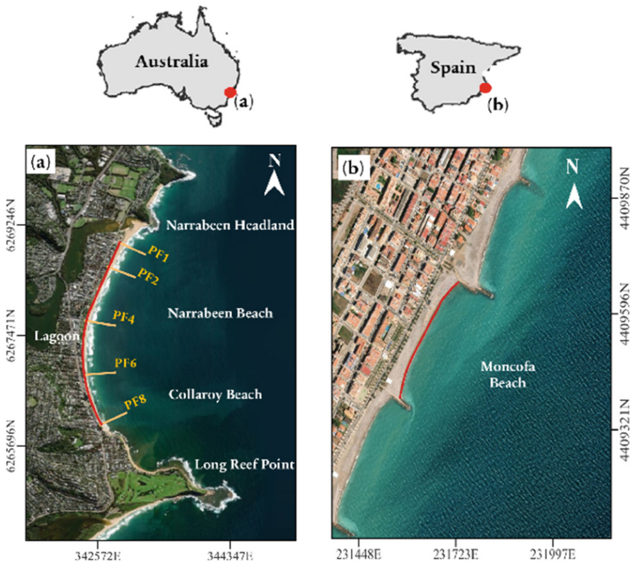

Fig. 1. Location of study sites: (a) Narrabeen-Collaroy Beach, Australia, highlighting the location of the five monthly survey transects (PF1, PF2, PF4, PF6, PF8); (b) Moncofa Beach, Spain.

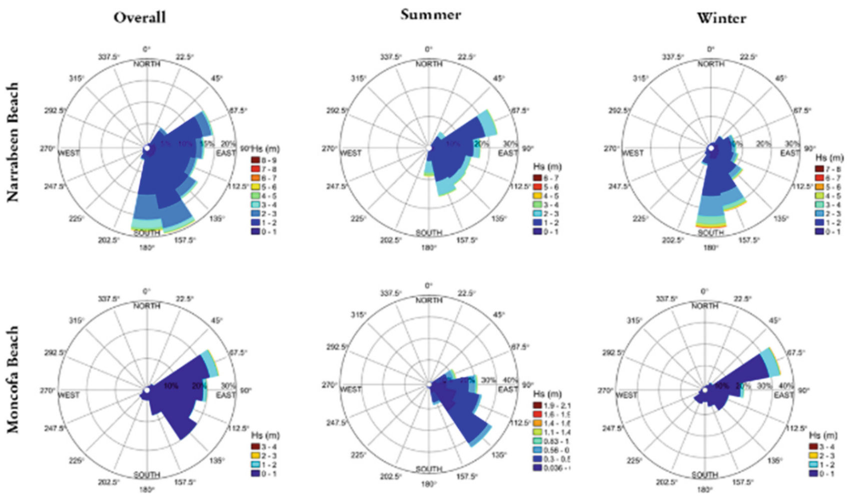

Fig. 2. Directional wave rose of Hs for Narrabeen Beach and Moncofa Beach categorised by all months, summer months, and winter months.

4 Results

This section presents the results obtained using the JA21 shoreline rotation evolution model for Narrabeen's sandy beach in Australia and Moncofa's gravel beach in Spain. Each panel provides quantitative statistics (RMSE, λ, NSE) to evaluate how well the model performs compared to the measurements and their corresponding calibration parameters (L^{+}, L^{-}, , a, b). The black line represents the model results, while the grey dots represent the measured orientation data over the study period.

4.1 Narrabeen Beach

The performance of the JA21 model for Narrabeen Beach was assessed from 1976 to 2019. The model effectively captured shoreline rotation variability, particularly from 1995 onward (Fig. 3a). This accuracy is supported by an RMSE of 0.23º, indicating close agreement with measured data. The λ value 0.82 demonstrates a strong correlation between predictions and observations, confirming reliable performance [7]. Additionally, the NSE value of 0.70 shows that the model explains 70% of the variance in observation data, which is acceptable for results based on NSE thresholds for environmental modelling [8, 9]. The maximum recorded variability in shoreline orientation at Narrabeen Beach was 1.96° during the study period, highlighting the beach's dynamic nature.

4.2 Moncofa Beach

The JA21 model demonstrated good performance in capturing the variability of shoreline orientation at Moncofa Beach during the study period (Fig. 3b). It effectively captured the general trends of shoreline rotation, with strong agreement with the observed data from July 2018 onwards. The model achieved a RMSE of 1.51°, reflecting the significant rotational dynamics of 12.34°, recorded on the beach. The λ of 0.79 and NSE of 0.65 indicate a strong correlation between the predictions and measured values [7, 9].

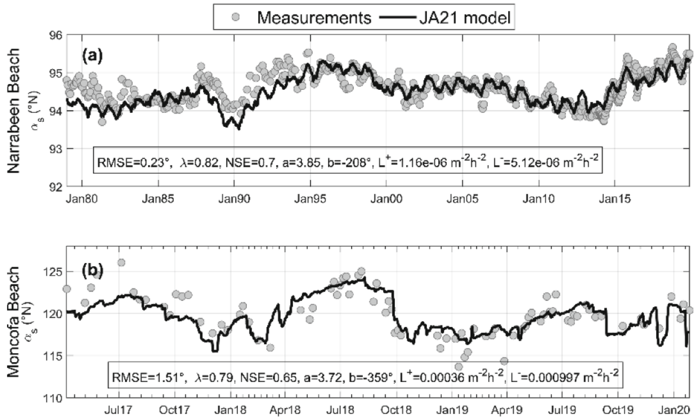

Fig. 3. Model results of the shoreline orientation evolution model (a) Narrabeen Beach and (b) Moncofa Beach.

5 Conclusion

The model effectively captured the natural variability of shoreline orientation across diverse morphological settings, integrating data from varying sources, frequencies, and durations. Quantitative metrics demonstrated satisfactory model performance, particularly in capturing seasonal rotation trends. At Moncofa Beach, the model accurately represented shorter-term clockwise rotations from summer to winter and counterclockwise trends from winter to summer. Similarly, Narrabeen Beach effectively modelled long-term rotational dynamics, highlighting the equilibrium-based shoreline evolution model's (EBSEM) capability to predict shoreline variability across short- and long-term temporal scales. These results emphasise the potential of EBSEM for diverse coastal management applications.

Acknowledgements. The authors acknowledge the support of the ThinkInAzul programme, which is supported by MCIN/Ministerio de Ciencia e Innovación with funding from European Union NextGeneration EU (PRTR-C17.I1) and Comunidad de Cantabria. C.J. has been supported by a Margarita Salas post-doctoral fellowship funded by the European Union-NextGenerationEU, Ministry of Universities and Recovery and Resilience Facility, through a call from the University of Cantabria.

References

1. Jaramillo C, González M, Medina R, Turki I (2021) An equilibrium-based shoreline rotation model. Coast Eng 163:103789. https://doi.org/10.1016/j.coastaleng.2020.103789

2. Turki I, Medina R, Coco G, Gonzalez M (2013) An equilibrium model to predict shoreline rotation of pocket beaches. Mar Geol 346:220–232
3. Blossier B, Bryan KR, Daly CJ, Winter C (2017) Shore and bar cross-shore migration, rotation, and breathing processes at an embayed beach. J Geophys Res Earth Surf 122:1745–1770
4. Morris BD, Turner IL (2010) Morphodynamics of intermittently open–closed coastal lagoon entrances: New insights and a conceptual model. Mar Geol 271:55–66
5. Turner IL et al (2016) A multi-decade dataset of monthly beach profile surveys and inshore wave forcing at Narrabeen Australia. Sci. Data 3:160024
6. Gomes da Silva, P., Jara, M.S., Medina, R., Beck, A.L., Taji, M.A.: On the use of satellite information to detect coastal change: demonstration case on the coast of Spain. Coast. Eng. (2024). https://doi.org/10.1016/j.coastaleng.2024.104517
7. Duveiller G, Fasbender D, Meroni M (2016) Revisiting the concept of a symmetric index of agreement for continuous datasets. Sci Rep 6:19401
8. Moriasi DN, Arnold JG, Va Liew MW, Bingner RL, Harmel RD, Veith TL (2007) Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans ASABE 50(3):885–900
9. Nash JE, Sutcliffe JV (1970) River flow forecasting through conceptual models part I — a discussion of principles. J. Hydrol. (Amst) 10:282–290

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.