SIMULATING LONGSHORE SHORELINE CHANGE: IMPROVING PERFORMANCE OF ONE-LINE MODELS

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BACKGROUND

One-line models are a popular reduced-complexity approach to simulating shoreline change driven by gradients in longshore sediment transport. The rate of sediment transport is typically calculated using an empirical formula based on the direction of incident waves relative to the shoreline, such as the CERC (US Army Corps of Engineers, 1984) or Kamphuis (1991) equations. Examples utilising this approach include well-known standalone models of longshore change like GENESIS (Hanson, 1989), CEM (Ashton et al., 2001), and more recently ShorelineS (Roelvink et al., 2020), as well as hybrid models combining cross-shore and longshore processes such as CoSMoS-COAST (Vitousek et al., 2017), COCOONED (Antolínez et al., 2019), and ShorelineEvol (de Santiago et al., 2021).

SENSITIVITY TO MEAN WAVE DIRECTION

Recently, Chataigner et al. (2022) demonstrated that one-line models of longshore shoreline change are highly sensitive to biases in mean nearshore wave direction data. They found that increasing the standard deviation of bias by 1° increased the standard deviation of shoreline position errors by 5 m at Narrabeen-Collaroy Beach, Australia. Without correcting for this, one-line models can produce substantially erroneous results dominated by realignment of the simulated shoreline (Figure 1). This issue is not confined to Narrabeen, with similar modelled shoreline realignment identified at sites along the US Pacific Northwest coast by Anderson et al. (2018) and Antolínez et al. (2019). Biases in nearshore wave direction data can easily arise when measured nearshore wave data is unavailable (typical of most sites world-wide) and wave conditions are propagated from offshore points using incomplete or coarse-resolution bathymetry, or at deeply embayed beaches where waves undergo further refraction from nearshore to breaking.

Chataigner et al. (2022) were able to resolve this issue at Narrabeen by adjusting the mean wave direction at each modelled transect by a different, but temporally constant, correction angle. These correction angles were optimised by running a two-stage Monte Carlo simulation of 25,000 total model runs. While very effective, this approach incurs significant computational expense as runtimes of one-line models are often on the order of several minutes for multi-decadal simulation periods. Additionally, this introduces an extra free parameter for every transect in the model's spatial domain, leading to tens or hundreds of free parameters for typical domains that use transect spacings of 100-200 m alongshore.

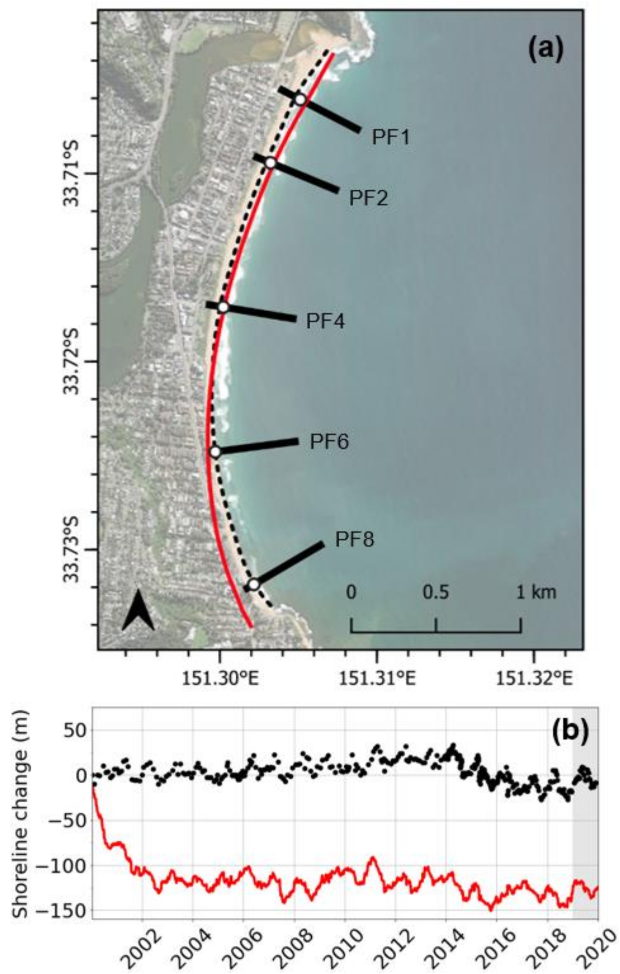

Figure 1 – A one-line model simulating incorrect shoreline realignment in response to biased nearshore wave direction data at Narrabeen-Collaroy Beach, Sydney, Australia. (a) Plan-view of discrepancy in shoreline position. The initial shoreline for the simulation (black dashed line) is interpolated from the shoreline position measured at five transects in January 2000. The modelled shoreline after a 20-year simulation period, averaged over the final year, is shown in red. In contrast, the final measured position along each transect averaged over the same year is shown as white points. (b) Timeseries of observed (black points) and modelled (red line) shoreline positions at transect "PF8", where realignment is most pronounced. The model correctly replicates many seasonal and interannual oscillations, but the mean shoreline position is substantially offset. (Period averaged to create final shoreline positions in (a) is in grey.)

METHODS

Here, three approaches were evaluated for their effectiveness in resolving the issue of biased wave direction data and improving one-line model performance at Narrabeen-Collaroy Beach, Sydney, Australia, a site considered to be a closed sediment compartment:

(1) The 'optimal correction angles' approach of Chataigner et al. (2022), as described above;

(2) A 'virtual equilibrium shoreline' approach based on Anderson et al. (2018), Antolínez et al. (2019) and Robinet et al. (2020), where the modelled shoreline was allowed to equilibrate with the uncorrected wave conditions and the model re-started with this equilibrium shoreline as the initial shoreline for subsequent simulations; and

(3) 'Shore-normal waves', where the long-term mean wave direction was assumed to be perpendicular to the shoreline at each transect in the absence of long-term trends in shoreline position, and the wave direction data adjusted accordingly.

Each approach was tested using a one-line model and shoreline position data from ongoing field surveys at Narrabeen, where weekly to monthly measurements are available from 1976. The 10-year period 2000-2010 was used for model calibration and the following 10-year period 2010-2020 was used for blind validation.

Subsequently, the transferability of these three methods will be examined by comparing them at an additional site in southeastern Australia, where the sediment compartment is open and gradients in sediment transport drive long-term shoreline change.

RESULTS

Preliminary results suggest that all three approaches are able to correct for biased wave direction data at Narrabeen and enable the one-line model to reproduce measured shoreline change. The most computationally expensive approach (method 1; 'optimal correction angles') resulted in the best model performance. The 'virtual equilibrium shoreline' approach (method 2) resulted in good performance but may be vulnerable to over-correcting if the equilibrium shoreline position incorrectly compensates for interannual variability in mean wave direction as well as bias. The final approach (method 3, 'shore-normal waves'), provided a simple, effective solution with no additional computational cost in running the model. However, it is only appropriate at sites where the mean wave direction is indeed perpendicular to the shoreline, which is not the case for drift-aligned beaches.

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