Exploring the role of vegetation and sediment supply to coastal dune states using integrated process-based modelling

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Exploring New approaches to simuLAte long-term Coastal Evolution

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Introduction – objective

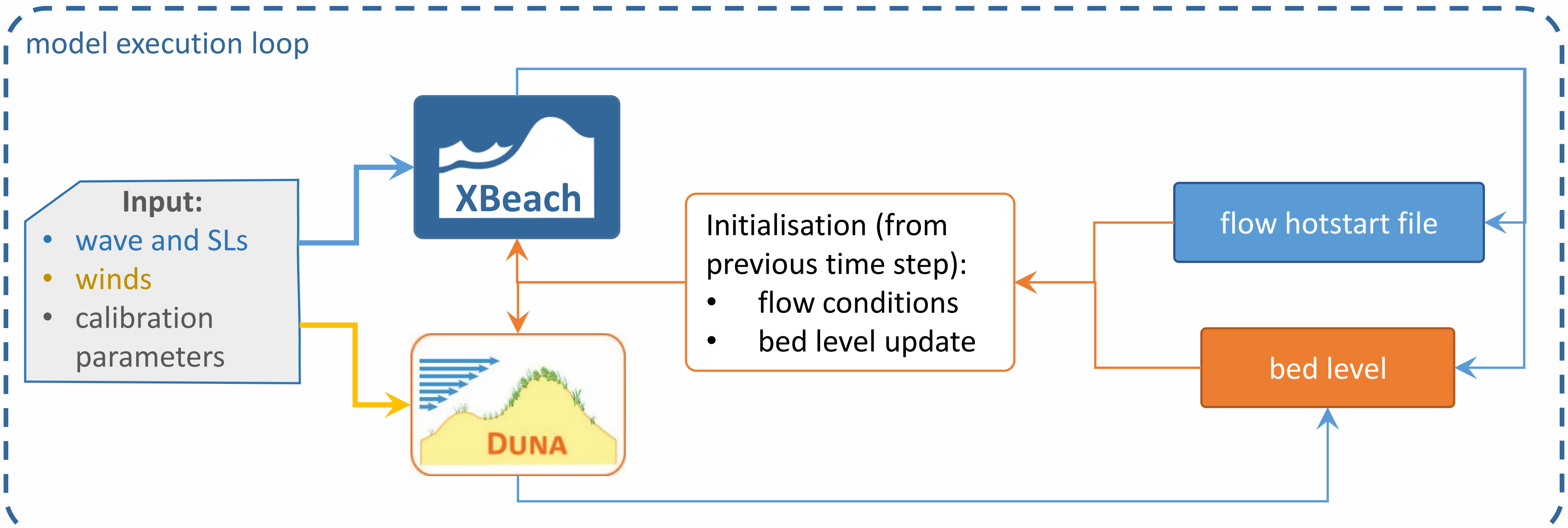
- Complex adaptive systems may exhibit a range of assembly "states or stability domains" (sets of unique biotic and abiotic conditions) derived from non-linear interactions among their components (Perry, 1995; Levin, 1999). Transitions occur from one state to another, in what is known as a state shift and occurs when the system is "perturbed".
- Coastal dune morphology is controlled by complex interactions and feedbacks between sediment transport and vegetation cover, displaying a continuum of topographic states that determine system resilience.
- Coastal dune morphology is key to achieve maximum efficiency of nature-based solutions. Therefore, developing approaches that integrate processes that are key to coastal dune morphology becomes crucial to efficiently design and test solutions that meet the timescale requirements of coastal management.
- The process-based XBeach-Duna model has been developed to integrate nearshore, aeolian and ecological processes across the beach-dune profile, thus allowing long-term simulation of complex coastal features and feedbacks.
- The potential of XBeach-Duna model to simulate the morphological response of coastal dunes to changes in sediment supply and vegetation cover over decadal timescales is examined here.

Problem setting

The Challenge

Can we reproduce the response to perturbations of highly intricate systems such as coastal dunes where morphology results from complex interaction between marine, aeolian and ecological processes?

The Approach

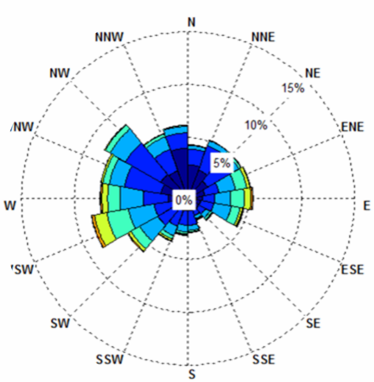


Roelvink & Costas (2019)

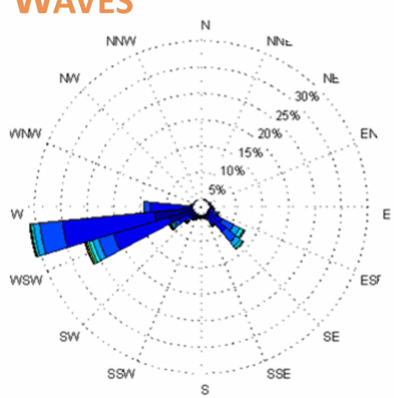
Study area

- The study area is **Praia de Faro** (Faro Beach) in the eastern part of Ancão Peninsula (W end of the Ria Formosa barrier system in S. Portugal; Figure).

WINDS



WAVES

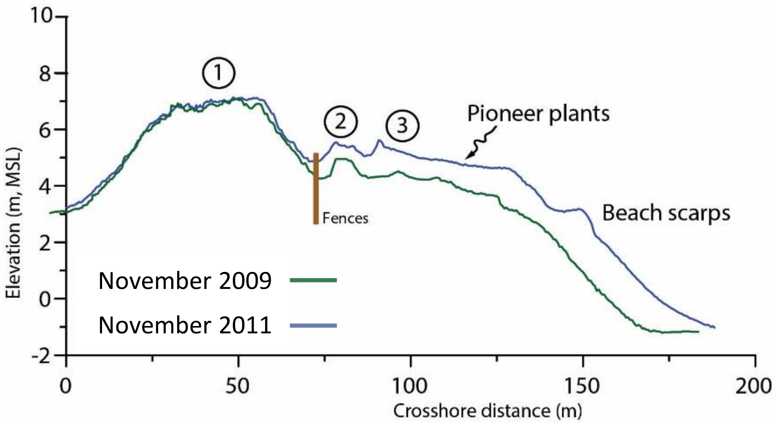


Eco-morphology

- The area is characterised by a **steep beach-face**, with average slope around 10%, varying from 6% to 15% (Vousdoukas, Almeida, & Ferreira, 2012), coarse to medium sand and multiple foredune ridges with relatively low vegetation density.

Cross-shore profile

Evolution of the profile between november 2009-november 2011



① Former and fixed dune ridge

② First active foredune

③ Second active foredune

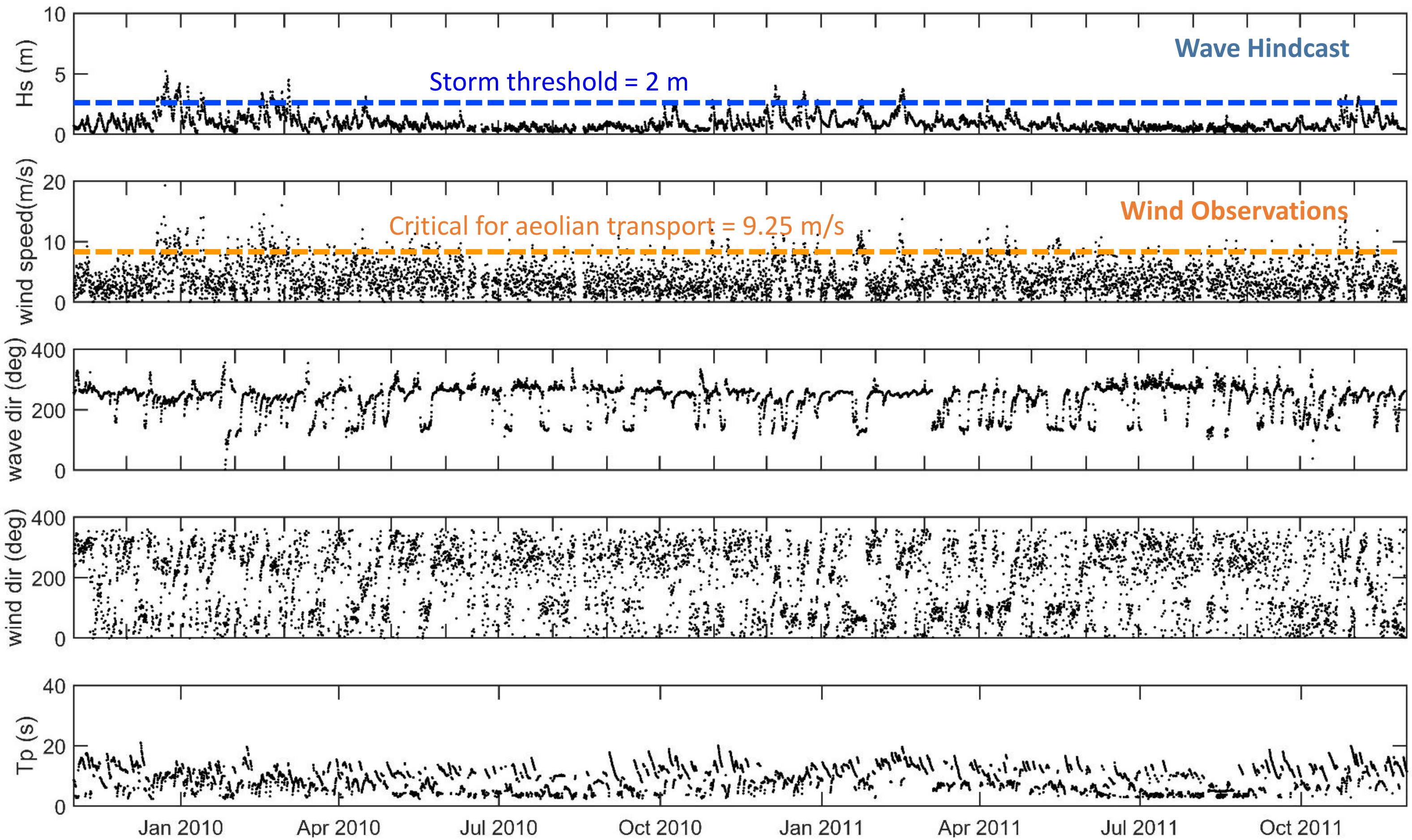
①

②

③

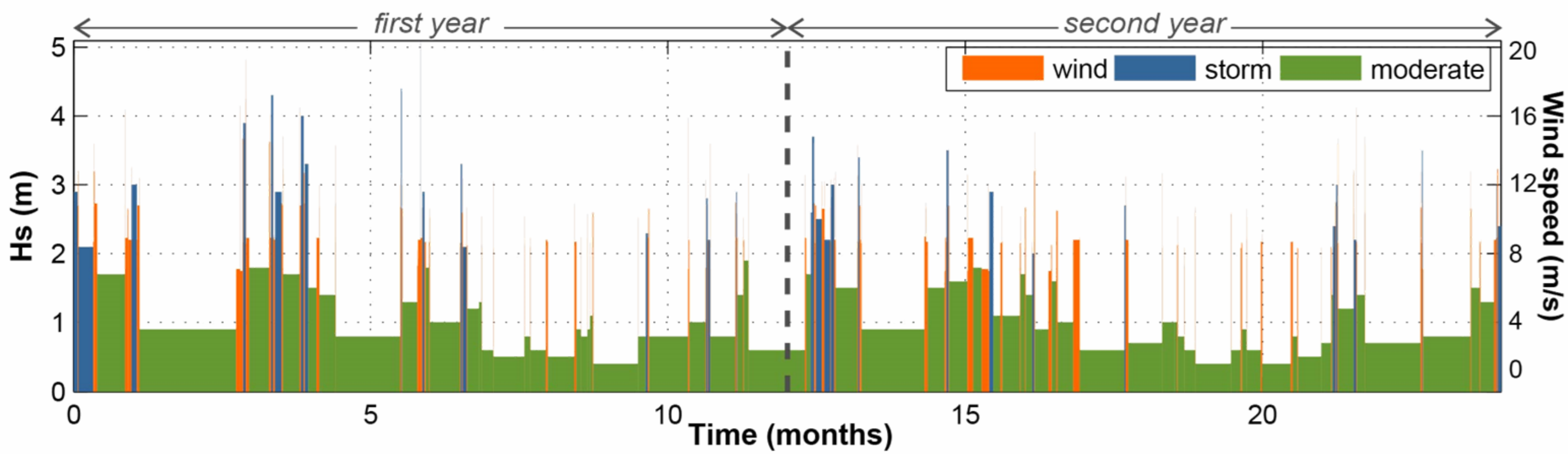
Meteocean forcing

- Meteocean conditions for the period November 2009- November 2011



The approach

- Schematisation of meteocean (wave and wind) conditions for the period November 2009- November 2011.



Input:

- Intra- and Interannual varibility;
- Moderate waves (green bars) $H_0 < 2$m
- Storms (blue bars) defined by $H_0 > 2$ m
- Winds (orange bars) above critical velocity
- Morfac parameter; moderate (25) and storms (5)
- Bermslope parameter (0.12)

Process-based models:

Wind	[V_{10m} dir]	→ **1D Duna**
Storm waves	[H_0 T_p dir z]	→ **1D XBeach** (surfbeat mode)
Moderate waves	[H_0 T_p dir z]	→ **1D XBeach** (stationary mode)

The approach

- Simulations run for …

1) Testing the effect of variable sediment supply and wind strenght on beach-dune profile evolution over 20 years

- Runs with variable longshore gradients and wind magnitude

DUNA & XBEACH	longshore gradient (LS in 10^{-4} m^{-1}) (progradation rate m/yr))		
	-2 (-5 m/yr)	2 (5 m/yr)	5 (11 m/yr)

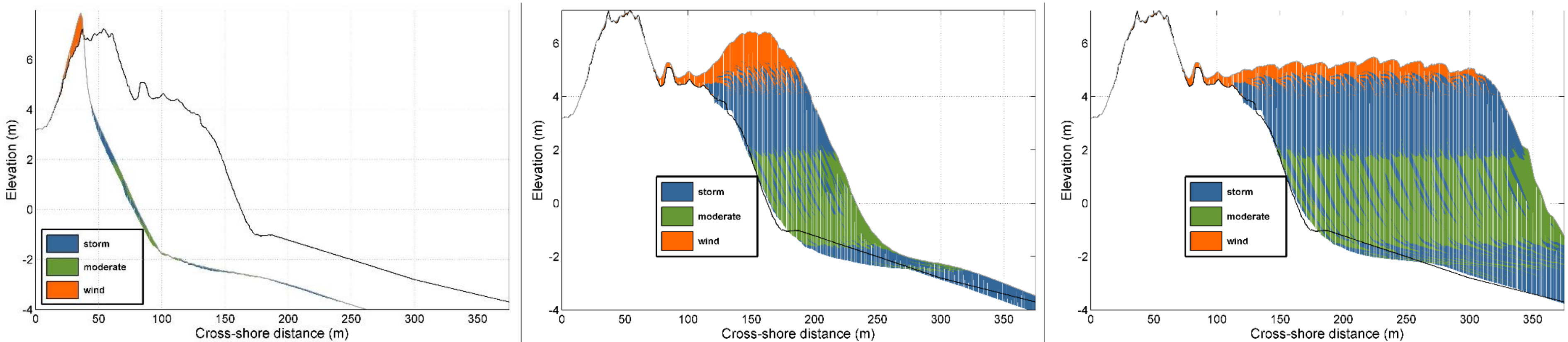
2) Testing the effect of different functional vegetation types on beach-dune profile over 20 years

- Runs with variable vegetation growth rates

DUNA & XBEACH	vegetation growth rates		
	very low	standard	very high

Results

- Testing the effect of variable sediment supply on the 1D beach-dune profile by changing longshore gradients (LS) and progradation rates (PR)

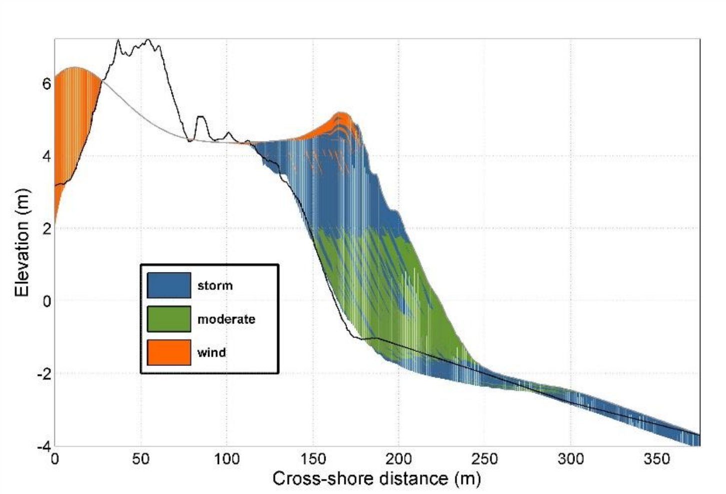


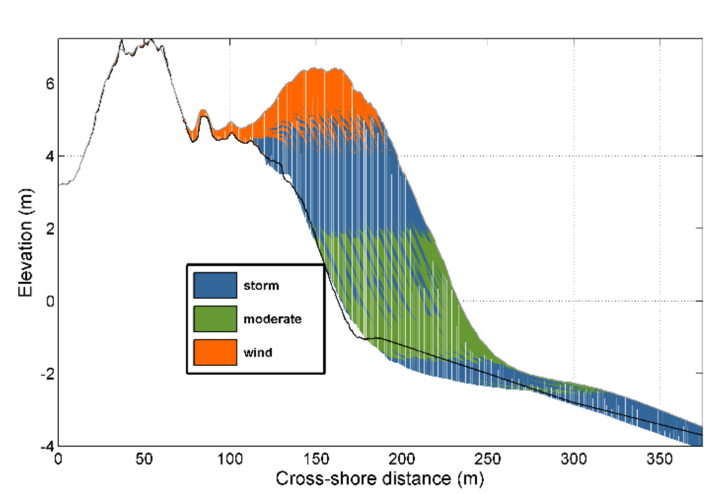
LS =	-2×10^{-4} m^{-1}	2×10^{-4} m^{-1}	5×10^{-4} m^{-1}
PR =	-5 m/yr	5 m/yr	11 m/yr
	Narrow ridge – close to cross a threshold – with relative increase in elevation	One large new dune ridge similar to former ridge (1)	Multiple and low dune ridges resembling ridges (2) and (3)

*The calibration of modelling parameters was done using the evolution of the profile observed between 2009 and 2011. Simulations used the same parameters and the schematized meteocean conditions between 2009 and 2011 repeated 10 times to simulate 20 years of change

Results

- Testing the effect of different vegetation functional groups (i.e. dune builders, burial tolerant and burial intolerant) on the 1D beach-dune profile as well as possible environmental changes that may modify vegetation growth (e.g. precipitation)





GR =	very low	high
PR =	5 m/yr	5 m/yr
	New state (transgressive dunes) after system perturbation ▪ Growth rate drops (e.g. very low precipitation) ▪ Shift in plant communities to burial intolerant	One single ridge state dominated by dune builder plant communities

Concluding remarks

- The approach was tested to reproduce the natural response to changes in sediment supply, shifting the shoreline position and simultaneously modifying the overall shape of the dune, within a range of dimensions that are in agreement with observations.
- In general, narrow and low dunes are formed under high supply conditions, wide and high dunes develop if sediment supply is low and the shoreline position stable, while narrower and higher dunes are created after a relative drop in sediment supply that induces a negative budget.
- The approach was able to reproduce different states as a consequence of changes in the feedbacks between morphology and plants community. The latter tentatively represented shifts in vegetation functional types provoked by perturbations affecting the system.
- Denser and healthier vegetation coverage favours taller dune morphologies while weak vegetation cover may favour the formation of transgressive dunes and inland transference of sand.
- The results demonstrate the capacity of the approach to reproduce different dune states, resulting from alternative evolutionary pathways, and its potential to identify coastal dune (in)stability domains and critical morphological shifts, factors that are key to better understand the efficiency of dunes as nature-based solutions for coastal management.
- Future steps will include the explicit introduction of different vegetation functional groups and real meteocean conditions

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