RESHAPING THE UNDERSTANDING OF BEACH RESPONSE TO SEA-LEVEL RISE FOR EQUILIBRIUM SHORELINE MODELLING

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INTRODUCTION

Sandy beaches are highly vulnerable to short-term and long-term erosion due to waves and sea-level rise (SLR), respectively. As global SLR is accelerating due to climate change, reliable projections of shoreline change on long time scales (>decadal) are critical for coastal adaptation planning. Some shoreline models that address such long-term projections rely on the equilibrium beach theory to estimate the effects of waves and SLR. However, so far, the effects of interactions between SLR and wave action are not resolved explicitly. In this work, we present a novel physical interpretation of the beach response to SLR in the context of equilibrium beach theory. Using this concept, we analyze the integration of SLR effects into wave-driven equilibrium shoreline models, while accounting for the interactions between SLR and incident waves.

METHOD

Based on the concepts of long-term (Dean, 1991) and short-term (Wright and Short, 1984) (dis)equilibrium of beaches, we decompose SLR-driven shoreline change in two main processes: passive flooding and an increased wave-driven erosion efficiency (or 'wave reshaping', Fig. 1, D'Anna et al., 2021). Passive flooding (PF, Fig. 1) is estimated as the instantaneous geometric landward shift of the shoreline in response to SLR (Anderson et al., 2018), as follows:

$$PF = \frac{SLR}{\tan(\beta)} \qquad (1)$$

where $\tan(\beta)$ is the slope of the beach foreshore (e.g. defined as the intertidal portion of beach). The wave reshaping effect stems from an increase in beach-wave climate disequilibrium induced by SLR.

To model the interaction between these two effects, we couple the passive flooding (Eq. 1) with a wave-driven equilibrium shoreline model (ESM, e.g. Yates et al., 2009) to resolve the wave reshaping effect explicitly. The two models are coupled dynamically allowing feedbacks between the modelled processes so that the disequilibrium condition of the ESM is influenced by PF (thus by SLR). As a first step, we test the integrated model on an idealized case, adopting a simplistic assumption on the SLR-driven disequilibrium. In this test case, an instantaneous 30 cm SLR and constant wave energy are applied to an idealized cross-shore transport dominated beach inspired by Truc Vert beach (France). The model results are also compared to the popular Bruun (1962) Rule, which describes both processes implicitly under a number of assumptions.

Current work is focused on quantifying the SLR-induced beach-wave disequilibrium analyzing data from existing laboratory studies that observed the equilibrium beach response to controlled SLR and wave conditions (e.g. Atkinson et al., 2018). Finally, based on the equilibrium beach theory (Dean, 1991) we plan to derive an analytical relationship to express the increase in beach-wave disequilibrium as a function of PF.

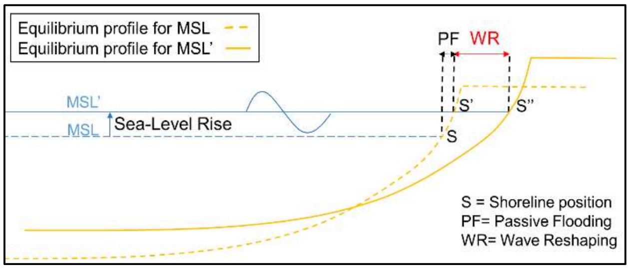

Figure 1 - Conceptualization of shoreline response to SLR decomposed in passive flooding (PF) and wave reshaping action (WR).

MAIN RESULTS AND IMPLICATIONS

The results of the idealized model application indicate that the integrated PF and ESM models reproduce the two components of the proposed physical interpretation of SLR-driven shoreline response (Fig. 2). In this idealized case, we observe the immediate shoreline retreat due to passive flooding in response to the step-wise SLR (~11 m) and the wave reshaping effect producing a further gradual erosion (~13 m) during the following 3-6 years (depending on the wave height).

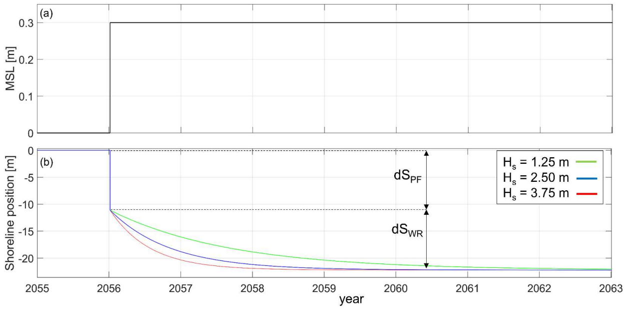

Figure 2 – Application of the integrated model for constant wave energy and a 30 cm instantaneous finite SLR. (a) Mean sea-level time series; (b) shoreline response showing the instantaneous PF and the progressive effect of wave reshaping for constant mean incident wave height of 1.25 m (green line), 2.50 m (blue line) and 3.75 m (red line).

A different idealized case application (not shown) showed that, when Bruun's assumptions are satisfied, the integrated model produces a long-term (80 years) shoreline recession consistent with the Bruun model estimate. This suggests that the proposed concept can describe the physical background of the Bruun model, which so far was implicit.

Preliminary analytical developments of Dean's (1991) equilibrium beach theory provided a simple formulation expressing the change of wave-driven erosion efficiency, directly as a function of SLR. The ongoing analysis of the available laboratory data will be used to validate or adjust this formulation.

Our results support the integration of SLR impacts in ESMs for future studies, making a step towards the development of a generalized equilibrium shoreline model. Indeed, such an approach describes the physics of shoreline response to SLR more explicitly than the most used existing models (i.e. Bruun Rule), removes many underlying assumptions of existing equilibrium-based models that limit their applicability to very few real cases.

Further ongoing work includes a deeper analysis of the laboratory data (e.g. Atkinson et al., 2018) and the model validation with real-case applications at sites where the wave reshaping is expected to be the dominant process, (i.e. characterized by fast sea level fluctuations and a low-energy wave climate) such as Dune Acre (Lake Michigan, USA), Fereydounkenar Port (Iran) and Hasaki (Japan).

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