LONG-TERM, ENSEMBLE, DATA-ASSIMILATED SHORELINE CHANGE MODELING

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INTRODUCTION

We present an ensemble Kalman filter shoreline change model to predict long-term coastal evolution due to waves, sea-level rise, and other natural and anthropogenic processes responsible for sediment transport. The model utilizes ensemble simulations to improve both reliability (via data assimilation) and uncertainty quantification. Coastal change projections exhibit significant differences when simulated with and without ensemble wave conditions. Many long-term coastal change projections rely on a single realization of the future wave climate, often derived from atmospheric conditions simulated by a global climate model. Yet, the single realization approach does not account for the stochastic nature of future wave conditions across a variety of temporal scales (e.g., daily, weekly, seasonally, and interannually). Here, by applying ensemble time series of wave forcing conditions, we demonstrate a sizable increase in model uncertainty compared with the unrealistic case of model projections based on a single realization (e.g., a single time series) of wave forcing.

DATA AND MODEL

We apply the developed ensemble shoreline change model to a well-monitored beach in Tairua, New Zealand. The shoreline change model is forced with waves derived from a climate-based stochastic emulator, capable of providing different realizations of hourly wave conditions for thousands of years. The main goal of the wave emulator is to reproduce not only the historical intra-seasonal, seasonal and interannual variability scales, but also the intra-storm chronology, a key issue for equilibrium shoreline change models.

The shoreline change model used here is a modification of Yates et al., (2009) and is given by

$$\frac{dY}{dt} = -\frac{H_s}{\Delta T}\left(\frac{H_s^2 - \bar{H}_s^2}{\bar{H}_s^2} + \frac{Y}{\Delta Y}\right) \quad (1)$$

where Y is the shoreline position, t is time, H_s is the significant wave height, and the model parameters are given by ΔT (the equilibrium time scale), ΔY (the equilibrium shoreline excursion), and $\bar{H}_s$ (the background wave height). The model applies an ensemble Kalman filter data-assimilation method (Evensen 1994) combined with observations of shoreline position to optimize the model parameters, which in this case, are found to be $\Delta T = 3.1$ days, $\Delta Y = 17.5$ meters, and $\bar{H}_s = 1.3$ meters.

RESULTS AND CONCLUSIONS

Ensemble forcing conditions are key to develop robust shoreline change projections in cases where the wave conditions are unknown (deterministically), yet exhibit consistent patterns (e.g., seasonally and interannually) in a statistical sense. We demonstrate that model uncertainty is increased considerably when using ensemble wave forcing conditions compared to the more common use of a single realization of wave climate (Figure 1). Additionally, it appears that the confidence bands of wave-driven equilibrium shoreline change simulations are predictable: The model uncertainty rapidly approaches a roughly constant (time invariant) value determined by a balance between the sum of the additive (i.e., prescribed) and inherent noise (e.g., due to forcing) of the system and the damping (or equilibrium response) of the shoreline change. This finding reveals a tight connection between stochastic wave forcing and shoreline response, which must be accounted for when seeking robust, uncertainty-aware projections of future coastal change.

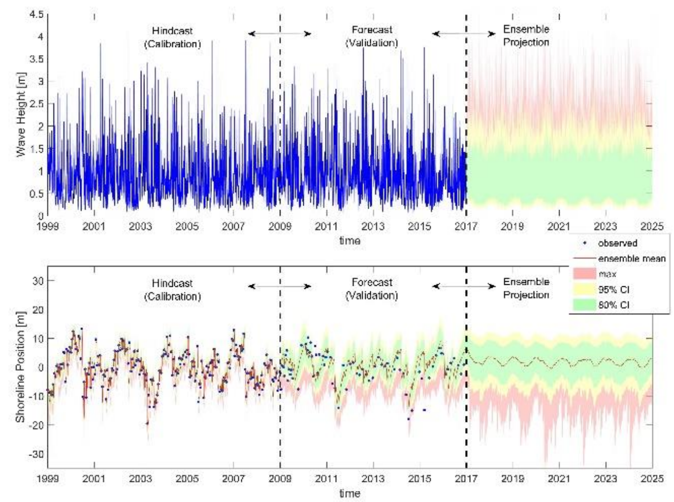

Figure 1 - The developed shoreline change model with a data assimilated ‘Hindcast’ period, a ‘Forecast’ period, and an ‘Ensemble Projection’ period produced from an ensemble of wave conditions.

REFERENCES

Yates, Guza, & O'reilly (2009). Equilibrium shoreline response: Observations and modeling. Journal of Geophysical Research: Oceans, 114(C9). Engineering, ELSEVIER, vol. 10, pp. 32-39.

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