# TIME-EVOLUTION OF COASTAL FLOODING UNCERTAINTIES USING GLOBAL SENSITIVITY ANALYSIS: INSIGHTS FROM OREWA BEACH, NEW ZEALAND

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## INTRODUCTION

Coastal flooding is caused by the combined effect of a variety of oceanographic processes that cause a rise in seawater levels, eventually leading to the breach of natural and man-made coastal defences like beaches, dunes, and coastal vegetation, as well as sea walls, revetments, and dikes. When combined with the expansion of coastal urbanisation, the negative effects of flooding events are exacerbated, impacting both environmental and socio-economic landscapes. To aid with adaptation, coastal scientists have worked over the past decades to develop predictions for future coastal flooding scenarios. Diverse methodologies, models, and datasets have been employed, each influenced by numerous variables. However, at present, the uncertainty associated to each variable is still unknown. Therefore, understanding the role of such uncertainties is critical for prioritizing research on those components that will have a larger effect and so for developing more accurate models. In this work, we applied a variance-based global sensitivity analysis to estimate the contributing uncertainty in total water levels by sea level rise, astronomical tide, storm surge and runup dynamics, both historically and until 2099. The study area is Orewa, New Zealand, a beach that is already suffering the consequences of coastal flooding and beach erosion (Figure 1).

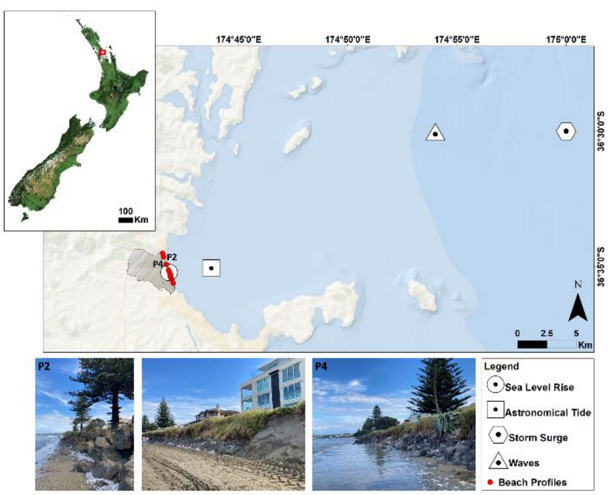


Figure 1 - Location of Orewa (hashed area) and of the data points used to extract the SLR, AT, SS, waves and beach profiles datasets. The images in the bottom panel were taken between the locations of beach profiles P2 and P4 on 18-02-2023 following the passage of cyclone Gabrielle in New Zealand (Photos from C. Dalinghaus).

## GLOBAL SENSITIVITY ANALYSIS

To investigate the uncertainty related to the various contributing factors to coastal flooding simultaneously and capture all interactions between them, a global sensitivity analysis (GSA) was applied. The purpose is to explore how variations in the input elements may impact variations in the model's output. Among the numerous GSA methods available, we used a variance-based GSA approach based on the Shapley effects (Song et al., 2016). Originally introduced in game theory, the Shapley value, ranging from 0 to 1, determines the fair contribution of each player to a game outcome, considering both their individual contribution and their interactions with other players. Here, the "players" represent the input values used in calculating total water level (TWL), which is defined as follows:

$$TWL = SLR + AT + SS + Runup \qquad (1)$$

To estimate past and, near and long-term future TWLs scenarios, we sourced four datasets:

- Sea Level Rise (*SLR*) projections from the SeaRise programme (Naish et al., 2022)
- Astronomical Tides (*AT*) predictions from the New Zealand National Institute of Water and Atmospheric Research (NIWA)
- Storm Surge (*SS*) data from Cagigal et al. (2019)
- A high-resolution partitioned wave database from Albuquerque et al. (2021, 2022), necessary to estimate wave *Runup*.

The storm surge and wave data are derived from two global circulation models (ACCESS1.0 and MIROC5) and for two representative concentration pathways scenarios (RCP4.5 and RCP8.5). The same scenarios were employed for SLR, whose evaluation includes vertical land movements. Additionally, we utilized reports from regional councils to assess beach slope (from beach profiles) and various swash (Stockdon et al., 2006; Passarella et al., 2018; Gomes da Silva, 2018, 2019) and setup (Ji et al., 2018; Dalinghaus et al., 2023) equations for runup calculations.

A Monte Carlo approach, sampling each input parameter from their respective distributions, was applied to calculate Eq. (1). We randomly sampled values of AT, SS and waves for the same day of each time series. Future SLR projections were produced assuming a Weibull distribution. These values were sampled on a yearly basis. For the choices of RCPs, global circulation models and swash and setup equations, we used a discrete uniform distribution with the same probability. Finally, we applied the variance-based sensitivity analysis on Eq. (1) for 100,000 estimations of TWL per year at Orewa beach. The results are presented across three different time periods: 1986-2004, 2026-2045 and 2081-2099.

## RESULTS AND CONCLUSIONS

The results of our analysis are presented in Figure 2.

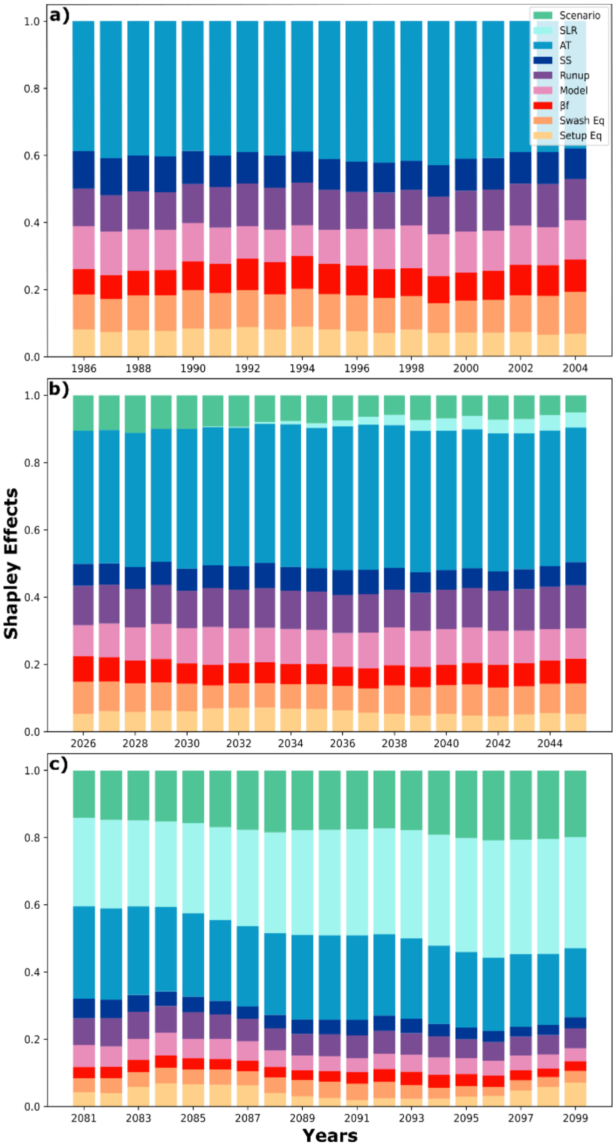


Figure 2 - Evolution of Shapley effects over time: (a) past, (b) near future and (c) long-term future, in relation to the drivers of coastal flooding applied to Orewa beach, NZ. These indices represent the relative importance of each input parameter (represented by different colours) on the variability of the model's output (TWL).

Our analysis shows that the relative importance of these sources of uncertainty changes significantly over time. In the recent past and the near future, tidal dynamics and local coastal processes are confirmed as the key drivers of flooding. Interestingly, the variability of using different wave setup and swash equations, beach slopes and models lead to similar weights. However, when we look further into the future, especially beyond 2080, sea-level rise becomes the dominant factor together with RCP scenarios uncertainties, while local coastal processes lose relative importance.

Overall, the challenge of estimating the risk of coastal flooding, particularly within the context of future scenarios, remains undermined by various sources of uncertainty. Our investigation of these uncertainties not only aids in understanding their temporal and spatial evolution but also provides valuable insights for effective adaptation planning in response to the changing climate. Most importantly, it ranks the priority towards the next steps in developing more reliable coastal models.

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