**Extreme Sea Level Estimation: Accounting for Seasonality and Long Term Changes**

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**Abstract**

Extreme sea levels pose an increasing risk to coastline communities. The UK is regularly subject to coastal flooding; the 1953 North Sea flood breached coastal defences in 1,200 places leading to the evacuation of 30,000 people, damage to 24,000 properties and a death toll of 307 in England alone. Following this event, coastal flood defences were upgraded around most of the UK. Global rises in mean sea level coupled with changes in storm behavior due to climate change have the potential to increase the likelihood of coastal flooding. Therefore, it is increasingly important to estimate extreme sea levels accurately. We develop a model from which we can estimate sea level return levels, allowing us to extrapolate past the observed range of data. We are particularly interested in rare events with large return periods to cover levels that are important to a range of industries, including agriculture and nuclear, as well as for Government organisations concerned with coastal flood risk management.

Early methods modelled sea levels directly, but this ignores the known tidal component and results were biased due to stationary assumptions being violated. Instead, we filter out waves and remove the mean sea level trend, to consider peak tide and skew surge as the only components of sea levels. Skew surges are stochastic and define the difference between the peak tide and maximum observed sea level within a tidal cycle. They are driven meteorologically, so are typically worse in winter and less extreme in summer. Methods currently used in the UK Coastal Flood Boundary report (CFB) made several restrictive and unrealistic assumptions. In our approach we correct these by accounting for seasonality, tidal interannual variations, longer-term trends and skew surge-peak tide dependence.

We model extreme skew surges using a generalised Pareto distribution. We capture seasonality, longer-term trends and the dependence between skew surge and peak tide through daily, yearly and tidal covariates in the scale and rate parameters. Since peak tides are predictable, we carefully choose our tidal samples to reflect monthly and interannual variations. To derive a distribution for the annual maximum sea levels, we combine the distributions of skew surges and peak tide. Our return level estimates are more accurate than those in the current CFB. We show that their estimates are lower than those estimated using our methodology; underestimation of return levels can lead to extreme sea levels breaching defences with devastating consequences.