Extreme Sea Level Estimation

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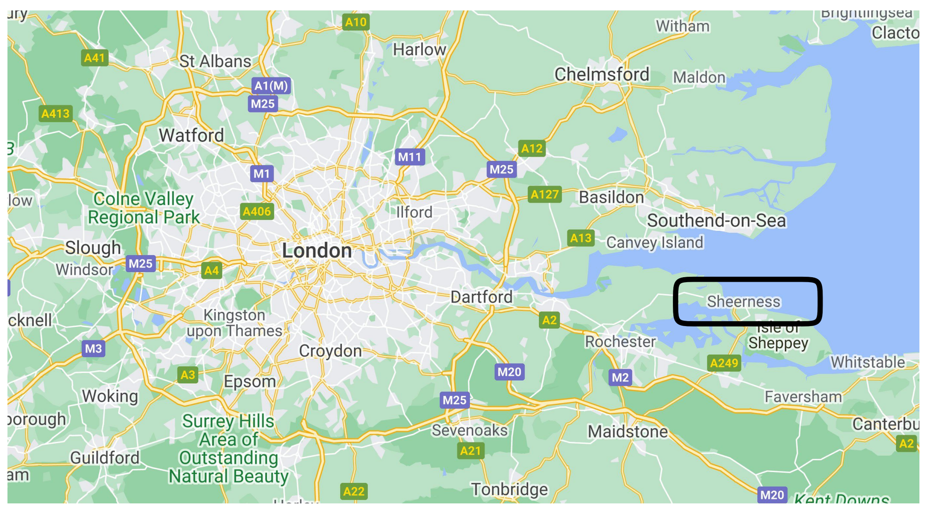
1. Motivation

- Extreme sea levels pose an increasing risk to coastline communities due to **climate change**.
- Consequences of **coastal flooding** include loss of life, damage to property and infrastructure, coastal erosion, and loss of habitats and ecosystems.
- Since the UK is regularly subject to coastal flooding, it is important that **coastal defences** are built to withstand the most extreme sea levels.
- Resources are wasted in building defences that are too high, whilst defences that are too low put coastal communities at great risk.
- The UK government spends **£1 billion** per year on flood defences.
- We study **Sheerness** as it has great societal and economic importance due to its proximity to London (see map). Here, **sea levels rise** at 1.8mm/year.



2. Modelling strategy

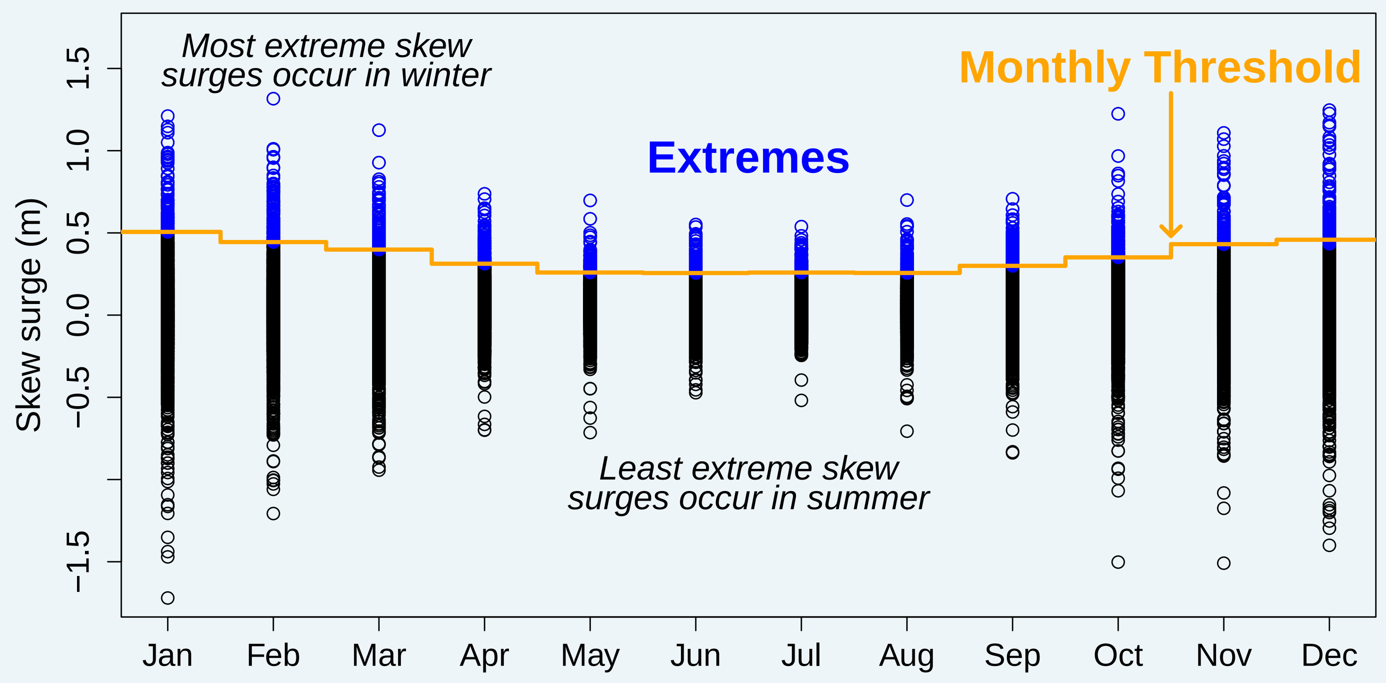
We present a novel method for sea levels from which we can estimate **return levels**. This is the value we expect sea levels to exceed every x years (**return period**). We are particularly interested in rare events, with a return period of $x = 100$ (for coastal flood defence design) or $x = 10,000$ years (for nuclear fleet protection). Return level estimation requires extrapolation to unobserved levels of the data. We use a principle based approach from **extreme value theory** to statistically model extreme values. We decompose sea levels into its components and model them separately, since extremes of each component result in extreme sea levels.

Skew Surge + Peak Tide = Sea Level

Current best estimates are based on a **method that makes several simplifying and false assumptions**. We address each of these in our **statistical model**. This is the first method to account for seasonality, long-term trends and dependence between the two sea level components. This poster describes how to capture these features and the consequences of ignoring them.

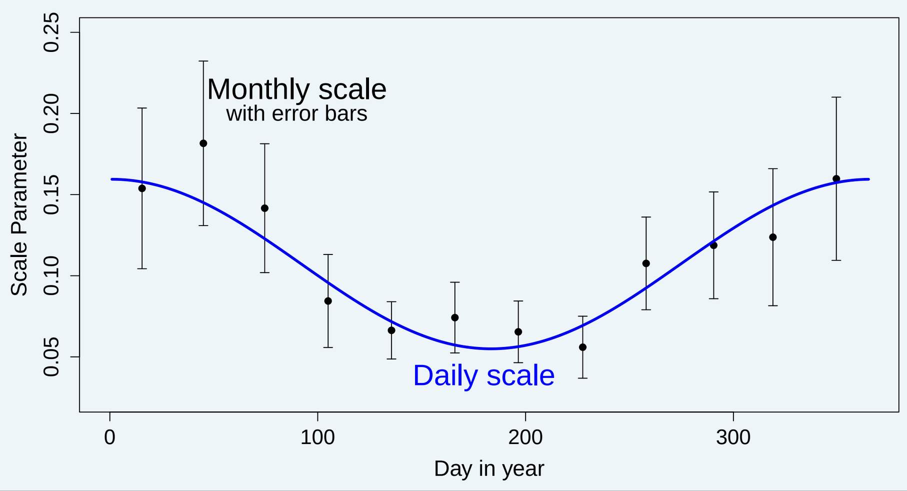
3. Modelling extreme skew surge seasonality

Skew surge is driven meteorologically and defines the difference between the maximum observed sea level and the peak tide. This requires statistical modelling; we are interested in the **extreme values**.



We define extreme values as exceedances of a **monthly threshold** and account for **seasonality**:

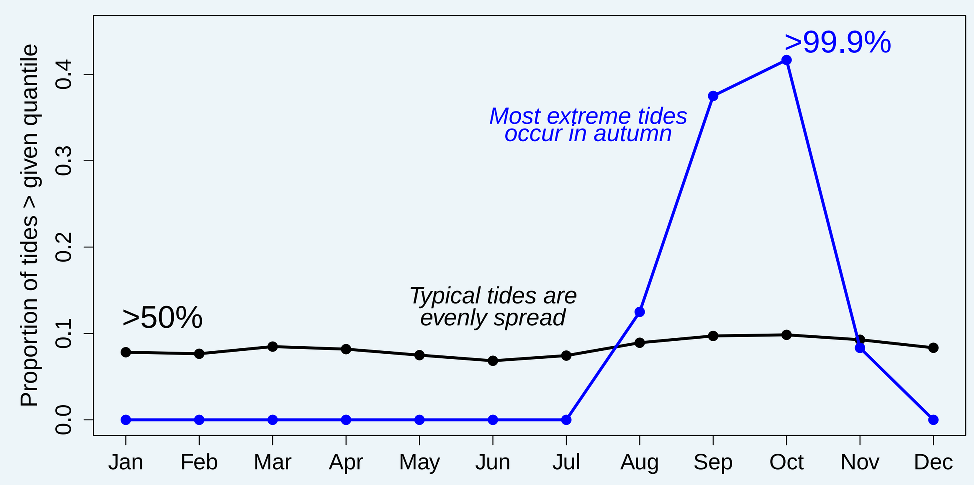
- We model exceedances of a threshold u using the **generalised Pareto distribution**, defined by a scale σ, shape ξ and rate λ parameter.
- We allow the **scale** and rate to vary with day d smoothly as a sinusoid with fitted curve, shown on the right.



4. Capturing peak tide seasonality

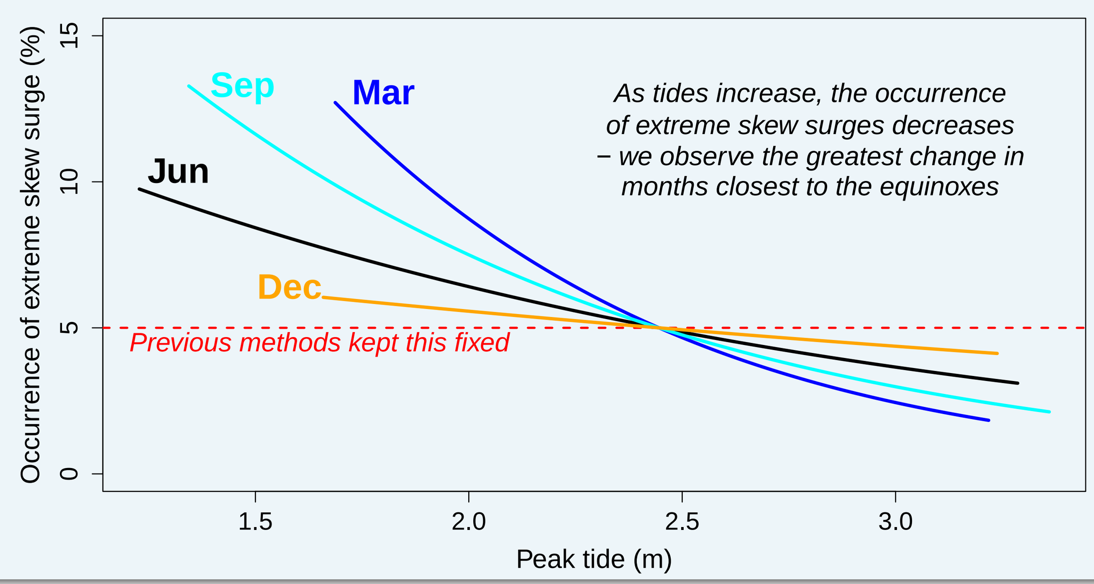
Peak Tides define the maximum tide in a tidal cycle of 12.5 hours and are the predictable rise and fall of the sea surface driven astronomically.

- We show the proportion of large peak tides that occur each month in the right figure.
- Generally, the most extreme peak tides tend to occur at the equinoxes. At Sheerness, these only occur in autumn.
- Tides vary annually but are bounded above by the **highest astronomical tide**.



5. Modelling skew surge-peak tide dependence

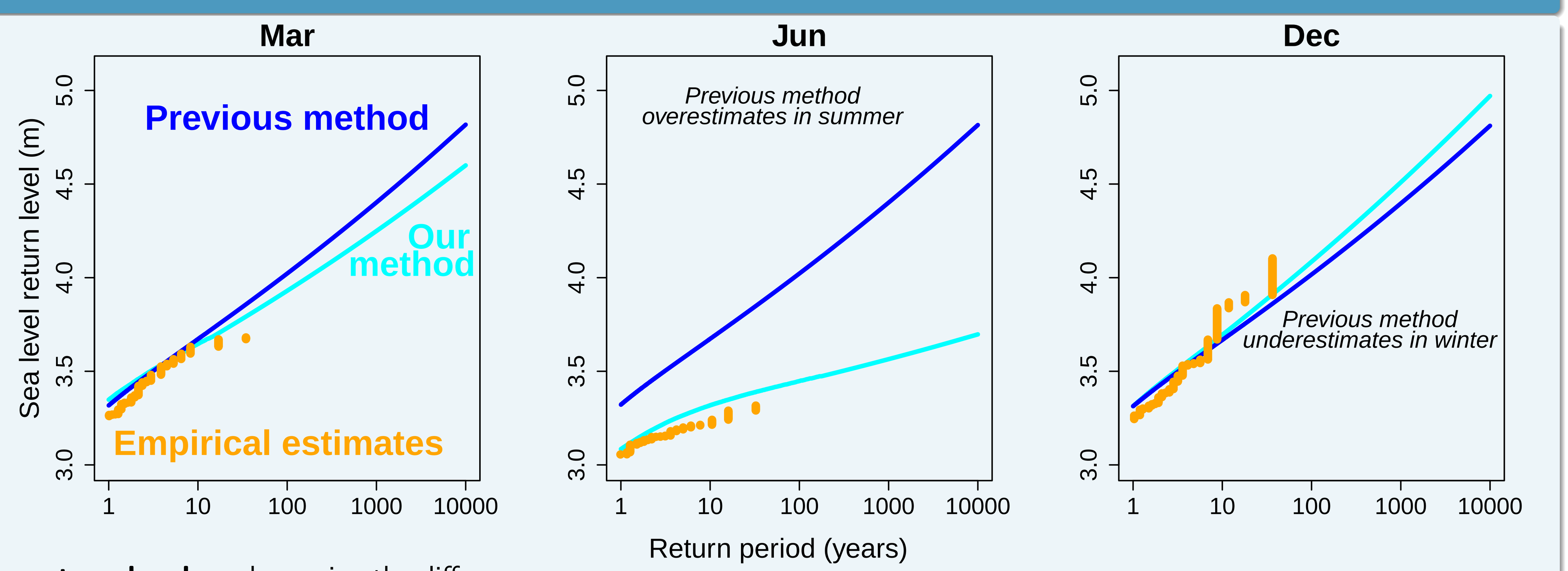
- Skew surge and peak tide exhibit **dependence** with extreme skew surges more likely to occur on lower tides.
- Ignoring this leads to overestimation of return levels.
- We allow for dependence by having the scale and **rate parameter** (right) changing with tidal level.

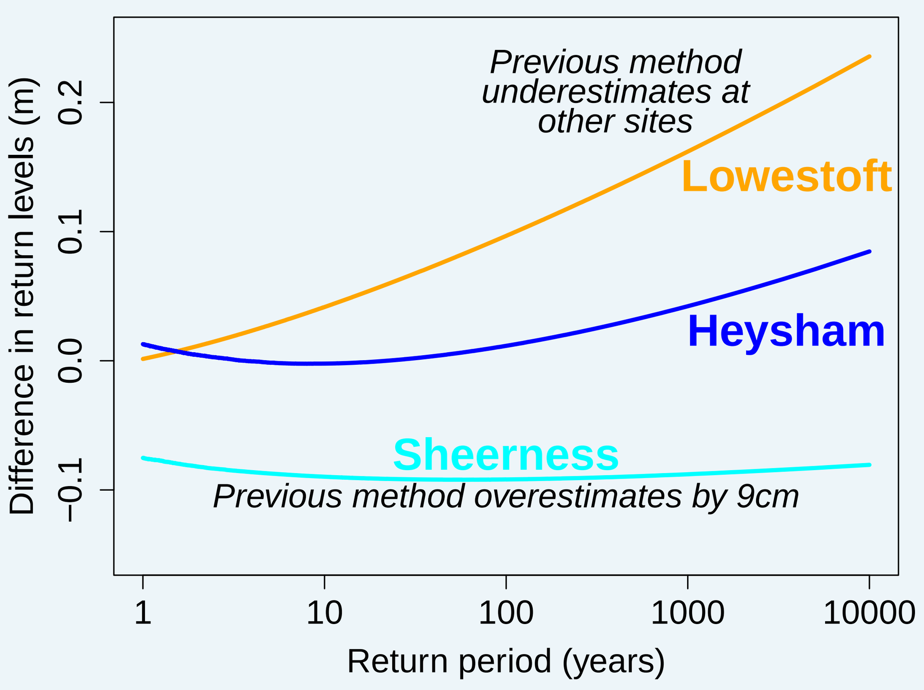


6. Results: return level estimates

The right figures show **monthly maximum return level** estimates from our method and the previous method. We compare these to **empirical estimates** (based on the data, without any statistical analysis). These provide best estimates up to the 50 year level, but give **no information about rarer events**.

- **Our model always lies closer to the empirical estimates** so is more accurate
- In June, the previous method gives an **overestimate of 1.1m** at 10,000 years
- In December, when skew surge is highest, the previous method **underestimates**.

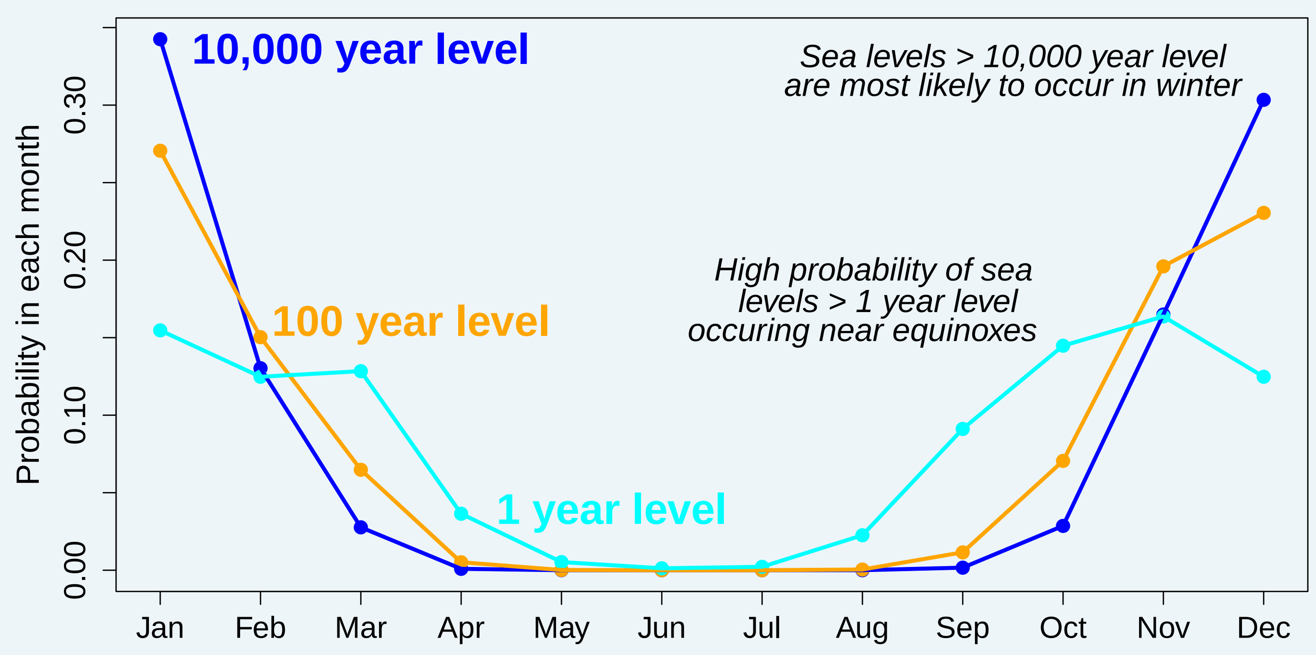




We estimate **annual maximum return levels** and examine the difference between estimates from our method and the previous method (left figure).

- We also show results for **Lowestoft** (east coast) and **Heysham** (west).
- At Sheerness, return levels are consistently **overestimated by 9cm**.
  - An extra **1m of sea wall costs £150,000 per 100m**, on average.
- At Lowestoft and Heysham, return levels are underestimated.
  - This reaches an **underestimate of 25cm** at Lowestoft at 10,000 years.

We study the **seasonality of extreme sea levels** by finding the probability a sea level occurs in each month given it is higher than a return level (right).



7. Impact

- This work is in collaboration with **EDF R&D UK Centre** whose aim is to protect nuclear fleet from coastal flooding.
- EDF are adopting our method to capture seasonality for other environmental variables, such as **significant wave height**.
- Our methodology will be used in the upgraded **Environment Agency Coastal Flood Boundary Report** to provide updated extreme sea level estimates at **all UK sites** for coastal flood risk management.
- Researchers at Southampton University intend to use our methods for seasonal extremes for **Thames Barrier** maintenance planning.

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