Euro Tempest

Water height observed during the 1953 coastal surge event to become a 1 in 10 year event by 2100

Abstract

Climate change is causing sea levels to rise around the UK. The latest scientific projections from the Met Office (UKCP18) indicate that mean sea level will continue to increase over the remainder of the century, regardless of mitigation efforts. As mean sea levels rise, the base level on which tides and storm surges are imposed increases, resulting in a greater capacity for extreme water level events. Both the frequency and magnitude of extreme events are expected to increase, leading to a rise in coastal flood risk, particularly across southern regions where net sea level change is expected to be greatest. Using tidal gauge and return period data with the latest Met Office climate projections, the return period for the extreme water height recorded at Sheerness (north Kent coast) during the 1953 storm surge event is investigated. As a result of rising sea levels under the most (RCP2.6) and least (RCP8.5) conservative climate scenarios, we find a decrease in the return period of the observed water height from ~1 in 300 years to ~1 in 50 and ~1 in 10 years respectively. Not only does this finding highlight the changing risk of extreme water levels as sea levels rise, but also exemplifies how the use of return periods is becoming a less appropriate method for describing flood risk. Return periods built on an increasingly unrepresentative historical climatology will become progressively more misleading, as in reality, a '1 in x year' event will represent different water levels as the climate changes.

Introduction

With 30% of the UK's population living less than 10km from the coast and well over £100 billion worth of infrastructure and natural resources currently at risk from coastal flooding, it is no surprise that coastal flood events are considered to be among the top four priority risks for the UK Government (HM Government 2010, Edwards 2017). Damages accrued due to coastal flood events are currently estimated to average around half a billion pounds a year, however it is arguable that this figure would be substantially higher if it weren't for the various coastal defences in force around the UK. Many of these defences were built using static return periods – calculated with reference to historical data to estimate the expected frequency of extreme water levels around the UK coast. However, as the climate changes, it is arguable that the past is becoming an increasingly poor indicator of the future. In particular, as mean sea levels continue to rise, both the magnitude and frequency of extreme tide heights are expected to increase, resulting in an increased risk of coastal flooding (Met Office UKCP18). As exposure to coastal flooding increases, owing to a continually growing UK population and increased coastal development, it is important to understand how traditional methods for understanding and adapting to flood risk may be questioned in the context of a changing climate.

Prepared by Emma Dyer

Climate Change and Sea Levels

Based on the observed record, global mean sea levels have already risen by ~20cm since the middle of the 19th century, with the rate of increase doubling to ~3mm/year in recent decades compared to the long-term trend (HM Government 2017). Figure 1 shows the mean sea level rise (MSLR) observed around the UK coast line since 1900 based on annual records from tidal gauges around the country (National Tidal and Sea Level Facility). However, change in sea level has not been uniform around the globe, with complex regional patterns resulting in some regions experiencing higher rates than the global average (and others lower). For example, even around the UK there are substantial differences in observed sea level rise between northern and southern regions due to changes in the Earth's crust following the last ice age. Due to the distribution of ice, some parts of Scotland are still rising by ~1mm/year while parts of southern England and Wales are sinking at an equal rate. The net effect is that sea levels across some southern parts of the UK have increased at a rate of ~2.1mm/yr since 1900 (0.7 +/-0.2mm/yr greater than the UK average), while in some northern areas, the median seal level rise has been 1.3mm/yr over the same period. This demonstrates that mean net sea level rise has been, and will continue to be, higher across southern regions of the UK.

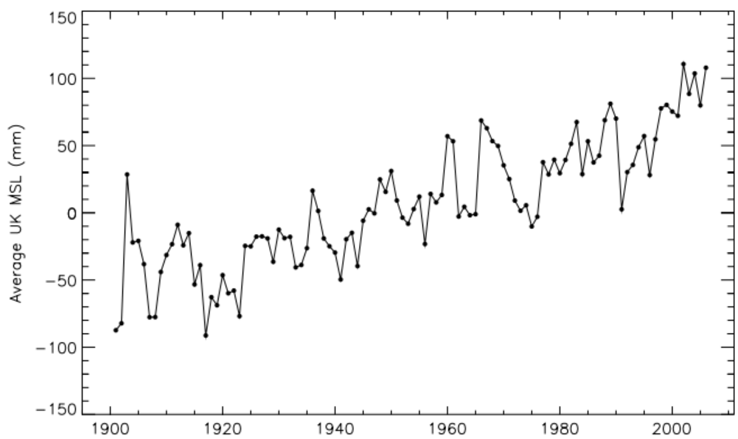

Figure 1 - UK average mean sea level change around the coast using tidal gauge and geological data. Source: Natural Environment Research Council: National Tidal and Sea Level Facility

Despite growing media interest in the role of melting ice caps and glaciers in global sea level rise, these sources account for only 60% of the current change in sea level (Edwards 2017). The other 40% is due to thermal expansion of the oceans owing to a warmer climate. Due to the slow response time of oceans and ice caps, even if severe climate change mitigation options were followed and anthropogenic contributions to climate change neutralised, mean sea levels would continue to rise over the next couple of centuries (Jevrejeva et al. 2011). This is consistent with the latest UK Met Office Climate Projections (UKCP18), which indicate that sea levels will continue to increase for the remainder of the century (and beyond) regardless of the emission scenario used (see box 1). These projections indicate the potential for higher sea levels than suggested by the previous set of outcomes (UKCP09), with scenarios ranging from a 25cm rise by 2100 to a rise of >1m (under a low probability, high impact scenario). The projected changes in sea level around the UK coastline are displayed in Figure 2, which indicate that even in the most conservative scenario (RCP2.6) sea level is expected to increase by between ~0.2 and ~0.6m (5th and 95th percentiles) by 2100.

> ***Box 1: What is an RCP?***
>
> *Representative Concentration Pathways (RCPs) are the scenarios used to represent possible futures. These futures take into account the trajectory of greenhouse gas emissions and mitigation strategies. The numbers represent the radiative forcing (RF) associated with each scenario. Positive RF causes warming of the climate, therefore RCP2.6 represents the most optimistic scenario, while RCP8.5 represents a higher end scenario.*

RCP	Model prescribed CO_2 concentration by 2100	Approximate Radiative Forcing in 2100, relative to 1750
RCP2.6	421 parts per million (ppm)	2.6 Watts per square metre (W/m²)
RCP4.5	538 ppm	4.5 W/m²
RCP6.0	670 ppm	6.0 W/m²
RCP8.5	936 ppm	8.5 W/m²

> *The UK Met Office use these scenarios to produce probabilistic projections of the future climate.*

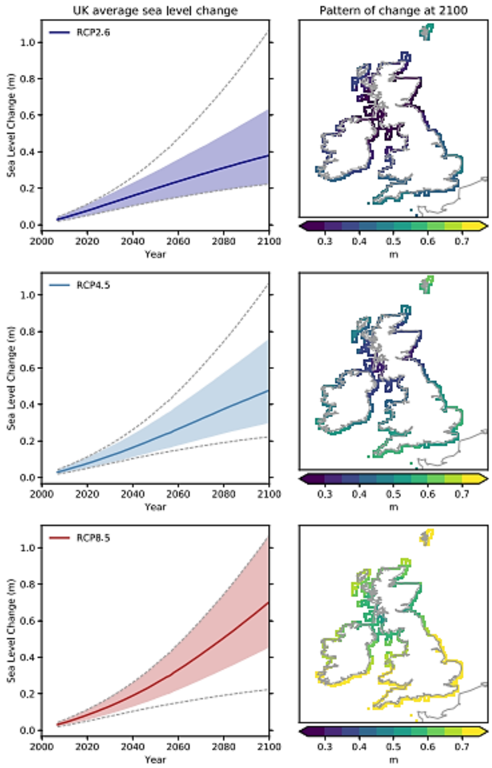

Figure 2 - UKCP18 sea level projections around the UK. Solid line in each graph represents the 50th percentile, the shading represents the area covered by the 5th-95th percentiles.

What do rising sea levels mean for flood risk?

As mean sea levels rise, the base level on which storm surges and tides are superimposed increases, shifting the distribution of observed maximum sea level towards the upper end of the scale. Due to this shift in distribution, it is important to question what ‘normal’ or ‘average’ reference periods extreme sea levels are being compared to in the calculation of return periods. Return periods for flood defences are often calculated using exceedance probabilities, which in turn are based on the number of times an event has been observed in relation to a period representing ‘climatology’. However, this method is only valid if there are no significant trends in the record – i.e. the climate is said to be stationary as the mean and variability are unchanging. However, both the mean and the distribution of some climate variables have changed over recent decades, for example this has been quite clearly observed in the temperature record, making the climatological reference period no longer a good indicator of current and future conditions. The increase in mean sea level already observed, together with the change in frequency and magnitude of extreme water levels predicted by the Met Office, suggest non-stationarity is also becoming evident here. It is therefore important to consider whether the use of return periods based on historic data is still the appropriate method for thinking and preparing for coastal flood events. The 1953 surge event is used as a case study below to investigate what the extreme water heights experienced during the 1953 event could theoretically reach today and in the future due to rising sea levels under the same meteorological conditions.

Case Study: 1953 surge event

In late January 1953 a rapidly-developing low-pressure system tracked south-eastwards across the North Sea, generating very strong winds along the east coast of the UK. The direction and magnitude of these winds, combined with a decrease in sea depth towards the coast, resulted in a storm surge being driven onshore. Extreme tide heights, with return periods greater than 1 in 500 years, were observed at 23 locations along the North Sea coast (Wadey et al. 2015). The resultant coastal flooding led to the evacuation of 32,000 people as well as the flooding of 24,000 properties, the disruption of >400km of transport network and 307 deaths. Some of the worst affected regions were along the north Kent coast and Canvey Island, where 100 and 38 people were killed respectively. Using recordings from a tidal gauge close to these locations - Sheerness (north Kent) – the effect of rising sea levels on maximum water height is investigated.

Due to the timing of the 1953 event, just two days after a full moon, high spring tides were also a contributing factor to the extreme total water heights observed. This is often the case in storm surge events, as the coincidence of high astronomical tides and the surge associated with the storm event make extreme water heights more likely to occur:

Max water height observed = mean sea level + tide + surge

A recent study has determined that, over the last 100 years, only 14% of extreme sea level events around the UK coast have been as a result of extreme storm surges, with the remainder being a result of the combination of only moderate storm surges with high tides (Haigh et al. 2016). As sea levels rise, high tides may become less important, removing a key temporal constraint in the achievement of extreme water levels.

The table below shows the maximum water level observed during the 1953 event at Sheerness. Using the Met Office UKCP18 projections (Figure 3), estimated high water levels have been added for 2020, 2060 and 2100 under two climate scenarios; RCP2.6 and RCP8.5.

	1953	**2020**		**2060**		**2100**	
		RCP2.6	RCP8.5	RCP2.6	RCP8.5	RCP2.6	RCP8.5
Surge (m)	2.16	2.16	2.16	2.16	2.16	2.16	2.16
MSL + tide 1953 (m)	2.58	2.58	2.58	2.58	2.58	2.58	2.58
Increase in MSL (m) (median value)	0	+ 0.09	+ 0.12	+ 0.28	+ 0.38	+ 0.44	+ 0.78
Total Water Height (m)	4.74	4.83	4.86	5.02	5.12	5.18	5.52

Even under the most conservative climate projection (RCP2.6), in 2100 the meteorological and tidal conditions responsible for the 1953 surge event would result in a total water height at Sheerness >40cm greater than was observed. Using return period curves developed by the Environment Agency, the increase in total water height would change this event from a 1 in 300 year to a ~1 in 1000 year event (Environment Agency, 2011). Based on this example, it is clear that defences which may have been built to withstand events similar to that of 1953, for example with a return period of 1 in 500 years in mind, may no longer be sufficient if the event were to happen in the future, in a world with higher mean sea levels.

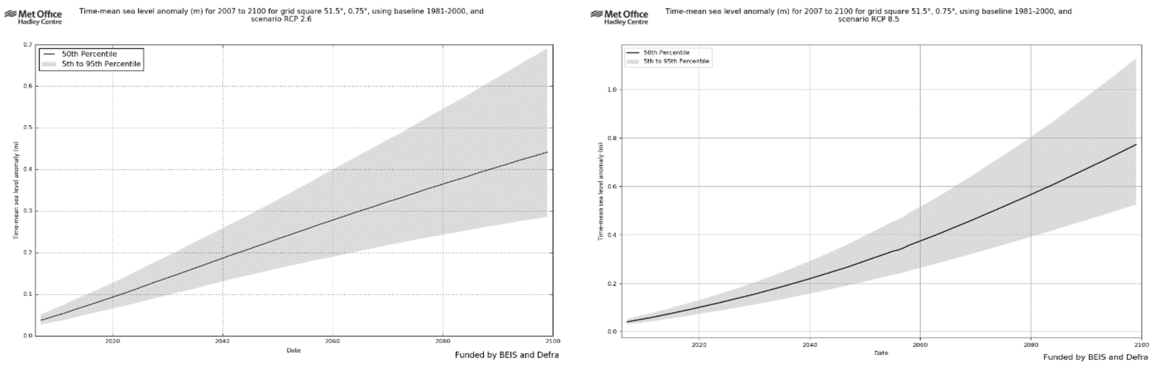

Figure 3 – Projections of sea level rise at Sheerness as anomalies with respect to the 1981-2000 baseline under RCP2.6 (left) and RCP8.5 (right) from the UKCP18 project. The solid line represents the 50th percentile and the shading the 5th- 95th

However, it is not only the magnitude of extreme events that is expected to increase, but also the frequency. Due to the steepness of return period curves, even what may be considered a small change in total water height, driven by changes in mean sea level, can have a significant effect on the return period. For example, based on an observed height of 4.74m at Sheerness during the 1953 event, the return period for this extreme water height changes from a 1 in 300 year event (Environment Agency 2011) at the time of occurrence, to a ~1 between 100 and 200 year event by 2050 using either RCP2.6 or RCP8.5. By 2100 the return period of this event has decreased even further, becoming a roughly 1 in 50 year event using the conservative RCP2.6 scenario or ~1 in 10 year event using RCP8.5! (See figure 4 – note log scale).

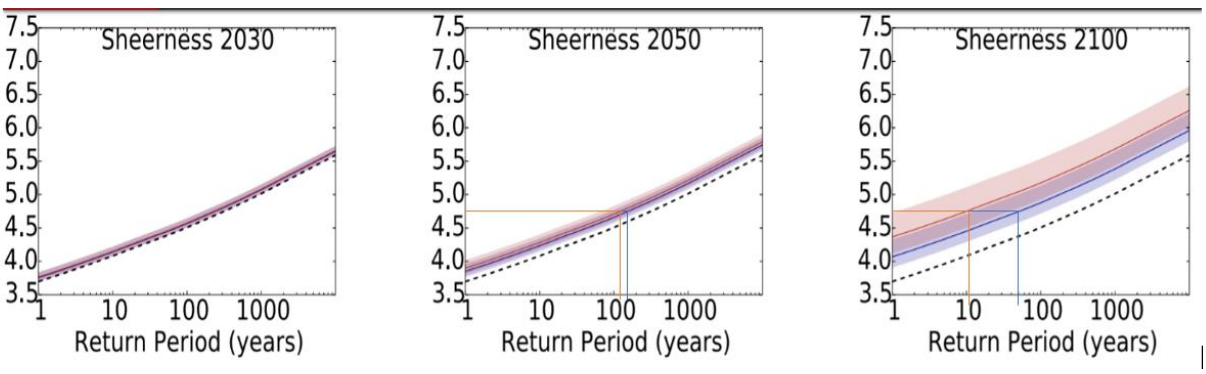

Figure 4 – Projected return periods for extreme water heights at Sheerness. The black dashed line represents the present-day curve from the Environment Agency (2018), the solid blue and red lines indicate the curve under RCP2.6 and RCP8.5 respectively. The blue and red shading indicate the ranges in the UKCP18 projections. Source: Palmer et al. (2018): UKCP18 Marine Report. Met Office.

Static return periods currently used in flood defence management will become less relevant over time, as the climatology these values are built on becomes less and less representative. Instead, as mean sea levels rise and extreme sea level events become more frequent, return periods themselves will change, with a 1 in x year event representing different water levels over time. For example, figure 4 from the UKMO18 Marine Report indicates how return periods are expected to change for Sheerness under RCPs 2.6 and 8.5 (Palmer et al. 2018). The dotted line represents the return period curve used today, while the blue and red line represent the 50th percentile for RCP2.6 and RCP 8.5 respectively. Using a return period of 1 in 100 years as an example, the water level expected changes from ~4.5m in 2030 to ~4.8m under RCP2.6 in 2100 and >5m under RCP8.5 (using the median values). Therefore, the use of static return periods defined in reference to historic data become less meaningful, as rising sea levels alter the associated water level over time.

Concluding Remarks

It is clear from observations and the latest scientific projections that sea levels have risen around the UK in recent decades and will continue to do so over the remainder of the century. As sea levels continue to rise, the base level on which tides and storm surges are imposed increases, resulting in a greater capacity for extreme water level events. Owing to a shift in the distribution of observed water levels around the UK towards higher levels, the frequency and magnitude of extreme events is expected to increase, resulting in a rise in coastal flood risk, particularly across southern regions where sea level rise is expected to be greatest. Using the 1953 storm surge event as an example, we demonstrated how changing sea levels can have a substantial impact on the return period of extreme events. At Sheerness, the return period for the extreme water height observed at during the 1953 event was found to decrease from ~1 in 300 years to ~1 in 50 and ~1 in 10 years using RCP2.6 and RCP8.5 scenarios respectively.

The historic record is increasingly becoming an insufficient guide to the future and therefore static return periods are likely to become less relevant, as a 1 in x year event will not mean the same today as it did in 1953 or indeed as it will in 20 years. It is therefore important to question the use of return periods in the conversation around flooding and adaptation methods in order to understand the limitations and determine whether alternate approaches may be more suitable in the context of a changing climate.

NB. The estimates of sea level rise and the resultant effect on extreme water levels stated in this article assume no change in rate of MSLR and therefore should be considered as lower bound estimates for what is possible over the coming decades.

Prepared by Emma Dyer

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