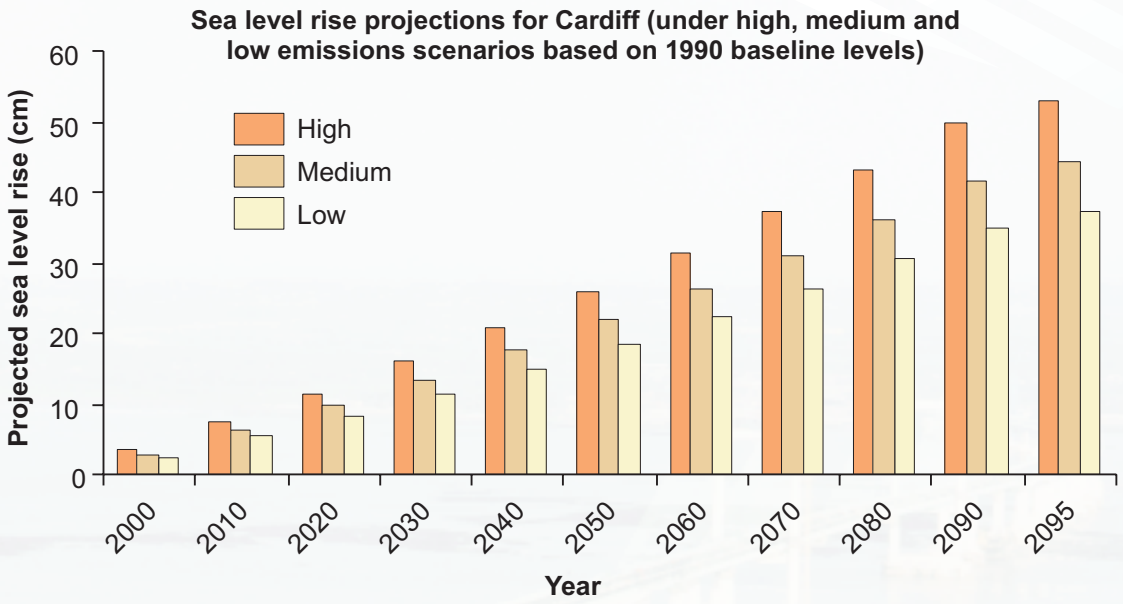
Introduction

The marine environment of the Severn Estuary is one of the most dynamic in Europe and sea level, waves and storms all play their part in shaping this coastline. Historical records show that severe storms have caused much coastal erosion and flooding and modern research suggests such events are likely to occur again. Perhaps one of the biggest threats to the estuary is from rising sea levels which coupled with a significant storm event could exacerbate the effects of coastal erosion and flooding and cause significant issues for coastal planners, engineers and local communities. The Severn Estuary coastline is already significantly defended, especially around the Wentlooge and Caldicot levels on the north (Welsh) coast and around the Somerset Levels on the south (English) coast, with several small scale localised defences elsewhere.



	Greenhouse gas emissions scenario		
Year	High	Med	Low
2000	3.5	2.9	2.5
2010	7.3	6.2	5.3
2020	11.5	9.7	8.2
2030	15.9	13.4	11.4
2040	20.8	17.5	14.8
2050	25.9	21.8	18.4
2060	31.4	26.3	22.2
2070	37.1	31.1	26.3
2080	43.3	36.2	30.5
2090	49.7	41.6	35.0
2095	53.1	44.4	37.3

Table/Figure 1: Sea level projections for Cardiff (cm) years 2000 - 2095 (with respect to1990 baseline levels (source: UKCP09)

Sea level trends and projections

- A recent comprehensive review [1] of tide gauge data for the Bristol Channel and Severn Estuary over a 15 year time period (1993 to 2007) concluded that there had been a rise in mean sea levels. Sea level rise of about 30cm by 2050 and a rising trend of 2.4mm/year-1 were also suggested, which is in line with other research results [2] and UK Climate Projections 2009 (UKCP09) [3].
- The projections in UKCP09 have also been examined on an estuary basis and are in broad agreement with these figures (see Figure1 and Table 1). **It is estimated that by 2080 sea levels will be 30-40cm higher than they are at present based on a medium greenhouse gas emissions scenario*.** This in itself poses serious issues as much of the coastline around the estuary is at or close to current sea level.
- The landmass of the UK is also naturally shifting. The north west of Scotland is rising relative to sea level while the south east of England is sinking. This process is linked to the last ice age and is termed isostatic adjustment. Locally, the south west of the UK, which includes the Bristol Channel and Severn Estuary, has been sinking at a rate of 0.6 to 0.9mm/year for the past 4,000 years [4] and this trend is expected to continue for the next 100 years [5].
- UKCP09 projections also suggest that sea level rise is highly unlikely to be over 1metre by 2100 (but for contingency planning this extreme scenario cannot be ruled out completely).

**Sea level projections are determined using the 1990 baseline level.*

Wave climate trends and projections

Waves can affect coastal communities significantly. Waves on their own or (more often) in combination with strong winds, high tides and/or storm surges can cause coastal erosion and damage to infrastructure. Breaches of defences can lead to major flooding incidents.

It has been reported that wave heights in the North Atlantic have increased over the last 25 years [6, 7]. Increases in monthly mean and maximum wave height in the north-eastern Atlantic occurred between 1960 and 1990; however, this rise in wave height may be part of long-term natural variability (natural variability in wave climate is large and the role of human influence is still very unclear)[8]. There has been no clear pattern of change since 1990. There is no firm consensus on the future storm and wave climate for North Western Europe since projected future storm track behaviour varies among atmospheric models.

Overall, data from UKCP09 indicates that seasonal mean and extreme waves are generally expected to increase slightly to the south west of the UK, including the Bristol Channel, which is consistent with rising sea levels (Figures 2 and 3). There are large uncertainties associated with seasonal mean wave heights and especially with the projected extreme values.

Projections of storm behaviour used by the UKCP09 wave model show storm tracks moving south, resulting in lower wave heights to the north of the UK and slightly larger wave heights in some southerly regions, especially the south west. It is, however, important to note that there is low confidence associated with this statement [9].

Models suggest that coastal squeeze, habitat loss, coastal erosion and steepening of beach profiles will all increase in the future because of further sea level rise and possible changes to wave conditions [10].

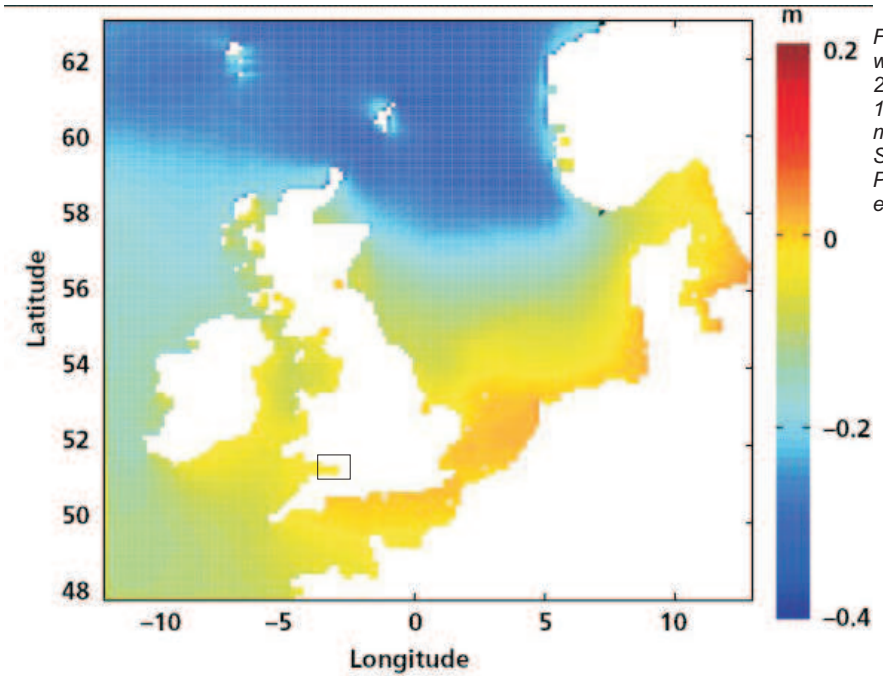


Figure 2. Change to the mean winter significant wave height for 2070-2099 compared with 1961-1990 values, under a medium emission scenario. Source pages in UKCP Marine Projections report: pp58 (Lowe et al 2009)

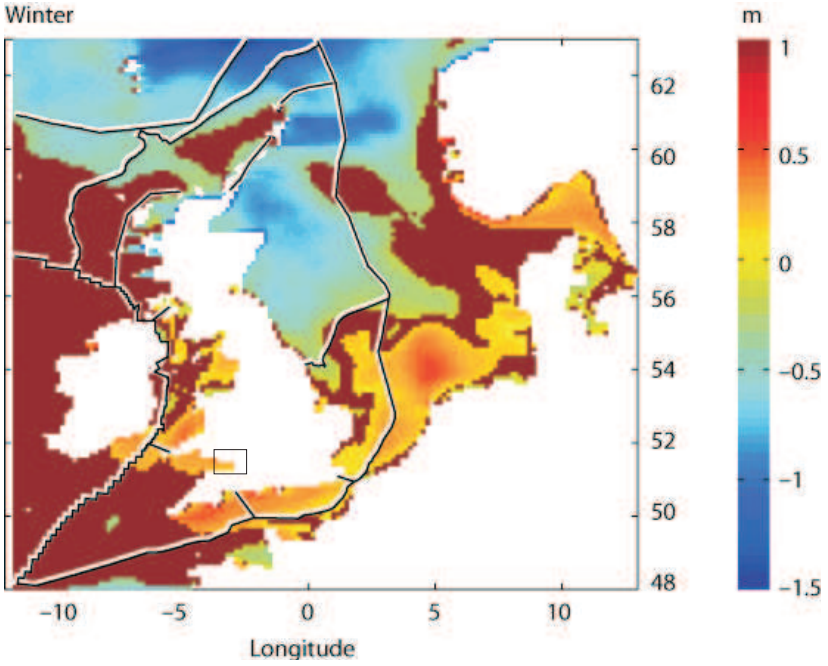


Figure 3. Change to the mean winter maximum significant wave height (SWH) for 2070-2099 compared with 1961-1990 values, under a medium emission scenario. The darkest red shading indicates areas where the change in mean SWH is not statistically significant compared to 1961-1990 levels. Source pages in UKCP Marine Projections report: pp60 (Lowe et al 2009)

Storminess trends and projections

The frequency of severe wind storms in the UK has increased since 1960, but not above levels recorded during the 1920s (a particularly stormy period, see Figure 4) [11, 12].

Recent research for the southern UK, including the Severn Estuary locality, has supported this trend [13]. However, severe wind storm trends around the UK are difficult to identify for several reasons low numbers of such storms, their decadal variability, unreliability and lack of direct wind speed observations.

Some research has shown that although man-made factors have influenced sea level pressure distributions (and hence atmospheric circulation patterns) over the second half of the 20th century, there continues to be little evidence to support suggestions that the recent increase in storminess over the UK is related to man-made climate change[14].

The recent strong trend in the North Atlantic Oscillation* (NAO) (bringing stormier conditions to the UK) is apparently unique in its history, but it is controversial whether this is a response to greenhouse gas forcing or not.

Figure 5 highlights some examples of severe storm and tidal events that have affected the Severn Estuary. It is severe storms like these, when coupled with increased sea levels, which pose the greatest risk to the region in terms of marine erosion and tidally induced flooding[20, 21] and research is being undertaken to model this risk and the potential impacts[22].

** The North Atlantic Oscillation (NAO) is a phenomenon associated with winter fluctuations in temperatures, rainfall and storminess over much of Europe (source: Met Office).*

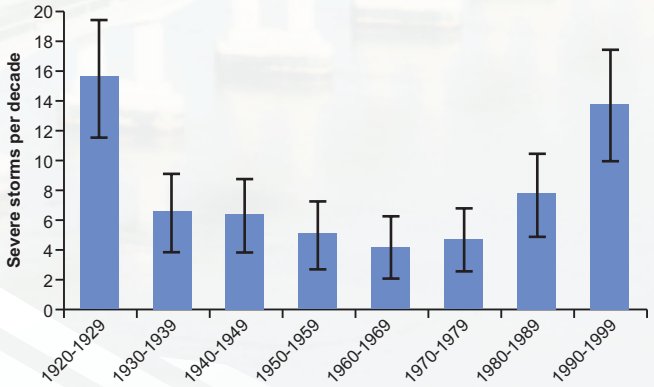


Figure 4: The total number of severe storms per decade over the UK and Ireland during the half year period October to March, from the 1920s to the 1990s. Error bars show ± one standard deviation. (Source: Rob Allan, Met Office Hadley Centre)

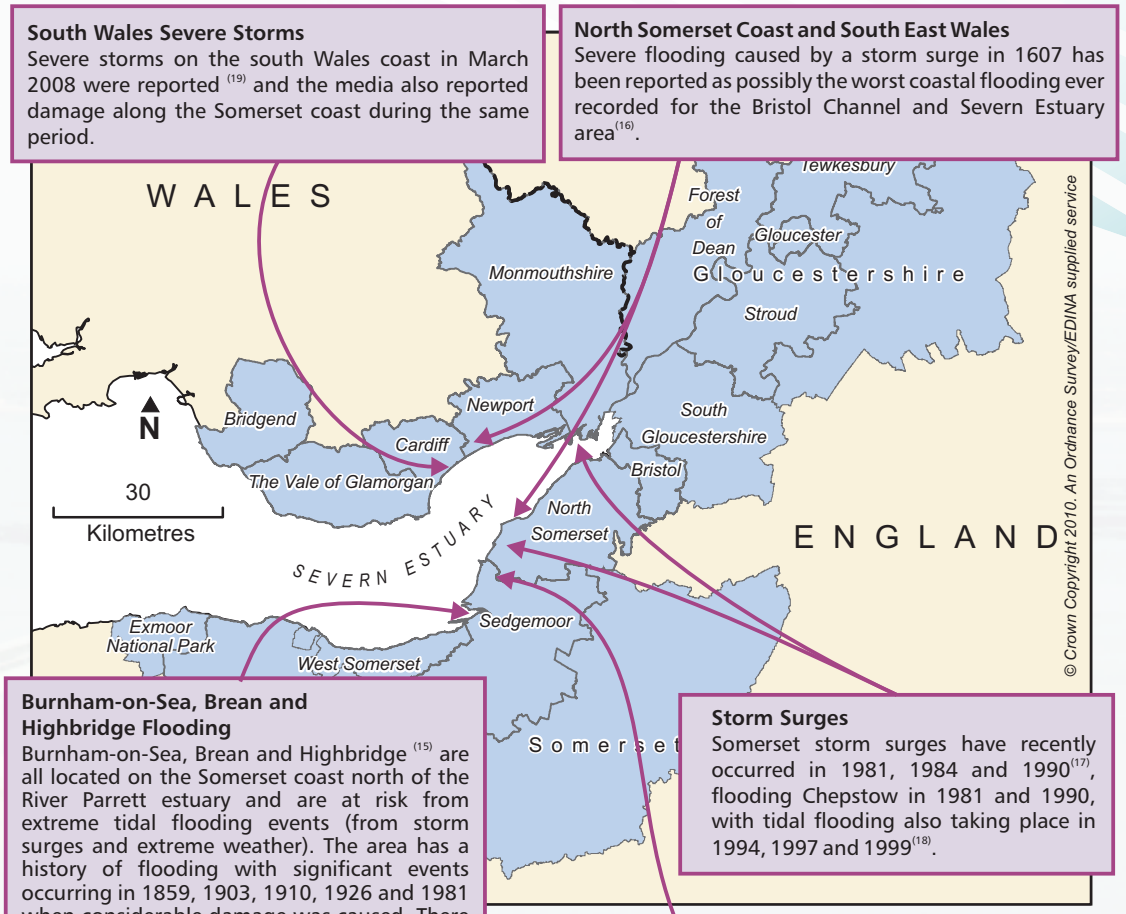


Figure 5: Examples of severe storm and tidal events affecting the Severn Estuary

Storm surges

Significant damage to coastlines can be caused by storm surges[23] (or tidal surges) which are flows of higher than normal sea level that can flood coastlines. They are usually caused when low atmospheric pressure occurs together with driving winds and high tides. These events, whilst rare on the estuary in their extreme form, can overtop or breach sea defences and cause flooding and erosion depending on the exact weather conditions at the time. It has been possible to identify the specific weather conditions which have helped to cause such events in the past which can then be used as a guide to the future.

Around the UK the size of storm surge expected to occur on average about once in 50 years is projected to increase by less than 0.9 mm/year over the 21st century (Figure 5)*. This does not represent a significant rise and is considerably reduced from the UKCIP02 projections. In most locations this trend cannot be clearly separated from natural variability in storminess conditions[24].

The largest projections for the UK are found in the Bristol Channel and Severn Estuary (Figure 5), where an increase in the 50-year skew surge return level of around 0.8 mm/year is anticipated.** In addition, recent research [25] indicates that the height of extreme high water in the Bristol Channel and Severn estuary has shown a decrease over a 15 year time period (1993-2007). This research also suggests, however, that these levels are not the same across the estuary, highlighting local changes in current extreme high water trends and future projections.

Storm surge events are difficult to predict beyond a few days ahead as they are controlled by various interlinked weather and marine factors and this is why much uncertainty remains in future projections[26, 27].

**Storm surge projections here do not include the projected rise in relative mean sea level, as outlined on page 1.*

***According to UKCP09, a skew storm surge is a way of calculating the height of a storm surge, and is the height difference between a predicted astronomical high tide and the nearest (in time) observed or modelled high tide.*

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Example of current research:

Work by University of Bristol in association with Great Western Research and the National Oceanography Centre - Storm Tide Flooding in Somerset.

Complex coastal computer models are used to reproduce the extent of storm tide flooding based on historical events. Ground-based checking of the spatial differences in water heights that are used as inputs to these models is difficult but satellite images capturing coastal storm events can be used to select the most accurate storm tide model. This provides enhanced input to coastal flood risk prediction models whilst reducing the uncertainty of future flood hazard and risk estimations to the North Somerset region. In addition, work is being undertaken to examine the flood risk for Somerset given the uncertainties over possible sea level rise[28].

Summary

- Sea level around the Bristol Channel and Severn Estuary is projected to increase by 20-30cm by 2050, and 30-40cm by 2080.
- Seasonal mean and extreme wave heights to the south west of the UK, including the Bristol Channel and Severn Estuary, are projected to increase slightly. However, large uncertainties are associated with these projections and there is no agreement on local changes to current wave climate trends.
- The Severn Estuary coastline has suffered several coastal flooding and erosion events historically due to stormy conditions. Evidence suggests a potential increase in severe storm events annually but it is uncertain if this is due to natural variability in weather patterns or longer term climate change.
- Storm surges around the UK are projected to show the highest increase in size along the Bristol Channel and Severn Estuary. It is important to note that although this increase is slight at 0.8mm/year, when coupled with stormy conditions and a rise in sea level coastal flooding and erosion impacts could become more severe.

Uncertainties and knowledge limitations

There is a high degree of uncertainty still associated with the topics presented here (as well as the key uncertainties associated with climate change projections, as highlighted in the Climate Change in the Severn Estuary Report Card[29]). Some specific limitations in knowledge exist[30] such as:

- regional and local variability in sea level changes are poorly dealt with in current global climate modelling methods this will need to be improved to provide planners and local authorities with the local information they need for adaptation[31];
- the single largest uncertainty for mean sea level projections is the ice melt contribution in response to increased global mean temperatures. This ranges from global sea level rises of 10-20cm, as considered within the Intergovernmental Panel on Climate Change (IPCC) (2007)[32], to values of 1-2 metres[33];
- the wave climate at regional and local scales has high levels of uncertainty because local conditions such as sea bed shape (bathymetry) and wave direction are poorly monitored and under-represented in global climate models. This means that creating detailed projections for a specific local scale such as the Severn Estuary remains too uncertain to produce;
- marine projections are only useful to coastal managers where they can be localised at least to the scale of the "Charting Progress" regions[34]. A global climate model produces a useful large-scale projection, but some uncertainty remains as to the most appropriate methods for downscaling those projections to a useful scale.

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