Coastal flooding and adaptation to climate change inquiry.
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Evidence submitted by the National Oceanography Centre

Introduction

The National Oceanography Centre (NOC) undertakes world-leading research in large-scale oceanography and ocean measurement technology innovation. We work with Government and business to turn great science and technology into advice and applications. We support the UK science community based in universities and smaller research institutes with scientific facilities, research infrastructure and irreplaceable data assets - enabling the UK to harness the full power and diversity of its scientific talent in ocean science.

Our main mission is to make sense of changing seas, upon which future human prosperity and wellbeing depends. The way in which we intend to achieve our mission is by

- Undertaking internationally competitive marine science research in an Earth system context with a long-term focus – working with others for the effective translation of new and existing knowledge into demonstrably high societal benefit
- Managing, developing, coordinating and innovating high quality large research infrastructure, equipment pools, facilities, databases and other science, enabling functions for the benefit of the whole UK science community to deliver excellent science with impact.

The NOC is part of the Natural Environmental Research Council (NERC), which is part of UK Research and Innovation, a new organisation that brings together the UK's seven Research Councils, Innovate UK and Research England to maximise the contribution of each Council and create the best environment for research and innovation to flourish. The vision is to ensure the UK maintains its world-leading position in research and innovation.

The NOC is pleased to respond to question one - the remaining questions fall under the remit of the Environment Agency and local authorities.

What are the risks and consequences of coastal flooding?

The most up to date sea level, waves and coastal flood science relevant to coastal engineering and management in the UK can be found in the Impacts Report Cards of the Marine Climate Change Information Partnership (MCCIP). The MCCIP partnership brings together scientists, government, its agencies and NGOs to provide co-ordinated advice on climate change impacts and adaptation around our coast and in our seas. Three Report Cards are relevant to the information requested. These are:

- **Impacts of climate change on sea level rise relevant to the coastal and marine environment around the UK** (authored by Kevin Horsburgh, NOC;

Alistair Rennie, Scottish National Heritage; Matthew Palmer, Met Office). In review.

- **Impacts of climate change on storms and waves relevant to the coastal and marine environment around the UK** (authored by Judith Wolf, NOC; David Woolf, University of Highlands and Islands; Lucy Bricheno, NOC). Review complete.

- **Impacts of climate change on coastal flooding, relevant to the coastal and marine environment around the UK** (authored by Ivan Haigh, University of Southampton; Robert Nicholls, University of Southampton; Edmund Penning-Rowsell, Middlesex University; Paul Sayers, Sayers and Partners LLP). In review.

These three Impacts Report Cards are either ready to publish or at an advanced stage of review. Over the next month they will supersede the previous ARC Report Cards that were published in 2013, and can be found here: http://www.mccip.org.uk/

Another source of information concerning the changing marine climate can be found in the Marine Report (Palmer *et al*., 2018) of the UK Climate Projections. The UK Climate Projections provides the most up-to-date assessment of how the climate of the UK may change over the 21st century. https://www.metoffice.gov.uk/research/collaboration/ukcp . However, all the information in "**Impacts of climate change on sea level rise relevant to the coastal and marine environment around the UK**" is consistent with information in the UK Climate Projections Marine Report.

Extract from: **Impacts of climate change on coastal flooding, relevant to the coastal and marine environment around the UK**

Coastal floods are amongst the most dangerous and costly natural hazards. Coastal flooding is one of the top four priority risks for the UK Government and one of the top three for non-malicious risks (Cabinet Office, 2015). Recent flood events (e.g., over the winter of 2013/14) have demonstrated the ever-present threat of serious flood impacts in coastal regions despite improved flood protection measures and technology which has provided tools to forecast and mitigate risks. While flood defence standards are among the highest in the world in the UK, the significant populations and assets located in the coastal flood plain are threatened in the event of defence failure. In England, it is estimated that 520,000 properties are located in areas with a 0.5% or greater annual risk from coastal flooding (CCC, 2018). About £35 billion worth of assets in London would currently to be exposed to a 1% annual chance of flooding without the Thames Barrier and associated defence and preserving Foreign Direct Investment to the London economy (by alleviating concern of flood risk) is valued at £2 billion per annum. Annual average economic damages from coastal flooding in the UK are estimated to be £540 million (Sayers *et al*., 2015). Furthermore, coastal flooding is a growing threat due to accelerating mean sea-level rise and possible changes in tides and storminess associated with climate change (IPCC, 2013), as well as continued population growth, urbanisation and development in the flood plain (Stevens *et al*., 2016).

During the recent winter of 2013/14 the UK experienced an unusual (but not unprecedented) sequence of extreme storms and some of the most significant coastal floods in the last 60 years (Kendon and McCarthy, 2015). However, due to better defences and forecasting and warning systems, the damages were much lower than in 1953 (Spencer *et al*., 2014; Wadey *et al*., 2015). Even so, floods over that winter season still resulted in approximately £1.3 billion in damages (Environment Agency, 2016).

Extreme sea levels have increased over the last 150 years, driven primarily by the observed rise in relative mean sea level. Furthermore, nature defences, such as saltmarshes, shingle and sand dunes, which provide important buffering against floods, are in decline. Population growth, changes in land use and increasing asset values in floodplain areas have also enhanced exposure to coastal flooding. However, overall the consequences of flooding have reduced slightly over time due to improvements in flood defences, together with advances in flood forecasting, warning and emergency response and spatial planning. Extreme sea levels are very likely to increase during the 21st century and beyond, driven primarily by the changes in relative mean sea level, rather than any changes in the wave or storm surge climate. Without appropriate adaption, the projected increases in extreme sea levels will significantly increase coastal flood risk. Population growth and accompanying development is likely to continue, particularly in areas that are current defended. Therefore, significant populations and assets remain located in the coastal flood plain and will be threatened in the event of a defence failure.

Extract from: **Impacts of climate change on sea level rise relevant to the coastal and marine environment around the UK**

- Increases in future extreme sea levels are expected to result in increases to flooding and erosion in the coming decades, although precise changes are highly location and context specific.

- Future extreme sea levels will be dominated by changes in mean sea level not the storm surge component nor changes to tides.

- Several independent studies consistently estimate the rate of regional sea level rise around the UK, observed by tide gauge records and attributable to climate change, to be between 1 and 2 mm per year. When vertical land movement is also included, this rate is increased for the south of England and decreased for some parts of Scotland.

- Future projections of sea level rise around the UK (from climate models) are taken from the UK Climate Projections Marine Report (Palmer et al., 2018). These projections supersede those of UKCP09 (Lowe et al., 2009) used in previous scorecards.

- Projections for the year 2100 (relative to the 1981-2000 average) contain considerable uncertainty. For London, the central estimate sea level projection for the year 2100 ranges from 0.45-0.78m, depending on the emissions scenario. Similar ranges of the central estimate at 2100 for other cities are: Cardiff 0.43-0.76m; Edinburgh 0.23-0.54m; Belfast 0.26-0.58m.

- All projections show spatial variation due to differential rates of vertical land movement and also the spatial pattern of sea level change linked to polar ice melt. For the year 2100, sea levels for southern England are projected to be approximately 0.4m higher than for parts of Scotland.

- Model results suggest that sea levels will continue to rise until the year 2300 and beyond. Upper estimates for London and Cardiff under the highest emissions scenario exceed 4m. These estimates have much lower confidence than the projections to 2100.

- There is no observational evidence for long-term trends in either storminess across the UK or resultant storm surges.

- Storm surge simulations for the 21st century suggest no significant changes to storm surges.

- For the European coastline, annual damages due to coastal flooding are estimated to increase by two to three orders of magnitude (from €1.25 today) by 2100 (Vousdoukas *et al*., 2018). Recent work by Jevrejeva et al. (2018) warns that without additional adaptation the UK would be exposed to flood risk of 6.5% of UK GDP (£800 billion per year) by 2100 if the worst greenhouse gas emissions scenario is realised.

- A large gap remains in the translation of our scientific knowledge of sea level changes into the necessary steps policy makers (government, society and businesses) need to take to remain resilient. The practical implications of even modest sea level rises are significant: increased erosion and erosion enhanced flooding, exposure of assets on shorelines, continued development within high risk areas. We must devise incentives and mechanisms to plan differently for sea level changes.

Extract from: **Impacts of climate change on storms and waves relevant to the coastal and marine environment around the UK**

This report updates the review by Woolf and Wolf (2013) by summarising the results of the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2013) and by reviewing recent work since 2013. There are similar conclusions to the 2013 Report Card: wave model results are controlled largely by the quality of the wind data used to drive them and the forcing climate models have slightly improved in accuracy as well as resolution. In general, trends are obscured by large natural variability and a low signal to noise ratio. Assessment of changes in storminess and waves over the last 200 years are limited by lack of data, while future projections are limited by the accuracy of climate models.

Recent work has led to more insight in some areas. There is a move towards higher resolution models, which give better accuracy for simulation of tropical and extra-tropical storms. Further work is being done with coupled atmosphere-ocean-wave models, which give insight into key dynamical processes.

There is evidence for an increase in North Atlantic storms at the end of the 20th century. All wind and wave time series show a great deal of variability including inter-annual and inter-decadal fluctuations, but in some cases a distinct persistent trend is observable within the variability, over various time periods. In the late 20th century there was a period of increasing wave heights over the NE Atlantic, while trends in wind speed around the UK were much weaker, and therefore most of the increase in wave heights is attributed to Atlantic swell (waves generated far outside of UK waters but propagating here from the ocean). Wave heights may have been enhanced by an increase in persistence of westerly winds.

Some future projections for North Atlantic storms over the 21st century show an overall reduced frequency of storms and some indication of a poleward shift in the tracks, in the northern hemisphere winter, but there is substantial uncertainty in projecting changes in storm tracks, especially in the North Atlantic. Climate projections for waves in the North Atlantic show a reduction in mean wave height but an increase in the most severe wave heights. There is a likelihood of larger wave heights to the north of the UK as the Arctic sea ice retreats and leads to increased fetch.

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