Severe extratropical cyclones and their impact on coastal flooding in the UK; past, present, and future

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Motivation and Aims

The value of the UK's assets at risk from flooding by the sea have significantly increased in recent years, and currently stands at a value of £132.2bn, with some 4 million properties in England and Wales alone under threat (Office of Science and Technology, 2004). Currently, there is a lack of robust and integrated "clouds-to-coast" frameworks for coastal flood risk. The interactions between atmospheric, oceanic and coastal processes are poorly understood, resulting in large uncertainties in the performance of sea defences in extreme conditions.

By generating an ensemble of coastal flooding predictions the EPIRUS (Ensemble Prediction of Inundation Risk and Uncertainty arising from Scour) project aims to improve the quantification of the likelihood of incipient defence failures during extreme storm events through the integration of atmospheric conditions, wave generation and propagation, surge and tide propagation models. In addition, the propagation of uncertainty from atmospheric mesoscale modelling to overtopping and scour predictions in the presence of extreme events will be quantified using a novel, integrated ensemble prediction framework of coastal flood risk.

Above: **Examples of wave overtopping. Overtopping resulted in the temporary closure of the London-Penzance mainline railway and extensive damage to sea defences along a large portion of the South and Southwest coastline of the UK.**

Coastal Flooding

Flooding often occurs as a result of defence failure, which includes functional failure (where the conditions exceed those for which the defence was designed) and structural failure (where some element or components of the defence do not perform as intended under the design conditions).

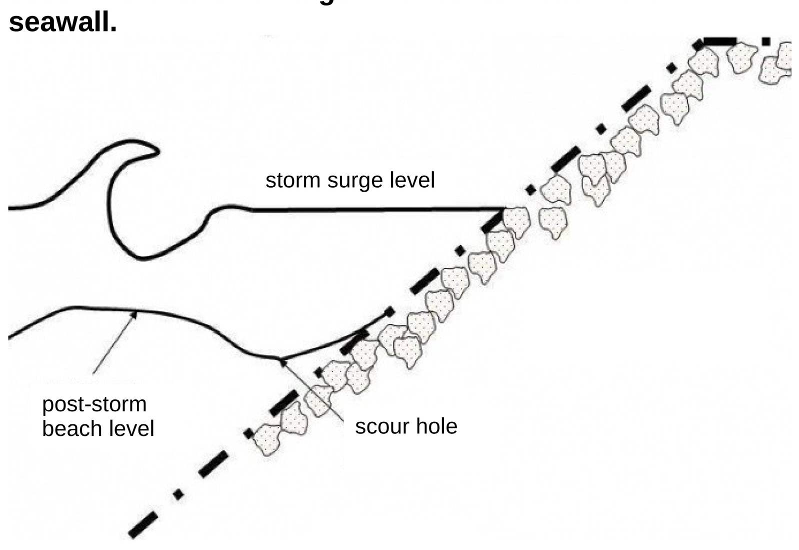
Two major causes of structural failure are: low freeboard leading to excessive wave overtopping of the defence, leading to erosion of the back and crest of the defence, or even damage to the armour layers; and toe failure, where erosion of the foreshore at the base of the defence occurs to such an extent that the structure is undermined and collapses.

The importance of scouring

The assessment and design of sea defences often relies on a qualitative review of the morphological variability of the bed levels and slopes in front of the sea defence. During large storms it is not uncommon for beach levels to lower by several metres or more, with beach material being moved tens or hundreds of metres offshore. Such beach lowering will lead to an increase in the still water depth at a structure for a fixed tide level, and thus enable larger waves to reach the structure before breaking. This is a positive feedback mechanism, with beach lowering allowing larger waves to reach the structure. In turn larger waves create more lowering and the process continues.

Left: **An example of scour at a seawall in Teignmouth (southwest England) after a severe easterly storm, showing beach lowering near the base of the structure. Beach levels in this photograph are approximately 2m below 'typical' levels.**

Below: **Schematic of scouring in front of a seawall. Meteorological conditions generate a storm surge, which creates a scour hole. This results in a positive feedback mechanism as the scour hole allows larger waves to reach the seawall.**



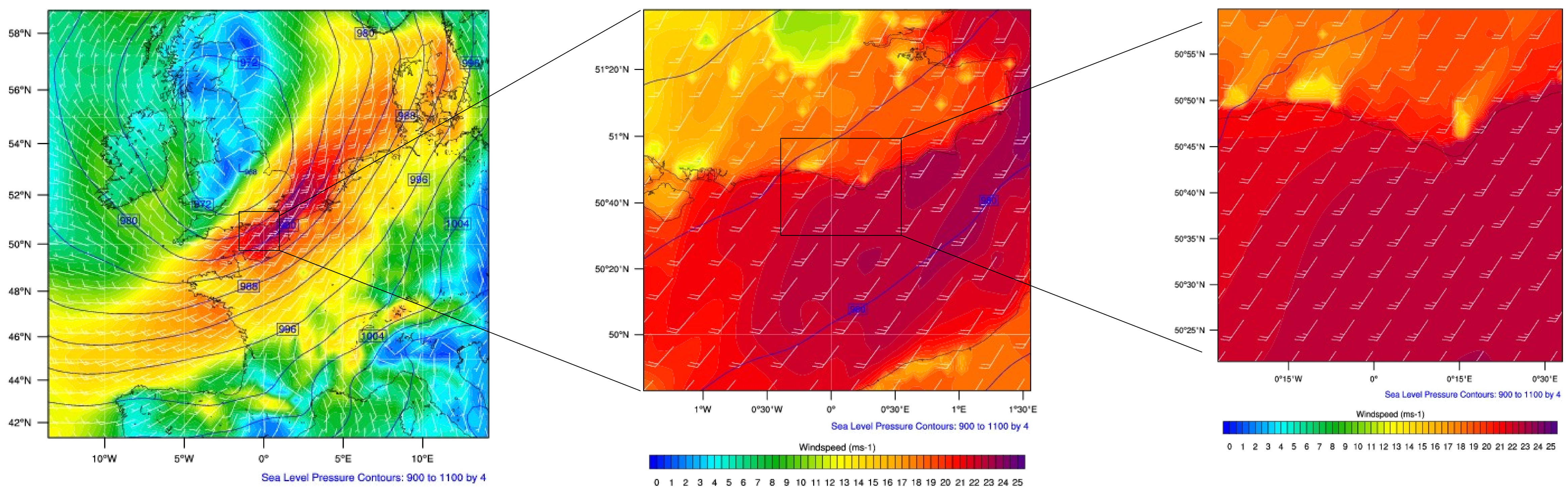
Storm surge is also important in determining water depth and depth-limited wave breaking in front of the structure. Therefore, research is needed to improve our ability to predict the morphological evolution and water level change during the course of a storm through detailed stochastic analysis of coastal morphological processes and changes.

Simulating wind and atmospheric pressure fields of severe storm events

Models that are routinely run over the UK domain in national weather centres, have such a coarse spatial resolution that coastal models have difficulty utilising their output as an effective input. Therefore, a downscaling procedure is required to bridge the scale gap between the large-scale meteorological modelling domains and coastal modelling domains.

This study utilises the WRF modelling system (version 3.0) to resolve the dynamics over 1km grids. The ECMWF forecasts/ analyses datasets are used to define the boundary conditions. The research focuses on generating a high-resolution ensemble of wind and pressure fields of extreme extratropical cyclones. The use of ECMWF ERA40 dataset enables an analysis of the last 40 years of extreme storm behaviour, by providing the low-resolution historical boundary conditions required to drive WRF.

Hence, an assessment of the past and current flood risk may be made, using output from WRF in conjunction with the oceanographic models described below.



Above: **Windspeed and sea-level pressure fields at 03:00UTC on 16 October 1987. The "Great Storm" produced gusts in excess of 50 ms^{-1} in coastal locations, with sustained windspeeds in excess of 25 ms^{-1} observed (Burt and Mansfield, 1988). Coupled with the high tide, the high windspeeds resulted in the speed of propagation of the surge peak to be equivalent to that of a tidal wave (Pirazzoli et al., 2007). However, fortunately for coastal locations on either side of the English Channel, it was the day after a neap tide and the severity of flooding was dramatically reduced.**

Oceanographic Models

The meteorological information generated by WRF is transformed into hydrodynamical parameters, suitable for local engineering applications, through the use of a set of well established modelling systems, including:

- Atlantic WAM model (continental scale, ~1000s km) - provides wave forcing for regional model.
- POLCOMS (regional scale, ~100s km) - takes the regional meteorological information (wind and atmospheric pressure), to produce wave, swell and surge conditions for local models. The model, developed at the Proudman Oceanographic Laboratory (POL), is comprised of a baroclinic three-dimensional current model with coverage of both the deep ocean and the continental shelf. The output of POLCOMS provides the boundary conditions to the coastal zone model at a specific site with a much finer resolution.
- COAST2D (coastal zone scale, ~10s km) - produces further detailed hydrodynamics in the coastal zone, and provides information for coastal flooding and erosion studies. Included within the model are the main coastal processes, such as wave refraction/diffraction, breaking, reflection, tides and wave-current interaction. The hydrodynamic conditions simulated by the model are utilised by surf zone models for studying coastal flooding and erosion.

Future Climate Change

The intensity and frequency of extratropical cyclones over the UK is likely to be affected by future climate change (IPCC, 2007). In addition, sea level rise is now acknowledged as a real threat to coastal towns and cities in the UK. The current UK coastal flood defences have typically been designed to cope with severe storm events with a return period of 50-100 years, and in the future may be inadequate to protect the coastal areas under threat. Were a similar meteorological event to the Great Storm (described above) to occur at the time of a spring tide, the results would be devastating. While the October 1987 storm is the strongest on record for the southern region of the UK, there is some postulation that the return period for extreme windspeeds, such as those associated with this event, may be reduced in future climates (e.g. Woth et al., 2006; Leckebusch et al., 2006).

Future projections of climate generated by a variety of GCM-RCM chains, including those used in the IPCC's Fourth Assessment Report, are available from the PCMDI (Program for Climate Model Diagnosis and Intercomparison). These projections will be downscaled using WRF, enabling high resolution wind and pressure fields of potential future storm events to be simulated. The meteorological fields from each member of the ensemble of future storms events will drive the oceanographic models. The subsequent simulations of oceanic conditions will in turn drive the surf zone model to predict the beach and structure response to potential future storms. In addition to assessing the uncertainty between the different model projections (and model chains), projections with a number of different emissions scenarios will be considered.

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