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

Richard Hewston[1*], Qingping Zou[2], Dominic E. Reeve[2], Ian Cluckie[1], Shunqi Pan[2], Dawei Han[3], Judith Wolf[4], Xin Lv[2], Yongping Chen[2] , Zhong Peng[2].

[1] School of Engineering, Swansea University
[2] School of Engineering, University of Plymouth
[3] Department of Civil Engineering, University of Bristol
[4] Proudman Oceanographic Laboratory

1. INTRODUCTION

Among all natural catastrophes in Europe, extra-tropical cyclones pose the greatest threat to human life and have resulted in significant economic losses. The value of the UK's assets at risk from flooding by the sea have significantly increased in recent years and currently stand at a value of £132.2bn with some 4 million properties in England and Wales alone under threat (Office of Science and Technology, 2004).

The EPIRUS (Ensemble Prediction of Inundation Risk and Uncertainty arising from Scour) project aims to develop a robust and integrated "Cloud-to-Coast" modelling framework which will include the complex interactions between atmosphere, ocean and coastal flood, so that the flood risk in the coastal areas from extreme events, can be accurately assessed.

High-resolution atmospheric pressure and wind fields of historic severe storms will be generated using reanalysis data to initialise WRF. These variables will, in turn, drive wave, tide and surge models, allowing an assessment of the current coastal flood risk to be made. The intensity and frequency of extratropical cyclones over the UK are likely to be affected by 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 future may be inadequate to protect the coastal areas under threat. Future projections of climate over the North Atlantic and north west Europe will be dynamically downscaled using WRF, with the output fed into the wave, surge and tide models. Subsequent output from the 'cloud-to-coast' system will provide a useful tool for coastal engineers and coastal zone managers to assess possible future changes in flood risk.

Figure 1: Wave overtopping of a seawall in southern England. The overtopping resulted in the temporary closure of a mainline railway and extensive damage to sea defences along a large portion of the south coast.

2. METHODOLOGY

The 'cloud-to-coast' modelling system comprises of;

1) Numerical Weather Prediction model: The Advanced Research WRF model (version 3.0) (Skamarock et al., 2008) will

* *corresponding author address: School of Engineering, Swansea University, Singleton Park, Swansea, United Kingdom, SA2 8PP. Email: r.hewston@swansea.ac.uk*

be used to generate simulations of historic and future severe storm events. Wind and pressure data will be extracted and fed into tide, surge and wave models.

2) Regional wave, surge and tide model: The regional POLCOMS offshore waves and tides model, the POL 2-D tide-surge shelf-scale model and an existing 2-D high resolution coastal processes model are being used for transforming the surface meteorological fields into coastal parameters (Flather and Williams, 2004, and references therein). The updated POLCOMS model includes coupled waves and current. The coastal process models include wave refraction /diffraction, breaking, reflection, wind, tides, and wave-current interactions.

3) Surf zone model: State-of-the-art surf zone hydrodynamics model, based on Reynolds-average Navier-Stokes equations (RANS) to determine wave overtopping, breaking, turbulence and streaming arising from the wave and water level outputs from the tide/surge/wave models. This model includes a free surface tracking scheme using Volume of Fluid technique and will include predictions of future beach morphology.

In addition to using reanalysis data for boundary conditions in WRF simulations, output from the ECMWF forecast system will be utilised. The 51-member Ensemble Prediction System (EPS) produces global forecasts of atmospheric conditions at 40 km resolution on 12-hourly timesteps. Each member will be used to initialise WRF, producing a perturbed physics ensemble of historic severe storm events. This will allow the quantification of the uncertainty involved in the dynamical downscaling process of the meteorological variables. Furthermore, the clouds-to-coast nature of the model system, will enable the propagation of uncertainty through the model chain to be assessed.

The Great Storm

Initially the main focus will surround the Great Storm (16 October 1987) and the Burns Day Storm (25 January 1990). Both storms resulted in extensive structural damage across the UK, with significant coastal flooding and erosion occuring on the south coast.

The extratropical cyclone tracked across the North Atlantic on 15 October 1987, with a sea level pressure nadir of 952 hPa, and reached the English channel at midnight. The storm centre made landfall over Devon in south west England, before tracking over central England in a north eastward direction and moving into the North Sea. Gusts in excess of 50 ms^{-1} were recorded in coastal locations, while sustained windspeeds in excess of 25 ms^{-1} were measured, as shown in Figure 2 (Burt and Mansfield, 1988).

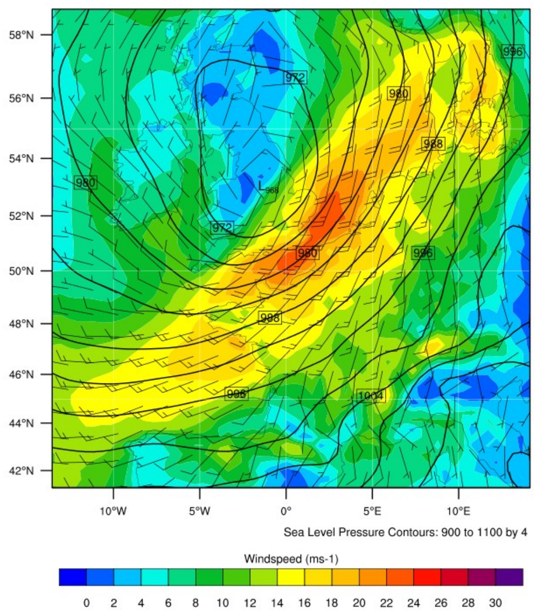

Figure 2: Sea level pressure and 10-metre windspeed over north west Europe at 03:00 UTC 16 October 1987 (as simulated by WRF initialised with ERA40 data).

The record windspeeds and track location of the storm resulted in extreme surge heights in the English Channel. Coupled with the high tide, the speed of propagation of the surge peak was 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.

Future Climate Change

Were a similar meteorological event to the Great Storm 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 are available from a variety of GCM-RCM chains from the PCMDI (Program for Climate Model Diagnosis and Intercomparison) used in the IPCC's Fourth Assessment Report. Data from these models will be used as boundary conditions for WRF, enabling high resolution wind and pressure fields of potential future storm events to be simulated. The downscaled meteorological variables fields from each member of the ensemble of future storms events will be used to drive the wave/surge/tide models. The subsequent simulations of offshore wave and mean water level will in turn are drive the surf zone model to predict the beach and structure response in the future. In addition to assessing the uncertainty between the model projections (and model chains), projections with a number of different emissions scenarios will be considered.

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