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Modelling water from clouds to coast

9 September 2009 by Qingping Zou and Dominic Reeve

New research could help scientists provide better warnings ahead of natural disasters like coastal flooding. Qingping Zou and Dominic Reeve explain.

Flooding and erosion threaten four million people and properties in England and Wales. Within the UK, assets worth an estimated £132·2 billion are at risk from flooding by the sea and £7·8 billion more from coastal erosion. In contrast, assets at risk on river flood plains are valued at £81·7 billion.

These values are likely to grow significantly as the climate changes. Sea levels are rising and storms will become more frequent and more intense. Protecting coastal communities and cost-effective government spending on flood defences depend on being able to predict the impact of worst storms on sea defences and to quantify and manage flood risks.

In 2006 the Natural Environmental Research Council (NERC) launched a £8 million research programme called Flood Risk from Extreme Events (FREE). By an 'extreme event', we mean one with a return period of more than 50 years. The most devastating of storm surges, such as the 1953 event that killed 307 people along the east coast, had a return period of 250 years (return period is the expected time between events of the same severity. It is often used to define extreme events.) The idea is to improve the predictability and reliability of modelling systems from clouds to rivers to coasts.

The UK government spends around £325 million a year maintaining sea defences and shore protection along its 4,300km coastline. Coastal flood defences are usually designed to withstand storms or floods with a return period of 50 to 200 years. It is too expensive for engineers to build defences that protect against all eventualities, so they design for all events that are likely to occur more than once every 50 years, or 200 years, depending on the policy.

Scour is the removal of sand at the base of the wall, leading to structural undermining and collapse

Weighing the risks

The appropriate return periods are set through mutual agreement between the client and the consultant. Where the client is the government then protection levels for flood defence are usually specified in policy guidance documents. These are based on assessments of the level of risk that we communally call 'acceptable', given the perceived balance between the cost of constructing the defences and the possible consequences of not doing so.

So design periods are not immutable, but change over time according to public perceptions of risk. (This will often be higher after a major flooding incident, when public awareness of the risks is raised as a combination of direct experience and media coverage).

The return period for a particular scheme will depend on what is being defended and the cost of construction, or the 'benefit-cost ratio'. The return period for coastal defences is currently chosen within the range 50-200 years for all but the most exceptional cases - the Thames Barrier was designed to resist a 1-in-1000-year event.

Currently, we don't have a robust and integrated 'clouds-to-coast' framework for coastal flood risk. The interactions between the atmosphere, oceans and coasts are poorly understood. There are large uncertainties in the performance of sea defences and predictions of coastal flood risk in extreme conditions.

Within the FREE programme, NERC has funded the Ensemble Prediction of Inundation Risk and Uncertainty arising from Scour (EPIRUS) project to bring together a team of hydrometeorologists, oceanographers and coastal engineers. Dr Qingping Zou is the principal investigator and co-investigators are Professor Dominic Reeve and Dr Shunqi Pan at the Coastal Engineering Research Group of University of Plymouth.

Predictions by ensemble

We are collaborating with a team from the University of Bristol led by Professor Ian Cluckie (now at Swansea University) and Proudman Oceanographic Laboratory as well as industrial and public-sector partners including the Halcrow Group and the New Forest District Council.

By bringing together models of atmospheric weather conditions, waves, surge and tide propagation, and physical changes near the shore, we hope to create a new way of predicting coastal flooding. The system will let us better quantify the risk that defences will fail during extreme storms. In particular, this project will focus on processes leading to flooding due to failure of defences; that is, toe scour and wave overtopping.

We use an 'ensemble' approach to improve predictions. The Monte Carlo simulation is one well-known example of an ensemble prediction system. These systems are now common in weather forecasting, but are not widely used in coastal engineering.

Weather forecasting systems are chaotic. A small error in the initial conditions, say wind speed or direction, or entering a slightly lower land-surface temperature in some areas, can amplify rapidly with time. At present, we can forecast major weather patterns reasonably well up to about three days ahead. Beyond that uncertainties in the forecasts can become so large that the forecast is no longer meaningful.

With ensemble forecasting, instead of running just a single forecast, we run the model many times from slightly different starting conditions. The complete set of forecasts is referred to as the ensemble and individual forecasts within it as ensemble members.

This type of ensemble prediction approach allows us to estimate the relative probabilities of different outcomes and so improve our understanding of the reliability of results. This approach also provides a measure of the uncertainty associated with predictions. Extreme events are rare, and ensemble predictions are more likely to capture them than conventional forecasts.

Overtopping is when water passes over the top of the sea defence crest line

This three-year project started in early 2007 and consists of three strands: meteorological modelling; regional scale wave and surge modelling; and surf zone hydrodynamic and morphological modelling.

One of the issues is to make global climate predictions for this century meaningful to the UK. We are developing a linked set of numerical models to apply global atmospheric predictions to a UK scale. From this we want to predict the associated sea surges, tide and waves, simulate wave propagation into shallow water and show what happens when these waves hit sea walls and the beach. These models will be used to create a set of physically possible outcomes (the ensemble) from which uncertainties in flood predictions can be quantified.

Predictions of beach and sea defence response to each ensemble of storms will establish a statistical description of the ensemble coastal flood risk arising from overtopping and scour.

This ensemble system will then let us assess the uncertainty in predicting overtopping and scour as well as the associated coastal flooding, which is particularly large during extreme events. The modelling results will help evaluate how suitable the way we currently design coastal defences is for future extreme events. We will gain an improved understanding of the combined risks of scour and overtopping, together with a measure of the uncertainty in predicting them

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Dr Qingping Zou is principal investigator for the EPIRUS project and senior lecturer in coastal engineering at the University of Plymouth. Dominic Reeve is professor of coastal dynamics at the University of Plymouth.
qingping.zou@plymouth.ac.uk

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Planet Earth editors
editors@nerc.ukri.org