Flood Risk from Extreme Events (FREE)
Summary Progress Report May 2008

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INTRODUCTION

Progress reports from all but one of the FREE PIs have been received for the quarter ending March 2008. Information from these reports has been extracted, and used to generate this report. This information has also formed the basis of a paper to be presented by the Science Coordinator at the forthcoming Floodrisk2008 Conference 29 September to 3 October 2008 at Oxford. Some of the introductory material is of course well known to members of the Steering Committee, but is retained here to set the scene. Some other material has been omitted as not necessary for this report. It is the intention from now on to generate a summary report like this for the Steering Committee on approximately a quarterly basis.

1. PROGRAMME OBJECTIVES

The broad programme objectives embody consideration of the meteorological, hydrological and coastal oceanographic processes involved. Such processes include floods arising either through the occurrence of extreme rainfall and subsequent flows underground, overland or in river channels to the sea, or within estuaries and sea areas generated from storm surges around our coast (**Figure 1**). These components were highlighted by major flood events during the summer of 2007 in Tewkesbury and Gloucester, and the 9th November 2007 North Sea storm surge which so nearly spelt disaster for east coast communities.

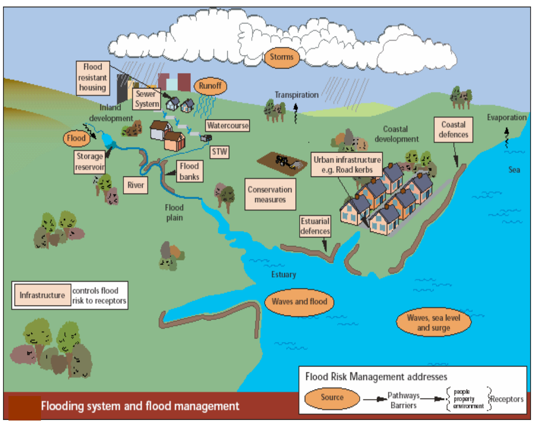

Figure 1. **The scope of the FREE programme (courtesy M. Bramley).**

2. PROGRAMME LINKS

The FREE programme is bound together by the use of advanced mathematical techniques to represent physical understanding. Numerical representations (models) of the physical processes involved in flooding are linked together, and driven by quality controlled data inputs. However, the way in which models are driven requires mathematical structures to assimilate these data providing the basic state from which model equations maybe integrated forward in time. In addition, uncertainty in both the forecasts and in the likely occurrence of extreme events requires sometimes complex statistical approaches to analyse past events.

Improved modelling and forecasts through new data assimilation methods	*New approaches to modelling uncertainty in an integrated modelling environment*	*The statistics of extremes and their use*	*The Impacts of a changing climate on the occurrence of flooding*
Illingworth – NWP and new remote sensing observations	**Zou** – linking meteorological, hydrological and coastal models using ensemble methods	**Svensson** – joint probability analysis of fluvial and estuarine floods	**Osborn** – changing occurrence of rainfall
Dance – initialisation of coastal sediment models	**Beven** – constraining uncertainty in hydrologic modelling	**McSharry** – quantifying flood risk using density forecasts based on a new digital archive and weather ensemble predictions	**Cloke** – changes in hydrological and hydraulic flows
TBC – reducing the risk of pluvial flooding	**Wheater** – groundwater modelling of rare events	**Toumi** – a hybrid model for predicting the probability of very extreme rainfall	**Reynard** – changes in fluvial flooding and inundation
	O'Connell – impact of land use on behaviour of floods		**Williams** – changes in characteristics of coastal floods

Figure 2. FREE Programme at a glance showing the PIs for each consortium project.

FREE science is being undertaken within 13 individual projects. **Figure 2** shows how these projects from a coherent balanced programme of four components with specific elements providing knowledge exchange with stakeholders. A data management policy has been developed by the British Atmosphere Data Centre (BADC) linking a wide range of data sources including data sets managed by the Met Office and the Environment Agency. Substantial new datasets will **not** be produced in FREE. Any data that are collected with output from numerical model runs will be preserved and will be fully documented at the BADC, NEODC, BODC, or data centres at CEH, Wallingford and BGS as appropriate. An arrangement, known as the FLOod Action Team (FLOAT), is also in place to assemble specific data should major extreme events occur during the programme as happened during 2007.

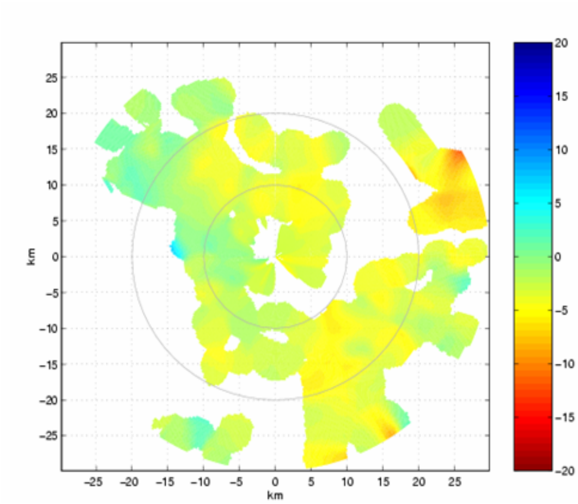

Figure 3. **Refractivity change between 03:00 and 04:00, 30/09/2007 from the Cobbacombe Cross radar. A refractivity unit (N) is approximately equal to a 1% change in relative humidity (courtesy J. Nichol).**

3. ADDRESSING SPECIFIC ISSUES

Flooding is the consequence of the interaction of a number of different physical processes. To forecast flooding, be it fluvial, pluvial or coastal, requires numerical representations (models) of these processes to be linked together. Such models are driven by quality controlled data inputs, but the way in which data are assimilated requires mathematical structures which enable models to be initialised, and then integrated forward in time in ways which retain numerical stability yet allow changes to occur in ways which are physically realistic.

The FREE Programme is addressing the initialisation of Numerical Weather Prediction (NWP) forecast models by assimilating new types of weather radar data (**Figure 3**). This will lead to the generation of probabilistic rainfall forecasts using ensembles of forecasts achieved through multiple model runs based upon slightly different initial conditions. The first set of ensemble simulations at 4km grid spacing using a NWP model perturbation technique have been carried out. These forecasts have been inserted into a hydrological model to produce probabilistic river flow forecasts. This work has been untaken through collaboration between the Joint Centre for Mesoscale Meteorology (JCMM, University of Reading) and the Centre for Ecology & Hydrology (CEH).

The extreme storm of 16 August 2004 causing catastrophic flooding of Boscastle village in Southwest England (HR Wallingford, 2005) has been selected as a case study. Deterministic rainfall forecasts using the high-resolution 1 km NWP (Roberts, 2006) predicted the timing and location of the convective cells well and with remarkable lead-times of up to 10-12 hours, although the actual totals were underestimated. Good NWP performance at such long lead-times was only possible for the Boscastle event due to the particular forcing mechanisms in play (Roberts, 2006; Golding, 2005); more commonly the location and evolution of convective cells cannot be forecast with any certainty beyond 1 to 2 hours.

Notwithstanding the significant improvements in NWP, the resulting rainfall forecasts will always possess inherent uncertainties relating to, for example, spatial location, rain-rates and evolution. The effect of such uncertainties for flood forecasting and warning can be particularly acute when extreme convective rainfall is forecast over regions with small fast-responding catchments. This was exactly the case for the catchment to Boscastle which drains an area of circa 20 km^2 via steep-sided convergent valleys. In such a situation, small changes in the location of the forecast rainfall of only a couple of kilometres can have a significant impact on the resulting flood forecast, particularly when distributed hydrological models are used (Moore et al., 2006).

Ensemble NWP rainfalls used as input to distributed flood forecasting models provides an attractive way of quantifying the uncertainty of hydrological forecasts attributable to the forecast rainfall input. Whilst more advanced methods for generating high-resolution NWP ensembles are being developed (e.g. physically-based perturbations) a simple method of ‘pseudo-ensemble’ generation has been used initially. The method consists of two steps: (i) a scalar multiplier is applied to the entire high-resolution NWP forecast, and (ii) ensemble members are generated by displacing the spatial origin of the storm randomly within a selected (here, 20 km) radius (see **Fig. 4(a)**).

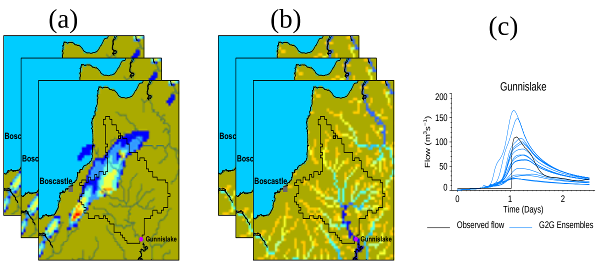

Figure 4. Example of the exploitation of new data sources, data assimilation and ensemble techniques for storm and flood forecasting’ using the Boscastle storm as a case study: (a) a ‘pseudo-ensemble’ of high-resolution 1 km NWP rainfall, (b) an ensemble of distributed hydrological model simulations of river flow using the Grid-to-Grid (G2G) model, (c) comparison of G2G ensembles with observations for the River Tamar at Gunnislake (location and 1 km catchment boundary is given in (a) and (b)) (courtesy R. Moore and S. Cole).

These ensemble rainfalls have been used as input to the distributed Grid-to-Grid (G2G) hydrological model (Moore et al., 2006; Bell et al., 2007). The G2G model has been configured to a large part of Southwest England encompassing the ungauged Boscastle catchment and the River Tamar catchment gauged at Gunnislake (circa 900 km^2). **Figure 4(b)** shows the ensemble river flows simulated using the G2G model, with the colours reflecting changes in flow magnitude across the river networks. The benefits of using the Grid-to-Grid model are that it can provide forecasts ‘everywhere’ including gauged and ungauged locations, portrays the spatial evolution of flooding across a whole region and is sensitive to the spatial pattern of rainfall input. Ensemble forecasting outputs that can aid the flood warning decision-making process range from traditional ‘spaghetti’ ensemble plots of hydrographs (see **Fig. 4(c)**) to spatial probability maps of exceeding a flow threshold of interest, such as the 50-year return period flood.

An alternative approach to improving the quality of predictions of the probability of rainfall is to combine advanced methods of statistics, the output from NWP models and an archive of extreme rainfall events (PI: McSharry, Oxford). So far both autoregressive and generalized autoregressive conditional prediction models have been tested on rainfall time series with some success. A more sophisticated model has been produced making use of Generalized Linear Models based upon the use of non-Gaussian densities to produce probabilistic forecasts of daily rainfall totals.

A similar, albeit novel, approach is being adopted for coastal sediment models of the River Dee estuary and Morecambe Bay. Future bathymetry is predicted and a modified version of the Proudman Laboratory hydrodynamic model initialisation is achieved via a computational 3D-VAR assimilation structure (PI: Dance, Reading) (**Figure 5**). Data being used include satellite and RADARSAT, airborne lidar, swathe bathymetry and beach transects.

An attempt to link meteorological, hydrological and coastal inundation models will be made to investigate uncertainties in forecasts using ensemble techniques in the Ensemble Prediction of Inundation Risk and Uncertainty arising from Scour (EPIRUS) project (PI: Zou, Plymouth). So far the MM5 atmospheric model has been used to analyse two historic storms ready for the model output to be used to provide input to the POLCOMS model providing forecasts of waves for use with 2-D and 3-D surf / scour models. A particular aim will be to investigate wave transformation from off-shore to near shore to predict wave overtopping and scour near coastal defence structures.

However, more detailed investigation of uncertainties, and how to constrain them, in the assimilation of data into hydraulic routing models is needed (PI: Beven, Lancaster). The models for the Dee and Ribble catchments will incorporate data from a network of GridStix sensors, developed at Lancaster, that measure river depth in real-time.

In addition, floods do not always arise from rivers overtopping, they may result from groundwater sources reaching the surface, particularly in Chalk catchments. Extreme floods of this type require new approaches to groundwater modelling as their occurrence is rare and difficult to forecast. (PI: Wheater, Imperial College, London). So far a two dimensional model for simulating the unsaturated / saturated zone interactions, and particularly the water table response to extreme events has been configured for a hillslope segment through the East Ilsley field site. In addition, a model grid structure has been decided upon for modelling the Pang and Lambourn catchment in Berkshire.

Although Chalk catchments have a specific type of land use associated with them, other catchments attract different types of land use which may have impacts on the occurrence and behaviour of floods. This too is being investigated in FREE (PI: O'Connell, Newcastle). So far a comprehensive library of local-scale metamodels that represent the hydrological response of individual fields / hillslopes has been developed. At present the focus is on the Pontbren (Upper Severn), the Eden and the Hodder (Ribble) catchments.

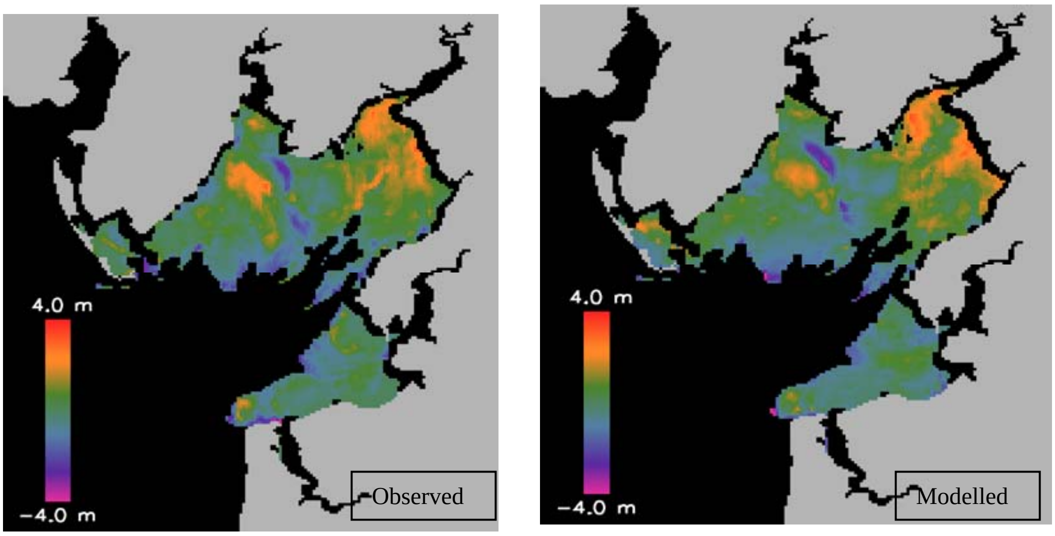

Figure 5. Observed and modelled changes over a three year period of the sea bed morphology in Morecambe Bay (from Scott and Mason, 2007).

Forecasting extreme floods using the outcome of FREE research as articulated above takes no account of climatic change. Our climate is changing due to human activity. Research on how this impacts the occurrence of rainfall (PI: Osborn, UEA), hydrological and hydraulic flows linking Hadley Centre and other climate data to the Lisflood and Dynamic-TOPMODEL models (PI: Cloke, Kings College, London) (Figure 6), the whole of the fluvial flooding chain from rainfall to river inundation (PI: Reynard, CEH, Wallingford) and coastal flooding (PI: Williams, Plymouth) are being investigated in FREE.

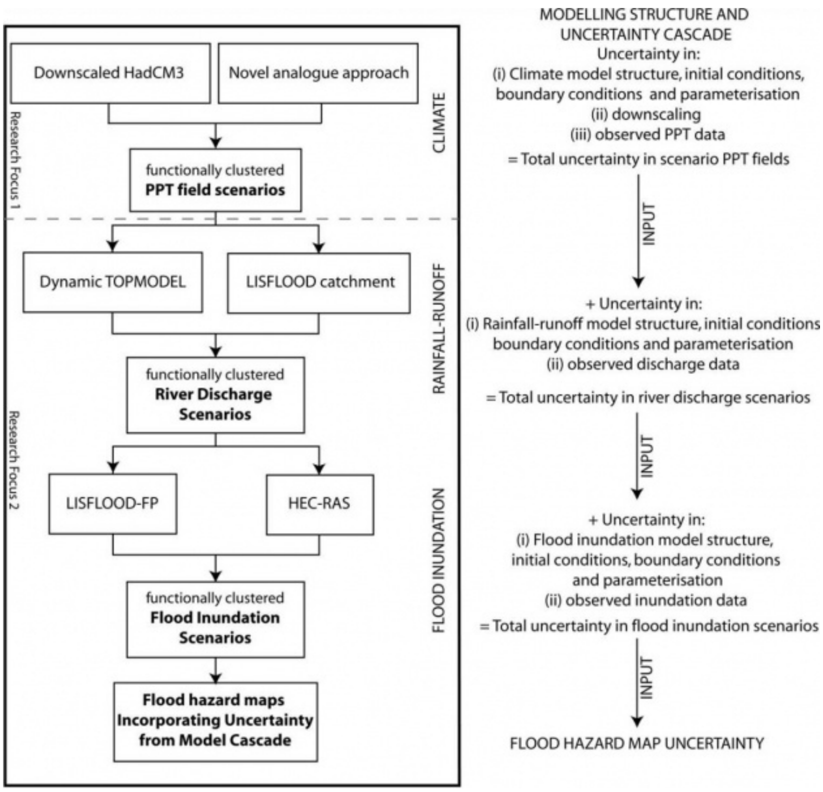

Figure 6. Modelling structure and uncertainty cascade in the project aimed at assessing uncertainty in flood inundation impacts (courtesy H. Cloke).

An enhanced version of the CEH Grid-to-Grid model, incorporating variable soils data and lateral flows of soil moisture is being trialled on the Thames region. Enhanced 1 km gridded flow directions have led to more realistic artificial river networks and catchment areas, leading in turn to reduced errors in the water balance and modelled river flows. This and the Newcastle NSRP model will be used with future climate data scenarios from the Hadley Centre (PI: Reynard, CEH, Wallingford).

Figure 7. The Sefton coast. Note the proximity of the urban area (courtesy J. Williams).

CoFEE Project Partners and part of the Sefton Coastline, NW England.

The Coastal Flooding by Extreme Events (CoFEE) project (PI: Williams, Plymouth) is investigating the impact of severe storms on erosion of the sand dunes along the Sefton coast and concomitant flooding (Figure 7). Recent results published by Maraun et al (2008) (PI: Osborn, UEA) support the existence of a long-term increase in winter precipitation intensity, although the summer rainfall intensity has exhibited changes that are more consistent with inter-decadal variability than with any overall trend (Figure 8).

Finally, the mathematical recurrence of extreme fluvial or estuarine flooding, important for the engineering design of mitigation measures, requires statistical analytical approaches such as joint probability analysis which incorporate seasonality and geographical variation. This work will concentrate on floods with return periods of up to 1000 years and beyond (PI: Svensson, CEH, Wallingford).So far autocorrelation and lagged cross-correlations between observed rainfall, observed and modelled river flows and modelled soil moisture deficits have been estimated at two trial locations. Also regression models for extremes of river flow at a single site have been developed, with particular attention being paid to whether pre-processing the flow data using such models might improve marginal tail models. In addition the use of the Met Office Numerical Weather Prediction model offers a basis for investigating the recurrence of extreme rainfall events. Such work began ain January 2008 (PI: Toumi, Imperial College, London). Idealised experiments have been undertaken using the NCAR Weather Research and Forecasting (WRF) atmospheric model to investigate the effect of atmospheric moisture on the individual convective systems that contribute to very extreme rainfall events. The results suggest that for an idealised squall line there is a near linear relationship between atmospheric moisture and maximum rainfall depth. Future work will employ the Met Office Unified Model (UM).

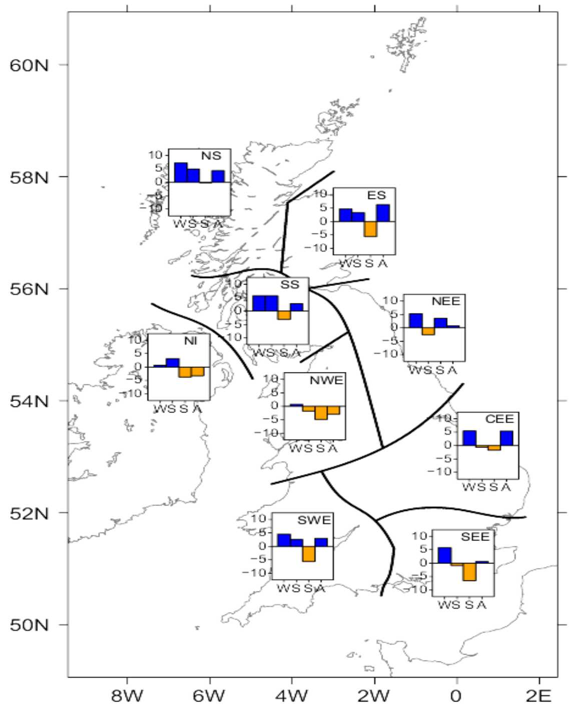

Figure 8. 1961-2006 trends of category 10 (heavier events) contributions for winter, spring, summer and autumn. The results are given as the absolute contribution change in percent over the whole period (from Maraun et al., 2008).

4. DATA EXCHANGE

FREE is a basic science research programme, and as such it is reasonable to expect the outcomes to focus on advances to our knowledge of how extreme floods occur, how we might forecast them, and how climate change may impact their occurrence and recurrence. Validated modelling methodologies will form the basis of useful tools for weather and flood forecasters, for managers concerned with putting in place warning procedures and for civil engineers concerned with designing and building flood mitigation measures.

Pluvial floods (overland flows) in both urban and rural areas also present challenges for modelling, which will be examined through knowledge transfer activities. A call for Knowledge Exchange Projects is being drafted.

Data exchange activities with stakeholders is a central part of the FREE programme. Stakeholders directly involved in the programme include the Environment Agency, Defra, the Met Office (including the Hadley Centre), HR Wallingford and ECMWF. If we needed a reminder on how timely this programme is after the flooding in 2007, FREE has already been able to show that it will make a contribution to several of the Interim Conclusions and Recommendations from the Pitt Review.

5. PROGRAMME MANAGEMENT

All PIs have been reminded that Quarterly Progress Reports are required. The progress reports from the last quarter have been archived on a CD and are available for inspection.

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