Joint Centre for Hydro-Meteorological Research

Report on research activities: 1 February 2007 to 14 March 2008

1. Short-range precipitation forecasting R&D

1.1 Trial of the Short Term Ensemble Prediction System (STEPS)

The operational trial of STEPS within the UKPP (UK Post-Processing) system continued throughout 2007. This involved the routine running of a control member forecast and ensemble (15 members) on the Met Office's NEC supercomputer, and the production of a range of continuous and categorical verification statistics. Upgrades to STEPS in July and December 2007 improved aspects of the advection scheme and noise generation. A further upgrade will be delivered in March 2008 to generate products for trial within the Environment Agency.

1.2 Improvements to the formulation of the STEPS

a. Improvements to the advection scheme

STEPS diagnoses a motion field from a pair of radar and satellite inferred analyses of rain-rate by solving the optical flow constraint (OFC) equation in two dimensions. This backwards-in-time advection scheme divides a time synchronous pair of rain analyses (for T-15 min. and T+0 min.) into a series of square blocks and then solves the OFC equation for each block. The block velocities are subject to a smoothness constraint to ensure that neighbouring blocks have consistent velocities. The weighting on this constraint has been increased to ensure that the resultant, higher resolution velocity fields maintain the correct structure.

When generating an ensemble, the components of the diagnosed advection velocity field are perturbed using noise whose distribution has been inferred from empirical analyses of the errors in the advection velocities. The distribution of these perturbations has been reviewed and fine-tuned.

A collaborator in the Australian Bureau of Meteorology has undertaken vectorisation work to improve the efficient execution of the STEPS code on the NEC SX6/8 supercomputer. Recent tests confirm that execution time for a single forecast has been reduced by a factor of ~5 since February 2007.

b. Tuning of the noise generation algorithm

Following modifications to the noise generation algorithm in 2006 to improve the correspondence between noise power spectra and those derived from UK weather radar composites, the dynamic scaling model for noise power spectra has been fine-tuned. This

is designed to ensure that the distribution of rain-rate remains realistic in both frontal rain bands and in showery regimes.

2. Development of post-processing for high resolution UK NWP models

The following changes were made to the precipitation post-processing algorithms within the UKPP system.

(i) Generation of a product to indicate the likelihood that rain will turn to snow

At the request of forecasters in the Met Office's Operations Centre, a new precipitation product was added to the UKPP system to diagnose the likelihood that persistent rain will turn to snow in the case of marginal snow events. This algorithm diagnoses a critical precipitation rate above which persistent rain is likely to turn to snow at the earth's surface. This is based upon empirical studies equating the fall in height of the wet-bulb freezing level to the intensity of persistent precipitation.

(ii) Preparations for the trial of products generated by the Short-Term Ensemble Prediction System (STEPS) in the Environment Agency

Modifications have been made to the UKPP suite to run the STEPS control member on a 15 minute cycle. This control member will provide the Environment Agency with 15 minute resolution nowcasts of rain rate and rain accumulation with a range of 6 hours, and a 5 minute resolution nowcast of rain-rate with a range of 6 hours.

3. Use of probability forecasts

This jointly funded, Met Office-Environment Agency project began in May 2006. The first phase of this project (FY06/07) established an initial, Environment Agency user requirement for probabilistic precipitation forecasts in relation to fluvial flood forecasting and warning.

Commencing in Spring 2007, Phase 2 of the project implemented a web-based operational trial of probabilistic precipitation forecasts for the Environment Agency. This trial included the provision of probability of exceedence maps and stacked probability charts for predefined areas and rain accumulation thresholds. Following completion of the trial in December 2007, a workshop was held to review feedback and clarify aspects of the user requirement.

Phase 3 of the project, due to start in Spring 2008, aims to deliver an operational, web-based service providing a similar range of products to those trialled in 2007.

4. First guess heavy rainfall warnings

An Environment Agency funded project concerned with the generation of a first guess heavy rainfall warning began in the summer of 2007. This project aims to enhance an

existing heavy rainfall warning service provided to the Environment Agency by the Met Office.

Software has been developed to generate first guess heavy rainfall warnings for a set of Agency defined areas and warning thresholds using a range of precipitation forecasts produced by the Met Office. These include those generated by the UK 4km configuration of the Unified Model, STEPS and the North Atlantic and European (NAE) configuration of the Met Office's Global and Regional Ensemble Prediction System (MOGREPS).

A trial of this first guess heavy rainfall warning service will commence in Spring 2008.

5. Blending convective-scale NWP with ensemble nowcasts

This new Met Office-Environment Agency jointly funded project aims to integrate precipitation forecasts generated by MOGREPS, STEPS and a high resolution (1.5 km) configuration of the Unified Model to produce a seamless, high resolution ensemble precipitation forecast, suitable for driving hydrological models and for use by forecasters in the Met Office.

The proposed blending algorithm will exploit the STEPS cascade model framework to allow the scale selective combination of the various model forecasts. The resultant, blended ensemble forecast will have a horizontal resolution of $\leq$2 km, a forecast range of several days and comprise at least 24 members.

A paper proposing several plausible blending formulations was circulated in the autumn of 2007. A report reviewing the comparative performance of the models on 8 precipitation cases studies from 2007 was prepared in January 2008. These will serve to guide the development of the blending algorithm during 2008.

6. Assessment of MOSES-PDM

A project jointly funded by the Met Office and the Environment Agency (EA) project began in July 2006 with the aim of allowing operational Nimrod/UKPP-MOSES-PDM hydrological products to be used in EA water resource models which have been calibrated with corresponding products from a long offline run of MOSES-PDM driven by 40km MORECS meteorological data. The operational data are first aggregated to the 40km grid and then correlation statistics are computed against the offline data (and vice-versa).

The first phase of the project used the data generated using the version 1.0 offline model and the operational Nimrod-MOSES-PDM data for September 2004 to August 2006. Correlations for Potential Evaporation (PE) are fairly good except in winter months where the offline run has to use sunshine hours observed over the short days to estimate cloudiness over the long nights. This leads to poor correlation with the operational data which have the benefit of satellite observed cloudiness overnight (from infrared channels).

The offline model formulation and ancillary fields have been updated so that they are consistent with the operational UKPP-MOSES-PDM (this is called version 2.0). The comparison of the UKPP and new (v2.0) offline PE has now been done for the summer months (June, July & August) and for the autumn months (September, October & November) of 2007.

Correlation statistics for the comparison of offline and UKPP-MOSES-PDM grass PE for JJA 2007 are much poorer than those for the comparison of offline and Nimrod-MOSES-PDM in JJA 2005-06. It has been established that this is not because of the change from the Nimrod to UKPP systems but rather the particular meteorological conditions in the summer of 2007 which was cloudier and wetter than the summers of 2005 and 2006. Again a major cause of the poor PE correlations is the poor correlations between the two model setups' meteorological drivers, particularly downward radiation at the surface. Similar statistics for SON 2007 are much better and comparable to those found for previous years with the Nimrod system.

The Environment Agency would also like an indication of where, or for which catchment types, the operational MOSES-PDM products are less reliable either because of poor input data or because of limitations in the MOSES-PDM formulation, e.g. in the treatment of particular soil types. Verification of daily mean river flow from a River Flow Model (RFM) coupled to MOSES-PDM for a variety of locations and catchment types has been done for August-November 2007. The hope had been that inadequacies in MOSES-PDM could be determined from river flow verification; in particular, that any soil-type dependency of MOSES-PDM errors could be determined from river flow verification for catchments small enough to be fairly homogeneous in their soil-types. This hope could easily be dashed by other sources of error (in the precipitation derived from radar data, in the RFM's catchment areas and routing paths and in the parameters in the RFM's flow propagation scheme) and the difficulty of disentangling these from MOSES-PDM errors. The river flow verification statistics are not good anywhere but the worst values are for chalk dominated catchments. This is unsurprising as chalk is known to be poorly represented in MOSES. Most importantly, there is no representation of groundwater in MOSES-PDM. Most of the runoff from the chalk comes from groundwater whereas MOSES-PDM produces significant surface runoff for this soil type.

If there are systematic errors in the observed rainfall field which drives a model then these will lead to accumulated errors in the derived soil moisture field. For this reason an assessment of time-means of the composite radar rainfall fields which drive MOSES-PDM in the Nimrod and UKPP systems should give some guidance on the modelled soil moisture accuracy. A time-mean radar rainfall analysis reliability indicator has been produced by forming differences between the National Climate Information Centre (NCIC) seasonal rainfall accumulations, based on a large set of gauge observations, and the corresponding radar rainfall accumulations.

7. Hyrad and RFFS

CEH's Hyrad system supports the real-time receipt, processing and display of weather radar and hydro-meteorological space-time images, especially for use in flood and water resource management. It is being used by the Environment Agency across England and Wales and by SEPA in Scotland to display Met Office Nimrod products and to support interfaces to their flood forecasting systems.

CEH's RFFS (River Flow Forecasting System) suite of modelling software encompasses both Model Calibration tools for application off-line and Model Algorithms streamlined for real-time use. The Model Calibration suite includes: "PDM for PCs" rainfall-runoff model, "KW for PCs" channel flow routing model and "PSM for PCs" rainfall-runoff model (encompassing the TCM and IEM models). These are in use by the Environment Agency as part of their NFFS (National Flood Forecasting System) deployment throughout England and Wales. The real-time Model Algorithms PDM (including data assimilation by state correction), KW and ARMA error predictor are being used within flood forecasting systems operated by SEPA in Scotland.

With the above developments, the EA and SEPA have the capability to use Met Office Nimrod products (radar, NWP and MOSES), via CEH's Hyrad system, for use in flood warning and water resource management throughout England, Wales and Scotland.

Hyrad is being used to support RFFS-FloodWorks applications in Dender, Centrale and Demer catchments in Belgium. A live feed of European Nimrod analysis and forecast products are delivered by the Met Office to the Hyrad system, to complement the Belgium High Resolution Radar Composite actuals and Aladin NWP forecasts. The analysis and forecast rainfall products - for different time-space resolutions, map projections and coverage areas - are merged within Hyrad according to user-set priorities and fed through to the flood forecasting systems. Training and operational trials were carried out during 2007.

8. Extreme Event Recognition

This Defra R&D Project involved a Met Office lead consortium encompassing inputs from CEH and the University of Salford. The overall objective was to improve the capability to provide warnings of extreme flood events via improving rainfall forecasts and flood forecasting models/procedures (including decision-support). CEH developed spatio-temporal rainfall datasets, using radar and raingauge data from historical heavy rainfall events, enhanced to represent extreme events. These datasets were used to evaluate and improve the performance of hydrological models under such extreme event conditions. They were also used for model destruction testing.

A central question addressed by the study was "What makes an extreme storm an extreme flood?" The study served to highlight the potential value of distributed models in forecasting unusual extreme storms. Also, their area-wide coverage yielded maps of river flow that gave fresh insight into the space-time shaping of a storm into a flood under the

controls of landscape form. The results of the project are of particular relevance to flood warning for ungauged locations.

The final project reports are now freely available on the web (see Publications). A Training Workshop for the Environment Agency was convened at Wallingford in February 2007 to discuss the project results, the Extremes Dataset and accompanying software for use with Hyrad and forecasting models. A paper was presented at the European Geophysical Union conference in April 2007, focussing on the rainfall estimation methods developed and assessed for use with lumped and distributed hydrological models. Two papers on this work have been submitted to refereed journals and a presentation is to be made to the "Weather Radar and Hydrology" conference (Grenoble) in March 2008. A further paper was presented in June 2007 to the British-Russian Conference on "Hydrological Impact of Climate Change" in Siberia: this highlighted the relevance of the research to gaining insights into the flood response to extreme rainfall in a changing climate.

9. Flood modelling and forecasting

9.1 Modelling for ungauged basins

The Environment Agency are seeking improved ways of providing warnings for ungauged and low benefit locations that presently receive only a general Flood Watch service. CEH was commissioned, under the EA/Defra National R&D Programme, to develop and evaluate improved techniques for flood forecasting at such locations with the eventual aim of the Agency offering a more targeted and technically sound flood warning service. The final reports are now freely available on the web (see Publications), whilst highlights are contained in IAHS Publication 305. Presentations of different aspects of the research were presented under the umbrella title "Flood forecasting for ungauged locations: what approach is best?" at EGU (Vienna) and IUGG (Perugia) in 2007.

9.2 Flood forecasting using NWP model rainfalls in deterministic and ensemble forms

The NERC FREE (Flood Risk from Extreme Events) programme is funding a three year project, that started in January 2007, entitled "Exploitation of new data sources, data assimilation and ensemble techniques for storm and flood forecasting". This project provides an important opportunity for collaboration between meteorologists at Reading (the University and Met Office JCMM) and CEH hydrological modellers at the JCHMR, Wallingford. The aim is to obtain probabilistic flood forecasts through using ensembles of high resolution NWP rainfalls as input to hydrological models, using data assimilation to improve the initialisation of the models. CEH's component of the project is concerned with research on initialisation, data assimilation and uncertainty for hydrological flood models.

Work began on investigating the use of high-resolution NWP rainfalls as input to hydrological models to reduce and estimate uncertainty in flood forecasting, in

collaboration with the JCMM. The Carlisle flood (6 to 8 January 2005), caused by an orographic storm over the Cumbrian hills, was used as a case study. The investigation - using 1, 4 and 12 km NWP models - demonstrated the improvements in rainfall prediction using the better resolved model topography that feed through to better flood forecasts, at least for longer lead-times. A paper has been prepared for publication in Meteorological Applications that employs the PDM model, as typical of a lumped rainfall-runoff model that would be used operationally in support of flood warning (this work has also been submitted as a poster at EGU2008). Initial work on applying the distributed Grid-to-Grid (G2G) model to this case study was presented at the AGU2007 Fall Meeting in San Francisco.

A scheme for initialization of the G2G hydrological model has been developed and tested based on simple steady-state assumptions. A simple empirical state-correction data assimilation scheme for this model has also been devised. The scheme has been assessed in two ways: (a) in terms of the spatial transfer of the state-correction to internal catchment locations at the time of river flow data assimilation (i.e. filtering rather than forecasting), and (b) in terms of "fixed-origin variable lead-time" and "fixed lead-time variable time-origin" forecasts. This research was presented at the AGU2007 Fall Meeting under the title "Parameter estimation, model initialisation and data assimilation issues for distributed flood forecasting models". Consideration of more complex data assimilation schemes, such as the Ensemble Transform Kalman Filter (ETKF), has been advanced at a theoretical level in collaboration with the Data Assimilation Research Centre (DARC) at Reading.

Past work on employing STEPS ensemble rainfall forecasts with the lumped PDM model has been advanced by using the STEPS forecasts in gridded form as input to the distributed G2G model. The STEPS forecasts have been provided by the JCHMR (Met Office) and Bureau of Meteorology (Australia). Animated "postage stamp" displays of gridded runoff maps from each ensemble member have been produced. Gridded "probability of exceedence of a threshold" maps (using gridded 10 year return period flood estimates calculated by an FEH automated procedure) have proved valuable in exposing the severity of flood risk across a catchment, and how this changes over the course of the flood. Simple "spaghetti plots" of forecast flood hydrograph ensembles have been augmented by easier-to-use quartile (25, 50, 75%) and envelope plots. Evaluation of the flood forecast ensembles has employed "forecast lead-time plots" of rmse (root mean square error), mae (mean absolute error) and CBS (Continuous Brier Score) performance measures. The Mole at Kinnersley Manor (144 km^2) has been used as the case study catchment for this work.

CEH is convening and chairing a session at EGU2008 on "Predictive probability, uncertainty and data assimilation in hydrological forecasting" (with co-convenors from Denmark, Italy and Greece) of direct relevance to this FREE project. A paper on initialisation and data assimilation of a distributed flood forecasting has been accepted for oral presentation.

9.3 Hydrological modelling using convective scale rainfall modelling

The EA/Defra Project 'Hydrological Modelling using Convective Scale Rainfall Modelling' began in January 2007, as a collaboration between WL | Delft Hydraulics and CEH, and continues for two years. This Environment Agency led project is a response to ongoing enhancements in the Met Office to its numerical weather prediction capability, including its nowcasting STEPS (2km out to 6 hours) and MOGREPS (24km out to 2 to 3 days) systems both providing ensemble rainfall forecasts. These developments offer interesting opportunities for the Agency and open the door to using a probabilistic approach to flood forecasting. Operational research is required to realise the potential benefits of these developments to the flood warning service of the Agency.

In addition, Met Office research is aiming to improve the prediction of convective events by using much finer grid sizes, moving from 12km to consider 4 and 1km models. With such data available as input to hydrological models, it should be possible to predict the risk of flooding more accurately and with longer lead times. However, the potential benefits for operational flood warning will only be fully realised if appropriate hydrological modelling concepts are applied. The project aims to investigate what hydrological model concepts and associated computational methods allow for making best use of the latest Met Office developments in NWP. A focussed aim is to make operational the use of ensemble data generated by the Met Office's regular weather models as well as considering the future potential of convective-scale rainfall predictions. The project aims to employ both operational lumped rainfall-runoff models and new distributed hydrological models as part of the investigation.

CEH is responsible for the application of the lumped PDM rainfall-runoff model and the G2G area-wide hydrological model within the project; the latter model is especially relevant for flood forecasting and warning at ungauged locations. The NFFS, based on Delft-FEWS, is being used to trial the use of these models in an historical emulation of the operational system.

The Grid-to-Grid (G2G) Model has been developed in Module Adapter form so the model can be used to emulate operational use within the NFFS environment. Because the G2G Model employs gridded rainfalls as input, a Module Adapter form of HyradK has been developed to calculate gridded rainfalls from either raingauge data or raingauge-adjusted radar data. To facilitate efficient transfer of space-time data in and out of the Grid-to-Grid Module Adapter, use has been made of Hyrad's Spatial Image DataBase, SIDB, as part of the Module Adapter software. Note also that CatAvg had previously been developed as a Module Adapter for the EA to calculate catchment average rainfall from gridded rainfall data. These integrated developments have culminated in the 'CEH Spatial Hydrology Module Adapter'. This brings together CEH's spatial hydrology processing applications and models under one umbrella providing a harmonised interface to facilitate integration with the NFFS.

A large case study area over Southwest England has been chosen, encompassing Boscastle, and hydrometric and radar rainfall records obtained for a 5 year period. High-

resolution NWP model rainfall outputs for the Boscastle storm have been supplied by the JCMM (Met Office). CEH and the JCMM are working together to generate pseudo-ensembles from these outputs that will emulate (at a functional level) NWP ensemble rainfall products that will become available in the future. A strategy for model assessment in deterministic and probabilistic modes has been developed, along with consideration of the forms the operational output will take to support flood warning decision-making. A Feedback Workshop with the Agency was convened in June 2007 and a further one planned for April 2008.

10. Global water and carbon cycles

(i) IMOGEN

IMOGEN (a joint CEH and Hadley Centre venture) is being used by Sheffield University to implement a new Dynamical Global Vegetation Model (DGVM) that introduces 'height classes' to TRIFFID (the DGVM is called ED, or Ecosystem Demography). IMOGEN is being used to obtain the variables that are believed to affect fluxes of VOCs (Volatile Organic Compounds) between the land surface and the atmosphere. This is in collaboration with the QUAAC (QUEST Atmospheric Aerosols and Chemistry) component of QUEST.

Also, through collaboration between CEH, the Hadley Centre and Sheffield University, IMOGEN has now been coupled to JULES, making a global "gridded" version of JULES available to the community.

(ii) Plant-Ozone interactions

A mechanistic model to simulate the effect of ozone exposure on plant production has been implemented into MOSES. The model has been evaluated against field manipulation experiments and compared with global decadal carbon budgets with good results. The model has subsequently been applied over the 21st Century with varying fields of future Ozone concentration and global atmospheric CO_2. Results suggest a significant O_3-induced suppression of land production, and imply reductions in future land carbon uptake as hitherto expected by climate-carbon cycle models. This result has used the IMOGEN model, and the work is now published.

(iii) Dynamic Global Vegetation Model Intercomparison

Five DGVMs were run in the framework of the IMOGEN fast climate-carbon cycle model for four SRES (Special Report on Emissions Scenarios) future emission scenarios. Results highlight a large uncertainty in the future climate-carbon cycle feedback among DGVMs, equivalent to several hundred ppmv of CO_2 by 2100. Simulated regional vegetation responses to the same pattern of climate change differ among DGVMs, indicating the need for extensive evaluation of models against field data from drought experiments. A paper on this has now been accepted for publication in Global Change Biology.

(iv) Influence of raised CO_2 concentrations on stomatal closure and associated alteration to runoff.

The original work of Gedney *et al.* (2006) has been extended to consider likely future changes.

11. JULES

The Joint UK Land Environment Simulator (JULES) has now been established as a community land surface model. The first version available to the general community was released as JULES vn2.0 in the summer of 2007. This configuration included additional features over the original version, including the ability to run as a distributed set of points.

The next version of JULES (vn2.1) has a planned release at the end of March 2008. This will include a restructuring of the code to ensure that it is clearer and easier to understand for general users within the community. In addition, it will also include the first stages of the new multi-layer snow scheme for JULES.

The first two JULES Science Meetings have now been held. The first meeting was at the University of Exeter in June 2007. This attracted an audience of around 100 people. The second JULES science meeting was held at CEH Wallingford in January 2008. Again, around 100 people attended the meeting, demonstrating the continuing momentum behind this community initiative. The presentations from both of these meetings are now available on the JULES website (http://www.jchmr.org/jules).

There have been a number of JULES management meetings, most of them concentrating on the development protocols for JULES and also IPR issues. Whilst these issues have not been resolved as yet, good progress is being made. In addition, to the management committee, a scientific steering committee has been established. This comprises of a number of module leaders within JULES, responsible for the scientific development within their area. The scientific steering committee have held two meetings, coinciding with the JULES science meetings.

The scientific steering committee have agreed that there should usually be a general science meeting for the whole community held in January of each year, and then a more specific science meeting held in the summer. The summer meeting will concentrate on one or two modules, with that for 2008 looking at the benchmarking of JULES.

A number of flux-tower sites from around the world are being considered as 'benchmark' tests for JULES. The criteria for their selection are that they should represent a range of climate types and vegetation types and there should be reasonable energy closure. Modelled energy, water and carbon fluxes can be assessed in this way. In addition, larger-scale benchmarking datasets are being considered for the distributed version of JULES. These include remotely-sensed soil moisture and temperature, landscape-scale

carbon fluxes (from ABACUS), river flow data and remotely-sensed vegetation and wetland distributions. The benchmarking of global carbon fluxes is being dealt with under data assimilation projects (e.g. CCMAP) although the concepts are the same. Plans for benchmarking trace gas emissions from JULES are not yet finalised. A series of benchmarking papers for JULES is envisaged, covering the different scales of benchmarks. A benchmarking meeting will be held at CEH Wallingford in July 2008. The strategy will be presented at the IGBP congress in Cape Town in May 2008.

A new post has been set up at the Met Office to help with the co-ordination of developments within JULES and to set up benchmarking tools and protocols. This post is jointly funded between the Met Office and NERC through a sub-contract from QUEST. The post is located in Wallingford and is currently (March 2008) being advertised.

12. WATCH

WATer and Global CHange (WATCH) is an EU Framework 6 project led by CEH at Wallingford. It is scheduled to last four years and will investigate both past and future water resources over the globe. As part of the work, a new global forcing dataset for land surface models is being developed for the whole of the 20th Century. The plans are for the new dataset to have a high temporal and spatial resolution of 6 hours and 0.5 degrees respectively.

To develop this new dataset, a number of existing datasets are being exploited. This mainly consists of using the Climate Research Unit (CRU) monthly mean climatological data and spatially downscaling using the ERA40 data. Whilst this is straightforward for the 40 year period of the ERA40 data, a methodology needs to be developed for the first half of the 20th Century. This is being achieved by studying both the spectral behaviour of the various parameters, along with the co-spectra to ensure that the final dataset is consistent.

Initial work has also been undertaken to rescale the National Climate Centre (NCC) data from 1 degree to 0.5 degrees. This has then been distributed to the modelling partners within WATCH to be used as an initial forcing data to produce some intercomparison data. Provisional results from the intercomparison will be presented at the modelling workshop being held at Wageningen in April 2008.

13. Snow Heterogeneity

Testing of the Unified Model undertaken by the Norwegian meteorological service have shown that the treatment of snow within the Met Office Surface Exchange Scheme (MOSES) can lead to unrealistically low screen-level temperatures. This occurs when there is little snow on the ground and hence likely heterogeneity in the snow cover.

Within the MOSES tile scheme each surface can have a snow cover on it. However, when snow is present the surface temperature is prevented from rising above the freezing point, with any residual energy being used to melt the snow. This causes near surface

temperatures to be unrealistically held close to the freezing point unless all the snow disappears.

A fix within the current snow scheme has been designed. This entails using the permanent land ice tile as a tile for snow on short vegetation and non-vegetation surfaces. When snow is present, the fraction of each of the surfaces within MOSES is dynamically allocated according to the amount of snow present. This allows there to be heterogeneity within the snow area by having fractions of snow-covered and snow-free surfaces. This fix has helped to reduce the cold temperatures problems.

14. Flood estimation in a changing climate over the UK and Europe using river flow modelling, regional climate model outputs and incorporating estimates of uncertainty

The Met Office's Hadley Centre and CEH Wallingford are collaborating on developing methods to predict flood frequencies over the UK in current and future climates. The focus of this Defra-funded research is to provide national estimates of how river flows would evolve throughout this century by linking an ensemble of regional climate model (QUMP-RCM) experiments with a gridded hydrological model (Grid-to-Grid, or "G2G"). A spatial picture of changes in flow regimes from an enhanced formulation of the G2G Model will be supported by more traditional, conceptual hydrological model estimates of river flows for particular catchments. Analysis of the results will provide insight into whether certain regions are at particular risk from changes in hydrological extremes, and if so, why. The national estimates will take into account current knowledge of the uncertainties arising from climate and hydrological models and will aim to provide significant results relevant to UKCIP.

Ongoing research integrating the gridded hydrological model into the regional application of the UM (Unified Model) is nearing completion, and will extend the modelling work over the UK into Europe as far as possible. The output from this work is relevant to assess the joint probability of flooding around river estuaries and other tidal regions, and will provide the important freshwater inputs to the shelf-seas model for marine scenarios.

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