Joint Centre for Hydro-Meteorological Research

Report on research activities: 15 March to 17 October 2008

1. Short-range precipitation forecasting R&D

1.1 Operational implementation of the Short Term Ensemble Prediction System (STEPS)

The focus of work in this reporting period has been on operational acceptance and implementation of STEPS within the UKPP system, and the generation of products to replace those previously provided by the Nimrod and Gandolf precipitation nowcasting systems. The current product suite includes (i) a 5 minute control nowcast of surface precipitation rate with a range of 60 minutes produced every 15 minutes, (ii) 15 minute resolution control nowcasts of surface precipitation rate and accumulation (15 minute accumulation period) with a range of 6 hours generated every 15 minutes, and (iii) 28 member ensemble nowcasts of precipitation rate and accumulation (15 minute accumulation period) produced every hour. Operational acceptance and implementation of STEPS should be completed in October 2008.

1.2 STEPS R&D

Dr Alan Seed of the Centre for Australian Weather and Climate Research at the Australian Bureau of Meteorology visited the JCHMR in May to review the STEPS formulation and discuss possible improvements and further R&D. The modelling issues addressed included the performance of the hierarchy of second-order autoregressive models used to determine the time evolution of the extrapolation nowcast. Early in 2008, case studies and statistical verification demonstrated that the there was a negative bias in the estimation of the autocorrelation coefficients at scales below 64 km. This bias has since been corrected for through the application of a correction factor to the computed autocorrelation coefficients. Verification statistics showed a significant improvement in STEPS performance following the change made in March 2008.

The scope and performance of the observation uncertainty algorithm were also reviewed. The scheme adds a perturbation to the analysis of surface rain-rate at the start of an ensemble nowcast. In its current form, the algorithm has been designed to account for errors arising from use of a fixed Z-R relationship when estimating instantaneous rain-rate R from radar reflectivity Z. The possible extension of this algorithm to account for vertical profile of reflectivity (VPR) correction errors relating to radar beam elevation was discussed.

Following feedback from the Environment Agency on the performance of STEPS products over the summer of 2008 and subsequent case study based investigations, minor changes have been made to the MetUM-4km skill climatology. This determines the

extent to which the control nowcast tends towards the MetUM-4km forecast at maximum range (6 hours ahead).

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

The UK Post-Processing (UKPP) system, which incorporates a suite of post-processing and nowcast algorithms including the Short Term Ensemble Prediction System (STEPS) and the surface hydrology diagnosis scheme based on the Met Office Surface Exchange Scheme (MOSES), underwent operational acceptance testing during the reporting period in advance of operational implementation in October 2008.

a. Trials of STEPS in the UK and overseas

A trial of STEPS products within the Environment Agency commenced in April 2008 and ran for 6 months. A range of queries relating to STEPS performance were received from the Agency's flood warning officers during this period. Five case-specific performance issues were investigated at the end of August 2008. These related to the blending of satellite and radar in the UKPP rain analysis (the starting point for a STEPS nowcast), the performance of the STEPS advection scheme and a negative bias in the intensity of nowcast showers. A brief report was written to explain model performance and propose model improvements, where appropriate.

Also during the same period, STEPS successfully took part in a World Meteorological Organisation sponsored Forecast Demonstration Project (FDP) in Beijing during August and September 2008. This FDP involved the operational trial and comparative verification of nowcast models from various National Meteorological Services (NMSs) and research institutions including the Met Office and Australian Bureau of Meteorology (joint developers of STEPS), Environment Canada, the United States' National Center for Atmospheric Research and the Chinese and Hong Kong meteorological services. Verification results from the FDP will be published in 2009.

b. Development of MOSES within the UKPP system

The current version of MOSES within the UKPP system uses the IGBP-DIS van Genuchten parameters as the basis for its soil hydraulic properties ancillary fields. Research in the MetUM ancillary fields development group at the Met Office HQ has determined that better van Genuchten parameters could be derived using WISE input data (Batjes, 2006) and the Woesten model (Woesten *et al.*, 1999 and Schaap *et al.*, 2004). The soil ancillary generation algorithm for UKPP-MOSES has been modified to produce parameters based on Woesten-WISE. If implemented these ancillaries would make the UKPP soil moisture more consistent with that of trial configurations of the MetUM also using Woesten-WISE. However, the trial of Woesten-WISE van Genuchten parameters in the MetUM led to some shortcomings in model forecast performance and so implementation was not recommended. Instead investigation of the Harmonised World Soil Database:

www.iiasa.ac.at/Research/LUC/luc07/External-World-soil-database/HTML/ has begun. A trial of the soil fields generated from Woesten-WISE within UKPP-MOSES may still be useful.

A new method of deriving the soil thermal conductivity using relations derived by Lu *et al.* (2007), for the dry value, and Johansen (1975) for the saturated and actual values has been coded for UKPP-MOSES. This parametrization has already been implemented in operational forecast configurations of the MetUM.

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.

In 2007/08, a second phase of the project implemented a web-based operational trial of probabilistic precipitation forecasts for the Environment Agency. This trial included the provision of MOGREPS NAE (North Atlantic and European configuration of the Met Office Global and Regional Ensemble Prediction System) based 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.

A third phase of the project will commence in October 2008. This aims to deliver a report on the skill and value of probabilistic precipitation forecasts and an operational, web-based service providing a range of MOGREPS NAE and STEPS based probabilistic precipitation products (stacked probability charts) similar to those trialled in 2007.

4. Blending convective scale NWP with ensemble nowcasts

This 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, work on which is due to commence in October 2008.

5. First guess heavy rainfall warnings

Aimed at enhancing an existing heavy rainfall warning service provided by the Met Office to the Environment Agency, this project began in the summer of 2007. Software was subsequently 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 included those generated by the UK 4km configuration of the Unified Model (MetUM:4km), 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 ran from May to August 2008 inclusive. This service gained operational status at the end of September 2008, following a review of the trial with weather forecasters undertaking heavy rainfall warning duties in the Met Office's Operations Centre.

6. First guess extreme rainfall alerts

The JCHMR, JCMM(Reading) and the Met Office's Mesoscale Model Development and Diagnostics group have jointly developed and implemented software to generate first guess extreme rainfall alerts in support of the Extreme Rainfall Alert service recently launched by the Met Office. This software generates probabilities of exceeding a set of predefined extreme rain accumulation thresholds somewhere within National Severe Weather Warning (NSWW) areas. The probabilities are derived from two sources: nowcast ensembles generated by the Short-Term Ensemble Prediction System (STEPS), and short-range, MetUM:4km based time-lagged ensembles. Probabilistic, first-guess warnings are automatically sent to forecasters on the newly established Wet Bench, and form the basis of the Extreme Rainfall Alerts issued to NSWW service category 1 and 2 responders.

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 hydrometeorological 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 hydrometeorological products (radar, NWP and MOSES), via CEH’s Hyrad system, for use in flood warning and water resource management throughout England, Wales and Scotland. Within the reporting period there have been changes to the operational configurations of Hyrad, in use by the EA and SEPA, to accommodate changes introduced with the move to the new UKPP (UK Post-Processing) system for product delivery (see sections 2 and 3). In parallel to these configuration changes, there have been developments of the software to better handle NWP (e.g. rainfall and temperature) forecasts that are time-offset relative to midnight and daily MOSES products that employ the “Water Day”. A video production tool has been developed to support the use of Hyrad display animations in Powerpoint presentations. The Hyrad display has been configured to have a “new look”, exploiting improved handling of large polygon Shapefiles for infilling shapes used as background to data displays.

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. There have been modest support and maintenance activities relating to the operational system in the reporting period. The system has also been extended in 2008 to encompass circa 350 new subcatchments in the Dijle basin.

8. Extreme Rainfall & Flood Response

Research under this science theme at CEH began under the Defra R&D Project “Extreme Event Recognition”, involving a Met Office lead consortium encompassing inputs from CEH and the University of Salford. The project 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 Science Report of previous reporting period); the Extremes Dataset and accompanying software (for use with Hyrad and forecasting models) are in use by the Environment Agency. Research under the theme "Extreme Rainfall & Flood Response" continues at CEH with Science Budget funding support. A paper on this work has been published in the Journal of Hydrology in 2008. A presentation was made to the "Weather Radar and Hydrology" conference (Grenoble) in March 2008 and a paper, based on the presentation, is in review.

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 list on the JCHMR web site), whilst highlights are contained in IAHS Publication 305. A paper entitled "Distributed hydrological modelling using weather radar in gauged and ungauged basins" has been submitted to the journal "Advances in Water Resources" and is in review. A poster entitled "How far can topographic control of flood response be used in distributed flood modelling and forecasting?" was presented at the Cemagref Scientific Workshop "The Court of Miracles" in Paris in June 2008.

Ongoing developments under this theme, now funded under the CEH Science Budget, are focussed on the Grid-to-Grid Model for area-wide forecasting. Improved formulations for runoff-production, utilising terrain/soil/geology/land-cover spatial datasets, and for flow routing are being explored through regional and nationwide case-studies.

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 in the present reporting period has focussed on initialisation and state-correction for an extended form of the G2G Model (this employs spatial data on soil properties as a control on runoff production and alternative routing functions). Ongoing collaboration with Reading University on the use of physically-based ensembles of NWP rainfall in probabilistic flood modelling is developing a case study around the Boscastle convective storm. A JCMM/CEH/EA collaborative paper on the Carlisle flood (6 to 8 January 2005), using deterministic high-resolution NWP rainfalls as input to the PDM rainfall-runoff model, has been accepted for publication in Meteorological Applications (special issue on Flood Warning, March 2009). This paper demonstrates, for an orographic storm, the improvements in rainfall prediction obtained using the better resolved NWP model topography and how this feeds through to better flood forecasts, at least for longer lead-times.

CEH is convening a session at EGU2009 on "Uncertainty and data assimilation in hydrological forecasting".

9.3 Hydrological modelling using convective scale rainfall modelling

The EA/Defra Project 'Hydrological Modelling using Convective Scale Rainfall Modelling' is a collaboration between Deltares and CEH and runs from January 2007 to March 2008. 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 6hours) 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 4 (now operationally available) 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.

Phase 1 of the Project was concerned with "inventory and data collection". The Grid-to-Grid (G2G) Model was developed in Module Adapter form, allowing the model to be used in the Project to emulate operational use within the NFFS environment. Because the G2G model employs gridded rainfalls as input, a Module Adapter form of HyradK was 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 was 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 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, encompassing Boscastle, was chosen under Phase 1 as the focus of the Phase 2 'Pilot' work. This was used to assess the performance of lumped and distributed models for a variety of catchments, some treated as ungauged, and also investigated their suitability for use in producing probabilistic flood forecasts. A collaboration between CEH and the JCMM (Met Office) employed high-resolution NWP model rainfalls for the Boscastle storm to generate pseudo-ensemble NWP rainfall forecasts. These emulate (at a functional level) NWP ensemble rainfall products that will become available in the future. A Feedback Workshop with the Agency was convened on 1-2 April 2008 and an internal report on the Phase 2 work completed in July. Phase 2 of the project demonstrated that the G2G distributed hydrological model, set up using a digital terrain model, can be operated on the Environment Agency's National Flood Forecasting System (NFFS) platform, with short enough run-times for use in real-time forecasting. The distributed nature of the G2G Model means that it is sensitive to the position of the forecast rainfall and thus to the positional uncertainty of NWP rainfalls. It is thus well suited for interfacing to NWP rainfall ensembles for propagating this source of uncertainty, as part of a procedure aimed at providing probabilistic flood forecasts.

Phase 3, concerned with verification and synthesis, is employing two further case studies: (i) a national case study involving configuration and assessment of the G2G Model across England and Wales, and (ii) a more detailed regional case study (the Summer 2007 floods in a part of the Midlands). The latter will use high-resolution NWP rainfall forecasts, and pseudo-ensemble forms of them, to trial probabilistic flood forecasting. Lumped

hydrological models will also be used in the assessments to mirror current operational practice, but extended to provide flood forecasts in probabilistic form.

10. Global water and carbon cycles: JULES and WATCH

The Joint UK Land Environment Simulator (JULES) is now well established as a community land surface model: see www.jchmr.org/jules . It is being used as a land surface model within WATCH, and thus science progress on both projects is reported on here.

WATCH

WATer and Global CHange (WATCH) is an EU Framework 6 project lead by CEH at Wallingford: see www.eu-watch.org. 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 Reseach 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 climate variables, along with the co-spectra to ensure that the final dataset is consistent.

a) Forcing data

The National Climate Centre (NCC) forcing data spanning 1948-2000 (Ngo-Duc *et al.*, 2005) have been re-gridded from one- to half-degree resolution using the CRU landmask, stored in netCDF format and made available to the WATCH community. These data have been used for the initial WATCH land-surface model inter-comparison effort and the results presented at the WATCH inter-comparison workshop in Wageningen, Netherlands (April, 2008).

New half-degree spatial resolution WATCH forcing data (WFD) for land surface models, including JULES, are currently being generated. The first set of data span 1958-2001 and are derived from the ERA40 re-analysis product, corrected for elevation changes between grids and bias-corrected via CRU TS2.1. Projected availability is November 2008. Data formatting will be identical to the re-gridded NCC forcing data. WFD spanning 1901-1957 (i.e. pre-ERA40 period) are projected to be available in February 2009.

b) JULES and WATCH

Global JULES has been extended to include lateral groundwater flow (Clark & Gedney, 2008). The timing of the modelled seasonal peak flow is now generally closer to observations.

A simple irrigation scheme is currently being developed for global JULES whereby water required for irrigation is supplied from either the river, surface or groundwater stores depending on the relative saturation of each store.

The TRIP river routing scheme (Oki *et al.*, 1999) is currently connected to global JULES. It is now being extended to include dams based on Hanasaki *et al.* (2007). Reservoir flow control for irrigation and non-irrigation demand is considered separately.

The river routing scheme based on TRIP has been modified so that it can run on any specified grid.

In April, researchers from CEH and the Met Office attended a workshop in the Netherlands on the WATCH-GWSP model intercomparison, which will compare the simulated terrestrial water cycle in land surface models (including JULES) and global hydrological models of the type normally used for water resource research. Since then, results from JULES have been submitted to the first round of this intercomparison.

c) Feedbacks in the Global Water Cycle

There is collaboration between the Met Office and CEH to help quantify the impact of feedbacks in the land-atmosphere system on the overall global water cycle and on local water resources. Collaborative projects within WATCH include:

a) LUCID (Land-Use and Climate, IDentification of robust impacts) – an international modelling intercomparison of the impact of land-cover change on regional and global meteorology. CEH will be carrying out the LUCID model experiments using the Hadley Centre Global Climate Model (GCM)
b) irrigation experiments within WATCH
c) impact of CO_2 fertilisation on river flows
d) Planetary Bounday Layer feedback on potential evaporation
e) use of Earth Observation data to explore location and strength of feedbacks globally with data from Vrei University (Amsterdam)
f) research into the role of the cryosphere in Northern Latitude water resources.

The issue of evaporation and feedbacks was the subject of the GEWEX/WATCH workshop in the Netherlands in June 2008. At the meeting the issue of atmospheric feedbacks on the surface fluxes of evaporation and the impact of evaporation fluxes as a feed into rainfall triggering and fuelling was discussed. It is possible that the JULES model will be included in the Land Information System (LIS) to further this study. An overview paper will be written on the issues of feedbacks. A letter to GEWEX News on the workshop has been written. It is expected that the subject of feedbacks will be brought into the work of Jim Shuttleworth during his JCHMR fellowship.

JULES

a) Benchmarking exercise

Fluxnet data (i.e. meteorological or forcing variables and energy-, water- and carbon-flux measurements) have been compiled into single concatenated files (including gap-filling

of forcing variables) for 23 sites in Europe, 25 sites in USA and 6 sites in Brazil (spanning between four and twelve years each). Based on screening these data according to the quality of the energy and water flux measurements ten sites have been selected for use in benchmarking exercise for JULES. Work has been carried out in defining 'tests' for the daily and the hourly evaporation fluxes based on these data. JULES has been run for each of the sites and metrics will be calculated for the JULES model for each site. A paper is being prepared describing the results.

The Benchmarking strategy extends to distributed data on carbon as well as the water and energy fluxes. Initial datasets have been chosen for this exercise and agreed at an international level at a meeting of the IGBP in May 2008. A workshop on Benchmarking of JULES was held at Wallingford in July 2008, attended by scientists from across the UK.

Benchmarking the Carbon Cycle is the subject of a QUEST project called CCMAP (Climate-Carbon Modelling, Assimilation and Prediction). Several techniques will be used, including inverse modelling, but they will all use the same benchmark datasets. Collaboration between the Met Office and CEH is particularly strong in this project, with a shared post to work on the project (the JULES office).

b) Development of JULES 2.1

There has been considerable progress towards a new version of JULES and this is likely to be released to the community in October 2008 as version 2.1. The major changes have been to restructure the code so that the same surface exchange routines can be used over land and sea ice, and the addition of the first stages of a multi-layer snow model.

c) JULES in QUEST

JULES is being developed for its role as the land surface model in the QUEST Earth System Model (QESM). Recent work has focussed on coupling JULES and the ECOSSE (Estimating Carbon in Organic Soils - Sequestration and Emissions) model of soil carbon and nitrogen. An earlier version of JULES-ECOSSE has been modified to make it more suitable for global applications, including QESM, and this version is working in an offline environment. The dynamic vegetation model ED (Ecosystem Demography), the fire model SPITFIRE, and the nitrogen uptake model FUN (Fixation and Uptake of Nitrogen) are now being added to this new version of JULES, in collaboration with researchers at the universities of Sheffield, Reading and Oxford. Preliminary work has begun on moving this code to a FLUME version of JULES.

Progress is being made on the coupling the ED forest stand model to JULES, to enable improved ecological representation of plant dynamics in the land surface model. This will also enable JULES-ED to be evaluated against a wider range of forestry and ecological data. Significant progress has been made on inclusion of a nitrogen cycle into JULES, including coupling the ECOSSE soil nitrogen scheme and the plant N model FUN (Fisher *et al.*). In collaboration with ILEAPS (Integrated Land Ecosystem – Atmosphere Processes Study), JCHMR scientists have written a review paper highlighting the state-

of-the-art in modelling trace gas exchange between the biosphere and atmosphere (Arneth *et al.*, in review).

A study exploring the likelihood and mechanism of a climate-change induced dieback of the Amazon rainforest has been submitted to Proc. National Academy of Sciences (Mahli *et al.*).

Data from the recent DGVM (Dynamic Global Vegetation Model) evaluation study (Sitch *et al.*, 2008) is being made available to the community via the internet. Several spin-off studies are currently under review (Piao *et al.*, Friedlingstein *et al.*).

A global IMOGEN (Integrated Model Of Global Effects of climatic aNomalies) study investigating long-term impacts of climate change on terrestrial processes (runoff and carbon cycle) will be submitted for publication shortly.

d) JULES in CLASSIC

The effect of historical and future changes in radiation on land carbon sink has been quantified in a new JCHMR study (Mercado *et al.*, submitted). Plant photosynthesis tends to increase with irradiance; however plants are also more efficient under diffuse light conditions. Changes in cloud cover and atmospheric aerosol loadings alter both the total photosynthetically active radiation (PAR) reaching the surface and the fraction of this radiation which is diffuse, with uncertain overall effects on global plant productivity and the land carbon sink. Here, Mercado *et al.* estimate the total impact of variations in clouds and atmospheric aerosols on the land carbon sink using JULES modified to account for the effects of variations in both direct and diffuse radiation on canopy photosynthesis during the period 1901-2100. This research forms part of the activity of CLASSIC (Climate and Land-Surface Systems Interaction Centre), a NERC Collaborative Centre.

11. 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 main focus of research planned for the next two years will be to provide a national estimate of the impact of predicted future changes in the weather on river flows throughout the century. These results and the methodology used to derive them will form part of the guidance for UKCIP08 on the use of regional climate model (RCM) output for impact assessment. The hydrological models used will include a gridded hydrological model (Grid-to-Grid, or "G2G") and a catchment-based model (the Probability Distributed Model or "PDM").

A spatial picture of changes in river flow regimes obtained from the G2G Model will be complemented by changes for particular catchments estimated using a more traditional,

lumped conceptual hydrological model. Estimates of impact uncertainty and variability will be improved through the use of a weather generator. This will be used to transform a limited number of climate model predictions into a large ensemble of localised weather estimates, suitable for estimating river flows in small catchments with a model such as the PDM. Analysis of the range of predicted flows for selected catchments across the UK, coupled with a spatial map of estimated change in flows from the RCM/G2G will provide guidance as to which regions are at particular risk from changes in hydrological extremes, and our confidence in these predictions.

Ongoing research is integrating the flow routing scheme of the gridded hydrological model into the climate model HadREM3 (V7.1 of the Unified Model) in preparation for being ported to the new Met Office Supercomputer. Testing over Northern Europe is scheduled for Autumn 2008.

An investigation of various different sources of uncertainty involved when modelling the impact of climate change on flood frequency in England has suggested that the largest uncertainty comes from modelling of the future climate (i.e. from the choice of Global and Regional Climate Model) rather than from emissions or the hydrological model (Kay *et al.*, 2008). Another investigation (Kay and Davies, 2008) concerning the calculation of potential evaporation (PE) from climate model data (for 5 GCMs and 8 RCMs), showed that temperature-based formulae are perhaps better at reproducing current PE than the use of more complex formulae such as Penman-Monteith (PM). However, for each climate model the changes in temperature- and PM-based PE between Current (1961-1990) and Future (2071-2100) periods varied. For three example catchments in Great Britain, it was shown that this could result in quite different impacts on any part the flood regime. The uncertainty introduced by the PE formulation is less than that due to the choice of climate model, but could still be important for some applications.

The Met Office Hadley Centre, the Centre for Ecology and Hydrology (CEH) and the Proudman Oceanographic Laboratory (POL) collaborated on the Environment Agency's Thames Estuary 2100 Project to help plan future flood risk in the Thames Estuary. They addressed the issue of flood protection from the tidal Thames this century. The Hadley Centre used POL's storm surge computer model to show that climate change is less likely to increase storm surge height and frequency in the North Sea than previously thought. A key finding from CEH's river flow modelling is that peak freshwater flows for the Thames, for example at Kingston, could increase by around 40% by 2080. However, the modelled change in peak flows varies from river to river: some locations in the Thames Basin may experience only minor changes while, for others, the future change may be considerably larger. It is important to note that even using state-of-the-art modelling, these projected increases have high uncertainty bands attached to them. Previous flood defence planning was based upon a 20% increase in river flows over the century. As a result of the Thames Estuary 2100 programme, the Environment Agency will now be testing their flood management options against a potential increase to 40%. The results were released in September 2008 at the international conference "Climate change impacts and adaptation: Dangerous rates of change" at Exeter University and detailed reports of the findings will be published soon.

Publications

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