Joint Centre for Hydro-Meteorological Research

Report on research activities: 17 October 2008 to 23 March 2009

1. Short-range precipitation forecasting R&D

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

Work during this period has focused on two areas: migration of STEPS source code to the new supercomputer, and the resolution of performance issues with STEPS ensembles.

A few difficulties were encountered with the migration of the source code to the new supercomputer. These related to the optimal choice of maths library routines (random number generation and Fast Fourier Transform (FFT) decomposition) and the choice of appropriate compilation optimisation switches when building the executable within the FCM (Flexible Configuration Management*)* code management system.

Extensive verification of STEPS ensembles was undertaken early in 2009 to demonstrate that previously identified performance issues associated with intermittent, poor radar data quality had been resolved. Verification statistics were compiled using one month's worth of ensemble forecasts. Summary statistics including the Brier Skill Score demonstrated improvement in performance over that reported during the summer and autumn of 2008.

1.2 STEPS R&D

An improved method of noise generation has been developed in collaboration with Dr Alan Seed (Australian Bureau of Meteorology). Previously, noise fields were generated by applying a power law filter to white noise. This approach assumed that precipitation fields always exhibit scaling behaviour and the 2-D power spectrum can be described by a power law relationship incorporating a break in the scaling regime at a fixed scale. In practise, the statistical properties of rainfall are more complex than such a model will allow for. It has been shown that whilst this scaling approximation may be valid on most days, it does not hold on days when showers predominate.

Consequently, a non-parametric algorithm which does not rely on the fitting of a power law model to the radar power spectrum has been developed. The new methodology involves taking the FFT of the radar-inferred precipitation field, then normalising the FFT to form an array of weights which when applied to the FFT of a field of white noise will return a stochastic field with the same power spectrum as the input precipitation field. This method of generating stochastic fields has the advantage that it can reproduce anisotropic precipitation features.

2. Post-processing for high resolution UK NWP models

The UK Post-Processing (UKPP) system 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). It was made operational in October 2008.

2.1 Operational implementation of STEPS

In October 2008 STEPS-generated deterministic precipitation products became operational. These replaced nowcast products previously provided by the Nimrod and Gandolf systems. In the months following the change several feedback requests were received from the Environment Agency. These related to the performance of the blending algorithm in STEPS. On occasions when the evolution of the MetUM: 4km model differs significantly from that of the extrapolation nowcast an unrealistically rapid evolution of the nowcast precipitation field could result. These occurrences have been shown to be relatively rare. Extensive comparative verification of STEPS, Gandolf and Nimrod prior to October 2008 demonstrated that the STEPS control member not only outperforms the other nowcast models, but also produces a more realistic field evolution.

2.2 Performance of MOSES within the UKPP system

During the widespread snow events of the winter of 2008-09 it was noticed that large areas of lying snow were being removed in the outputs from UKPP-MOSES. This was traced to errors in the input field of snow-cover derived from Meteosat Second Generation (MSG) visual images. Until the algorithm for determining the presence of snow-cover and distinguishing it from cloud are improved it is proposed to remove the updating of MOSES lying snow amounts with MSG snow-cover data. The UKPP-MOSES snow-cover will then revert to ‘running free’ as it did in the (now retired) Nimrod system.

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 began in October 2008 and is now nearing completion. This will deliver Heavy Rainfall Warning area-based MOGREPS NAE and STEPS based stacked probability charts to the Environment Agency via an operational web service provided by the Met Office. Software to process the ensembles and produce the graphical products required has been written and tested. A set of interactive web pages for displaying the products, developed by the Met Office, were reviewed by Environment Agency flood forecasting and warning staff at a Met Office led workshop in February 2009. An operational service is due to commence in April 2009.

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 ≤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 eight precipitation cases studies from 2007 was prepared in January 2008. Following completion of this report, work was suspended as a result of staff shortages. The project recommenced in November 2008 with the completion of a detail software design for the blending algorithm. Coding of the algorithm is scheduled to start in March 2009.

5. First guess heavy rainfall warnings

An operational, first guess heavy rainfall warning service was launched at the end of September 2008 to support the existing heavy rainfall warning service provided to the Environment Agency by the Met Office. This followed a review of the performance of a trial service, run over the summer of 2008, involving weather forecasters undertaking heavy rainfall warning duties in the Met Office's Operations Centre. Routine, monthly and quarterly verification statistics are now generated routinely.

6. First guess extreme rainfall alerts

Following the joint development by Met Office staff at the JCHMR (Wallingford), JCMM (Reading) and the Mesoscale Model Development & Diagnostics group (Exeter) of an automated, first guess extreme rainfall alert capability in support of an Extreme Rainfall Alert pilot service (launched in July 2008), an the evaluation of this service was done and a report written including a performance summary and recommendations for operational implementation. The pilot service was deemed to have been a success, although some enhancements were recommended prior to the launch of an operational service, planned for summer 2009. These enhancements relate to improvements in the calibration of the probabilities of exceedence inferred from time-lagged, MetUM: 4km ensemble precipitation forecasts, the generation of these probabilities of exceedence on a regular, square grid across the UK, and enhancements to graphical and text based products delivered to category 1 and 2 responders (emergency services and local authorities).

7. Flood modelling and forecasting

7.1 Weather Radar and Flood Forecasting System Developments

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.

RFFS Developments

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. "PSM for PCs" rainfall-runoff model (encompassing the TCM and IEM models) and the PACK snowmelt model. 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; extension to include the PACK snowmelt model is underway.

Hyrad Developments

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. The period reported on here saw the release of the latest version of Hyrad. This included a new video production tool for putting Hyrad display animations in Powerpoint presentations; improved handling of NWP (e.g. rainfall and temperature) forecasts that are time-offset relative to midnight and daily MOSES products that employ the "Water Day"; a more modern "look and feel" to the displays exploiting colour-filled polygons as background; improved "grouped" playback of multi-window displays; and an updated User Guide (produced in an automated way from the on-line Help pages).

Hyrad is being used to support RFFS-FloodWorks applications in Dender, Centrale, Demer and Dijle 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. In March 2009 further configuration extensions have been made for the Demer catchment (circa 125 new subcatchments) and the Ijzer catchment (circa 113 subcatchments) has been added.

Midlands Catchment Runoff Model

The Midlands Catchment Runoff Model (MCRM) developed and used within Midlands Region has been converted by CEH to run at a variable time-step on behalf of the Environment Agency. The model was defined and coded only for a 1 hour time-step and there was a requirement to run the model at a 15-minute time-step in real-time for flood forecasting. The work involved extending the mathematical model formulation to asccomodate the variable time-step requirement, documenting the revised model, modifying the NFFS adapter form of the model code and testing it across a set of applications. A model description and user guide was produced along with the revised code.

Rainfall-runoff models extended for groundwater catchments

The PDM rainfall-runoff model formulation had been previously extended to accommodate groundwater pumping, external springs and underflows: these influences can lead to ephemeral flow in chalk streams. The Environment Agency Southern Region have contracted CEH to evaluate the model on the rivers Lavant and Ems, with the eventual aim of including the extensions in the PDM model used operationally within the NFFS if successful. The Phase 1 Report was completed in February 2009. This reported on data collection and quality control, developed a strategy for the Phase 2 modelling study and made recommendations relevant to future work. Of hydrometeorological interest is a comparison of the operational MOSES and MORECS products over these catchments. In contrast to the comparison by Hough (2003), which used MORECS-based input data to MOSES, MOSES was found to consistently estimate more PE than MORECS when monthly totals were compared from July 2005 to August 2008; the relative difference increases with increasing PE. Modelled river flow is therefore likely to be reduced if MORECS is simply swapped for MOSES in existing rainfall-runoff models calibrated using MORECS PE as input: the magnitude and importance of this has yet to be assessed.

7.2 Flood 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.

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.

A presentation, made to the “Weather Radar and Hydrology” conference (Grenoble) in March 2008, on “Distributed hydrological modelling using weather radar in gauged and ungauged basins” has been accepted for publication in “Advances in Water Resources” and is now available online.

An invited paper on "Countrywide flood forecasting using grid-based hydrological modelling" was presented to the Sniffer/SEPA meeting on "pluvial Flooding" in Edinburgh in November 2008. This highlighted the potential of the G2G Model to forecast "everywhere" on a 1km grid, albeit at an indicative level for some locations and for longer lead-times.

7.3 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 continued to work 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). An approximate data assimilation scheme for intialising both linear and nonlinear routing variants of the G2G Model has been developed based on steady-state assumptions, complementing the exact scheme previously developed for the linear case. The work has progressed to the multi-site data assimilation problem required by a countrywide application and the spatial transfer of information in either upstream or downstream directions.

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 now been published in the March 2009 special issue of Meteorological Applications on Flood Warning. 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" and presenting a paper entitled "Model initialisation, data assimilation and probabilistic flood forecasting for distributed hydrological models". This work also formed a poster presentation to the 2nd FREE Science Meeting in November 2008 at the University of Reading. This encompasses first results on probabilistic flood forecasting in spatial form as flood risk maps of flood exceedence and using the Boscastle storm as a case study.

7.4 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 1.5km 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). High-resolution NWP rainfall forecasts from the 1.5km model for two storms with embedded convection have been produced by the JCMM Reading and transferred to CEH: the next step is to generate 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. Work on preparing national and Midlands Region datasets for hydrological model calibration, assessment and emulated real-time trial within the NFFS is close to completion. The real-time construction of gridded rainfall datasets (using radar and raingauge data with HyradK) with England and Wales coverage on a 1 km grid at 15 minute intervals, for input to the G2G Model, has been demonstrated. The emulation employed a large part of the EA's network of telemetry tipping-bucket raingauges along with the national radar composite. An initial England and Wales configuration of the G2G Model with multi-site data assimilation will be transferred to the test NFFS system at the end of March 2009 for trials operated by Deltares on behalf of the EA.

7.5 River flow and flooding forecasts for military deployed areas

CEH is working with the Met Office and the MOD to further develop the Crisis Area Model (CAM) to provide a demonstration system for forecasting river flow and flooding for military use.

The CAM will use MOSES-PDM (or MOSES-LSH) to estimate surface and sub-surface runoff which will be routed via the River Flow Model (RFM), the routing component of the Grid-to-Grid (G2G) Model to produce estimates of river flows on a grid covering the areas of military deployment. Ongoing work at CEH is deriving high-resolution (~1km) river flow paths from high resolution digital terrain model (DTM) data using the COTAT+ network derivation method (Davies and Bell, 2008). Bankfull discharge, river width and depth are estimated for every river grid-cell location using a mixture of river flow observations, satellite imagery and scientific literature. Once model estimates of river flows have been produced using the 1km flow directions, they can be compared to estimates of the capacity of the river at every grid-cell location to give an indication of whether any part of the river is likely to be flooded.

8. 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) is an EU Framework 6 project led 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.

8.1 Developments in JULES

Benchmarking of JULES
An agreed set of 5 datasets that express our current knowledge of the regional carbon and water cycle are being used to build a benchmarking system for JULES. The system will be given out as part of the community model, for future users and developers of JULES. The benchmarking system has been chosen in collaboration with other international land surface modellers, with the idea that it will be possible to make a comparison of performance of all land surface models against the same data. A report is being prepared that outlines the datasets, the tests and the performance of JULES.

In particular, the use of fluxnet data to benchmark the evaporation modelling part of JULES is now well developed. Ten fluxnet sites have been chosen which represent a wide range of climates and biomes and 4 tests which look at the evaporation characteristics at different timescales (annual, seasonal, dry-down and diurnal) have been developed. A paper is being prepared on this.

A tool for automating the associated model runs and post-processing is in the early stages of development. The post-processing will involve generation of headline statistics and graphics indicating the performance of the model relative to observations. This will be written in IDL (Interactive Data Language). A Python program will handle the automation of the model runs and will call the IDL post-processing module. The choice of languages was dependent on end-users being able to run the program at no cost (i.e. licences). Python is open source, and although IDL requires a licence to develop, there is a no cost virtual machine that allows users to run programs. The whole application will be modular in nature, potentially allowing adaptation for other models in the future if there is demand for a generic benchmarking system for land surface models.

Validation of JULES
Satellite data of Normalized Difference Vegetation Index (NDVI) and observed precipitation data have been used to assess how well JULES responds to soil water limitations temporally and globally (Ellis et al., submitted). The satellite data can be used to find when vegetation becomes stressed due to lack of water availability. The methodology is able to analyse when and where vegetation growth is sensitive to historical precipitation over much of the globe. These data are then used to assess how well JULES predicts when vegetation is water-limited across the globe. There is also

a focus on a number of regions of particular interest which have a strong seasonal cycle in water availability. It is found that how the land surface model partitions rainfall into runoff and evaporation is critical in being able to determine the successful onset of vegetation stress. As such, the detailed depiction of the model soil properties appears to be more important than that of the vegetation.

Urban model intercomparison

JULES has been used to create a number of versions of the urban tile to submit to an international urban model intercomparison (a PILPS experiment for urban surfaces). The results from this comparison will help to formulate the future development plans for the urban tile within JULES.

There are two elements of the intercomparison. The first is using a small dataset that has already been widely used by the urban community. The second element is to use a large dataset from an unknown site to investigate the dominant physical processes for urban environments and parameter requirements for the various types of model. This second element has been broken down into a number of simulations with additional information being provided at each stage, the final stage being an optimisation against the observations. We are currently undertaking the final stage of the model simulations.

The initial results from the first element of the intercomparison were presented at the AMS annual conference in January. These results show that with the particular site being studied with this first element, there was surprisingly little difference between the various types of model. This is despite the large variation in complexity between the models.

Development of JULES vn2.1

Deficiencies in the initial implementation of the new multi-layer snow scheme for JULES vn2.1 have been addressed and a prototype has been run offline successfully with a variety of forcing datasets.

The release of the new JULES version (vn2.1) has been merged with the work to implement JULES back in the Unified Model. Originally the plan was to release the new physics changes within JULES and then have a second release with the UM (Unified Model) version. However, the timelines for these developments and the overhead of new JULES versions gave the motivation to merge these changes into one single release.

In addition to the developments within JULES, the MOSES scheme within the UM has also been developed over the last few year. This has lead to a divergence of the two sets of code. A large amount of effort has gone into merging these two sets of changes into the new version of JULES. This will inevitably lead to some undesirable elements within the standalone code, but will ensure that there is just a single version of the JULES code for all applications.

As part of the implementation of JULES within the UM, the top level structure of the UM has been changed so that there can be a variable number of surface tiles, which can have an elevation above the mean grid-box height associated with it.

The current status of this work is that the new version of JULES has been put into the UM system and the code compiles. Work is currently being undertaken to debug the code to achieve a working version. In parallel to the UM implementation, the standalone control code is being updated so that there is one common JULES code for both applications.

JULES in QUEST
Further work has gone into developing JULES for its role as the land surface model in the QUEST Earth System Model (QESM). The nitrogen uptake model (FUN; Fixation and Uptake of Nitrogen) has been updated and coupled to a version of JULES that contains the ECOSSE (Estimating Carbon in Organic Soils - Sequestration and Emissions) soil carbon and nitrogen model, and this version is now being tested. Work on a prototype of the FLUME version of JULES that is required by QESM is well-advanced with current efforts being focussed on implementing the Ecosystem Demographics (ED) vegetation model in this configuration.

8.2 WATCH

Forcing data
As part of the WATCH, a new half-degree resolution six-hourly global forcing dataset is being created suitable for running JULES for the whole of the 20th Century. This involves two stages: firstly ERA40-reanalysis-based data for 1958-2001 and secondly weather generator-based data for 1901 to 1957. The first stage has now been completed.

The ERA40 data have been interpolated from one- to half-degree resolution which required sequential adjustment for elevation differences (in the order: 2m temperature, surface pressure, specific humidity and finally long-wave downwards radiation). Subsequent bias-correction, at the monthly scale of the 2m temperatures used CRU-TS2.1 data that had been specifically modified by Hermann Oesterle (PIK-Postdam) to remove spurious, localised residual inhomogeneities. Monthly average short-wave downwards radiation values were adjusted to be consistent with observed CRU cloud-cover and allow for long-term (multi-year) changes in direct- and the first indirect-effects of tropospheric model-derived aerosol loading plus the direct effect of stratospheric aerosol loading. Two versions of the rainfall and snowfall data were created in collaboration with the University of Lisbon using different precipitation-gauge observation datasets: (i) GPCCv4 full product (released in October 2008) and (ii) CRU-TS2.1. Both versions of the precipitation data were corrected for gauge-undercatch using mean monthly half-degree catch ratios applied separately for rainfall and snowfall as supplied by Jennifer Adam (Washington State University). The different precipitation datasets will be used to assess uncertainty in precipitation observations within JULES.

Data for 1901 to 1957 is currently being generated, with Lisbon University using a weather generator, and then adjusted to match the spectral and cross-spectral (coherency and phase) characteristics of the 1958-2001 data and then bias-corrected using the monthly gridded observations.

WATCH-GWSP model intercomparison

Scientists from CEH and the Met Office attended a workshop on the WATCH-GWSP model intercomparison, which compared the simulated terrestrial water cycle in several global models. Preparations are now underway for the next round of intercomparison simulations in 2009, which use the WATCH forcing data (generated by the Met Office).

JULES and WATCH

Irrigation

An irrigation model is currently being developed and tested offline in global JULES within the WATCH project. The water demand component of the model has been developed so that there is a separate soil moisture component for irrigated crops within a given grid-box.

The scheme uses the model diagnosed state of "water stress" to add water to the top 1m soil layer (the crop rooting zone). Thus photosynthesis is not limited by stomatal closure over the irrigated crop. The scheme is highly efficient as implicit in the model is knowledge of the timing and amount of water required by the crop.

The impact of irrigation on crop biomass is found to have a significant spatial variation. For example, in Northwest India crop biomass increases by 1500%. Irrigation in some regions is found to be costly in terms of water consumption but can be highly efficient.

This addition of moisture to the soil cools the land surface, decreasing the heat flux to the atmosphere and increasing evaporation: In Northwest India where the coverage of irrigated crops is greater than 75%, the surface cooling effect is considerable (4°C).

Dams and reservoirs

A scheme to include the effects of dams and reservoirs in JULES has been designed, based on Hanaskai *et al.* (2007) and is now being implemented in the code for use in the WATCH project.

Runoff

A report has been written outlining the important issues that affect runoff generation in Northern Latitudes. Soil freezing and snow heterogeneity are key aspects of the land surface and future studies to address these issues are planned. A combined large-scale modelling and Earth Observation study is planned under the WATCH project to look at snow heterogeneity at large scales, with the aim of testing out tiling schemes that account for altitude. In addition, a smaller scale study will be carried out using a small-scale version of JULES to look at scaling issues up to the 10km scale. It is possible that an MSc student will look at Remotely Sensed data to inform this scale of modelling. The report is published on the WATCH website.

JULES has been run globally and the modelled river flow has been analysed to see if including sub-grid scale soil moisture improves the model simulation. JULES has been extended to include a simple representation of groundwater (JULES_LSH; Clark & Gedney, 2008) and in order to incorporate this into the JULES land surface model a TOPMODEL-type approach has been applied.

The application of this approach at the GCM grid scale assumes that relationships between sub-grid scale soil moisture and topography hold even over areas which are much larger than a typical river catchment. The relationship between the local water table depth to the grid-box mean is driven by the local topography. Hence the probability distribution function of the sub-grid scale topographic index (Beven & Kirkby, 1997) and grid-box mean water table depth can be used to determine the sub-grid scale distribution of water table depths and soil moisture.

However, there is some uncertainty in the parameter values required for JULES_LSH. This is especially the case for the topographic data, where the use of relatively coarse elevation data leads to an apparent smoothing of the surface. In order to gauge the impact of uncertainty of the additional JULES_LSH parameters and whether including the groundwater representation improves the model simulation, the standard JULES model and JULES_LSH are run globally offline using observational forcing data. The long-term mean modelled river flows across the globe are compared to observations.

The standard JULES model allows for free drainage out of the base of the deepest soil model layer which reaches a depth of 3m. In JULES_LSH an additional deep layer is added in which the saturated conductivity K_s reduces with depth according to an exponential decay factor f. The values of f that were chosen to experiment with were 0.5, 1.0, 2.0, 3.0 (default) and 5.0. (Note that JULES_LSH has been modified so that K_s only reduces with depth below the standard 3m soil model). The default LSH model (LSH_CTL) uses topographic index values from Verdin & Jenson, (1996) and f=3.0

The results were compared to observations from the GRDC dataset. A sensitivity analysis of some of the model parameters has also been carried out. Incorporating a groundwater representation within JULES results in significantly different runoff components. The groundwater model is sensitive to the topographic input and the magnitude of porosity reduction at depth. Over most regions, including the groundwater model produces long-term mean runoff closer to that observed. Improvements in the modelled daily discharge over some river basins are also seen.

WATCH feedbacks

The issue of the impact of atmospheric feedbacks on water resources is being developed in partnership with European partners in WATCH. A strategy of using atmospheric profiles from ERA40 to initialise a PBL model to assess the diurnal development of the evaporative demand and cloud development in response to the land surface has been discussed. A report outlining this strategy is published on the WATCH website.

The Land Use and Climate, IDentification of robust impacts (LUCID) project aims to examine the robust impacts of past and future land-cover change. It has combined the output from a number of GCMs to look for consistent changes in the modelled climate. The Unified Model (vn6.1) will be run with prescribed sea surface temperatures and land cover to contribute to the LUCID project. The LUCID land-cover and sea surface temperature data have been transformed into UM driving files and a trial run has been conducted. Initial results from the other groups, suggested that the representation of crop phenology had an impact in some models. Further runs with the UM will examine the impact of phenology and the representation of crops on the modelled climate.

Also under the WATCH programme, a case study of how wetlands can influence precipitation has been undertaken using satellite data. This has focussed on seasonal inundation of the Niger River in Mali, West Africa. The results show a substantial difference in the evolution of observed convective cloud systems according to the extent of flooding. Changes in precipitation extend several hundred kilometres downstream of the wetland because once initiated, the storms can have a lifetime of many hours. The upper Niger region may be used as a test-bed for new river runoff and inundation schemes within the RCM by the Met Office in order to further investigate these feedbacks.

8.3 AMMA

A scheme has been implemented with JULES for assimilating Meteosat Second Generation (MSG) estimates of land surface temperature (LST) for West Africa. The aim of this work is to produce model estimates of the surface state and fluxes at the MSG spatial scale of 3-5 km when JULES is forced with the 0.5° near-surface meteorology supplied for the AMMA Land Model Intercomparison Project. The assimilation scheme assumes that in this sparsely vegetated region of the Sahel differences between modelled and MSG observed LST are related closely to differences in surface soil moisture availability, which in turn are related to errors in the forcing precipitation amounts. The scheme derives the rainfall perturbations that reduce the RMS differences between modelled and observed LST while retaining time-series of the JULES state and fluxes that are consistent with the model temporal dynamics.

8.4 National Centre for Earth Observation

CEH are involved in the new National Centre for Earth Observation (NCEO), which provides funding to continue work in CLASSIC on land-climate coupling. CEH leads the Land-Climate sub-theme involving Exeter, Swansea, Durham and Leicester, with links to the Met Office through the JCHMR. There was a well-attended meeting in Exeter in January 2009 of the NCEO Climate theme with interested parties at the Met Office which has helped to establish new links. CEH will be focussing on using EO data to evaluate and improve the representation of soil moisture memory in JULES. Results from PhD work carried out at CEH indicate good potential for diagnosing problems in JULES at the regional scale with satellite land surface temperature data.

8.5 Carbon cycle

A gas exchange model has been used to simulate Amazon forest canopy photosynthesis using eddy correlation fluxes for evaluation and validation (Mercado *et al.*, 2009). Scaling functions are derived to provide estimates of canopy photosynthetic parameters for a range of diverse forests across the Amazon region. This is done by utilizing the best fitted parameter for maximum carboxilation capacity of Rubisco and foliar nutrients (N and P) for all sites.

Collaborative work between CEH and Hadley Centre scientists aims to understand the behaviour of the global carbon cycle following sudden cessation of CO_2 emissions. A paper (Lowe *et al.*, 2009) has been "fast-tracked" by Environmental Research Letters (ERL) to be available at the Copenhagen conference in March 2009.

9. Flood risk assessment and climate change

9.1 FRACAS

FRACAS (Flood Risk Assessment under climate ChAnge Scenarios) is funded under the NERC FREE programme and will produce a linked system of rainfall, hydrological, defence performance and flood inundation models for strategic flood risk assessments. This framework will be capable of a full national assessment, and will be demonstrated through the application to a number of selected regions and large river basins in the UK. The consortium is made of CEH (lead), the Met Office Hadley Centre, the University of Newcastle and HR Wallingford.

Recently CEH have developed an enhanced version of the Grid-to-Grid model, incorporating variable soils data and lateral flows of soil moisture, which had been trialled over the Thames Basin. The performance of the model is being assessed with reference to observed river flows. Improved 1km-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. The model has also been implemented at the national scale, driven with RCM data.

The river flow time-series data have been passed to HR-Wallingford for application in the Eden case study catchment where they are implementing a (semi)continuous version of the RASP (Risk Analysis for Strategic Planning) tool by sampling key extreme events from the river flow series.

9.2 River flow modelling, flood frequency and climate change

The Met Office's Hadley Centre and CEH Wallingford are collaborating on developing methods to predict flood frequency over the UK in current and future climates. The main focus of this research is to provide national estimates of the impact of predicted future changes in the weather on flood frequency throughout the century. We use a grid-based methodology to translate Regional Climate Model (RCM) meteorological variables into gridded time-series estimates of river flow and fluvial discharges to the sea.

The performance of the Grid-to-Grid Model or 'G2G', used as the distributed hydrological model in this work, has been assessed for gauging stations across the UK using historical data. A single area-wide model with one set of parameters is used to estimate river flows across the UK on a 1km grid. Use of RCM output as input to the G2G Model has enabled us to derive maps of estimated future percentage changes in flood frequency across the UK, including some quantification of uncertainty.

- The results and methodology form part of the guidance for UKCP09 on the use of climate model output for impact assessment. We have prepared a worked example demonstrating the use of UKCP09 (UK Climate Impacts

Programme) climate scenarios to estimate probabilistic change in flood frequency across the UK.
- At the regional scale, we have assessed the performance of the RCM coupled with the G2G Model implemented at a 25km resolution over a selected region of Europe.

Ongoing work will investigate how estimates of impact uncertainty and variability can be improved through the use of a weather generator to transform a limited number of climate model predictions into a large ensemble of localised weather estimates.

9.3. Simulating snow cover in the Austrian Alps

Together with the Technical University of Vienna and the Met Office Hadley Centre, CEH have been investigating the use of JULES-G2G to model snowmelt and associated runoff in the Austrian Alps. This work is funded through a British Council researcher exchange programme grant. Initial findings have demonstrated that JULES performs well at simulating snow cover when compared with observations at ~600 climate stations in Austria. Further work will examine the potential effects of climate change on snow cover and snow depth, with particular emphasis on extreme events.

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