Joint Centre for Hydro-Meteorological Research

Report on research activities: 27 April 2006 to 1 February 2007

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 2006. This involved the routine running of a control member forecast and ensemble (20 members) on the Met Office's NEC supercomputer, and the production of a range of continuous and categorical verification statistics. Upgrades to STEPS in May and September 2006 addressed performance issues with the advection scheme and stochastic noise generation algorithms. These are discussed in more detail below. A further upgrade was delivered at the end of November to allow STEPS to run on a larger, rectangular domain incorporating the Northern Isles of Scotland and the Channel Islands (see below). Precipitation nowcasts from STEPS are due to replace those from the Gandolf and UK Nimrod systems during 2007.

1.2 Improvements to the formulation of the STEPS

a. Tuning of 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 choice of block size is a compromise between resolving small-scale motions and obtaining velocity vectors which correctly represent the large-scale structure of the velocity field. Following off-line investigation, the dimensions of the blocks were reduced from 45 pixels (90 km) to 30 pixels (60 km) to improve the treatment of small scale motions. The block velocities are subject to a smoothness constraint to ensure that neighbouring blocks have consistent velocities. The weighting on this constraint was increased to ensure that the resultant, higher resolution velocity fields maintain the correct structure.

b. Tuning of the noise generation algorithm

Following earlier modifications to the noise generation algorithm to improve the correspondence between noise power spectra and those derived from UK weather radar composites, further case study based work was undertaken in October 2006 to improve the statistical properties of the noise under different precipitation regimes. The dynamic scaling model for noise power spectra, implemented in May 2006, was further enhanced by applying upper and lower bounds on the slope of the spectrum at scales below 32 km.

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

c. Development of an algorithm for quantifying uncertainty in NWP forecasts of convective precipitation

An ensemble-based method for modelling the uncertainties in Numerical Weather Prediction (NWP) forecasts of precipitation arising from a failure to resolve sub-grid scale convection was demonstrated in June 2006. A series of case study experiments were performed during August 2006 to explore the value of this approach when applied to the ~4km UK NWP model. These showed a similar level of benefit to that demonstrated by the Convection Diagnosis Programme (CDP – Hand, 2002) when post-processing UK Mesoscale Model forecasts. An efficient method for representing these uncertainties within the noise fields generated by STEPS has been proposed by a collaborator, Dr. Alan Seed, at the Australian Bureau of Meteorology. In 2007, a proof-of-concept case study will explore how CDP generated probability of convective initiation fields and convective cell life cycle properties might be used to inject localised noise into STEPS ensemble precipitation forecasts to represent shower initiation and development.

Reference: Hand, W. H., 2002. The Met Office Convection Diagnosis Scheme. *Meteorol. Appl.*, **9**, 69-83.

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

The domain of the UK NWP Post-Processing (UKPP) system was extended in November 2006 to exploit the extended domain of the 4km UK NWP model. This larger, rectangular domain incorporates all of the Northern Isles of Scotland and the Channel Islands.

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

(i) Modifications to the Short-Term Ensemble Prediction System (STEPS)

The Fast Fourier Transform algorithms employed within STEPS to perform cascade decomposition and re-composition on the precipitation fields were originally constrained to process square fields whose dimensions were powers of two. Work undertaken by collaborators in the Australian Bureau of Meteorology has removed this power of two constraint and allowed cascade decomposition to be performed on a square domain slightly larger than the enlarged, rectangular UKPP domain (1096 km E-W, 1408 km N-S) implemented in November 2006.

Rain analyses and NWP forecasts on the rectangular UKPP domain are ingested by STEPS. These are copied into the centre of larger, square arrays packed with missing data around the edges. During the forecast evolution, noise is added to replace areas of missing data advected into the domain. When the forecast is complete, the relevant portion of each of the forecast fields is extracted for output by STEPS.

(ii) *Modifications to MOSES-PDM-RFM*

The MOSES-PDM surface hydrology module, which has been running within the Nimrod nowcast system at 5km resolution, has now been implemented at 2 km resolution on the extended rectangular domain of the UK NWP Post-Processing (UKPP) system. The River Flow Model (RFM) based on CEH's Grid-to-Grid model is also implemented in the UKPP system at 1km resolution.

Snow cover from Meteosat Second Generation is now used to correct the UKPP-MOSES-PDM lying snow (modelled lying snow is removed where none is observed and a small depth of snow is added, with appropriate surface temperature changes, if snow cover is observed where the model has none).

The 'B' parameter in the PDM has been made to depend on slope; it has a value of 0.5 for flat terrain and rises to 2.0 for terrain with the largest slopes in the UK.

3. Use of probability forecasts

This jointly funded, Met Office-Environment Agency project began in May 2006. The first of several collaborative projects concerned with the exploitation of probabilistic forecasts, it aims to establish an initial Environment Agency user requirement for probabilistic precipitation forecasts in relation to fluvial flood forecasting and warning.

At the end of August 2006, the Met Office produced and distributed a questionnaire to Agency flood forecasting teams on the use and interpretation of probabilistic forecasts. This incorporated a range of prototype probabilistic precipitation forecast product examples, including maps of probabilities of exceedence for predefined rain accumulation and rate thresholds, and site specific products including forecast plumes and stacked probability charts for similar variables. In conjunction with feedback from a JCHMR-hosted one day Environment Agency workshop on the use of probability forecasts, the completed questionnaires have been used to produce a first draft of the user requirement.

Once finalised in February 2007, this user requirement will identify a subset of products suitable for implementation as an operational trial to commence in late spring 2007.

4. Assessment of MOSES-PDM

A jointly funded, Met Office-Environment Agency project began in July 2006 with the aim of allowing operational Nimrod/UKPP-MOSES-PDM outputs to be used in EA water resource models which have been calibrated with corresponding outputs from a long offline run of MOSES-PDM driven by 40km MORECS meteorological data. The operational data is first aggregated to the 40km grid and then correlation statistics are computed against the offline data (and vice-versa). Initially this has been done using the data generated using the version 1.0 offline model and the operational Nimrod-MOSES-PDM data for September 2004 to August 2006. [The Version 1.0 offline model was set up for the MOSES-MORECS comparison project which was completed in 2003; this version is therefore not up-to-date with the current operational version.]

Correlations for 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 generated with the benefit of satellite observed cloudiness overnight (from infrared channels). Other features of the correlation statistics can be explained by the differing formulations in the compared models. 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 data will be done for March to November 2007 at a later stage of the project.

The Environment Agency also need to know 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 for a variety of locations and catchment types is therefore part of this project. A time-mean rainfall analysis reliability indicator will also be mapped.

5. Study of performance of MOSES-PDM for soil moisture

A report was written on the new Chalk Soil parameterisation. It advocated a new parameter set for Chalk (high conductivity and high suction values) and new modules (by-pass drainage occurs at high levels of soil moisture). The dataset used never got wet enough to trigger the by-pass flow so the new module could not show an improvement. The results have therefore not been written as a paper, but remain as a report. The research results proved useful for a subsequent piece of work on the uncertainty of evaporation modelling with reference to Nimrod and data from the LOCAR area. This other study is being written up as a paper.

The Met Office sub-contract to look at the impact of the soil moisture control on evaporation (though the Beta function) is underway. A new ‘bendy’ parameterisation of the Beta function is coded up and the Monte Carlo package of parameter sweeps has been used to investigate appropriate values of Critical soil moisture, Rooting depth and the ‘bendiness’ parameter. For the Loobos data (so far the only data used) the evaporation is not sensitive to the rooting depth or the ‘bendiness’ parameter. Other datasets may reveal different sensitivities. The work will be reported in full at the end of February.

6. 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. A new release of Hyrad to the Environment Agency (EA) was made in June 2006 supporting three new enhancements: (i) display of averages and totals for rainfall forecasts within a user-specified time window, (ii) support to ESRI Shapefile import of overlays to the Display Client and catchment boundaries to the Server (for catchment average rainfall estimation for onward transmission to Flood Forecasting Systems), and (iii) export of image data as CSV files from Display Client.

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 include: "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 now 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 new flood forecasting systems being rolled-out across Scotland by SEPA. The latest release of Hyrad was supplied to SEPA in December 2006 to support display of Nimrod radar products and to interface to their new flood forecasting systems.

With the above developments, the EA and SEPA will 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.

A new release of Hyrad was made in December 2006 to support RFFS/FloodWorks applications in Dender, Centrale and Demer catchments in Belgium. The system is undergoing operational trials, configuration and further development during January and February 2007; training and handover will follow. The Met Office supplies a live feed of European Nimrod analysis and forecast products to the system, to complement the Belgium High Resolution Radar Composite actuals and Aladin NWP forecasts.

7. Extreme Event Recognition

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

The CEH project addressed the question "What makes an extreme storm an extreme flood?" A methodological framework was developed for investigating the shaping mechanisms of an extreme flood from storms of differing kind and catchments of varying form. Extreme storms of frontal, orographic and frontal origin were chosen from historical records and characterised in terms of return period for their critical rainfall depth and duration and other storm properties. The flood response over a catchment was assessed for flood peak return period and modelled using lumped and distributed approaches. Areal rainfall estimates for catchment and grid-square areas, used as model input, were obtained by multiquadric interpolation methods applied to raingauge data alone and in combination with weather radar data. Shortcomings of stage-discharge ratings affecting implied model performance were taken into account when assessing the results. A rainfall transformation tool was developed and applied to historical storms to change their speed and direction of movement and their magnitude and shape to create artificial storms of greater return period. The flood response was investigated for catchments co-located with the storm and, by invoking storm transposition, to other catchments of different form. One model experiment took a fast-moving extreme convective storm that failed to produce an extreme flash flood. When transposed to another catchment, reduced in speed and re-orientated to align with the river network, a modelled extreme flood response was found to be produced. The more extreme response obtained from the distributed rainfall-runoff model, relative to the lumped one, served to highlight the potential value of distributed models in forecasting unusual extreme storms. Animated images of flood forecasts with area-wide coverage, obtained from the distributed model, provided fresh insight into the space-time shaping of the flood by the catchment form. The results of the project have particular relevance to flood warning for ungauged locations.

The Final Report on the CEH component of the work, together with a companion report documenting the Extremes Dataset and associated Storm Transposition Software, was completed in August 2006 and revised following review. A consortium report on the overall project was finished in January 2007. These reports contain a summary of the conclusions and recommendations of relevance to the Environment Agency's flood defence function.

The Extremes Dataset is now available on DVD to the Environment Agency in support of model development and destruction testing, and for providing forecasters with an experience base of extreme events. Hyrad can be used to visualise the spatio-temporal datasets as animated images. Also Hyrad, together with new Storm Transposition software, can be used to relocate a storm over a catchment of interest and amplify it to give a catchment rainfall total of required magnitude or return period. Space-time rainfalls can be exported for use with rainfall-runoff models to perform further flood response experiments, to destruction test models and to perform "what-ifs?" in an operational environment.

A Training Workshop for the Environment Agency will take place at Wallingford in February 2007. A presentation on "Extreme Event Recognition and Flood Response Modelling" was presented at the ICE-BHS Conference on "Real Time Flood Forecasting – Developments and Opportunities" in November 2006. An abstract for 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 - has been accepted for presentation. A paper on this work has been prepared for submission to a refereed journal.

8. Flood modelling and forecasting

8.1 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.

A review of best practice was carried out along with proposing, investigating and prototyping some new improved methods. Seeking physically-based methods of applying conceptual hydrological models to ungauged catchments using digital datasets on basic properties, as opposed to employing empirical relations between model parameters and catchment characteristics, was identified as an important research area deserving further investigation. A new method of representing runoff production under the control of soil properties and topography, with an emphasis on lateral water transfers, was developed in prototype form and used to illustrate the benefits of area-wide grid-based modelling. Also, a variable time-step Muskingum-type flow routing methodology with links, via the St Venant equations, to channel properties was identified as deserving further investigation for application to ungauged areas. A range of options for data assimilation to support forecast updating, depending on the level of data availability and model structure, were developed.

An extensive Science Report on the work was completed in 2006. This is complemented by an Operational Guidelines Report that provides an overview of approaches and serves as a "roadmap" to the Science Report. Parts of this research were presented at the 8th Kovacs Colloquium on Frontiers in Flood Research in July 2006 at UNESCO, Paris and published as IAHS Publication 305. An abstract for the European Geophysical Union conference in April 2007, entitled "Flood forecasting for ungauged locations: what approach is best?", has been accepted for presentation.

8.2 Modelling using Numerical Weather Prediction rainfalls

Two initiatives are underway that investigate the use of NWP rainfalls as input to hydrological models for flood forecasting. The first concerns collaborative work with JCHMR (CEH) and the Joint Centre for Mesoscale Meteorology (Met Office) scientists using high resolution (1km) NWP rainfall fields as input to a hydrological model, using the Carlisle flood (6 to 8 January 2005) as a case study. This flood was caused by an orographic storm and the case study is expected to demonstrate improvements in rainfall prediction using the better resolved model topography that feed through to better flood forecasts, at least for longer lead-times.

The NERC FREE (Flood Risk from Extreme Events) programme has funded 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.

9. 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 get out 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.

(ii) Prediction of vegetation cover

Using NDVI (Normalized Difference Vegetation Index) to compare against MOSES simulations forced with Climatic Research Unit (CRU) climatology is continuing.

(iii) 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 21^{st} 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.

(iv) 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.

10. JULES

(i) Development of a community land surface model

A Royal Meteorological Society special interest group meeting was held on 2 October 2006 at Reading University to launch the new community land surface model JULES. The meeting consisted of a number of scientific presentations from users of the prototype version of JULES and some strategic overview presentations from some of the main institutions signed up to using JULES. The number of people attending the launch meeting was good (approximately 60 people) and the feedback from the meeting was generally very positive.

The launch meeting was followed on the next day by a workshop for users within the main institutions that will use JULES. The aim of the workshop was to start to coordinate the research activities being undertaken within the UK community. Again, this was a great success with very active participation in the workshop.

The first management meeting was held 16 October 2006. The committee defined its role within the development of JULES and agreed on a number of actions that need to be undertaken, including setting up benchmark testing for new code and creating a set of coding standards. It was agreed at the meeting that a dedicated post is required to maintain a "JULES Office" which would project manage future upgrades of the model and act as a first point of contact for the community for support and guidance.

The management committee also agreed that the code should be split into several scientific modules, with the lead for each module taken by a member of the UK research community. The role of this leader would be to coordinate research in this area, be a point of contact (especially for the management committee) and to help organise their module's contribution to future JULES science meetings.

(ii) Coding JULES for distributed applications

Work has continued on a new gridded version of JULES and prototypes have been successfully used in several projects within CEH and the Met Office. This version is expected to be formally released in early 2007.

11. Performance of JULES with water-balance

(i) Soil moisture and soil level resolution

A number of off-line simulations have been undertaken with the JULES code to investigate the impact of varying the resolution of the soil for soil moisture. This work has been done in collaboration with Pier Luigi Vidale from CGAM (Centre for Global Atmospheric Modelling) and Anne Verhoef from Soil Science at Reading University. The results of these studies for bare soil evaporation suggest that there needs to be much higher resolution in the soil to get recharge occurring near the surface. The top layers need to be of the order of 2.5 cm., with layers of 5 cm. not achieving the same amount of recharge.

This impacts upon the amount of water in the top soil layer and hence the evaporation from the bare soil and the dry down of the top soil layer during periods of little precipitation.

Using the standard JULES levels gives a top layer soil moisture (and hence evaporation) that is similar to the high resolution version, due to the deep moisture reservoir of the thick top layer. Hence the standard JULES layers give a good simulation in the experiment undertaken, albeit not for exactly the right reasons. However, analysis of the sub-surface runoff suggests that the high resolution versions all suffer from numerical noise, as there are spikes in the output. This is not seen with the standard JULES layers. Therefore it is possible that if higher soil resolution is required, then sub-timestepping of the soil physics is likely to be required.

(ii) Developments to the LSH scheme

Following on from some verification work against observations of river flow, the Large Scale Hydrology (LSH) scheme has been amended to give better simulations of the river runoff for the Rhone-Agg experiment. The simulations show that this new version on LSH is not only better than the original version, but is better than using the PDM model for this experiment. The amended code will be added to the UM system for vn6.4.

(iii) Analysis of large scale river flow with MOSES-LSH + TRIP

An analysis of the river flow from the MOSES model using the Large Scale Hydrology scheme, together with the river routing model TRIP, was undertaken and modelled flows compared with observations for the large river catchment areas around the World. These results showed the mean seasonal flows to be in good agreement with the observations, along with the daily recession curves, for all but the high latitudes, which could be up to 100 days out of phase.

Further analysis showed that the problems in the high latitudes could be overcome by changing the direction of flow for super-saturated soil moisture. This has its biggest impact in areas of frozen soil (i.e. high latitudes). Reverting the direction of the flow for super-saturated soil moisture removed the bias in the river routing and lead to a good simulation.

Results for the same simulations, but without the TRIP river routing scheme did not yield such good agreement with the observations. This demonstrates that the TRIP model adds benefit to the simulation of the river flow.

12. 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 the gridded G2G 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 UKCIP-relevant results.

A new computational scheme to estimate Penman-Monteith potential evaporation (PE) from vegetated surfaces has been developed and included as part of the QUMP-RCM ensemble experiments. Previously the climate models only output estimates of PE from open water, which is considerably higher than PE from vegetated surfaces such as grass, crop and forest. A historical analysis at three sites across the UK suggests that the new scheme yields PE values that are broadly consistent with those derived using the Penman–Monteith equation with meteorological variables used as input, and from MORECS.

Ongoing research integrating the gridded hydrological model into HadRM3/PRECIS is continuing, and will aim to 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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