Joint Centre for Hydro-Meteorological Research

Report on Research Activities 1 October 2004 to 11 April 2005

1. Short-Range Precipitation Forecasting R&D

1.1 Development of the Short-Term Ensemble Prediction System (STEPS) to improve model portability and efficiency

The initial version of STEPS was tuned to run using NWP forecasts from the Met Office's 12 km resolution mesoscale model. To allow the model to be run with other NWP inputs, both in Australia (at the Bureau of Meteorology) and other parts of the world, it has been necessary to write code for computing certain parameter climatologies on-line. These include the AR-2 model autocorrelation parameters, rain analysis to NWP forecast variability ratio, and the NWP skill parameter (see Met Office Forecasting Research Technical Report 433 at http://www.metoffice.gov.uk/research/nwp/publications/papers/technical_reports/fr.html).

To allow STEPS to run efficiently on vector processors, key components of the model have been manually vectorized. These include the Fast Fourier Transform and Inverse Transform functions. The model has also been re-structured to improve performance when run in both deterministic and ensemble modes. The bulk of this work has been undertaken by the Australian Bureau of Meteorology.

1.2 The implementation of an orographic enhancement scheme within STEPS

Orographic enhancement is one important example of the effects of local, surface forcing mechanisms that are not well represented by current operational NWP models, largely due to inadequate horizontal resolution. STEPS does not account for errors in the NWP model component, except insofar as they influence the weight given to the NWP precipitation forecasts in the merging scheme. Furthermore, since the statistical properties of the noise introduced into the forecast ensembles are area-averaged values derived from radar-inferred precipitation fields, STEPS is unable to account for the uncertainty arising from local variations in precipitation distribution caused by these unresolved, sub-grid scale forcings.

A scheme to improve the treatment of orographic precipitation within STEPS has been developed and tested. The formulation of the scheme is identical to the equivalent scheme implemented within the European and Polish versions of the Nimrod system. Based upon the model proposed by Alpert (1986) and extended by Alpert and Shafir (1989), the scheme assumes a direct relationship between moisture convergence at the top of the boundary layer and the magnitude of the orographic enhancement.

1.3 Development of an observation uncertainty algorithm for STEPS

Work on incorporating an observation uncertainty algorithm into STEPS is being undertaken by collaborators at the Bureau of Meteorology in Melbourne. This work seeks to represent the uncertainty in radar-inferred surface rain rate by adding stochastic perturbations to the best guess analysis of surface rain rate. The principal challenge lies in representing the complex spatial and temporal variations in uncertainty arising from numerous sources (e.g. assumptions made about: the drop size distribution, wave propagation, variation in the vertical profile of reflectivity).

1.4 Development of the European Nimrod nowcasting system

Work on the replacement of the Global Model feed into European Nimrod with one from the North Atlantic and European (NAE) model has been delayed due to issues with the performance of the NAE model. Work to migrate several nowcasting algorithms, including the MOSES-PDM soil moisture–runoff models, from the UK version of Nimrod to European Nimrod prior to retirement of the former, will commence later this year.

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

An initial version of a post-processing system for the 4km resolution UK NWP model has been developed and tested, and is now running under the parallel suite on the Met Office's supercomputer – the NEC SX8. The system incorporates algorithms for the interpolation of UK NWP model fields to a 2 km resolution grid and the nowcasting of precipitation type, visibility, wind and pressure. Algorithms for the prediction of precipitation and cloud, and the generation of site specific forecasts will be added in May 2005, following completion of work on the deterministic version of STEPS.

A web-based, interactive display system and verification software have been implemented on the Nimrod hardware in lieu of the introduction of a new, centralised data repository, planned for later this year.

3. Development of a storm-scale NWP model for quantitative precipitation forecasting

A scientist at the Joint Centre for Mesoscale Meteorology (JCMM), at Reading, who spent one day a week at the JCHMR, has completed a 2-year project to assess the hydrological performance of the Met Office NWP model when experimentally run with grid-lengths of 1-4 km. The work was jointly funded by the Met Office and Defra.

The final scientific report (Forecasting Research Technical Report (FRTR) No.455) has been issued (Jan 2005). The report documents the key findings from the work and tools for presenting and assessing the model output that have been developed during the course of the project. It concluded that a storm-scale model (grid spacing ~ 1 km) is capable of producing significantly more realistic and spatially accurate forecasts of convective rainfall events than is possible with current operational systems. Evidence has come from detailed investigation of selected cases and from performance statistics over a larger sample. There is now a prospect of producing useful forecasts of convective storms on scales applicable for flood prediction.

It is recommended that the development of a storm scale modelling system should continue towards operational implementation and that the generation of diagnostic products for flood warning should be an integral part of any operational system. The development of such a system will still require further core research, particularly in the area of data assimilation (the process of incorporating new observational information at the start of the forecast).

The final report delivered a review of the project and proposals for follow-up projects to take the capability a stage further. Three projects were proposed.
(1) An assessment of the ability of a model with a 1km grid spacing to predict extreme events (as classified by the extreme event recognition project).

(2) Investigation of blending forecasts from a 1km model with radar extrapolation forecasts.
(3) Investigating how outputs from a 1km NWP model can be used directly into hydrological models.

4. 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 warning and water resource management. A new release of Hyrad to the Environment Agency will provide the following new features: (i) IT Management Tool providing statistics on successful product delivery, (ii) Summary Rainfall Statistics (Minimum, mode, mean, median and maximum) for image-on-view and image sequences for a selected catchment or area (this will semi-automate the construction of "radar truth" for the Rainfall Forecast Assessment PC Tool outlined in the previous JCHMR Research Activity Report), (iii) Generation of time-series of catchment average and maximum rainfall accumulations to pass to telemetry/modelling systems for alarm generation, (iv) Self management of user prioritization to allow a wider user pool, (v) Improved and generalized dialogs for display, (vi) Time-series charts amended to use units from data type (relevant to the new NWP rainfall/temperature and MOSES soil moisture/snowmelt/evaporation/runoff products), and (vii) NFFS (National Flood Forecasting System) interface enhancements to deliver a single file per forecast (with revised name) and to manually populate the Met Office product reference. This release will become operational in May 2005.

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). The real-time Model Algorithms include PDM and KW, SNOW (PACK) snowmelt model, and ARMA error predictor (state correction forms of data assimilation are embedded within a given model type). The real-time algorithms are available in Module Adapter form (using an XML interface) for use with the Environment Agency's National Flood Forecasting System (NFFS). An Enterprise Licence for both Calibration and Real-time codes has been supplied, allowing their use in all regions of the Environment Agency across England and Wales. Work is also underway in supplying the PSM in real-time Module Adapter form.

With the above developments, the Environment Agency now has 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 and Wales.

At the invitation of the French Academy of Sciences, a position paper on "Forecasting for Flood Warning" was prepared and published in Comptes Rendus Geoscience in 2005.

5. 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 is developing spatio-temporal rainfall

datasets, using radar and raingauge data from historical heavy rainfall events, enhanced to represent extreme events. These datasets are being used to evaluate and improve the performance of hydrological models under such extreme event conditions. They are also to be used for model destruction testing.

Work has been completed on identifying Case Study events and catchments associated with extreme convective, frontal and orographic rain. Case study rainfall-runoff model applications have been carried out for convective storms over Boscastle (River Valency) and Blackburn (River Darwen) and for an orographic event over the rivers Kent and Upper Ure. Model performance has been assessed for a lumped (PDM) and a distributed (G2G) model: no obvious breakdown in performance has been observed for these extreme events. Assessment at higher flows however can be constrained by the range of validity of ratings used to transform river level to flow. A Rainfall Transformation Tool has been developed to amplify rainfall fields derived from historical data through the control of storm position, areal extent, magnitude/duration and storm movement/orientation. A new methodology for using raingauge and/or radar data to estimate rainfall for catchment and grid-square areas has been developed. When used with the Rainfall Transformation Tool, it provides a methodology for constructing artificial space-time rainfall datasets for use in model response studies and for model destruction testing. Modelled flood response experiments are underway using these new tools and case study datasets.

6. 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 has been 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 Guidelines Report on best practice is being developed alongside prototyping of new improved methods. A new method of representing runoff production under the control of soil and topography, with an emphasis on lateral water transfers, is being considered. Also, a variable time-step Muskingum-type flow routing methodology with links, via the St Venant equations, to channel properties appears to have benefits for application to ungauged areas. Seeking physically-based methods of applying conceptual hydrological models to ungauged catchments using digital datasets on basic properties, as opposed to empirical regression on catchment characteristics, is seen as a way forward. A range of options for data assimilation to support forecast updating, depending on the level of data availability and model structure, are being set down. A Technical Report, from which the Guidelines Report will be developed, is in draft form.

7. Post-event Evaluation

The extreme rainfall events of 8th (southern England) and 16th (Boscastle) August 2004 have been being studied and reports written describing the performance of nowcast and NWP forecast systems during these events. The report on the Boscastle event has been issued as Forecasting Research Technical Report No. 429 (http://www.metoffice.gov.uk/research/nwp/publications/papers/technical_reports/fr.html).

An extreme rainfall event produced flooding in Carlisle in early January 2005. The performance of operational weather forecasting systems has been studied and a preliminary report written. The performance of a Grid-to-Grid River Flow Model (RFM) which routes runoff from Nimrod-MOSES-PDM was also studied. A rerun of Nimrod-MOSES-PDM-RFM with a larger flow wave speed (which required a shorter timestep for the RFM) gave more realistic magnitude and timing for the flood peak flow.

A feature of recent post-event evaluation reports has been the plots of rainfall, runoff and river flow with map backgrounds produced with a Geographical Information System (GIS) software package.

8. Development and validation of soil state and surface hydrology models

(i) CEH have compared observations from two LOCAR catchments (the Pang/Lambourn and the Tern) with soil moisture from the operational Nimrod-MOSES-PDM during 2003. For the Pang/Lambourn catchment, neutron probe data were available (at roughly fortnightly intervals and down to depths in excess of 3 m) for the whole of 2003 but the profile data (hourly intervals down to 1 m depth) were available from mid-summer to the end of the year. The report highlights (i) the difficulty of using site-specific soil moisture measurements for validating 5km x 5km model gridsquare means; (ii) the deficient soil moisture from the version of Nimrod-MOSES-PDM which was operational in 2003 (note: the soil hydraulics and associated ancillary fields were changed to the van Genuchten formulation in May 2004); (iii) some problems with the radar rainfall analyses in late April to mid June 2003 and (iv) the special nature of water movement through chalk which isn't represented well in MOSES.

(ii) The ELDAS project (European Land Data Assimilation System to predict Floods and Droughts) is supported by the European Union in the context of the Fifth Framework Programme. Scientists from the JCHMR have been involved in a case study to compare the ELDAS soil hydrology to the operational data available for the Autumn 2000 floods affecting South East England. Soil moisture data, generated by the Tessel land-surface scheme, were used to replace soil moisture estimates within PDM rainfall-runoff models calibrated to 3 catchments within the Thames basin. It was found that the Tessel estimates of soil moisture had to be adjusted to correspond to the soil moistures required by the PDM models. This was done by comparing the soil moisture from the two sources and linearly transforming the Tessel soil moisture estimates. No overall advantage for flow prediction was found in using the Tessel soil moisture (even after adjustment) over the soil moisture intrinsic to the PDM rainfall-runoff model. Tessel soil moisture estimates were much less variable than those from the PDM and seldom reached saturation, even during the autumn 2000 floods. This may in part be related to scaling effects. The Tessel estimates are for a 40 km grid (1600 km^2), and use rainfall at this scale introducing smoothing, whilst the largest catchment modelled with the PDM was of the order of 300 km^2. Spatial invariance of the soil properties assumed in the Tessel land-surface scheme may be a further contributing factor. The ELDAS project is now finished and the Final Report is available on the ELDAS web site www.knmi.nl/samenw/eldas/ .

9. Global water and carbon cycles

9.1 Development of a community land surface model

A community land surface model (based upon the Met Office Surface Exchange Scheme, MOSES) is being developed in order to forge direct links between the UK research community and the Hadley climate model. This will enable new science to be tested within a climate change environment and contribute towards reduced uncertainty and understanding of climate change impacts.

The code is ready to be fixed for the first release. Permissions have been obtained to include observational datasets to accompany the model, so that users can immediately test new ideas. In addition, an ancillary program is being added to the code to enable default initial conditions to be determined for any location. It is anticipated that the first release of the Joint UK Land Exchange System (JULES) will be very soon.

To launch JULES it is anticipated that the model will be distributed to a selection of the UK research community that are used to dealing with such models. It has been proposed that after time for the users to become accustomed with the model, a workshop will be held to formally launch this new community tool.

9.2 Seasonal vegetation

Tests have been completed on the use of seasonal vegetation for both global and regional models. The seasonal variation in the vegetation has been determined from satellite data which has been used to determine the greenness of the land for different vegetation types using a simple algorithm.

In addition to these model simulations, comparisons between this simple algorithm and that used in the ECOCLIMAP dataset are being undertaken. The aim is to determine a more accurate method for deriving the greenness of each type of vegetation from the single satellite image at the resolution of the satellite.

9.3 Dynamic Global Vegetation Model Intercomparison

In recent years attention has focused on the role of terrestrial biosphere dynamics in the climate system, and the possibility of large land-atmosphere carbon cycle feedbacks under human-induced future climate warming. Of particular importance is the Hadley Centre study of Cox *et al.* (2000). They ran the TRIFFID Dynamic Global Vegetation Model (DGVM) coupled with the Hadley Centre climate model in a fully interactive carbon cycle experiment for one future CO_2 emission scenario. This study highlights the large potential land-atmosphere carbon cycle feedbacks in accelerating future climate warming, with important ramifications for climate change mitigation.

A more comprehensive study with multiple DGVMs and emission scenarios is needed to assess uncertainty in the magnitude of future climate carbon cycle feedbacks. The UK is in a unique position to address the issue, with four resident DGVMs, and a computationally efficient GCM analogue model developed at CEH. Also, to enable computationally efficient climate carbon cycle studies, CEH staff coupled the GCM analogue model to a land (MOSES/TRIFFID) and a simple ocean carbon cycle model, in a package called IMOGEN.

As part of this new initiative members of staff within the climate area of JCHMR (both Met Office and CEH) are involved. IMOGEN has been rewritten to enable easy exchange of land carbon cycle model, i.e. it can be coupled to other DGVMs. A standard simulation protocol has been written and adopted by each DGVM group. Each group have coupled their DGVM into IMOGEN and are currently running coupled climate-carbon cycle simulations with their DGVM for 4 future CO_2 emission scenarios and the analogue climate pattern of HadCM3.

9.4 Wetland methane emission feedback on climate change

Atmospheric methane concentrations and temperature trends have been highly correlated in the long-term historical records, implying that changes in climate modify the wetlands source and/or the atmospheric sink terms occurred. In order to reduce uncertainty in our assessment of the impact of future wetlands methane emissions on climate change (Gedney *et al*., 2004), an off-line simulation of the Last Glacial Maximum (LGM) is being conducted. This simulates a significant increase in potential wetland extent and methane flux in the present day relative to the LGM, which is in general agreement with observationally based data. The results also suggest that recent draining of land for agricultural purposes appears to be a significant factor in determining the net global methane flux for present day.

9.5 Climate change: Detection and Attribution

Work is underway to analyse the runoff time series over the 20th Century at the regional scale. The Met Office Surface Exchanges Scheme (MOSES) is forced off-line with observed data (e.g. precipitation and temperature) and the resulting modelled runoff patterns are compared with those observed. Using this methodology we are aiming to "attribute" runoff changes due to various factors .e.g. land use.

10. JCHMR Fellowship

Work continues on how best to exploit satellite data to initialize soil moisture for short term forecasts. The study area is West Africa, where strong surface soil moisture gradients can develop due to the passage of mesoscale convective storm systems. The case of interest occurred during August 2004 and is associated with the rapid intensification of a weather system which transformed into a tropical cyclone downstream of the continent. A pattern of wet and dry patches on spatial scales of the order of hundreds of kilometres are readily apparent from infra-red and microwave satellite imagery. We have been investigating how to best utilize the near-surface soil moisture product from the AMSR-E microwave sensor on board the AQUA satellite. Inspection of time series of soil moisture suggest that the estimates suffer from low frequency biases, possibly due to the slowly evolving vegetation canopy. This makes the direct use of the data problematic. An alternative qualitative method to initialize soil moisture has been explored based solely on the higher frequency data (daily anomalies from a longer term mean). When introduced into the atmospheric model, this method significantly reduces boundary layer temperature biases. Under the forthcoming African Monsoon Multidisciplinary Analyses (AMMA) project, a range of methods for generating soil moisture analyses will be explored.

11. Coupling CEH hydrological models to Met Office regional climate models

As part of a Defra-funded project, the Met Office's Hadley Centre and CEH are developing methods to predict flood frequencies over the UK in current and future climates. Regional Climate Models (RCMs) are being coupled to CEH hydrological models to predict fluvial flooding, and coastal flooding when coupled to a shelf-sea model.

An initial system to predict changes in fluvial flooding for the UK has already been developed (Bell *et al.,* 2004a,b; Kay *et al.,* 2005a,b). This system provides a grid-based methodology in the form of a grid-to-grid model for translating RCM meteorological variables, such as rainfall and evaporation, into estimates of river flow and fluvial outflow to the sea. The initial development work used a simple grid-based runoff-production scheme in order to progress the development of the routing component which transforms gridded runoff into river flow. This year the routing scheme, called the Grid-to-Grid model or G2G, has been linked to the Met Office land-surface scheme MOSES. The combined MOSES-G2G model now provides a stand-alone platform to support research into broad-scale runoff-production and routing schemes.

The combined model (Bell *et al.*, 2005) is currently configured to the UK National Grid used by the Met Office Nimrod nowcasting scheme with the Grid-to-Grid routing model operating at a 1 km resolution. Initial results over the Thames Basin indicate that the new model is performing moderately well, with modelled and observed flow in the Thames showing reasonable agreement. The new modelling platform will support 'offline' investigation of different models of soil-moisture and runoff-production within MOSES, and will support further development of the Grid-to-Grid routing model. Planned work in the coming year will apply the combined model to other areas of the UK at a 1km resolution, and to the European RCM domain at a 25km resolution.

In order to apply the Grid-to-Grid flow routing model to the European RCM domain, initially a set of hand-corrected 25km resolution flow-directions were used that had been inferred from 25km mean elevation data for Europe. Whilst the river networks and catchment areas derived from these flow-directions were considered acceptable following hand-correction, some errors remained. The hand-correction process proved time consuming, discouraging repeated application to new regions. This would be a particular problem when the model is implemented within the regional climate modelling system, PRECIS, which is applied to many regions across the world. With the aim of overcoming the need for time-consuming hand-correction of derived flow directions at a regional scale, three alternative methods for deriving river networks from higher resolution DTM data have been explored. The current preferred method of deriving flow directions at a coarse resolution involves first inferring flow directions using an automated procedure applied to higher resolution DTM data. Only a limited amount of hand-correction to overcome any residual errors is then required to obtain the final derived flow directions.

12. Climate change impact on dependence between river flow and sea surge

A small climate change impact study was undertaken as part of a larger study on joint probability issues in flood and coastal defence, funded by Defra (FD2308, Joint probability: dependence mapping and best practice). The water level in a fluvial-tidal river reach is affected by both river flow and sea level. If a predicted increase in these flood-producing variables is

combined with an increase in the dependence between them, the effect on the total water level corresponding to a particular return period can become very significant.

Regional climate model and shelf-seas model outputs were used to make a preliminary assessment of changes in the dependence between sea surge and river flow, using precipitation as a proxy for river flow (in anticipation of a larger study involving hydrological modelling of river flows). The UKCIP02 Medium-High emission scenario was assumed. Several locations on the south, west and northern part of the east coast of Britain show significant increases in the dependence between sea surge and precipitation in the period 2071-2100, compared to the control run 1961-1990. These significant changes are supported by smaller increases at other locations on these coasts (Svensson and Jones, 2005a; 2005b).

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