Joint Centre for Hydro-Meteorological Research

Report on Research Activities 13 August 2003 to 22 March 2004

1. Nimrod and Gandolf R&D

The Gandolf R&D programme in 2003-04 has been focused on two areas: quantifying errors in quantitative precipitation nowcasts in ways suitable for customer use and improving thunderstorm prediction. In the latter area, proposed work to integrate components of Gandolf's convective life cycle models with Météo-France's Rapidly Developing Thunderstorm (RDT) product unfortunately could not be completed. R&D planned for 2004-05 will explore incorporating elements of these models into the stochastic precipitation nowcast scheme discussed below.

Work on the development of a next-generation, operational quantitative precipitation forecast scheme, capable of predicting the space-time probability density functions (pdfs) of surface rain rate and rain accumulation has been completed. A Technical Report describing the scheme has been issued. This report incorporates the results of an off-line performance evaluation. Verification statistics show the best guess forecast generated by the stochastic scheme to be at least as skilful as existing Gandolf nowcasts. Evaluation of the forecast ensembles using the Brier Skill Score shows the pdf of rain rate to be reliable and to have good resolution for low rain rate thresholds, although, in line with expectation, the limited ensemble size used (30 members) limited the ability of the scheme to predict high precipitation rates. Performance statistics have also demonstrated the need to account for two additional sources of uncertainty before an operational trial of the scheme can take place: uncertainty in the radar observations, and errors arising from the mesoscale model's inability to resolve and predict small scale precipitation features such as those arising from localised orographic enhancement and convective initiation.

In January 2004 a case study was prepared to demonstrate the potential application of rainfall forecast ensembles to operational fluvial flow and flood prediction. Pdfs of rain accumulation were input to a rainfall–runoff model (the Probability Distributed Model) to estimate pdfs of river flow for a catchment in south-east England. Results of this 'proof of concept' study were presented at the 6th International Symposium on the Hydrological Applications of Weather Radar, held in Melbourne at the beginning of February 2004.

2. Implementation of a Nimrod system for IMGW in Warsaw, Poland

Work on the implementation of a Nimrod system at the operations centre (MROC) of the Polish Institute of Meteorology and Water Management (IMGW) in Warsaw was completed in September 2003. Site Acceptance Testing of Nimrod was held between 17 and 21 September 2003. The system passed all tests with the exception of two that could not be performed due to an absence of raingauge data. These outstanding tests will be conducted in Spring 2004 when the Polish raingauge network and associated telemetry are due to become operational. Following successful completion of these remaining tests, the Met Office will receive a guarantee certificate from IMGW indicating full acceptance of the operational system.

In October 2003, the Met Office commenced a support and maintenance contract with IMGW to last for three years. This will ensure that optimal Nimrod performance is maintained, and

technical issues which cannot be resolved by trained IMGW staff are remedied by Met Office experts.

3. Rainfall Collaboration Project

There are currently about 60 Environment Agency raingauges reporting routinely to the Met Office from three regions. Data acquisition from the remaining regions has continued to slip; no new areas have been added and problems with false zeroes remain in the data that are being received. A revised set of milestones for implementation in the remaining regions has been agreed by the project board. Work is progressing on development of a national composite of the combined radar/gauge rainfall accumulation analyses.

4. Hyrad and RFFS

The delivery of CEH's Hyrad radar display and processing system to Belgium, and its interfacing to FloodWorks as part of the Demer basin flood forecasting system trial, was completed in November 2003. Follow-on work to use an improved radar source is planned for 2004.

An upgrade to the White Cart River Flow Forecasting System (RFFS), providing flood warning support to an area south of Glasgow (Scotland) is underway. This involves a Met Office feed of Corse Hill Single Site Nimrod QC data to Hyrad. The RFFS will be configured to use radar- or gauge-derived catchment estimates of rainfall from Hyrad. The RFFS will be upgraded to the FloodWorks environment and extended to encompass an ISIS hydrodynamic model at its downstream end in collaboration with Wallingford Software. Training on the operational system is scheduled for mid-April 2004.

The Hyrad implementation for the Environment Agency has been extended to include an XML interface to Flood Forecasting and Modelling Systems for passing pixel and catchment average rainfalls (observed and forecast). Some modifications are being made to Hyrad to better handle Mesoscale Model product data and MOSES-PDM data supplied via the Nimrod environment.

Selected RFFS models – PDM rainfall-runoff, PACK snowmelt, KW channel flow routing, and ARMA error prediction – have been supplied to the Environment Agency in XML Module Adapter form for use in the National Flood Forecasting System development.

A paper on weather radar and flood forecasting, focussing on UK operational practice and Hyrad and the RFFS, was presented at the 6th International Symposium on Hydrological Applications of Weather Radar in Melbourne, Australia.

Work on probabilistic flood forecasting using rainfall ensembles, in part reported under 3.1 and involving use of the PDM rainfall-runoff model, was presented at the HEPEX (Hydrological Ensemble Prediction Experiment) inception meeting at Shinfield in March 2004.

5. Use of Nimrod in Flood Forecasting

Currently the Environment Agency's hydrological flood forecasting models are calibrated with data from raingauges rather than from radar products. This is a factor which limits confidence

when they are used with very-short-range precipitation forecasts derived from radar analyses and other fields available within the Met Office's Nimrod system. Also, in many areas the precipitation amounts analysed from radars have better spatial representativity than those derived from raingauges which should make the former the “best estimate” for input to rainfall-runoff models. This project aims to find out if there is a benefit to be derived from the use of Nimrod products in flood forecasting models, to quantify it and assess its sensitivity to changes and enhancements to the Nimrod products.

Nimrod data retrieval for the calibration and testing of Calder catchment hydrological models is now complete. A contract has been agreed between the Met Office and CEH for the latter to calibrate and test the hydrological models and to write a report. This work is ongoing.

Measures of the difference between the standard Nimrod hourly rain analyses and the corresponding analyses produced with real-time raingauge data combined with radar data have been monitored since last summer and a report will be written.

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

A scientist at the JCMM, Reading who spends one day a week at the JCHMR, is working on a project, jointly funded by the Met Office and Defra, to assess the hydrological performance of the Met Office NWP model when experimentally run with a grid-length of 1-4 km.

A report (Forecasting Research Technical Report (FRTR) No.402) has been issued which documents the results from simulations of four convective case studies using the model with horizontal grid-lengths of 12, 4, 2 and ~1km (and 38, 45 or 76 vertical levels). In all four case studies, an increase in horizontal resolution produced more accurate forecasts.

A second report (FRTR No.407) has been issued, documenting the sensitivity of high-resolution model forecasts to the convection scheme. This highlighted problems when using a 4km grid, and further emphasized the benefits of the 1km grid.

The report for Stage 3 of the project has been issued (FRTR No.423). A variety of new precipitation outputs diagnostics were examined including: catchment average and ‘worst case scenario’ average rainfall accumulations, the probability of a catchment average rainfall accumulation exceeding a threshold, possible extreme point precipitation accumulations and peak rainfall rates within regions.

The project board agreed a modification to the plan for Stages 4 and 5 to take account of dependencies on other work being carried out in the Met Office, and of the close relationship between analyses and forecasts. Stage 4, now completed, developed the tools for verifying both analyses and forecasts. The report (FRTR No.432) gives a description of the methodology to be used for quantitative evaluation of high resolution precipitation analyses and forecasts. The verification measures were tested in an idealised framework to determine the characteristics of different scenarios of forecast and radar differences.

Stage 5 of the project, currently in progress, involves carrying out the actual evaluation of both the fit of the analyses to radar, and the accuracy of the forecasts.

7. Post-event Evaluation

The 2002-03 New Year heavy rainfall and flooding event caused disruption over many areas. The meteorological and hydrological forecasting of the event have been analysed and a report has been written for the Met Office and the Environment Agency.

A heavy rainfall event on 19/20 May 2003 is being studied. The incident concerned the non-issue of a Heavy Rainfall Warning in northwest Wales on 19 May 2003, when significant rain fell.

8. Rainfall Forecast Performance Monitoring

This project undertaken by CEH, was commissioned jointly by the Environment Agency and the Met Office. It aimed to develop methodology and algorithms for monitoring the quality of rainfall forecasts produced for the Agency by the Met Office in the form of the Daily Weather Forecast, the Evening Update and the Heavy Rainfall Warning. It first reviewed current methodology and practice in monitoring the performance of rainfall forecasts. Recommendations relating to the content, format and delivery mechanisms of the forecast products were made. The study developed a framework for forecast assessment, addressing issues such as selection of performance measures, choice of "ground truth", and sources of comparative forecasts such as rainfall forecasts obtained directly from the Mesoscale Model and from the Nimrod radar-based product. New methods for assessing the accuracy of performance measures - as determined by a given rainfall forecast, ground-truth and comparative forecast dataset –were formulated. Application of the assessment procedure was demonstrated on a selection of storm events and served to develop practical experience in its use leading to recommendations for operational implementation by automated and manual means. The main conclusion points to the advantages of using a small and rather simple set of performance measures for assessment. The mean absolute error provides an easily understood and stable measure of the "typical size of error", in the same units as the rainfall forecast. For a categorical measure of rainfall threshold exceedence, the Critical Success Index and False Alarm Rate provide a useful pairing that are widely used and easily understood. For assessing probability forecasts, the Continuous Brier Score provides a simple measure analogous in form to the mean absolute error. Measures of forecast bias are also included in the selected set of performance measures considered important. The main project outputs were a project report and a PC tool (with User Guide) for Heavy Rainfall Warning Assessment.

New versions of the Heavy Rainfall Warning Assessment Tool and User Guide were delivered during January. These address a number of issues identified during the acceptance testing phase. These are now being considered by members of the Project Board. It is expected that the project deliverables will accepted and the project brought to a successful close.

9. Development of a soil state and surface hydrology model in Nimrod

Information on the hydrological state of the ground is required by a variety of customers: the Environment Agency need to know the antecedent soil state for flood forecasting and also for water resource assessments; the military need information to enable them to make decisions on the ability of the terrain (potentially anywhere in the world) to support and allow passage of heavy vehicles; water companies and farmers also benefit from knowledge of the amount of water in the soil and how much of it is evaporating into the atmosphere.

Work in previous years has resulted in improved surface runoff and hydrology in the Met Office Surface Exchange Scheme (MOSES) by including CEH's Probability Distributed Moisture (PDM) scheme, the implementation of MOSES-PDM in the Nimrod nowcasting system, the representation of heterogeneity of snow cover in MOSES, assessment of the sensitivity of the soil moisture diagnosed by MOSES to ancillary data describing the soil properties, the development of a technique to map the spatial distribution of soil moisture within a model grid-square, the improvement of the treatment of soil freezing and thawing and the development of a prototype flood routing and overtopping model for use in remote areas.

Work over the past year has further developed the flood water routing and overtopping model, begun to extend the validation of outputs from MOSES-PDM with new observed data and pulled through previous years' research by implementing new or improved components of MOSES-PDM into Met Office operational modelling systems.

Details of recent work:
(i) Implementation in the Met Office's operational Nimrod nowcasting system of a revised radiation scheme for deriving surface radiation inputs to the surface energy balance of MOSES-PDM. The new scheme is not location specific, thereby allowing the model to be more easily set up in any area of the globe.
(ii) Implementation of the flow routing scheme developed by CEH within Nimrod-MOSES-PDM. (See (iv) below.)
(iii) Observations from two LOCAR catchments (the Pang/Lambourn and the Tern) are being assimilated to make comparison with soil moisture from the operational Nimrod-MOSES-PDM. The data are available from Spring 2003, through the dry summer of 2003 and into the winter.
(iv) Routing and out-of-bank flows. The surface and subsurface runoffs generated from MOSES-PDM grid squares are being used as input to a flow routing and inundation model under development by CEH. The flow paths are automatically delineated using a digital terrain model. A preliminary formulation of the model and results from it applied on a 5 km model grid - for the Thames, Wharfe and Derwent rivers - are contained in the March 2003 contract report. A 1 km version of the model has recently been implemented which has involved redefining the flow paths at this scale, manually correcting for misaligned flow paths in the process. Representation of inundation requires inference of bankfull discharge at any stream location based on readily available information. A relationship with area and average annual rainfall has been established allowing a notional bankfull discharge to be estimated for all 1 km grid squares over the Nimrod domain. Refinement of the routing model formulation is being investigated involving a variable wave speed dependent on discharge and parameterised in terms of the bankfull discharge that can be inferred from the procedure discussed above. Results from a range of gauged rivers across England and Wales are providing useful feedback to the model development. The Nimrod team are currently testing the routing scheme for operational implementation.

10. Global water and carbon cycles

Global Soil Wetness Model Intercomparison. Various versions of MOSES were forced with 17 years of observed/analysed data as part of an intercomparison project, the Global Soil Wetness Project (GSWP2). The results of this are now being assessed in detail.
Topographic control on soil moisture in GCMs. A paper on the effect of including topography-based sub-grid soil moisture variation within the global climate model (GCM) has been written and published in the Journal of Hydrometeorology. The new land parameterisation improves the GCM's ability to simulate the present day climate. It also affects

the predicted climate change. This model is now being assessed within the framework of GSWP2 (see above).

Wetland methane emission feedback on climate change. An assessment of the potential feedback of wetlands methane emissions on climate change is near completion. The observed variability in present-day atmospheric methane concentration has been used to constrain a simple wetlands methane emission parameterisation. This new interactive wetlands model was then incorporated into the Met Office Surface Exchanges Scheme (MOSES) so that a suite of GCM-analogue model (IMOGEN) transient climate change simulations could be carried out to assess this potential feedback. The GCM-analogue model transient climate change simulations have been analysed. A draft paper is now ready for submission.

Climate change: Detection and Attribution. One of the key questions to be asked in the climate change debate is whether the initial effects of increasing atmospheric greenhouse gas concentrations can be seen already. Most climate models estimate that some change has already occurred due to the burning of fossil fuels between pre-industrial times and the present, and that this will manifest itself in not just a general warming, but also in quite complex geographical patterns of change. These computer-derived estimates of variation help us to understand whether emerging patterns of change seen in global sets of measurements are due to natural climate variability, or a real long-term signal of global change. A statistical method called "detection and attribution" has been developed jointly between Oxford University (department of Atmospheric Oceanic and Planetary Physics) and the Met Office's Hadley Centre whereby climate signals are extracted from noise in observations by the global set of weather stations. This is looking for, or "detecting" change. The second part is "attribution", whereby a statement is made that there is a high probability that a particular observed trend is due directly to human activity. At present, the numerical methods are tuned to work with the Hadley Centre GCM. However, in an exciting development, CEH have been working under subcontract to the Hadley Centre (and in collaboration with Oxford University) to extend the methodology to include model uncertainty. This enhancement of the numerical code makes it possible to include the output from other climate modelling groups. This will help to increase our knowledge of climate change, and in particular it will allow us to make stronger statements about human influence on climate. At present, the statistical modelling structure is nearly completed for simple generic examples and the initiative is about to apply this tool to global climate model output from a large range of modelling centres from around the world. It is hoped that this work will be of direct relevance to IPCC activities.

11. JCHMR Fellowship

Recent work using satellite data to observe the land surface has been applied to the issue of how surface moisture patterns influence subsequent rainfall. Images from Meteosat collected over the 2000 wet season in North Africa have been analysed using a simple cloud-screening algorithm developed previously. The cloud-screened thermal infra-red temperature provides qualitative information about where rain has fallen in previous days: low temperatures indicate that near surface soil moisture is present, associated with high evaporation and low sensible heat flux into the atmosphere. Patterns of wet and dry soil of different length scales have been composited to produce a picture of how a typical surface moisture pattern affects subsequent cloud characteristics (also based on Meteosat imagery). The analysis shows that over length scales of the order of several hundred kilometres, cold cloud (used as a proxy for rainfall) is strongly suppressed over dry soils. The converse is also true, large wet patches being associated with subsequent increases in cold cloud. This illustrates a positive feedback mechanism at work between soil moisture and rainfall. At smaller scales the strength, and even

the sign of the feedback changes. This is likely to be due to the dynamical response of the atmosphere to gradients in surface heating.

12. Flood prediction using the RCM

A flow routing model for coupling to a Regional Climate Model (RCM) is under development by CEH under the Hadley Centre's research programme commissioned by Defra. The model formulation is based on that already discussed under 9. (iv) and is being used in two ways:

- Across a wide area of coverage (Europe) and a coarser scale (25 km, the scale of the RCM grid currently in use) and at a daily rather than hourly time-step.

- At a 1km resolution over the UK

The main inputs to the model are RCM rainfall and RCM-derived estimates of potential evaporation (PE) which are transformed via a simple runoff production scheme to obtain surface and subsurface runoffs. This is an interim measure as the eventual aim is to use MOSES-PDM estimates of runoff to drive the routing scheme. The purpose of the model is two-fold: to provide water discharges to the seas around Europe for input to ocean models and to provide estimates of flood discharge and inundated areas across Europe, in today's and future climates. The 25km resolution model for Europe has now been integrated in the Unified Model Version 6.0 for use as an RCM-coupled model.

Ongoing work is assessing the 1km version of the model over the UK using RCM data disaggregated to 1 km using the gridded 1 km SAAR (Standard Average Annual Rainfall) dataset. Observed daily rainfall data at a 5km resolution are also proving useful for a study of the 2000 floods and the causal mechanisms involved. Flows estimated from the UK 1km routing model can be compared to those obtained using the PDM rainfall-runoff model as used in continuous simulation research (as reported in the August 2003 report). Results obtained using rainfall and PE data derived from RCM runs provide flood frequency curves that can be compared to observed flood frequency curves. Using outputs from a 2080s RCM run allows changes to the flood frequency curve to be analysed for future climate scenarios. The results are best seen as demonstrating the application of the methodology, and not providing reliable estimates of future flood frequencies, since they represent the outcome of a single RCM nested within a single GCM for one emission scenario. Ongoing work is using the PDM catchment model, along with the Grid-to-Grid flow routing model described above, to assess the 2000 floods in the context of the recent past.

13. Indices of flood and drought severity

When a drought situation is ongoing, it is common practice to assess how rare the current situation is by finding the total rainfall over a number of past months and then determining how rare this total is, taking account of the time of year. This can be done, taking several different durations over which to find the total rainfall and finding the rarity for each. It is tempting, but known to be incorrect, to use the most extreme of these rarities as an overall assessment of the drought. A study has been made of this and similar situations, to assess the actual properties of the incorrect procedure. For example, suppose that rarities are assessed for 8 durations, where monthly rainfalls are totalled over the past 1 month, 2 months, to 8 months, and the most rare of these is taken. Then an assessment of "one in 100 years" would in fact be made about every 25 years. The research has just been published in the Hydrology and Earth System Sciences journal.

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