Joint Centre for Hydro-Meteorological Research

Report on Research & Development Activities
5 February to 13 August 2003

1. Nimrod and Gandolf R&D

The Gandolf R&D programme for the current year is focused on two areas: improving thunderstorm prediction, and quantifying and conveying the errors in quantitative precipitation nowcasts to the customer. In the former area, an upgrade to the convective life cycle models in Gandolf is under way. This will integrate components of Gandolf's object-oriented convective precipitation nowcast scheme with the Rapidly Developing Thunderstorm product developed by Meteo-France. To date, progress has been limited due to the competing demands of the delayed Polish Nimrod project. However, it is hoped that software development can be completed by November 2003. A trial of the integrated scheme will take place in the summer of 2004.

The development of a next-generation, operational Quantitative Precipitation Forecast scheme capable of predicting the space-time probability density functions of surface rain rate and rain accumulation is nearing completion. This stochastic scheme is based upon the Spectral-PROGnosis (S-PROG) model developed by the Bureau of Meteorology in Melbourne. In keeping with the nowcasting philosophy adopted in Nimrod, the scheme combines extrapolation-based stochastic precipitation forecasts with downscaled, mesoscale NWP forecasts to produce forecast ensembles of rain rate and rain accumulation with a maximum range of 12 hours. Calibration and documentation of the scheme should be completed by early November 2003. A trial is planned for April 2004.

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

With funding from the World Bank in support of the decade of international disaster relief, the Met Office is working in collaboration with a German radar manufacturer, Gematronik, to deliver a Nimrod system to the Polish Institute of Meteorology and Water Management (IMGW) in Warsaw. This Polish Nimrod system will form part of a hydrological and meteorological monitoring and forecasting system (SMOK) designed to mitigate the impacts of disastrous floods, such as those experienced in the southern reaches of the rivers Odra and Vistula in July 1997. Delivery of an operational system should be completed by the end of September 2003.

A request for a change in the Nimrod data projection in Spring 2003 delayed completion of the software development phase of the project until the end of May 2003. In the first two weeks of June the Nimrod system was installed at the operations centre (MROC) at IMGW in Warsaw. In the following six-week period to the end of July 2003, the component algorithms, including the radar processing, satellite processing, rain and precipitation type analyses and forecasts were calibrated remotely. This phase of the project has yet to be completed as a result of telecommunications problems both within Poland and between JCHMR and IMGW. It is now hoped that the Polish Nimrod system will be fully operational by mid-August 2003. This will allow four weeks of unhindered system operation prior to the Site Acceptance Testing (SAT) due to commence on 17 September 2003.

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, with Wales now expected in October. It seems unlikely that the full proposed network will now be implemented.

The available data are being used routinely in the Met Office radar-gauge analysis scheme for the parts of the country for which data are available. However, the results are being frequently compromised by missing data appearing as zeros.

Use of the gauges in the radar correction step is awaiting their availability with standard 5-digit identifiers.

4. Hyrad

Routine maintenance and support to the Environment Agency's 200-user implementation of Hyrad (HYdrological RADar processing and display system) continues.

Implementation of Hyrad as part of a pilot flood forecasting and warning system for Belgium in the Demer Basin is on schedule for completion at the end of September. The system is currently undergoing operational system testing; training is scheduled in September ready for system handover on 1 October. New developments include derivation of catchment average rainfall from rainfall fields on any projection, raingauge-only rainfall forecasting, support of radar data received in BUFR format, and support of Floodworks interface formats for ingesting raingauge telemetry data and exporting catchment average rainfall time-series for use with flood forecasting models. The first of these developments would now allow the EA to immediately receive Met Office NWP rainfall fields on a rotated pole lat-long projection (and in Nimrod file format) and derive from them catchment-average rainfall time-series for use in its flood forecasting and modelling systems.

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 that limits confidence when raingauges 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.

The CEH bid to participate in this work is being considered by the Met Office and the Environment Agency. Nimrod data retrieval for the calibration and testing of Calder catchment PDMs is proceeding, but at a slower rate than planned. Code has been implemented to produce 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.

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

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

An interim report has been written which documents the results from simulations of four convective case studies using the model with horizontal gridlengths 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 interim report has been written, 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.

Code has been written to develop high-resolution output diagnostics and verification scores. The emphasis has been on verifying probabilities derived from the local neighbourhood surrounding each gridpoint in space and time, against radar data.

Additional case studies are being sought from the current summer.

7. Post-event evaluation

The New Year heavy rainfall and flooding event caused disruption over many areas. The meteorological and hydrological forecasting of the event is being analysed and a report is being written for the Met Office and the Environment Agency.

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.

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 in the current year will develop further the flood water routing and overtopping model, extend the validation of outputs from MOSES-PDM with new observed data and pull through previous years' research by implementing new or improved components of MOSES-PDM into Met Office operational modelling systems.

Achievements over the past six months have included:

(i) *Comparison with MORECS*. The completion of a comparative study of the outputs from MOSES-PDM and the older Met Office Rainfall and Evaporation Calculation System (MORECS) when both are driven by historical data for the past 40 years. A report was written and accepted by the Environment Agency as a basis for their decisions about if, when and how to change their systems to accept Nimrod-MOSES-PDM outputs in place of those from MORECS. The report concludes that the differences between MOSES-PDM and MORECS are largely due to known deficiencies in MORECS. It includes recommendations for implementation and further work. The 40-year run of MOSES-PDM using MORECS forcing data has been completed, and outputs are available to the Environment Agency for use in calibrating downstream models.

(ii) *Soil freezing*. The completion of tests to assess a new way of treating soil freezing in MOSES-PDM. The results showed that the response of MOSES-PDM did not compare well with observed data (from the BOREAS study in Canada, University of Alaska studies in Alaska and CEH data in Svalbard). Both the original and trial soil freezing schemes gave poor results. However, this may be partly due to the model canopy parameterisation being switched off in the tests. A report was written describing the trial and its results.

(iii) *Soil moisture mapping*. The completion of a report on mapping soil moisture onto the terrain using a Wetness Index derived from the soil moisture distribution and the Topographic Index. Use of the topographic index to downscale the soil moisture information worked well for the Wye catchment but very poorly for the Pang catchment, so cannot be considered of general applicability.

(iv) *Critical value of soil moisture*. The start of an investigation to find out why the Nimrod-MOSES-PDM soil moisture is persistently less than its critical value, even in winter periods when evaporative losses are small and rainfall frequent. There appears to be an incompatibility between the specified critical point and hydraulic parameters for the soil. Investigations have so far concentrated on the method of deriving MOSES' hydraulic parameters from the van Genuchten parameters in the basic soils data. A definition of the critical point valid for a large range of soils will be also be sought.

(v) *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 bankfu1l 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.

10. Global water and carbon cycles

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 was accepted for publication 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.

Global Soil Wetness Model intercomparison. Preparatory work is underway to assess MOSES within the intercomparison project, the Global Soil Wetness Project (GSWP2). The model is to be forced with 17 years of observed/analysed data allowing a detailed assessment of its performance to be made.

Analysing rainfall extremes using the RCM. An investigation is continuing, analysing rainfall predictions from the Hadley Centre Regional Climate Model. This fine resolution climate model is “nested” in the full GCM for different time periods corresponding to various prescriptions of atmospheric greenhouse gas concentrations. The emphasis of this collaboration with the Hadley Centre is on considering rainfall extremes. Originally used to provide understanding of the Autumn 2000 UK floods, this model was found to compare very well with the statistical properties of known rainfall records. Since that study, new simulations have become available including an upgrade from HadRM2 to HadRM3. Following on from the 2000 Floods Report to Defra, fuller investigations of the models and their differences are being made. In particular, we are now learning about the relative importance of the driving GCM, as compared to RCM parameterisation, upon extreme rainfall characteristics. There is an emerging requirement to understand the physical basis for projected changes in adjusted

rainfall return periods for higher CO_2 concentrations. This will require innovative model diagnostics.

Land-atmosphere feedbacks on the global carbon cycle. The global carbon cycle is being investigated, with an emphasis on land-atmosphere feedbacks. In many circumstances this could be a positive feedback due to ecosystem respiration losses in a greenhouse gas enriched climate, adding to anthropogenic fossil fuel emissions. This may be especially true of the South American region, and existing GCM simulations by the Hadley Centre predict major die-back from 2050 onwards. By comparing CEH datasets of CO_2 fluxes with Hadley Centre land surface models, this result is being investigated further. Sensitivity studies to perturbing parameters of the land surface are also being analysed and uncertainty bounds developed for the timing of any potential loss of Amazonian rainforest.

Global Climate and Carbon Impacts Modelling. The global carbon cycle has been added to the GCM analogue model. Coupled with MOSES and TRIFFID, this generates a new impacts tool called IMOGEN (Integrated Model Of Global Effects of climatic aNomalies). This climate model is based upon linearities observed in surface climatology (when compared to global land temperature) and as derived from the Hadley Centre GCM. The surface climatology is produced monthly and for the same gridbox scale as the GCM. IMOGEN represents a reasonable approximation to the full GCM and, although not a substitute for this, its most important application is to allow interpolation of existing computationally-demanding GCM simulations to a range of other emission scenarios. These runs are now being undertaken for the SRES emission scenarios. IMOGEN is also being configured for inversion "stabilisation" studies. It is hoped that IMOGEN will become a tool for answering policy questions by the Hadley Centre, allowing rapid estimates corresponding to "what if?" questions related to different projected uses of fossil fuels. Such results can be confirmed and refined later by full use of the GCM.

Wetland methane emission feedback on climate change. An assessment of the potential feedback of wetlands methane emissions on climate change is being carried out. 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. A draft paper on this is now being prepared.

11. JCHMR Fellowship

A study of synoptic scale land surface variability and its impact on the atmosphere has been completed. This work exploited Meteosat imagery over tropical North Africa to diagnose patterns of surface flux variations. When combined with atmospheric analyses this technique has illustrated for the first time how soil moisture variations can generate heat lows at the synoptic scale. Preliminary work has also been undertaken to assess the impact of soil moisture anomalies in case studies. These studies centre on the development of rapidly intensifying vortices, which subsequently became Atlantic hurricanes. This is currently being investigated further using the Unified Model. In collaboration with Reading Meteorology Department and the Hadley Centre, there has also been some progress in understanding the land-atmosphere "coupling strength" of the Unified Model, as compared with other GCMs, under the auspices of the GEWEX "GLACE" project. Finally, work has been completed assessing favoured time and length scale dependencies of soil moisture – rainfall feedbacks using a cloud-resolving model.

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 3.9 (v) but applied across a wider 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. Also, because runoffs from the RCM are currently unreliable, the main input to the model is RCM rainfall which is transformed via a simple runoff production function to obtain surface and subsurface runoffs as an interim measure. The purpose of the model is two-fold: to provide water discharges to the seas around Europe for input to ocean model and to provide estimates of flood discharge and inundated areas across Europe, in today's and future climates. An initial form of the model, and its application to the Seine, Elbe and Thames rivers, has been outlined in the March 2003 report to Defra. The prototype model has also been prepared for integration in the Unified Model Version 5.5 for use as an RCM-coupled model. Ongoing work is creating a fine resolution version of the model (1 km, 1 hour) for use with RCM data disaggregated to 1 km using the gridded 1 km SAAR dataset for application to UK catchments relevant to the study of the 2000 floods and the causal mechanisms involved.

A second component of the project is using the PDM rainfall-runoff model to derive, by continuous simulation, flood frequency estimates for UK catchments using rainfall and potential evaporation (PE) estimated from the outputs of a 25km Regional Climate Model (RCM). The PDM model parameters are determined through regression relationships to catchment properties established under an earlier Defra project. The previously reported initial investigation on 5 catchments has been extended to 15. Results obtained from an RCM run using ECWMF re-analysis boundary forcing provides flood frequency curves that compare well with those obtained using rainfall and PE estimates based on observed data. Using outputs from a 2080s RCM run allows changes to the flood frequency curve to be analysed. Possibly contrary to expectations, most catchments in the south and east of England show a decrease in flood frequency; others show very little change whilst some show moderate to large increases. 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. Reports have been submitted to Defra on the initial and extended investigation. Ongoing work aims to use the PDM catchment model, along with the flow routing model described above (in principle, more suited to larger catchments), to assess the 2000 floods in the context of the recent past.

Publications

Bell, V.A. and Moore, R.J. 2003. Development of a flow routing and flood inundation facility for Nimrod/CMetS: Preliminary formulation and results. Report to the Met Office, CEH Wallingford, 27pp.

Bell, V.A., Moore, R.J. and Jones, R.G. 2003. Development of a flow routing model coupled to a Regional Climate Model for Europe: Preliminary formulation and results. Annex 15a subcontract report to Defra, CEH Wallingford, 42pp.

Betts, R.A., Cox, P.M., Collins, M., Harris, P.P., Huntingford, C. and Jones, C.D.: 2004 The role of ecosystem-atmosphere interactions in simulated Amazonian precipitation decrease and forest dieback under global climate warming. *Theoretical and Applied Climatology*, accepted subject to revision.

Bowler, N., Pierce, C.E. and Seed, A. 2003. Development of a precipitation nowcasting algorithm based upon optical flow techniques. *Journal of Hydrology*, in press.

Clark, D. B., Taylor, C. M., and Thorpe, A. J. 2003. Feedback between the land surface and rainfall at convective length scales. *Journal of Hydrometeorology*, submitted.

Clark, D. B., Taylor, C. M., Thorpe, A. J., Harding, R. J. and Nicholls, M. E. 2003. The influence of spatial variability of boundary-layer moisture on tropical continental squall lines. *Q. J. R. Meteorol. Soc*., **129**, 1101-1121

Cox, P.M., Betts, R.A., Collins, M., Harris, P.P., Huntingford, C. and Jones, C.D. 2004. Amazon dieback under climate-carbon cycle projections for the 21st Century. *Theoretical and Applied Climatology,* accepted subject to revision.

Essery, R. L. H., Best, M. J., Betts, R. A., Cox, P. M. and Taylor, C. M. 2003. Explicit representation of subgrid heterogeneity in a GCM land surface scheme. *Journal of Hydrometeorology*, **4**, 530-543

Gedney, N. and Cox, P.M. 2003. The sensitivity of global climate model simulations to the representation of soil moisture heterogeneity. *Journal of Hydrometeorology*, in press.

Huntingford, C., Harris, P.P., Gedney, N. Cox, P.M., Betts, R.A., Marengo J. and. Gash, J.H.C. 2003. Investigating the potential for Amazon die-back in a future climate using a GCM analogue model. *Theorectical and Applied Climatology*, accepted.

Huntingford, C., Jones, R.G., Prudhomme, C., Lamb, R., Gash, J.H.C. and. Jones D.A.2003. Regional climate-model predictions of extreme rainfall for a changing climate. *Q. J. R. Meteorol. Soc*, **129**, 1607-1621

Jones, A.E., Jones, D.A. and Moore, R.J. 2003. Development of Rainfall Forecast Performance Monitoring Criteria. Phase 1: Development of Methodology and Algorithms. Report to the Environment Agency and the Met Office, CEH Wallingford, 291pp.

Jones, A.E., Jones, D.A. and Moore, R.J. 2003. Heavy Rainfall Warning Assessment Tool User Guide. Report to the Environment Agency and the Met Office, CEH Wallingford, 53pp.

Jones, C.D., Cox, P.M., and Huntingford, C. 2003. Uncertainty in climate-carbon cycle projection associated with the sensitivity of soil respiration to temperature. *Tellus*, **55**, 642.

Kay, A.L. 2003. Estimation of UK flood frequencies using RCM rainfall: An further investigation. Met Office Annex 15a Subcontract Report 2, CEH Wallingford, 48pp.

Taylor, C. M., Ellis, R. J., Parker, D. J., Burton, R. R. and Thorncroft, C. D. 2003. Linking boundary layer variability with convection - a case study from JET2000. *Q. J. R. Meteorol. Soc.,* **129**, 2233-2253

Taylor, C. M., Parker, D. J., Lloyd, C. R. and Thorncroft, C. D. 2003. Observations of synoptic scale land surface variability and its coupling with the atmosphere. *Q. J. R. Meteorol. Soc*., submitted.

Thorncroft, C. D., Parker, D. J., Burton, R. R., Diop, M., Ayers, J. H., Barjat, H., Devereau, S., Diongue, A., Dumelow, R., Kindred, D. R., Price, N. M., Saloum, M., Taylor, C. M. and Tompkins, A. M. 2003. The JET2000 project - Aircraft observations of the African easterly jet and African easterly waves. *Bull. Am. Meteorol. Soc*., **84**, 337-351.