Joint Centre for Hydro-Meteorological Research

Report on Research Activities 12 April to 13 October 2005

1. Short-Range Precipitation Forecasting R&D

1.1 Development of the Short-Term Ensemble Prediction System (STEPS)

Trial of a single STEPS forecast realisation was implemented within the initial version of the UK NWP post-processing system in July 2005. Further work on code vectorisation and tuning is required before a full ensemble can be implemented in the parallel (test) suite. This will focus on further improving the execution efficiency of the optical flow advection scheme, and modifications to the formulation of the weights to improve the representation of the NWP model component in STEPS forecasts.

A parallel trial of STEPS ensembles in collaboration with the Australian Bureau of Meteorology is planned to commence in November 2005. This aims to demonstrate:

- the generation of heavy rainfall warnings for urban hydrology applications e.g. pluvial flooding, and urban drainage;
- the estimation of probability density functions (pdfs) of fluvial flows for specified river catchments using existing deterministic, operational rainfall-runoff models. Off-line trials of STEPS and the Probability Distributed Model (PDM) have already demonstrated the operational viability of predicting pdfs of fluvial flows from STEPS rainfall forecast ensembles;
- objective decision-making in relation to fluvial and pluvial flooding with the aid of a cost-loss model.

These aims tie in well with the test-bed concept proposed by the Nowcasting Group of the World Weather Research Programme (WWRP). Hence, the forthcoming parallel trial of STEPS will also serve as a platform to demonstrate a stochastic, end-to-end nowcasting system with the endorsement of the WWRP.

1.2 Treatment of unresolved sub-grid precipitation processes

Currently, STEPS does not adequately model uncertainties in precipitation distribution below the effective resolution of the UK NWP model (~20 km or ~5 grid-lengths). The spatial-temporal statistical properties of the noise component, added as the extrapolation and NWP model skill scores decline with advancing lead time, are inferred from recent weather radar based rain analyses. Thus, the noise represents the average spatial-temporal variability in precipitation rate based upon observations in the recent past. To improve the treatment of showers in particular, a physically-based method is required to add power to the noise in appropriate areas. A method is being developed based upon that used in the Convection Diagnosis Procedure currently used for adding sub-resolved-scale stochastic convective information to mesoscale NWP forecasts.

1.3 Development of an observation uncertainty algorithm for STEPS

The incorporation of an observation uncertainty algorithm into STEPS is nearing completion. This 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 assumptions made about the drop size distribution, wave propagation, and variations 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 is about to commence. Work to migrate several nowcasting algorithms, including the MOSES-PDM-RFM surface hydrology modules, from the UK version of Nimrod to European Nimrod prior to retirement of the former, will commence in early 2006.

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 completed, and is now running in the parallel suite on the Met Office's supercomputer for final testing. The system incorporates algorithms for the interpolation and downscaling of UK NWP model fields to a 2 km resolution grid, the extraction of point data for site specific forecasts, and the nowcasting of visibility, temperature, cloud, precipitation type and rate, and wind and pressure.

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 spring 2006.

Work has started to implement the MOSES-PDM-RFM surface hydrology modules at 2 km resolution within the UK NWP post-processing system.

3. 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 has been made providing improved support of NWP and MOSES products, summary spatial-temporal statistics of product data, and enhancements to the interface to the National Flood Forecasting System.

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). A new release of the Model Calibration suite, planned as part of the EA's Enterprise Licence procurement, is undergoing Quality Assurance prior to release. 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). The PSM is also now available in real-time Module Adapter form and is to be used in the Thames Region implementation of the NFFS.

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.

4. 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 rain gauge 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), for an orographic event over the rivers Kent and Upper Ure, and for a frontal event (Easter 1988) over the contiguous Upper Thames (Cherwell and Sor Brook) and Stour catchments. 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. A strategy for delivering an extreme rainfall dataset to the Environment Agency has been developed and its implementation is ongoing.

5. 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.

Technical and guideline reports on best practice are 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 trialled. Also, a variable time-step Muskingum-type flow routing methodology with links, via the St Venant equations, to channel properties has been identified as having 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, have been set down. A Technical Report and Guidelines Report have been produced in draft form.

6. 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). A further report investigating the meteorological conditions leading to the event has been issued as Forecasting Research Technical Report No. 459 (see the website above).

An extreme rainfall event produced flooding in Carlisle in early January 2005. The performance of operational weather forecasting systems during this event has been studied and a report delivered to the Environment Agency.

7. Global water and carbon cycles

7.1 Development of a community land surface model

The prototype version of JULES was frozen and released in the summer. It has been distributed to a number of groups including CLASSIC (Climate & Land Surface Systems Interaction Centre) and CGAM (Centre for Global Atmospheric Modelling), and there are at present 13 official registered users.

Whilst it was anticipated that initial versions of JULES would remain within the UK research community, there has already been interest oversees. As such, it is likely that JULES will be included into the Land Information System (LIS) developed at NASA, which is publicly available and hence will also be available to the JULES community.

In addition, it is likely that a parameter optimisation program written by researchers at the University of Arizona will be implemented within the JULES code and made available to the JULES official release. The approach enables multiple parameters, between specified bounds, to be optimised on multiple output variables, using a Monte-Carlo sweep.

Version 2 of JULES is in the initial planning phase, but is likely to include a restructuring of the code into a modular format, flexible tile definitions, distributed code for running at more that a single point, enabled sub-gridscale heterogeneity for soil moisture, parameter optimisation routines and linking into IMOGEN (see item (vii) below).

7.2 Operational Global soil moisture assimilation

The Met Office has implemented a soil moisture nudging scheme into the operational Global model. An assimilation scheme is used to determine the screen level temperature and moisture errors from the model, which are then used to diagnose the change required in the soil moisture to optimise these screen level errors. The physical equations for the surface fluxes are used to link between the soil moisture and the screen level variables. This is different to other nudging schemes that are used operationally which use empirical relationships linking the screen level variable to the soil moisture. This means that unlike the other nudging schemes, changes to the surface physics do not require changes to the assimilation system.

7.3 Dynamic Global Vegetation Model Intercomparison

Four Dynamical Global Vegetation Models (DGVMs) have been used within the GCM analogue climate model IMOGEN. These four models have been run with four SRES (Special Report on Emission Scenarios, IPCC) emission scenarios to help address the following research question: What is the uncertainty in the future atmospheric CO_2 concentration associated with climate-carbon feedbacks due to choice of DGVM (Dynamic Global Vegetation Model) and SRES emission scenario?

The results from this work indicate large uncertainties in future atmospheric CO_2 concentration associated with uncertainties in the terrestrial biosphere response to changing climatic conditions. By 2100, atmospheric CO_2 concentrations differ by up to 224 ppm among DGVMs, equivalent to ~35% of the uncertainty associated with choice of SRES emission scenario (656 ppm). Simulated terrestrial climate-carbon cycle feedbacks range between 40 and 303 ppm for all DGVMs and 4 SRES emission scenario combinations. The maximum range associated with choice of DGVM is 211 ppm.

Uncertainty in future cumulative land uptake (361 PgC) associated with land processes is equivalent to ~45 years of anthropogenic emissions at the 2000 levels. Improving our understanding of and ability to model terrestrial biosphere processes is paramount to enhance our ability to predict the future development of the Earth system.

7.4 Impact of Ozone on land atmosphere carbon exchange

Plants are known to suffer ozone damage, which reduces both stomatal conductance and photosynthesis rates. O_3 causes cellular damage inside the leaves which adversely affects plant production, and thus reduces crop yields.

These effects of O_3 exposure on plants have been parameterised within MOSES. This has then been coupled to a GCM along with the STOCHEM tropospheric chemistry model to investigate the impact of O_3 on future land atmosphere carbon exchange.

The simulated present-day O_3 are high over many regions during the northern hemisphere summer. In Eurasia and eastern North America high O_3 coincide with the peak in growing season, and is likely to cause maximum effects on plant production.

Future levels of tropospheric O_3 are projected to increase further, exceeding 60 ppb in some regions. Of particular concern are the projected large concentrations across Eurasia, North America and East Asia during the northern hemisphere growing season. The densely populated areas of these regions rely heavily on their agricultural production for supplying their nutritional requirements.

This work should be considered as a preliminary sensitivity study. Further work is required to calibrate the model of O_3 effects on photosynthesis against experimental data from different plant functional types.

7.5 Large scale runoff: detection and attribution

A paper has been submitted to Nature explaining the historical trends in large-scale runoff in terms of climate, CO_2 effects on stomata, aerosols and land use change.

7.6 Wetland methane emission feedback on climate change

Elaine Matthews from NASA GISS visited informally for a couple of days in July to discuss potential areas of collaboration on wetlands and methane modelling.

A JCHMR Visiting Research Fellowship Scheme Proposal for Prof Nigel Roulet of McGill University on "Modelling wetlands hydrology and fluxes and their impact on climate change" has been accepted. He visited in the week beginning 3 October 2005.

7.7 IMOGEN

A key aspect of JCHMR collaboration has been based around the IMOGEN model (Integrated Model Of Global Effects of climatic aNomalies). This is a gridded version of MOSES/TRIFFID, forced by prescribed climate that in turn is derived from the “GCM analogue model” to mimic the full GCM. This allows extrapolation to a range of emission scenarios.

The tool captures HADCM3 behaviour (in the fully coupled carbon cycle simulation) up to modelled period 2050, and before major loss of terrestrial carbon (predominantly by soil respiration). The JCHMR is now embarking on re-running the original GCM simulation, but with high temporal resolution diagnostics to check the “weather generator” subroutines in IMOGEN, and see the influence on the “die-back” result. Once complete, this tool will be of major use for impacts assessment.

7.8 Detection and Attribution

There has been tight collaboration between CEH and the Hadley Centre on Detection and Attribution issues. This had led to work on detecting a temperature signal between different GCMs (Huntingford *et al*., submitted to GRL), detection of runoff changes (see Gedney *et al.*), and precipitation (Lambert *et al.*). There are now plans to extend this work to search for signals within the global carbon cycle.

7.9 Use of RCM output

Regional climate model output has been coupled to a description of the seasonal cycle of blue-green algae in a lake to understand the effect of global warming (and associated climatological changes) up to year 2100. See Elliott *et al.*

7.10 Africa and the G8

A CEH talk on “Aspects of climate change relevant to crops” was presented by Chris Huntingford at The Royal Society Meeting on 26-27 April 2005. Notes were forward by the Royal Society to the G8 meeting. This has led to the editorial by Huntingford and Gash (2005) and a paper for Proc. Royal Soc. B to be published in November.

7.11 Improving the light-interception and photosynthesis

Model evaluation at this site was done using measurements of the vertical profile of radiation through the canopy, carbon and energy fluxes from eddy correlation and leaf carbon isotopic fractionation. The use of leaf carbon isotopic ratio δ^{13} C measurements helped constrain parameterisation of the stomatal conductance model. Significant improvement of light interception and consequently photosynthetic carbon uptake was obtained when compared to the standard big leaf approach used until now within MOSES. Comparisons of simulated light interception through the canopy against measured vertical profiles of light at the studied site were satisfactory and suggest canopy architecture (i.e vertical distribution of LAI and leaf inclination) as important for realistic representation of light absorption. In general, using the new radiation description, model performance with a ten-layer approach for radiation interception and for photosynthetic uptake was better in terms of carbon uptake than in terms of energy partition, the later still being simulated as a big leaf. Work in progress aims to implement the new description globally.

7.12 Impact of the inter-annual and seasonal variations in vegetation coverage upon the land-atmosphere system

As part of the NERC-funded CLASSIC programme, work has been undertaken to investigate the impact of the inter-annual and seasonal variations in vegetation coverage upon the land-atmosphere system. To achieve this, 19 years of the fraction of Photosynthetically Active Radiation data (gridded at 8km and derived from AVHRR products) has been used to provide a varying leaf area index for the standard MOSES2/JULES plant functional types (PFTs), at a resolution of 1.25° by 1.865°. In the process, a new globally distributed PFT map was derived at 8km and 1.25° by 1.865° from the ECOCLIMAP land cover map. In the near future it is intended to examine the impact these forcing data have on the land surface fluxes: firstly within the JULES land surface model and secondly within the HADGAM global atmosphere model.

7.13 AMMA and use of EO data

JULES will be applied in a distributed mode across West Africa, driven by best-estimate observed data as part of the AMMA project. Surface flux and meteorological observation systems are being installed across the region for calibration of JULES.

7.14 Runoff production

A paper comparing runoff generation in MOSES with that when parameterisations based on PDM and TOPMODEL were included has been submitted to Journal of Hydrometeorology (The representation of runoff generation in a land surface model, D.B.Clark and N.Gedney).

7.15 Future climate of Amazonia

Coupled climate-carbon cycle simulations by the Met Office/Hadley Centre indicate that under future greenhouse warming tropical forest could become an unsustainable ecosystem across much of the Amazon basin (Cox *et al.*, 2000. ‘Acceleration of global warming due to carbon-cycle feedbacks’. *Nature.*). Subsequent GCM modelling work has shown that the rainfall reduction driving loss of forest is primarily an atmospheric response to shifts in the location of the warmest sea surface temperatures in the tropical Pacific and Atlantic, which shorten and weaken the South American monsoon (Harris, 2005). Similar responses are observed in present-day atmosphere-ocean variability (e.g. El Niño), which indicate that the future climate change is reasonable. Modification of the monsoon is enhanced by a warming of the tropical troposphere through mean sea surface warming, and by land-atmosphere feedbacks through reduced canopy conductance, increased surface albedo and reduced surface roughness.

8. 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 Wallingford are collaborating on 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). This system provides a grid-based methodology in the form of a grid-to-grid model for translating RCM-derived outputs, such as rainfall and potential evaporation, into estimates of river flow and fluvial discharges 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 community land-surface scheme JULES which contains the Met Office land-surface scheme MOSES. The combined JULES-G2G model now provides a stand-alone platform to support research into broad-scale runoff-production and routing schemes.

The combined model is currently being tested over Northwest Europe at a 25km resolution using ERA-40-driven RCM output from PRECIS. (ERA-40 denotes ECMWF re-analyses for 1960-2001, determined from a model that assimilates climate observations). Planned work in the coming year will apply the combined model to the UK at a 1km resolution.

Output from PRECIS driven by ERA-40 data has also been used as input to a catchment rainfall-runoff model in order to estimate flood frequencies for UK catchments. A spatially-generalised catchment rainfall-runoff model is used, as described in Kay *et al.* (2005a, b), where the model parameters are determined through regression relationships to catchments properties. The model is driven with catchment rainfall and potential evaporation (PE) inputs derived directly from RCM data on a 25 km grid, to simulate flow time-series from which flood frequencies are derived. Sixteen catchments, spread across Great Britain, are modelled. Previous work demonstrated the use of an RCM forced with ERA-15 boundary conditions to provide data that can be used to model flood frequency. Results compared well with those from simulations using observed rainfall and PE data for the period 1985-1993. Ongoing work with an extended period of record - 40 years of ERA-40 driven RCM output from 1960 to 2001- will provide an extended analysis of model performance. The simulations for recent UK floods (including Autumn 2000) will be of particular interest.

Publications

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