APPLICATION OF A LARGE SCALE HYDROLOGICAL MODEL TO THE ARKANSAS-RED RIVER BASIN

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1. *INTRODUCTION*

This paper presents the objectives and results of the application of a large scale hydrological modelling system within GCIP as part of the UK NERC Terrestrial Initiative in Global Environmental Research (TIGER).

The UP modelling system (Upscaling with a Physical basis, Ewen, 1997, Ewen et al., 1998, Kilsby et al., 1998) is designed for macro-scale simulations of land surface processes, both as stand-alone studies and with an atmospheric model. UP is designed as a tool for the determination and study of water budgets and the impacts of climate variability and land use change, and is being applied to the Arkansas-Red River basin (Large Scale Area - South West) as part of GCIP.

2. *THE UP MODEL*

UP differs from other land surface parameterizations which are simply point-scale process representations operating at a larger grid scale with an emphasis solely on vertical transfers. Rather, it is an upscaled representation of point-scale processes allowing for lateral transfers and variability. The upscaling attempts to account for sub-grid variability due to heterogeneity of physical properties (elevation, soil characteristics, geology and land cover) and their effects on hydrological variables (rainfall, runoff, soil moisture and evapotranspiration).

Furthermore, UP differs from other 'macroscale' hydrological models in that it retains a physical basis in its parameterizations. This is in contrast to the standard approach of calibration using discharge records to derive 'black-box' parameters which can only be used in the region of calibration, and may not be valid for altered land cover or climate regimes.

This is achieved in a two stage process: a simple distributed water balance model for the whole basin being simulated is run using parameterizations derived from detailed modelling at selected representative small catchments.

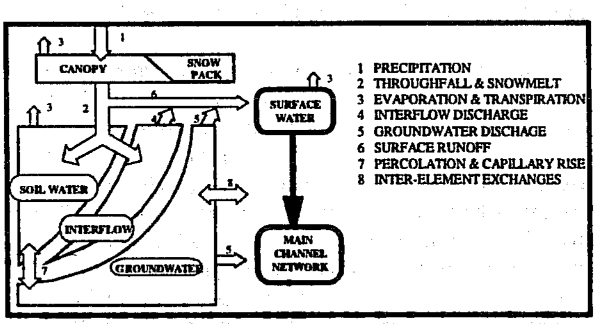

Figure 1 The UP element

The region to be modelled is divided up into sub-areas, each represented by an UP element with 4 or 5 water storages (Fig 1).

Parameterization is only performed for certain sub-areas representative of hydrological 'domains' and extended to other sub-areas using a simple scaling and GIS-based classification approach. A number of parameterization models are used, including process models for interflow, groundwater, and infiltration and percolation of soil moisture.

UP represents the whole range of hydrological processes including the effects of groundwater, interflow, soil, snow and canopy. Runoff is routed to the basin outlet in the channel network on an hourly timestep, thus enabling validation against streamflow records.

3. *APPLICATION*

The Arkansas-Red River basin provides a hydrologically very diverse and demanding test application:

- elevation: ranges east-west from 50 to 4000 m
- annual rainfall: ranges east-west from 1500 to 400 mm
- land cover: deciduous forest, irrigated agriculture, semi-arid scrub and coniferous forest.
- major aquifers underly parts of the basin

Classification

The Red-Arkansas basin was classified into hydrological domains using a GIS based clustering technique. Various combinations of hydrologically important input thematic maps at 1 km resolution were investigated. Best results were obtained using 5 input map layers; elevation, variance of elevation over 25 km^2, peak vegetation greenness, duration of greenness and annual rainfall. Geological and functional land cover classifications were unsuitable for this type of analysis because of their discrete variables. The classification produced four domains. Sub-divisions according to hydrogeology were also considered and a fifth domain on the Mississippian limestone in the NE of the basin was created (Fig 2).

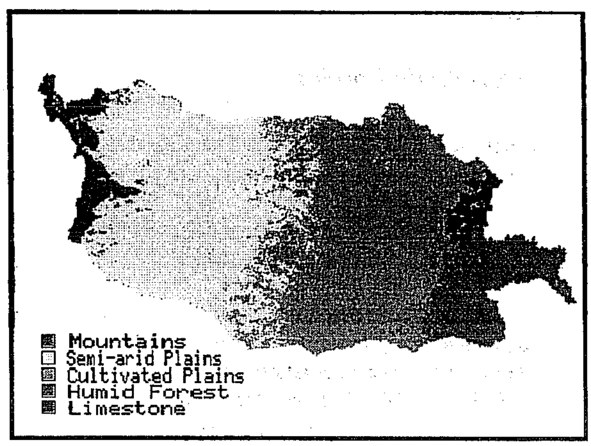

Figure 2 Hydrological domains

Parameterization

A small catchment (area < 1000 km^2) was selected in each of the domains according to data availability (Figure 3). A key requirement is a discharge record. Digital elevation models at 100m resolution were constructed and soils, land cover and hydrogeological data were obtained at 1km spatial resolution.

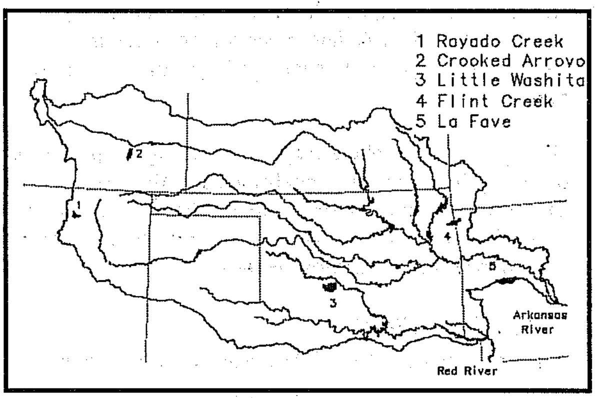

Figure 3 Parameterization catchments

Parameterizations of the soil column, interflow and groundwater have been developed for the five catchments. The parameterization procedure is based on using the best available physical property data in individual physically-based distributed models. A simulation model is then constructed for the catchment and driven with observed meteorological data. Comparison of the predicted catchment discharge with the observed record then allows validation.

4. *SIMULATIONS*

The basin hydrology is simulated using a grid of UP elements of size 17 km x 17km which is compatible with the Unified Model (UM) of the UK Met Office run at the mesoscale. It is planned to run simulations with coupling off-line, as a workstation version of the UM has been implemented at Newcastle. Parameterizations for each UP element have been scaled from those derived for the representative catchment appropriate to the hydrological domain of the element. A regional groundwater model is included.

Atmospheric Forcing

The model could be driven with a range of data sets:

i. Hourly rainfall and met data derived from observations
ii. Rainfall derived from radar data sets (4x4 km)
iii. Output from atmospheric model

The representation of rainfall intensity becomes progressively poorer from i to iii above, and an intercomparison of simulations using each of the data sets would be valuable. However, for practicality this work presents results using radar rainfall data.

River routing

River runoff from each element is routed to the basin outlets and intermediate points using a network width function scheme developed by consortium partners at the Institute of Hydrology (UK).

5 *RESULTS*

Two validation strategies are possible. Firstly, a number of discharge records are available for catchments coincident with grid squares, including those used for the model parameterization. Secondly, a number of aggregated measures *e.g.* basin discharges and annual mean fields, can be used to assess the model's performance.

Grid scale validation

One of the motivations for the physical basis of the UP modelling system is the ability to reconstruct consistent fields of simulation variables from the large scale variables. This is shown in Figure 4 by the use of the total runoff amount from the grid square containing the Little Washita catchment for validation against the observed record.

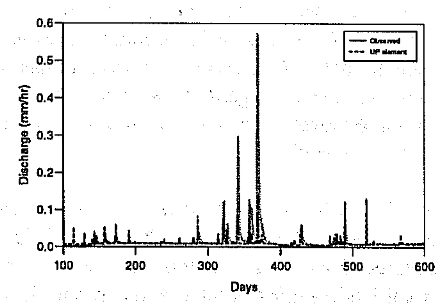

Figure 4 Simulated and observed discharge time series

Aggregated validation

The whole basin discharges aggregated to the daily level for the Arkansas and Red Rivers give generally good agreement, although there are substantial abstractions from the rivers which have not been accounted for.

Verification of the model is possible in a general sense by inspection of the spatial distribution of runoff and comparison with the precipitation distribution. The precipitation dataset is subject to significant error in the western end of the basin, where isolated rainfall events appear to be underestimated by the radar network. The sporadic and intense nature of the rainfall regime across much of the basin makes for a demanding application. Comparison with long term mean values is possible (for example maps of runoff derived from the period 1951-1980). Figure 5 shows the mean ratio of runoff to precipitation from the simulation compared with the observed. The distributions are in reasonable agreement; as expected, the long term mean fields show a smoother decrease from east to west than the two-year simulation which is affected by individual rainfall events of limited spatial extent.

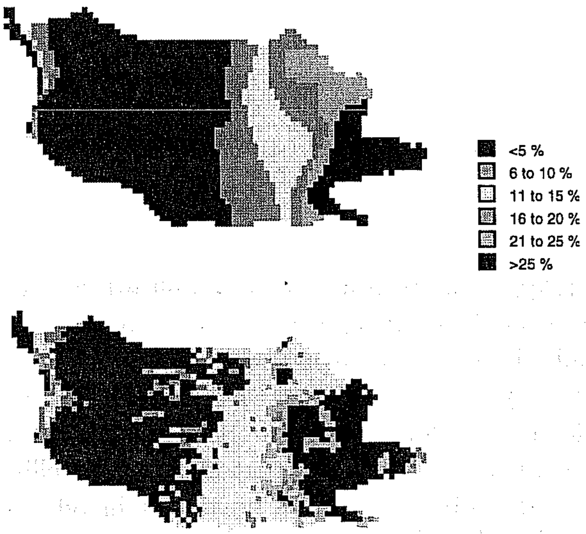

Figure 5. Annual mean ratio of runoff to precipitation. Top panel shows observed long term mean (1951-1980), bottom panel shows simulated values.

Further analysis

Analysis of model performance is continuing. One area of interest for land surface atmosphere coupling is the effect of spatial variability of rainfall on soil moisture patterns at the basin scale. Some spatial fields at 3 hour intervals for a storm in July 1994 are shown in Figure 6.

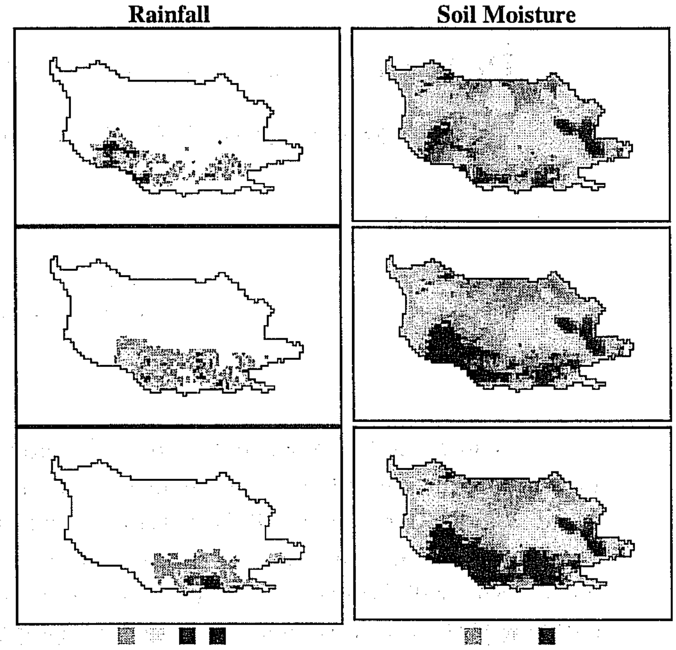

Figure 6 Snapshots of rainfall and simulated soil moisture

6 CONCLUSIONS AND DISCUSSION

Assessment of progress

The aims of this work were to develop and apply the UP modelling system to simulate the water budget and hydrological processes of the entire ARRB with reasonable computational efficiency whilst retaining a physical basis. The application has only reached the first stage however: simple validations have been performed, but no assessment of sensitivity has yet been done. Nonetheless, a fair degree of success can be claimed. The model is substantially physically based: the parameterizations are mainly derived from small scale simulations using physically-based process models. The simulation model is fast and simple to run, and suitable for coupling to an atmospheric model: the 2-year hourly-timestep full basin simulation takes 4 hours on a Unix workstation. Assessment of suitability for impact studies will strictly require a full sensitivity study to be done: however, the full range of hydrological processes have been included, and we should be optimistic of the model capabilities in this regard.

Applicability to other areas, and extension to global coverage remains a daunting task. Simple calibrated hydrological and land surface models have already been applied on a global scale, with very little basis for parameterization and validation. The UP system offers a great deal more physical basis for parameterization, but in turn imposes much greater demands on data supply.

Future work

Many practical problems remain. One is the degree to which an individual catchment is representative of others in the domain. In this application, a relatively small number of domains were chosen due to practical considerations; there is doubt therefore that the response of the parameterization catchments are representative.

Coupling the model offline to an atmospheric model is the next logical step within the GCIP programme. This would allow simulations over longer periods than at present, and would allow the assessment of the effect of using atmospheric model precipitation output rather than observed radar fields. Online coupling is the ultimate goal, in order to study feedbacks between land surface and atmosphere.

REFERENCES

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