

Model behaviour of distributed hydrological modelling with different forcing data resolutions

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Abstract Acquiring distributed data of particular grid resolution for a particular size of catchment is a matter of interest in distributed hydrological modelling. Using a macroscale distributed hydrological model in Huaihe River basin at Bengbu (132 000 km²), Wangjiaba (29 800 km²) and Suiping (2093 km²) in Japan, the behaviour of the model's performance was observed using the concept of IC ratio (ratio of input grid area and catchments area). An experimental 10-min data set was generated that refers to the 1.25-degree GAME Re-analysis data and 10-min HUBEX EEWB data. These data are averaged to create coarser distributed data before feeding it to the hydrological model. The change in behaviour of results displays a rapid improvement of performance with finer resolution. The rate of improvement saturates afterwards around an IC ratio range (1:10 ~ 1:20) suggesting the existence of a threshold IC ratio to obtain a satisfactory result. Higher sensitivity in model performance due to spatial resolution is observed in smaller catchments, but low sensitivity may appear if spatial variability is weak.

Key words: Huaihe River, Japan; IC ratio; macroscale distributed hydrological modelling

INTRODUCTION

Hydrological models, which can broadly be classified as either lumped-conceptual models or distributed physically-based models, have evolved to get a better understanding of surface runoff generated from complex watersheds. The lumped conceptual models are not capable of handling the spatial variability. Distributed models are developed, with a hope of obtaining a solution to the problems of lumped models, to represent the variability in physical watershed characteristics. For many of the problem areas the need for the distributed models reflects a demand for predictive capability on the effects of man-induced impacts (Refsgaard & Abott, 1996). The distributed models' strength to assess the effects of spatially variable impacts on hydrological responses has made it an essential tool for the analysis of the hydrological behaviour of a watershed with increased accuracy.

Development of hydrological simulations for gauged and ungauged basins frequently uses meteorological data inputs retrieved from global climatic scenarios, which are provided by General Circulation Models (GCMs). Unfortunately, the structure of GCMs is such that their space resolution is often too coarse and inadequate (Burlando, 2002) to describe variability in hydrological process components at the

basin scale. Large efforts to produce finer resolution GCM data with greater accuracy have increased the possibility of extensive use of GCM data in distributed hydrological models.

The use of distributed models is complicated by the need to establish a suitable spatial scale to be used in characterizing watershed conditions such as topography, drainage density, degree of soil saturation and rainfall properties, or in a broad sense the input information to the model. The challenge in applying distributed models to large watersheds is to determine a scale at which spatial variability can be neglected, with average characteristics of a given area providing sufficient information for accurate modelling of basin runoff generation (Molnar, 2000) with respect to catchments characteristics.

Some criteria are felt necessary to determine an acceptable scale of distribution. Shrestha *et al.* (2002) illustrated that the results of distributed hydrological models are better while an IC ratio (ratio between input data resolution and catchments area) is more than 1:10. Results of a distributed model are widely believed to be affected by data resolution. This paper will illustrate the model behaviour of a macroscale distributed hydrological model to clarify the effect of forcing data resolutions. This experiment is conducted for three basins in China, namely Huaihe (132 350 km²), Wangjiaba (29 844 km²) and Suiping (2093 km²).

DESCRIPTION OF MODEL AND DATA

A macroscale distributed hydrological model (Tachikawa *et al.*, 2000) is used to simulate the hydrological processes and obtain river discharge results. This model consists of a runoff process model based on Xinanjiang model (Zhao, 1992) and lumped stream kinematic-wave flow routing model for each grid cells to constitute an element model (see Fig. 1). Output from the runoff process model inside the grid cell is fed as lateral input to the routing model. These element models are interconnected as per the river network arrangement to construct the total simulation process of flow routing (see Fig. 2). The model parameters are calibrated on the basis of field observation records in the Shigan River basin (6000 km²), a sub-basin inside Huaihe

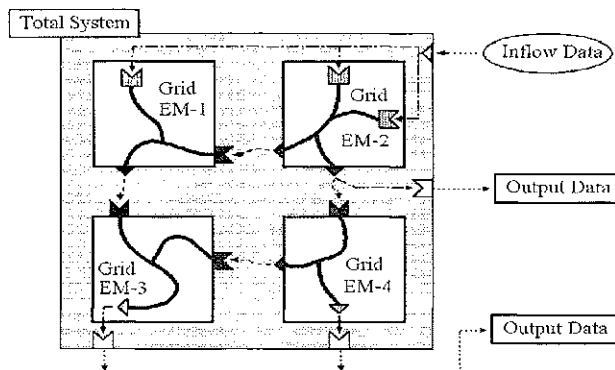


Fig. 1 Structure of an element model.

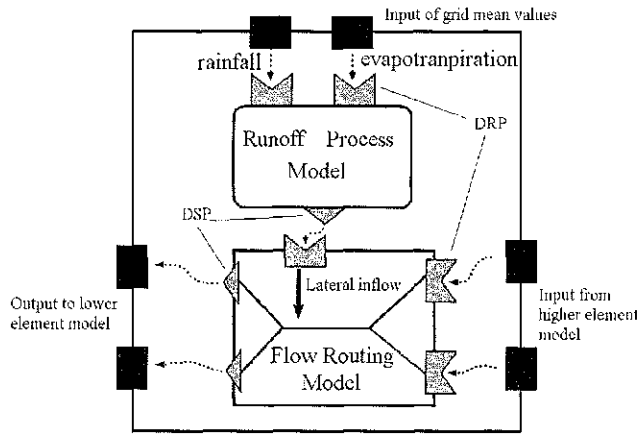


Fig. 2 Schematic total hydrological simulation system.

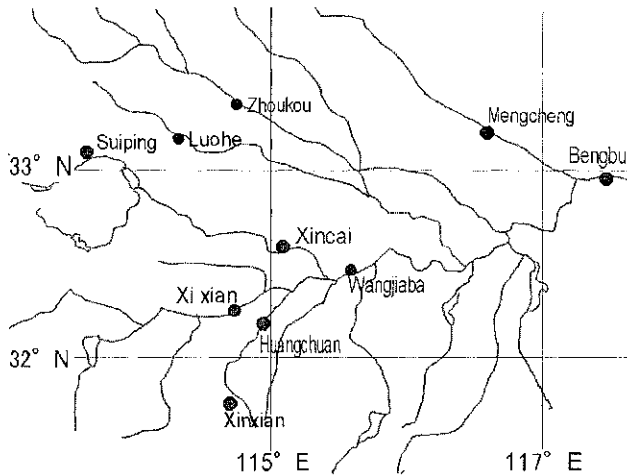


Fig. 3 River networks and location of basin confluences.

River basin (see Fig. 3), which is assumed to include the representative geomorphology of the entire basin.

A finest resolution of 10-min experimental data is created by preserving the spatial pattern of HUBEX-IOP EEWB data (Kozan *et al.*, 2001; termed EEWB data hereafter) and magnitude of GAME Re-analysis (Version 1.1) with 1.25 degree resolution (JMA, 2000; termed GAME data hereafter). EEWB data are basically ground-based data, which consider both distance and direction of each ground observation station to produce distributed 10-min grid data for the precipitation field. EEWB data also include evapotranspiration data simulated by a simple biosphere with urban canopy (SIBUC) model (Tanaka, 1998). The EEWB data set is the finest resolution data that is used for discharge simulation in the experimental basin (Tachikawa *et al.*, 2002) among the available distributed data until now. Therefore this data set is assumed to

represent the spatial pattern better than any other data. On the other hand, GAME data are coarse resolution data produced by the 4DDA system of the Japan Meteorological Agency, which has produced good simulation results (Shrestha *et al.*, 2002); therefore its magnitude is believed to contain fewer errors than the actual data.

An arithmetical approach is used in the process of generating the 10-min experimental data to include the spatial variability of EEWB with respect to its averaged figure at the scale of GAME data. Thus the new data set is represented as:

$$P_{4j} = \begin{cases} P_{1j} + P_{2j} + P_{3j} & \text{if } \geq 0 \\ 0 & \text{otherwise} \end{cases} \quad \text{for time } j = 1, 2, 3 \dots m \quad (1)$$

$$P_{5j} = P_{4j} \frac{\sum P_{1j}}{\sum P_{4j}} \quad \text{for time } j = 1, 2, 3 \dots m \quad (2)$$

Here, P_{5j} is the newly created experimental 10-min data set that preserves the spatial pattern of EEWB data and the magnitude of GAME data; P_{1j} is GAME 1.25-degree data; P_{2j} is EEWB 10-min data; and P_{3j} is an average of EEWB 10-min data at 1.25-degree resolution and P_{4j} is intermediate data. The experimental 10-min data is used further to create 20-min, 30-min data, etc. by passing an averaging window of (2×2) , (3×3) , etc. up to 150-min (2.5 degrees), respectively. The total accumulated values of the input data are kept constant.

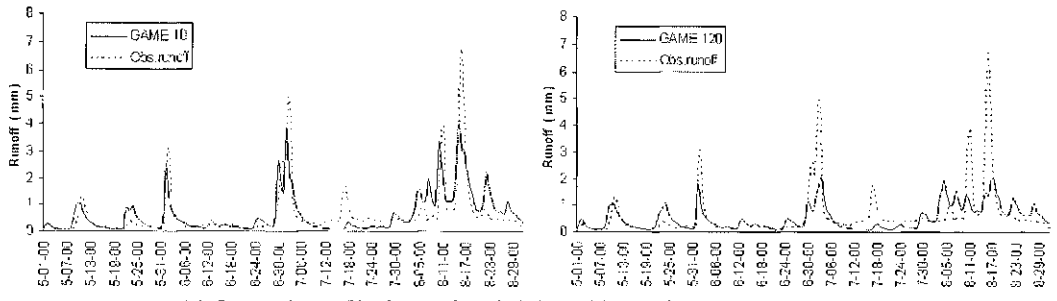
RESULTS AND DISCUSSION

Simulation results with experimental data, while compared against the observed discharge, are better obtained than the simulation results using either original EEWB or GAME data for all three experimental basins. The model performances are evaluated by using several indexes such as Pearson's Moment Correlation Coefficients (PMC coeff.), the Nash-Sutcliffe coefficient (NSI coeff.), the Index of Agreement (IOA), root mean square error (RMSE) and covariance of simulated and observed discharges.

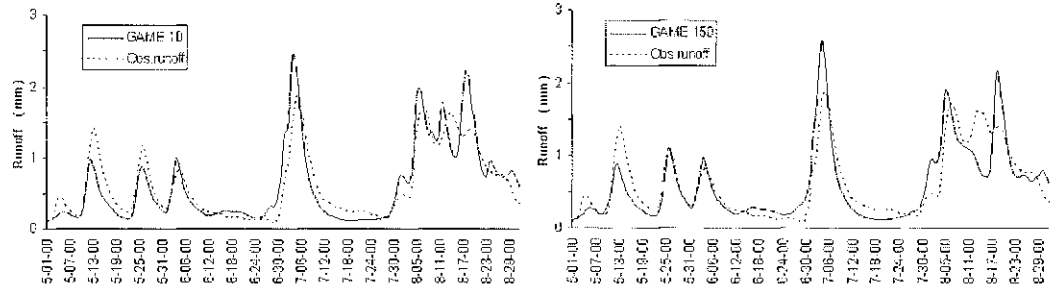
Distinct changes in the hydrograph are clearly visible for different values of spatial resolution data input. These changes indicate the influence of the spatial resolution with a clear sign of worse simulation results at coarser resolution (see Fig. 4). A point worth noting is that the coarser resolution data applied here are nothing more than the spatially averaged values from the same finer resolution data. Spatial averaging just smoothes the spatial variability at a coarser scale (Vieux, 1993) and keeps the same data pattern and the same accumulated values over the time series.

IC-RATIO: A COMPARISON INDEX

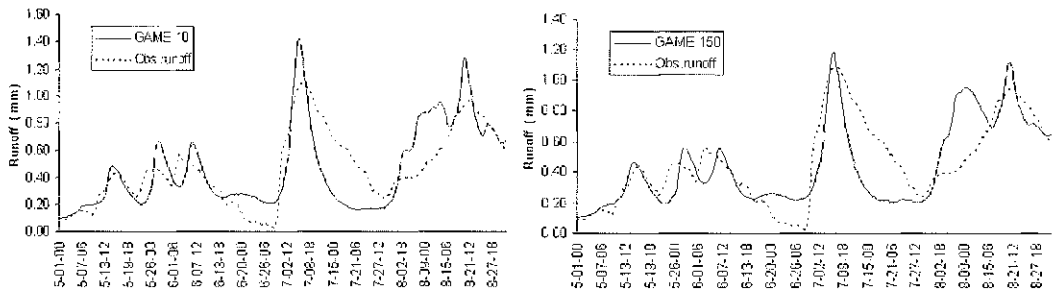
A poorer model performance with the coarser resolution forcing data than with the finer resolution is obvious; in addition, it is also expected that variable model performances are obtained with different test basins. The constitutive relations for different flow processes that are functions of the detailed geometry of flow pathways in different catchments are difficult to compare (Beven, 2002). Some indices, for



(a) Comparison of hydrograph at Suiping with 10 min and 2.0 degree data.



(b) Comparison of hydrograph at Wangjiaba with 10 min and 2.5 degree data.



(c) Comparison of hydrograph at Bengbu with 10 min and 2.5 degree data.

Fig. 4 Comparison between the simulated discharges and observed discharges at: (a) Suiping; (b) Wangjiaba; and (c) Bengbu.

example average slope, flow lengths, watershed relief, etc. exist to represent the catchments features but they may not be compatible to test against forcing data resolutions and scale issues.

Spatial variability of data reduces with the coarseness of resolution if catchment size is the same. If larger and larger catchment size is considered, then the magnitudes of spatial distribution of hydrological value such as precipitation become larger too. At the same time the effect of channel routing process attenuates the discharge, which may have a similar effect of variability smoothing. Therefore, while checking the model performance and comparing the effect of data resolution, the scale of catchment size cannot be neglected. In this regard, the concept of ratio between the input grid resolution and catchments size, termed IC ratio (Shrestha *et al.*, 2002), may generally

be a useful index for investigating the phenomenon observed due to effects of resolution changes.

The finest resolution in this experiment is 10 minute spatial distance (approximately 13.5 km). The input data for Suiping basin (2093 km²) varies from 10 minutes to 2 degree resolution. Therefore the IC ratio value ranges from 1:11.77 to 1:0.08. The IC ratio values for Wangjiaba basin (29 844 km²) and Bengbu basin (132350 km²) vary from 1:167.8 to 1:0.75 and 1:744.5 to 1:3.3, respectively, within the framework of this experiment.

CHANGE IN MODEL PERFORMANCE

As the output discharge hydrograph changes with change in resolution of data, the model performances also change. Model performances are consistently better toward IC ratio 1:10 (called higher IC ratio values here) from IC ratio 1:0.08 (lower IC-Ratio) in Suiping Basin (see Fig. 5). Higher IC ratio corresponds to finer resolution and lower IC ratio corresponds to coarser resolution of input as catchment size remains constant. The trend of change in model performance with IC ratio shows the smaller basin has higher sensitivity in response to the forcing data resolutions. The rate of change in performance is higher in Wangjiaba (29 844 km²) than that in Bengbu (132 350 km²) and higher still in Suiping (2093 km²) than that in Wangjiaba. This indicates a need for more attention to resolution issues for smaller basins than larger ones. Perhaps in larger basins, a larger heterogeneous part may be considered as homogenous parts, than in smaller basins.

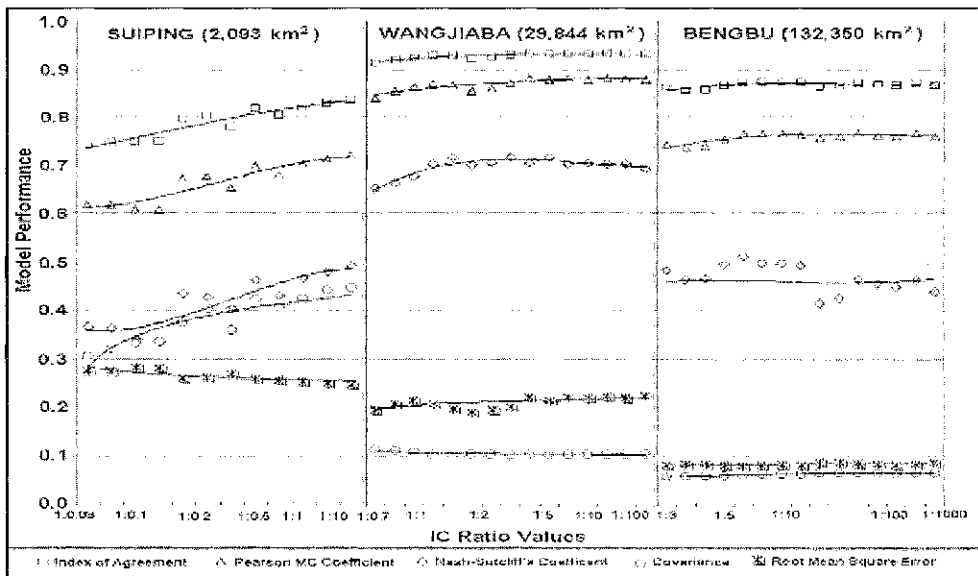


Fig. 5 The model performances of Suiping, Wangjiaba, and Bengbu at different IC ratios.

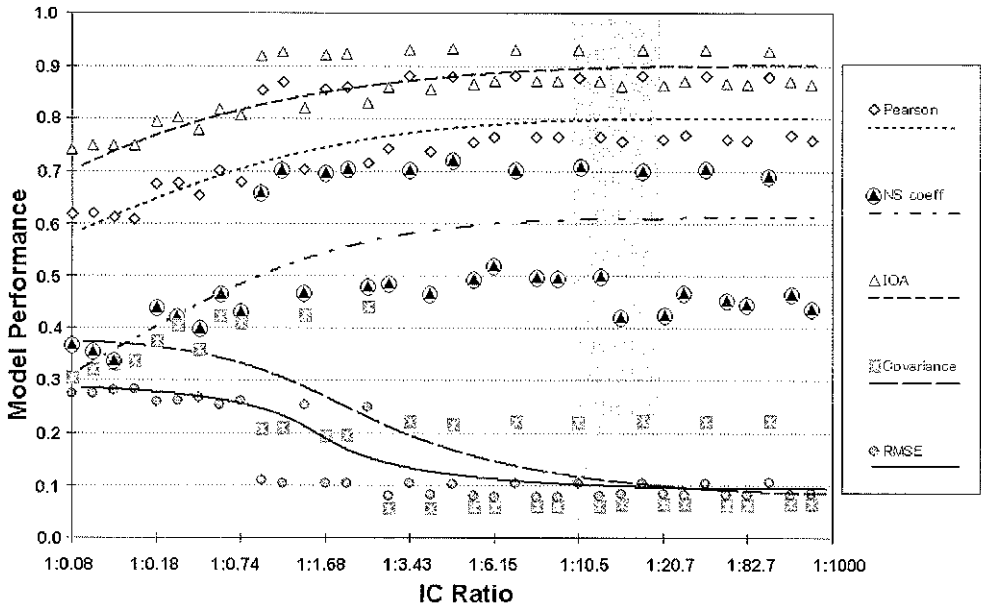


Fig. 6 Model performance vs IC ratio.

The rate of performance improvement is higher when the IC ratio is less than 1:10. It is an indication that less than 10 units of distribution inside a catchment may have a higher chance of obtaining better results by increasing the degree of distribution. When the IC ratio values reach higher than 1:20, the improvement rates of the model performances are not more significant but they tend to saturate (see Fig. 6). Conventionally, the more the degree of distribution was assumed to produce, the more accurate the result. It is an indication that there is some limit of improvement; at some point, no practical improvements can be obtained. Looking from this aspect, the IC ratio range (1:10–1:20) may be referred to as a marginal value to obtain the simulation result at a satisfactory level.

CONCLUSION

The performance of a distributed hydrological model is generally believed to be better than the lumped-conceptual type of modelling. However, it greatly depends upon the quality of modelling that refers to the quality of modelling technique, model parameters and input data. An increased tendency to use GCM data and other distributed data in hydrological modelling has increased concerns on their accuracy and resolution issues. Observing the behaviour of the model performance different resolution data are analysed using a macroscale distributed hydrological model. The ratio of input data resolution catchment area, termed the IC ratio, can be an index to evaluate the suitability of data resolution in distributed hydrological modelling.

In this experiment, three catchments, ranging from small (2093 km²) to large (132–350 km²), have been taken to study the data resolution effects on the discharge simulation results. Smaller catchments are found to be more sensitive than the larger

catchments, which indicates that the resolution issues need more attention in the smaller basins than in the larger ones.

The simulation results deteriorate sharply when the IC ratio is below 1:10. The improvement rate in model performance is small after increasing the IC ratio values above 1:20. A smaller improvement in model performance with higher IC ratio, using high resolution data, depicts no need of too high resolution data. A marginal IC ratio value of 1:10–1:20 seems to produce favourable performance of distributed hydrological modelling, viewing the need for efforts to process the high resolution data.

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