Discharge Simulation in the Huaihe River Using Fine Resolution Downscaled Experimental Data Derived from Game Data Product

*** R. K. Shrestha [1], Y. Tachikawa [2], K. Takara [2]**
(1: Graduate School of Urban and Environmental Engineering, Kyoto University, Japan,
2: Disaster Prevention Research Institute, Kyoto University, Japan)
*** DPRI, Kyoto University, Japan, 611-0011, Gokasho, Uji, Kyoto, Japan**
e-mail: roshan@rdp.dpri.kyoto-u.ac.jp

Abstract

There is a large scale-gap between the atmospheric model's output and the need of hydrological simulation tools. The simulation of spatial rainfall field based on non-homogenous random cascade method can be a powerful tool to fill this gap by disaggregating the large-scale data into a scale smaller enough to apply in hydrological simulations. We developed multiplicative random cascade HSA method and applied it to disaggregate the GAME Reanalysis 1.25 degree precipitation data into 10 arc-minute spatial resolutions. And thereafter applied the disaggregated data into the MaScOD model to simulate the runoff discharge. The disaggregated data has produced satisfactory results for three differently sized study catchments inside the Huaihe River basin. Further we aggregated the fine resolution data into a coarser resolution to investigate the suitable scale of input data for the distributed hydrological model. This part of study has reinforced the concept of IC-Ratio (the ratio between grid cell area and the catchment's area) (Shrestha *et al.,* 2002) to be higher than 1:10 in order to obtain a satisfactory result of discharge simulation using the distributed input. This finding suggests that the needed data resolution depends upon the catchment area. For a smaller catchment area, the resolution should be finer, but a coarser resolution data can well serve the simulation need for a larger catchment. This finding may help atmospheric modeler to understand the extent of data need for hydrological simulation.

Keyword: spatial disaggregation, MaScOD model, input resolution, IC-Ratio.

1. Introduction

Most of the current generation meteorological models and hydrological models are grid based models. These models are often dependent to each other. It is a normal practice to conduct a hydrological simulation to test, calibrate and validate the atmospheric model. Hydrological simulations use rainfall and evaporation data as the important forcing input. These data are usually supplied from the works conducted in meteorological discipline. The outcomes of both models not only provide feedback to improve themselves (e.g. Chiew et al., 1996; Polcher et al., 1996) but also make it possible to analyze the past present and future scenario of changes in meteorological regime, hydrological regime and their impacts on environment.

Linking the meteorological models and hydrological models are not as simple as a data-transferring mechanism in between the two different systems. But it has to think of the large scale-gap that exists in between the two modeling fashion. Hydrological models can not justify themselves to choose a coarse spatial resolution equal to the one chosen in meteorological practice. Hydrological models need a finer resolution to incorporate the effect of spatial heterogeneity of the runoff generation mechanism through surface sub-surface hydrological processes. On the other hand, meteorological models can not operate in a resolution as fine as the one required by the hydrological models because of the risk of numerical instability, need of huge parameter sets and lack of precise meteorological understanding in a finer resolution. To bridge the scale-gap, there are some scaling methods to transfer the data across the scale. However, it is quite uncertain that the meteorological data obtained from such a scaling method does really help the hydrological simulation or not.

In this study, we test the rainfall data produced by a disaggregation method, so-called random cascade HSA method, using a macro scale distributed hydrological model, the MaScOD (**M**acro **Sc**ale **O**HyMoS assisted **D**istributed) model. The source of the data before disaggregation is the GAME Re-analysis data (1.25-degree resolution, version 1.1).

In addition, there is a question, often asked by a meteorological scientist to a hydrologist, "What resolution of the data a hydrologist needs?" An exact answer of the question helps the meteorological scientist to devise the meteorological model and its parameterization more efficiently, at least for the scale that a hydrologist needs. But to answer the question is a difficult task because the hydrological analysis itself is highly scale dependent. We present here a criterion for selection of an appropriate input data resolution which is expressed in terms of the IC-Ratio (the ratio between the model input spatial resolution and the area of the catchment; Shrestha et al. 2002), based on the sensitivity of the MaScOD model's performance to the scale of an experimental hydro-meteorological input dataset based on GAME reanalysis data. The study is conducted inside the Huaihe River basin, taking the cases at Bengbu, Wangjiaba and Suiping having catchments areas of 132,350 km^2, 29,844 km^2, 2,093 km^2 respectively (Figure 1).

2. The MaScOD Hydrological Model

The MaScOD (**M**acro **Sc**ale **O**HyMoS- 'Object oriented Hydrological Modeling System' assisted **D**istributed) hydrological model has a fixed 10-minute spatial resolution in this study. The girded frame of 10-minute resolution, which is overlaid on the river network, breaks the network into smaller river segments defining connection relationships. Each grid cell contains a MaScOD Element Model (MEM). Each MEM contains a Runoff Process Model (RPM) for a river segment, and a Flow Routing Model (FRM) for a connected set of river segments within the grid cell. The RPM is based on the Xinanjiang Model (Zhao, 1992), and the FRM is based on the lumped stream kinematic wave model (Shiiba *et al.*, 1996). The OHyMoS (Takasao *et al.*, 1996; Ichikawa *et al.*, 2000) assists all those units of the model to link each other and develop a total simulation system. Details of the model are given by Tachikawa et al. (2002) and Shrestha et al. (2004b).

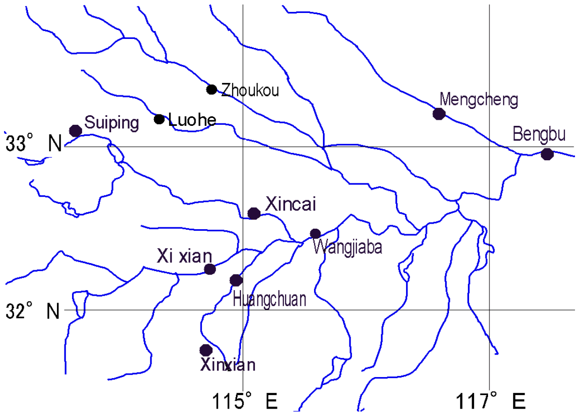

Fig. 1: Major rivers and discharge observation stations.

3. Discharge Simulation results using the disaggregated data

The GAME Re-analysis data having 1.25 degree resolution was successfully applied in the Huaihe River Basin by Shrestha *et al.* (2002). They reported that the data was successful to simulate discharge at Bengbu having catchment of 132,350 km^2, but failed in other smaller catchments to produce good results. To investigate whether the failure in smaller catchments is due to a very coarse forcing data that could have insufficient description of the spatial variability of the rainfall, a disaggregated rainfall data of 10-minute resolution was felt necessary to test as the input data to the MaScOD model. The model parameters and modeling conditions are the same for both the GAME 1.25-degree data and downscaled 10-minute data. Figure 2 shows a typical spatial pattern of both data

We used the random cascade HSA method to obtain the disaggregated data. An important point to note is the outcomes of the MaScOD model using a disaggregated input data would be highly affected by a particular method adopted for the purpose of disaggregation. In this paper, we omit discussing about the methods of disaggregation. Interested readers are referred to Shrestha *et al.* (2004a). The results of discharge simulation obtained at Bengbu, Wangjiaba and Suiping having catchments areas 132,350 km^2, 29,844 km^2, and 2,093 km^2 respectively. Figure 3 show the results obtained from both the GAME 1.25-degree reanalyzed data, and the disaggregated 10-min Experimental data.

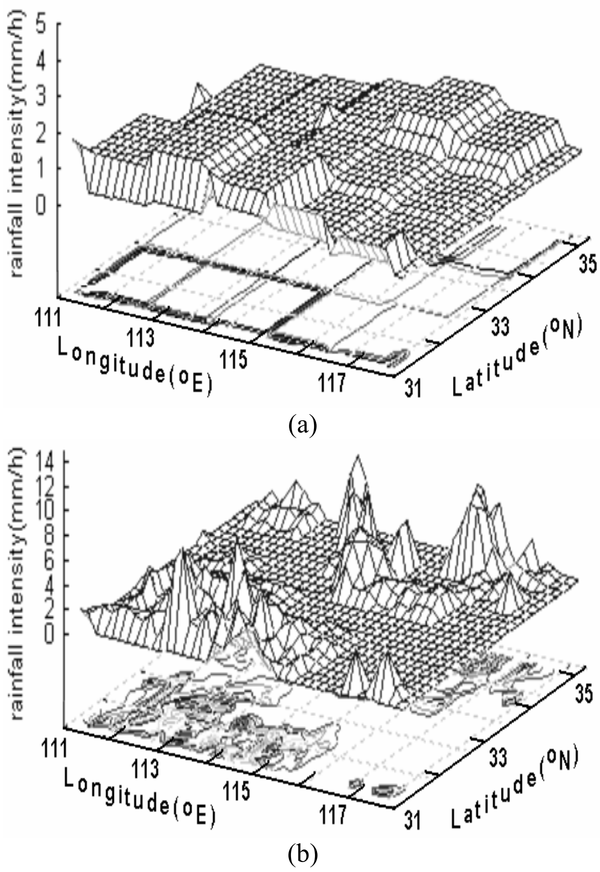

Fig. 2: Spatial patterns of the rainfall data, a) GAME 1.25-degree resolution; and b) Downscaled 10-minute resolution data.

Comparing between the results obtained in differently sized catchments from the GAME 1.25-degree resolution data, and the Experimental 10-min resolution data, we can understand some important features related to the resolution and scale issues. For example, in a large catchment like the Bengbu (Figure 3a), there is a little difference between the simulated discharge by the coarser resolution GAME data and by the finer resolution disaggregated data. But, in a smaller catchment, like the Wangjiaba (Figure 3b) and the Suiping (Figure 3c), the disaggregated data produced significantly improved discharge than the coarse resolution GAME data, while comparing with the observed discharge. The disaggregation method might have included the needed sub-grid scale variability of the rainfall in the finer resolution data. Otherwise, there is no other possible reason to cause the differences in discharge simulation, provided the constant simulation conditions. This means that the GAME data have had described the rainfall appropriately for the region but that merit was disappeared due to its coarser resolution – causing failure to model smaller catchments properly. This also means that a smaller catchment may need to have finer resolution data in order to include the needed degree of sub-grid scale variability in their data description.

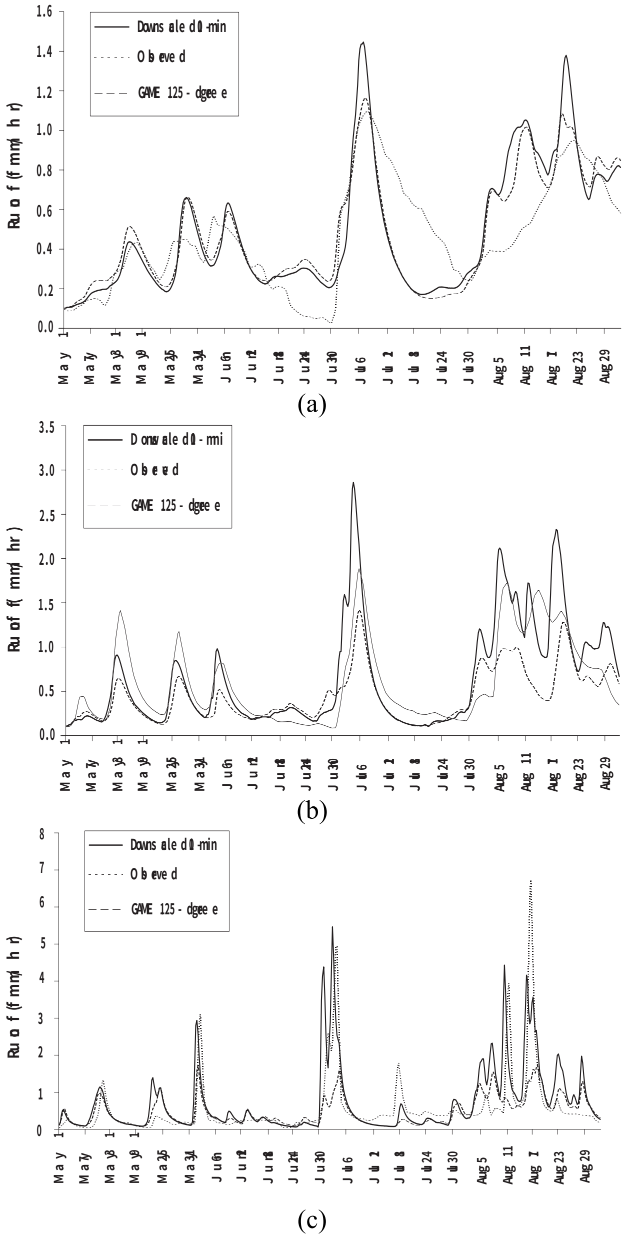

Fig. 3: Comparison of discharge simulation results using GAME 1.25-degree data and the 10-minute disaggregated data with observed discharge at a) Bengbu (132,350 km^2); b) Wangjiaba (29,844 km^2); and c) Suiping (2,093 km^2).

4. Simulation results using various input resolutions

Use of the disaggregated data produced good results in different catchments of different size and characteristics using the 10-minute Experimental data as the input data for the hydrological modeling, the 10-minute resolution may not be a suitable resolution for modeling the catchments. This is to investigate with input data of various resolutions. In this study, because of the MaScOD model's limitation, we could not test the input data resolution finer than 10-mintues although it is possible to obtain them. However, we can have coarser data e.g. 20-minutes, 30-minutes and so on to use as the input data of various resolution. The input data having various resolutions are fed into the MaScOD model to simulate the discharge and compare the performance.

5. Suitable input resolution in terms of IC-Ratio

In this section, we briefly describe the results obtained from the hydrological model using various resolutions of input data.

5.1. What is the IC-Ratio?

The IC-Ratio is a ratio between the area of input grid cell and the size of a catchment (Shrestha *et al*., 2002). It is difficult to compare the constitutive relations for different flow processes that are function of the detailed geometry of flow pathways in different catchments (Beven, 2002). In many cases, the simulation result characteristics are found to be dependent on sizes of catchments. Size of catchments is the only absolute figure to provide consistent information that provides a sound base to investigate on the suitable resolution for hydrologic modeling. The IC-Ratio is the index that relates these two components. This is a useful index for investigating the effects of various input resolution in multiple catchments having different size, particularly in case when other information are not consistent. The convention of the index is fixed to keep the numerator always one such that a higher denominator value corresponds to finer resolution of input data and is called as the higher IC-Ratio. Similarly a lower denominator value corresponds to coarser resolution of input data and is called as the lower IC-Ratio, because the size remains constant for a catchment while examining the data of various resolutions. We analyze here the performance of hydrological model in terms of the IC-Ratio index.

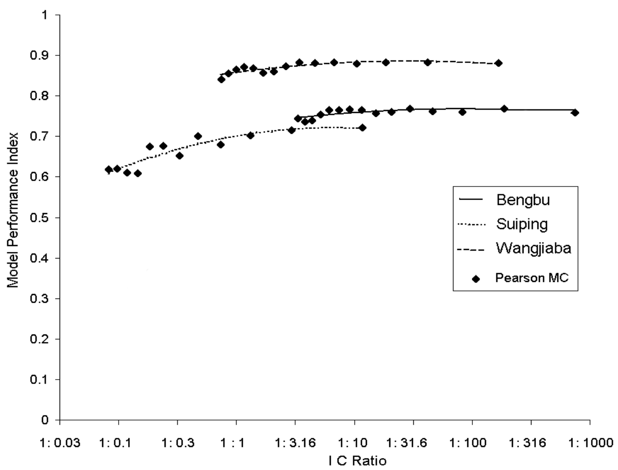

Fig. 4: Effect of input data resolution in model performance in terms of the IC-Ratio

5.2. The IC-Ratio for optimal performance

The goodness of fit of the simulated discharge and observed discharge is evaluated by performance measuring criteria. Figure 4 show the differences in performance those obtained using the various input resolutions and expressed in terms of the IC-Ratio. In this figure the performance measuring index is the Pearson's Moment Correlation coefficient. It is clear that the performance increases with a higher IC-Ratio irrespective of the size of catchments. Sensitivity of the input data resolution is higher in smaller catchment. However, the improvement of performance tends to level off while the IC-Ratio is very high.

Figure 5 is showing the model performance versus the IC-Ratio using some additional performance measuring indices. The results obtained in this experiment has displayed that a range of IC-Ratio values produce satisfactory results. Poorer performance below the IC-Ratio 1:10 is likely to mean that if there is less than 10 units of distributization of the input data in the catchment, the distributed model does not yield nice result, which is more critical in smaller basins. Looking toward higher degree of distributization has tendency to yield better result always, but too much distributization of the input data is also unable to improve the performance much. For example the model performs almost similar at 1:20 and 1:200, but the later one needs much more data and efforts in modeling. Thus the range of IC-Ratio in between (1:10 ~ 1:20) can be considered as optimal range keeping the efforts needed to model in mind. This idea is likely to be very useful to set up a criterion of suitable resolution of hydro meteorological data product.

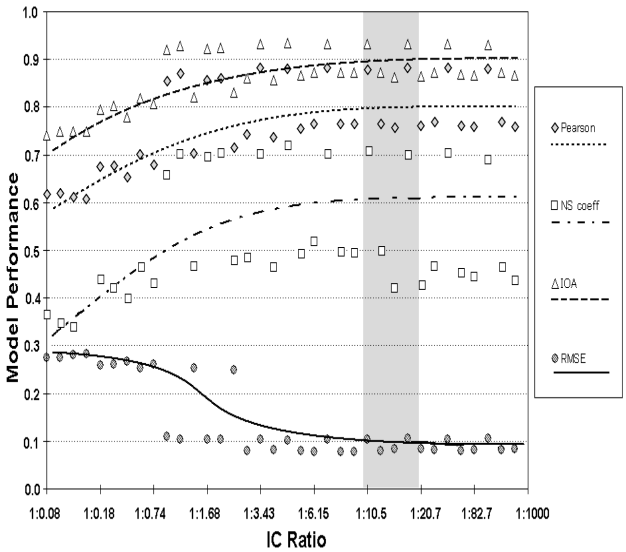

Fig. 5: Model performance versus IC-Ratio for the four indices.

6. Conclusion

The grid based description of meteorological model and hydrological model are sensitive to resolution setting. They need a different resolution setting that causes a scale-gap while linking their products. Since the studies in both disciplines are somehow mutually dependent, it is necessary to investigate the issue well.

GAME 1.25-degree data were reported successful in discharge simulation at Bengbu (132.350 km^2) but failed in smaller catchments like the Suiping (2,093 km^2). This shortcoming was largely removed while the data is disaggregated using a downscaling method so-called the random cascade HSA method. This shows the need of finer resolution data for a smaller catchment.

Further investigation on sensitivity of the input data resolution in the hydrological simulation using the MaScOD model revealed the importance of catchment size and the input data resolution to be considered. The IC-Ratio successfully related these facts by showing the change in model performance with respect to the IC-Ratio. The obtained results showed that the IC-Ratio within the range of 1:10 ~ 1:20 performs optimally, which could guide to select an appropriate input data resolution for a catchment in terms of the size of the catchment. The appropriate resolution of input data to a hydrological model may provide a criterion of selecting the resolution of a meteorological model.

References

Beven, K., Towards an alternative blueprint for a physically based digitally simulated hydrologic response modeling system, *Hydrol. Process*. **16**, 189–206, 2002.

Chiew, F. H. S., . Pitman, A. J and McMahon, T. A., Conceptual catchment scale rainfall-runoff models and AGCM land-surface parameterisation schemes, *Journal of Hydrology,* **179**, 137-157 1996.

Ichikawa, Y., Shiiba, M., Tachikawa, Y. and Takara K., Object oriented hydrological modeling system, *The Fourth International Conference on HydroInformatics CD-ROM,* Cedar Rapids, Iowa, 2000.

Polcher, J., Laval, K., L. Dümenil, J. Lean and P. R. Rowntree, Comparing three land surface schemes used in general circulation models, *Journal of Hydrology,* **180**, 373-394, 1996.

Shiiba, M., Ichikawa, Y., Ikebuchi, S., Tachikawa, Y. and Takasao, T., Scale-up of a runoff model using GIS and an object-oriented hydrological modeling system. *Proceedings of HydroGIS 96*: *Application of Geographic Information System in Hydrology and Water Resources Management,* (eds. K. Kovar & H. P. Nachtnebel), IAHS, **235**, 63-70, 1996.

Shrestha, R., Tachikawa, Y. and Takara. K., Effect of forcing data resolution in river discharge simulation, *Annual Journal of Hydraulic Engineering, JSCE,* **46**, 139-144, 2002.

Shrestha, R., Tachikawa, Y. and Takara. K., Downscaling spatial rainfall field from global scale to local scale using improved multiplicative random cascade method, *Annuals of Disaster Prevention Research Institute, Kyoto University, No. 47 B,* 2004a.

Shrestha, R., Tachikawa, Y. and Takara. K., Performance analysis of different meteorological data and resolutions using MaScOD hydrological model, *Hydrological Processes,* (in Press), 2004b.

Tachikawa, Y., Takara, K., Tanaka, K., Suishu, T., Ichikawa, Y., Shiiba, M., Simulation of River Discharge in the Huaihe River Basin in China, *Journal of Japan Soc. Hydrol. & Water Resource,* **15**.(2), 139-151, 2002.

Takasao, T., Shiiba, M. and Ichikawa, Y., A runoff simulation with structural hydrological modeling system. *Journal of Hydroscience and Hydraulic Engineering, JSCE,* **14(2)**, 47-55, 1996.

Zhao, R. J., The Xinanjiang model applied in China, *Journal of Hydrology*, **135,** 371-381, 1992.