Flood prediction for large scale catchment with atmospheric model output

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Abstract A distributed hydrological model linked with an atmospheric simulation model is an indispensable tool to predict floods, droughts and future water resources for densely populated but less gauged river basins. In this study, a development of a macro-scale grid based distributed hydrological model and its application to the Huaihe River basin in China (132,350km^2) with atmospheric model outputs are presented. The model simulates river discharge properly by including a channel routing model with a digitized channel network data set. The simulated river discharges show better accuracy depending on the grid resolution of input forcing data. Here, the effect of channel routing to estimate river discharge for a large river basin and the effect of different input resolutions for river discharge simulations are studied. Three different grid resolution input data obtained from HUBEX-IOP EEWB data and GAME reanalysis product are used to simulate river discharges and they are compared against the observed one. As a result, GAME reanalysis 1.25-degree resolution data is found quite satisfactory for larger basins; HUBEX-IOP EEWB 10-minute resolution data is better for small catchments; while GAME reanalysis 2.5-degree resolution data did not give good results. Simulated results by using spatially interpolated data are rather worse than using original data. Through this experience, data and information needs for flood forecasting are discussed.

Key word flood forecasting; macro scale hydrological modeling; GAME reanalysis product

INTRODUCTION

Hydrologists often practice discharge simulation not only to know the flow pattern but also to use the flow data information in several decision-making and strategy formulation processes. However, correct prediction of river discharge is still a challenging job. Macro scale hydrological models are tools to predict the river discharge. However their results largely depend on the quality of input data and grid resolution. Very high-resolution data may not be necessary especially on the verge of catchment size as it adds cost. Using minimum data to obtain better result is always highly prioritized. Suitability of grid resolution to a certain range of catchment size may be a matter of discussion. In this study, effects of grid resolution of forcing data in river discharge simulation are investigated.

Also the performance of the channel routing model developed here is examined, because channel routing has a dominant role on forming a hydrograph especially for large basins.

Basin and sub-basins of the Huaihe River in China are taken as the case to study. Grid precipitation and actual evapotranspiration data are referred from (1) HUBEX IOP EEWB data with 5-minute spatial and 1 hour temporal resolution, (2) GAME reanalysis product (Version 1.1) with 1.25-degree spatial and 6 hour temporal resolution and (3) GAME reanalysis product (Version 1.1) with 2.5-degree spatial and 6 hour temporal resolution for the period from May 1, 1998 to August 31, 1998. The effects of data interpolation in distributed hydrologic simulation are also presented. A brief description of the model and findings for the information needs for flood forecasting of large catchments are presented.

MODEL DESCRIPTION

A macro-scale grid based distributed hydrological model (Tachikawa *et al*., 2000a, 2000b, 2001) is used here. It simulates water movement following automated procedures like basin partitioning, sub-basin hydrological modeling and linking sub-basin models together to produce a total runoff simulation model with the use of OHyMoS, Object-oriented Hydrological Modeling System (Ichikawa *et al*., 2000). Main features of the model are as follows:

(a) The model is able to consider exact location and linkage of river segments even within a grid-cell on physical basis to give better flow routing, which has dominant effect on hydrograph.
(b) Dividing watershed basin into grid-cells according to an atmospheric model, this model incorporates the atmospheric model output into hydrological model effectively. For each grid-cell, a runoff process and a flow routing process are modeled separately before constructing a total runoff simulation system.

In addition, this model considers the channel width in accordance to the catchment coverage.

River network arrangement

Figure 1 shows the channel network data for the Huaihe River above Bengbu, the outlet of the study area (132,350km^2). The channel network data is generated from the 1:500,000 scale TPC, Tactical Pilotage Chart, series and the GLOBE, Global Land One-km Base Elevation, data sets.

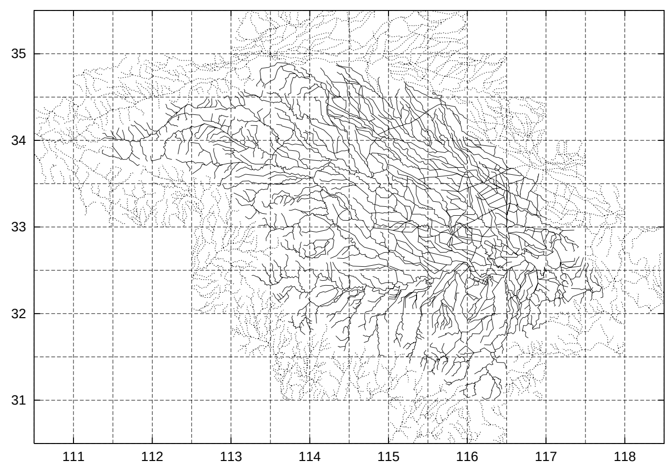


Figure 1 Channel network for the Huaihe River. Solid lines show the channel network of the Huaihe River for the upper part of Bengbu.

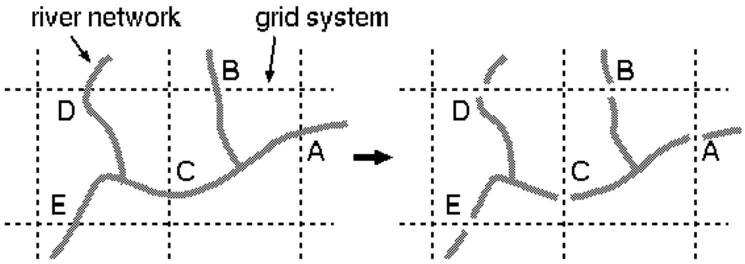


Figure 2 Division of river network

This model rearranges the river network before simulation. 10-minute grid-cell frames divide the existing river network (Figure 1) into piecewise sub-networks and assigns new identity defining an independent sub-network within a grid-cell. Figure 2 displays the process schematically. Existing network data intersects grid-cell frames at points A, B, C, D and E, which is rearranged by dividing at A, B, C, D and E to produce sub-networks within individual grid-cells.

Runoff process model (RPM)

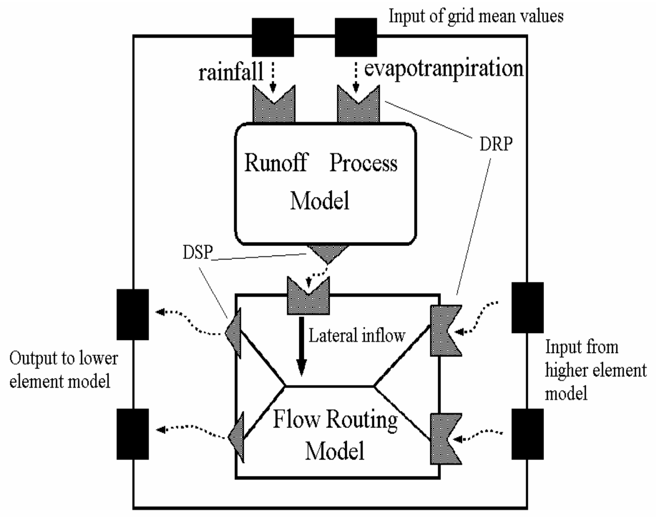
A simple hydrological model (Tachikawa *et al*., 2001) based on Xinanjiang model (Zhao *et al*., 1992) is used for runoff simulation within a grid-cell, which assesses hydrological processes in view of spatial distribution of soil water capacity. The runoff appears only after soil water storage exceeds its capacity to hold. The runoff process model has three model parameters to be identified by hydrological data sets.

Flow routing model (FRM)

A lumped stream kinematic wave model (Shiiba *et al*., 1996) computes river flow within each grid-cell. It assumes river discharge varies linearly along each river segment within a grid-cell at each time step instead of computing discharge for each computational cross-section. If we assume that a shape of cross sections of river segments is a wide rectangle, model parameters of the flow routing model are Manning's roughness coefficient and channel width.

Constructing total simulation process

A total hydrological simulation model (Figure 3) is constructed using functions of OhyMoS (Ichikawa *et al*., 2000) to connect element models with Data sending port (DSP) and Data receiving port (DRP). For each grid-cell, the runoff process model (RPM) receives grid-mean input data (precipitation and evapotranspiration) and calcurates grid-discharge. The flow routing model (FRM) receives the information through its DRP from the RPM and adjacent upper element models (EMs) to compute river discharge to the lower EMs (see Figure 4).



Catchment	Area (km^2)
Suiping	2093
Wangjiba	29844
Bengbu	132350

Tabl e 1 Catc

hment area of test basins.

Figure 3 Schematic drawing of total model.

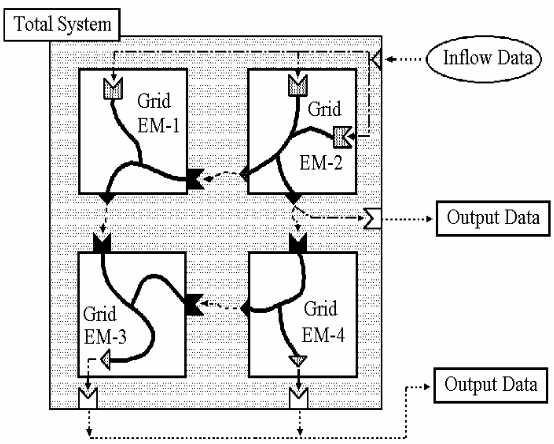


Figure 4 Structure of element model.

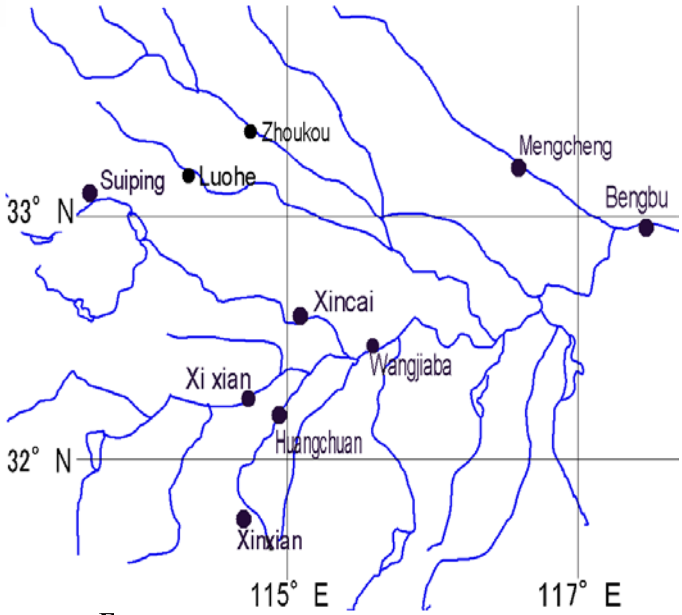


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Figure 5 Location of discharge stations.

Before exchanging information between EMs, the model automatically accumulates the calculated values and transfers that to lower EMs only on request. The flow path of river network arrangement defines the upper and lower EMs. They are linked in accordance with the network connection relationship to transfer the computed outputs. Total runoff simulation model is thus a combination of EMs.

BASIN AND SUB-BASINS

The Huaihe River Basin and two sub-basins are taken for this study. Three points namely Suiping, Wangjiba and Bengbu (see Figure 5) are adopted to compare the model output against the observed discharge. The largest catchment is Bengbu and smallest is Suiping (see Table 1).

INPUT DATA DESCRIPTION

The input hydrological data is grid-mean precipitation and actual evapotranspiration. Original data, after extraction, is fed into the model with resolution conversion. The simulation model accepts 10-minute spatial and 1-hour temporal resolution data. Therefore data resolution is converted as the simulation model's requirement. Following two kinds of data are used for discharge simulation and the results are compared.

HUBEX-IOP EEWB data

A five-minute grid resolution data set created for Estimation of Energy and Water Budget (EEWB) in the Huaihe River Basin, China (Kozan *et al*., 2001) is used in this study. The data set is generated based on the data observed during Huaihe River Basin Experiment - Intensive Observation Period (HUBEX-IOP) in 1998. Grid-mean precipitation data is produced by interpolation of the ground observation points. This interpolation considers both distance and direction of each observation station. Hourly precipitation data is interpolated from 12 hour accumulated values. Grid-mean evapotranspiration data is generated from the observed surface meteorological data with the use a land surface model, SIBUC model (Tanaka *et al*., 1998).

GAME reanalysis product

Using 2-dimensional forecast data of GAME (GEWEX Asian Monsoon Experiment) reanalysis product (Version 1.1) with 1.25 and 2.5-degree resolutions (Meteorological Research Institute, Japan Meteorological Agency, 2000), the precipitation and actual evapotranspiration data are extracted for all the grids lying in the basin. These data sets were produced using JMA 4DDA (4 dimensional data assimilation) system in a cooperative study of MRI/JMA and EORC/NASDA. The data sets have an advantage of including the GAME special observation of off-line radio-sonde data set. The temporal resolution of these data is 6-hour.

DISCHARGE SIMULATION

Discharge simulation by using HUBEX-IOP EEWB data

HUBEX-IOP EEWB data is converted to 10-minute spatial resolution by averaging the adjacent grid data before feeding into the hydrologic model. It gives quite satisfactory result while simulating the discharge with HUBEX-IOP EEWB data input at Suiping and Wangjiba catchment (see Figures 6 and 7). However, the simulation remains good at Bengbu only for initial 60 days, and after then the runoff is predicted below observed values (see Figure 8). The water budget (Figure 9) clearly reflects this distinct difference between observed and simulated values of accumulated discharge, showing significant mismatch after 180th days.

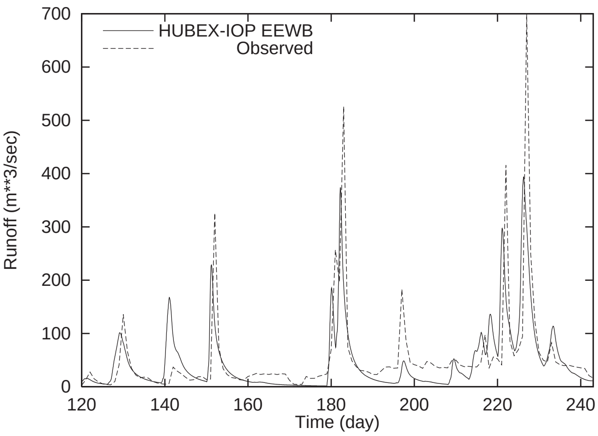

Figure 6 Simulation result at Suiping with HUBEX-IOP data.

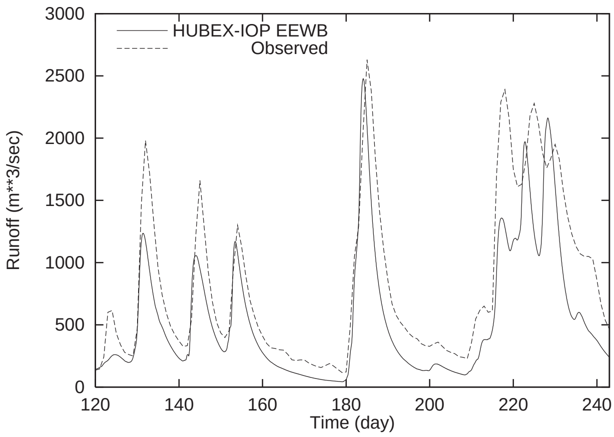

Figure 7 Simulation result at Wangjiba with HUBEX-IOP data.

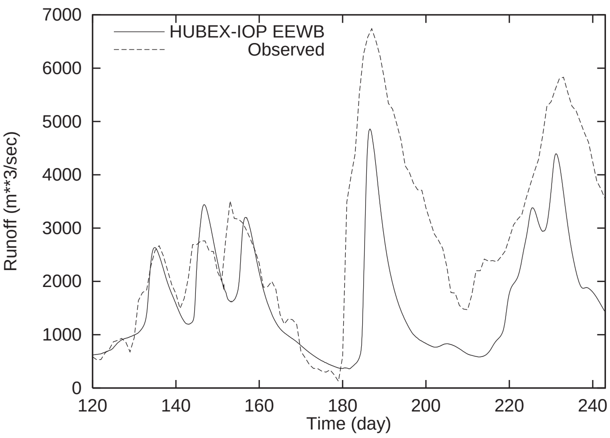

Figure 8 Simulation result at Bengbu with HUBEX-IOP data.

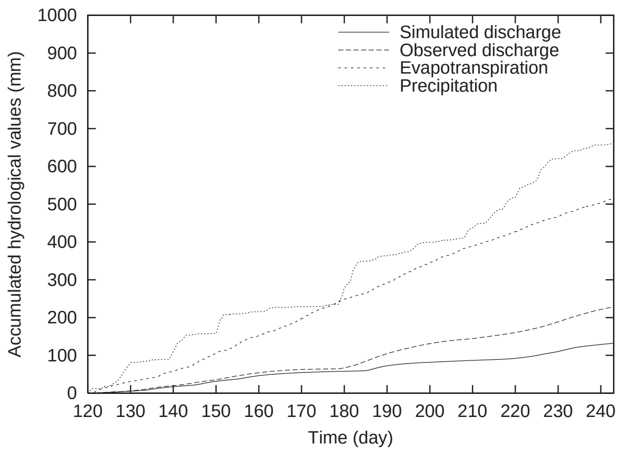

Figure 9 Water budget at Bengbu with HUBEX-IOP data.

Discharge simulation by using GAME reanalysis product

GAME reanalysis data is rearranged to fit according to the need of the model input requirement. While rearranging input data, all 10-minute grid cells, lying within 1.25-degree grid coverage, are assigned same value to maintain 1.25-degree resolution. The intersecting grid-cells are assigned average values. The original 6-hour data is changed to 1-hour data assuming uniform distribution to maintain 6-hour interval data. Thus the resolution of input data is maintained as 1.25-degree 6-hour data. Similar practice is applied in the case of 2.5-degree resolution data as well.

1.25-degree resolution input

The simulation results at Suiping using GAME 1.25-degree data input are not satisfactory, as it fails to attain the peak values several times (Figure 10). Also, it is hard to follow the observed discharge at many places especially after 70th days. The simulation results at Wangjiba are nearly following the observed hydrograph but it fails at many places (Figure 11). Distinct error is seen in attaining peak values and between 220th to 230th days, however trend is represented better. However, it gives good result at Bengbu (Figure 12). The observed low flow in between 165th and 180th days are not represented properly, but the peak flow is simulated quite better than that with HUBEX-IOP EEWB data. The recession limb of the hydrograph is still not simulated properly. Errors are present in further periods too but the trend follows the observed hydrograph. Looking over the accumulated discharge, it gives very good matching with observed one (Figure 13), and shows satisfactory agreement with the water budget.

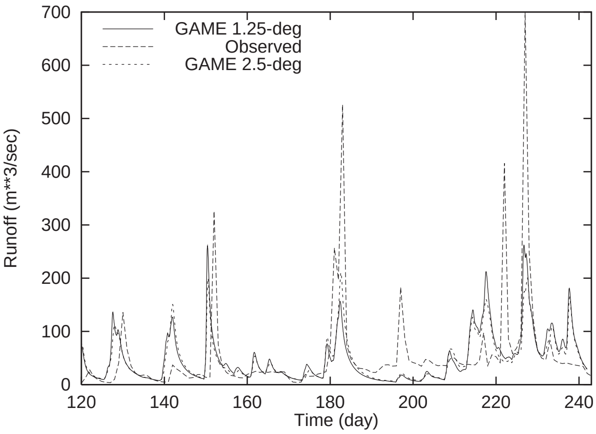

Figure 10 Simulation result at Suiping with GAME data.

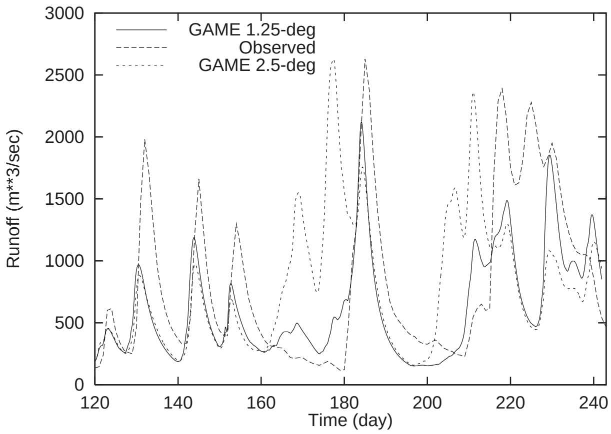

Figure 11 Simulation result at Wangjiba with GAME data.

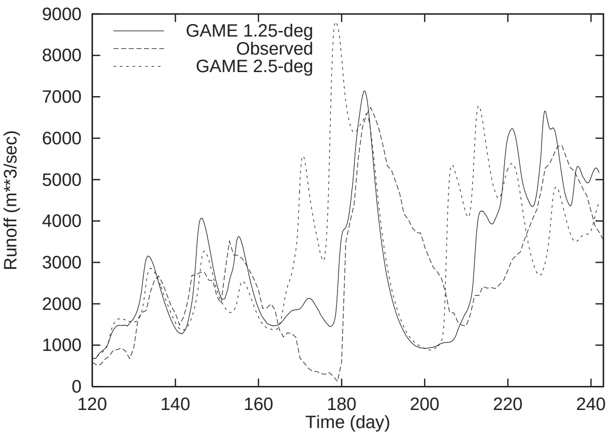

Figure 12 Simulation result at Bengbu with GAME data.

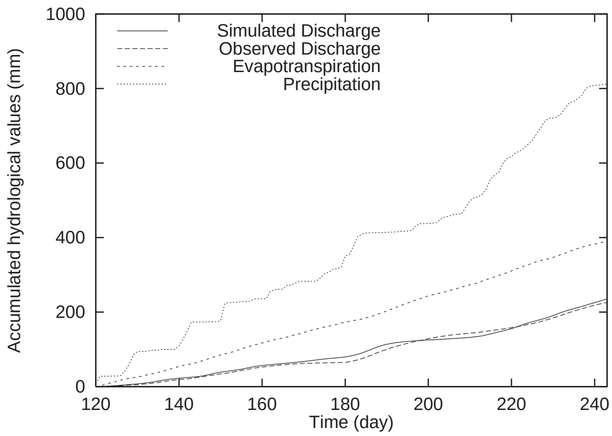

Figure 13 Water budget at Bengbu with GAME 1.25-deg data.

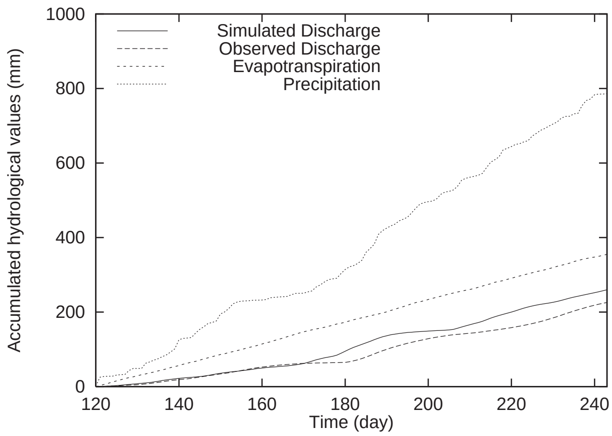

Figure 14 Water budget at Bengbu with GAME 2.5-deg data.

2.5-degree resolution input

This data did not give good simulation results in either basin (Figures 10, 11, 12). In the water budget at Bengbu, accumulated discharge shows better in initial 50 days, and then there is great mismatch (Figure 14).

Why so much variation in result?

The largest basin, Bengbu, touches seven 2.5-degree grid cells but only one lies completely within it. Diverse local hydrological and meteorological behaviors are impossible to be reflected in coarse grid information. The river basin's diverse variability, which the present data does not reflect, may be influencing factor in flow routing process. Hence the mean value of all the locations within its coverage is believed as the major cause of failure to represent the true basin conditions. On the other hand, the results are quite satisfactory with 1.25-degree data, where the same basin touches eighteen 1.25-degree grid-cells, among them ten grid-cells lie completely within it. This provides a base to accept that the increased number of grid cell within the catchment improves the result.

Looking over the smallest study basin Suiping, the simulated results are almost similar for 1.25-degree and 2.5-degree data, both not matching with observed one (Figure 10). The grid area is larger than the catchment area in both cases. Thus, the simulation model with uniform spatial data, which does not represent the true site condition, produces much deviation in a simulation result than the real one.

Effects of interpolation

GAME 1.25-degree data and the Bengbu catchment are chosen for observing the effects of data interpolation, as it is the best simulated combination among the alternatives in previous section. Data are separately interpolated in space and time, and then fed into the model to observe the effects in discharge simulation.

Spatial interpolation

Assuming that the original grid data refers to the grid intersection points, the bilinear interpolation is applied before feeding the input data to the hydrological model. This experiment gave worse simulation result at Bengbu than the original data unlike the expectation (Figure 17). The peak values did not match, although it is able to represent the trend. The error is quite distinctive after 220th days of simulation at Bengbu. In addition to that, the spatially interpolated data did not give better simulation results in Suiping and Wangjiba (Figures 15, 16). Significant variations in simulation results are observed with respect to original data as an effect of spatial interpolation.

Temporal interpolation

Using linear interpolation, the original data with 6-hour interval is changed into 1-hour time step data. This data gave almost similar result as that of original data (Figures 15, 16, 17). The output values are changed slightly but still they are not significant for all three basins.

Spatial and Temporal interpolation

Integrating both spatial interpolation and temporal interpolation, a new data with 10-minute spatial and 1-hour temporal resolution data is created. It gives almost similar result as that of spatial interpolation only (Figures 15, 16, 17). This means that spatial interpolation has dominant effect for discharge simulation.

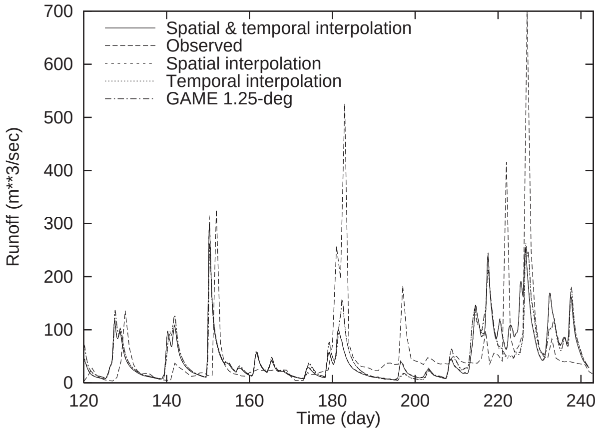

Figure 15 Simulation result with interpolated data at Suiping.

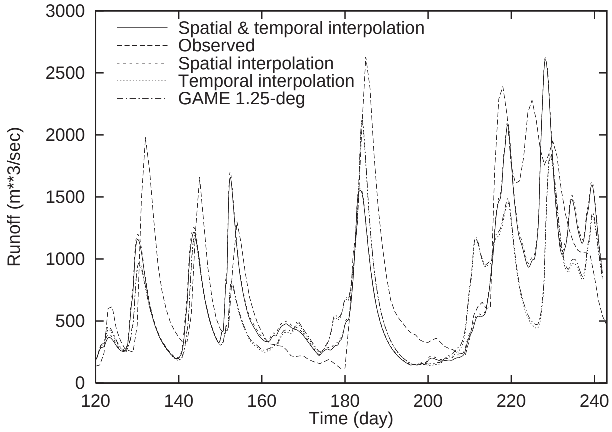

Figure 16 Simulation result with interpolated data at Wangjiba.

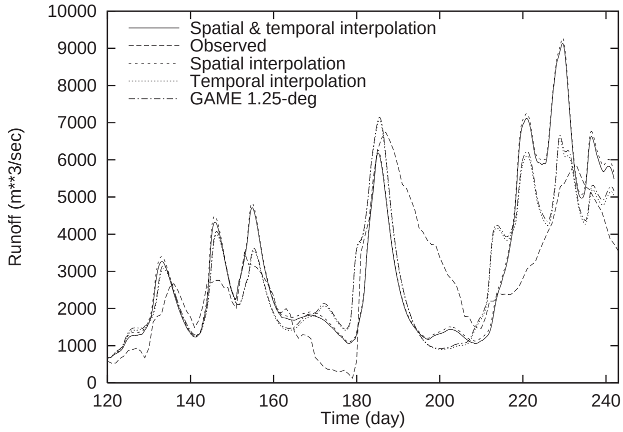

Figure 17 Simulation result with interpolated data at Bengbu.

Performance of channel routing model

Figures 18, 19 and 20 show the effects of the river flow routing model on simulation results with the use of HUBEX-IOP EEWB data. In these simulations, the channel width is determined by using the relationship shown in Figure 21. The relationship is obtained using the channel cross section data of the Huaihe River. In the simulated hydrographs, the solid line represents the hydrograph simulated with the river routing model and the broken line shows the one without the river routing model. The solid hydrograph in Figure 20 and the solid hydrograph in Figure 8 is the same hydrograph. This simulation shows that the effect of river routing to estimate river discharge for a large river basin is quite large and it is quite important to incorporate the effect into the hydrological model effectively.

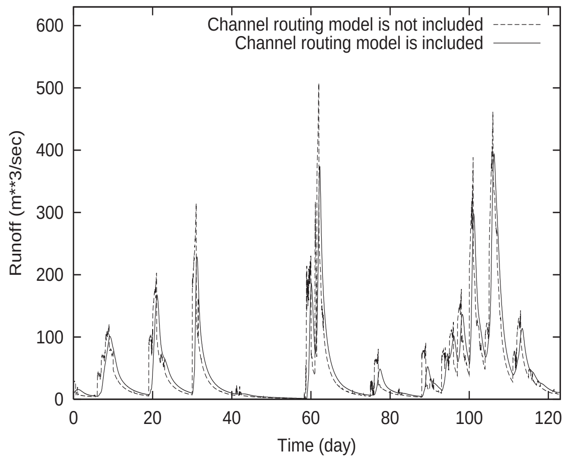

Figure 18 Simulation result without routing at Bengbu.

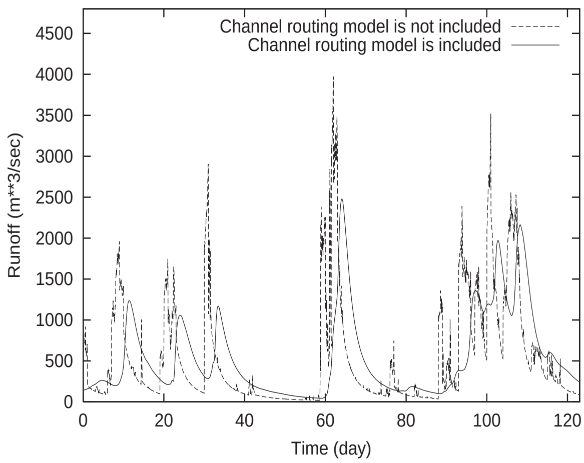

Figure 19 Simulation result without routing at Wangjiha

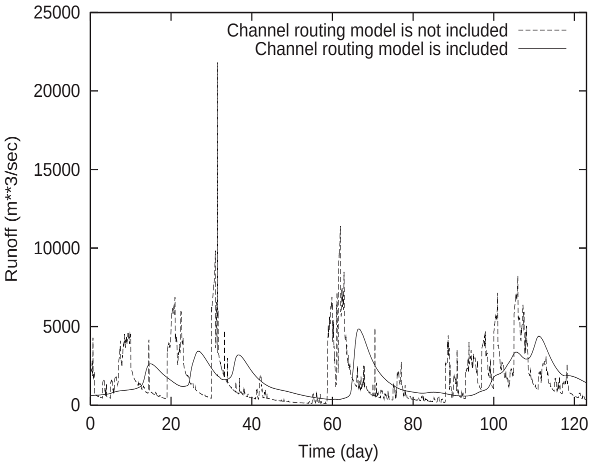

Figure 20 Simulation result without routing at Suiping.

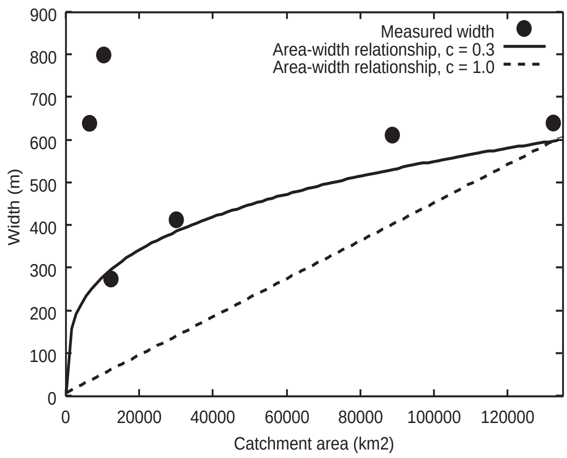

Figure 21 Relationship between catchment area and channel width.

INFORMATION NEEDS FOR FLOOD FORECASTING

Forcing data resolution

The obtained results clearly indicate that the distributed hydrological model is very sensitive with resolution of forcing data. Of course, the accurate higher resolution data gives better solution. If we see over the ratio of input-resolution and catchment size (IC ratio), it indicates that there exists some ratio which provides the suitability of the forcing data resolution to input in the distributed hydrological model with respect to catchment size. A summary of IC ratios is presented in Table 2.

While the ratio of input-resolution and catchment size (IC ratio) is 1:13, it gave good result at Bengbu. The results are found satisfactory with the IC ratio is 1:168 at Wangjiba and with the

IC ratio 1:11 at Suiping. Simulation is not satisfactory with lower IC ratios. It may be too early to draw some specific conclusion, but still this study suggests that the results of distributed hydrologic models are better while IC ratio is more than that of 1:10. To set a general acceptable IC ratio or to investigate the relationship of IC ratio with other hydrological factors may be a good research topic in the coming days.

Table 2 Input-resolution-Catchment (IC) ratio.

Resolution	Bengbu	Wangjiba	Suiping
2.5-degree (GAME Re-analysis)	1: 3.3	1: 0.75	1: 0.05
1.25-degree (GAME Re-analysis)	1: 13.24	1: 2.98	1: 0.21
10-minute (HUBEX-IOP EEWB)	1: 744.5	1: 167.9	1: 11.78

Forcing data interpolation

The results of interpolated data display that the effect of spatial interpolation is dominant in distributed hydrologic simulation than the temporal interpolation. This means the spatial distribution effect is very sensitive. It is obvious to have less effect of temporal distribution in large basins like Bengbu and Wangjiba because of larger travel time, and also it did not affect much in the simulation result of Suiping. This phenomenon is present in the result with spatially and temporally interpolated data as well.

The higher grid resolution is not necessarily good in hydrological modeling. Basically, the high-resolution data generation using interpolation techniques from the coarse grid intervals may have poor performance than the original one for large catchments. Spatially interpolated input data given to simulate river flow at Bengbu has shown this (Figure 17). The larger grid data includes the average values within the grid cell but linear or bilinear spatial interpolation does not reproduce the data that considers topographical variations, catchment boundaries and hydrological characteristics exactly. Therefore, in distributed hydrological modeling, it cannot simulate the hydrological behavior of zonal variation by applying such interpolation techniques.

Incorporation of river flow regulation by human activity into hydrological model

In the study basin area, large numbers of dams are operating but this model does not consider the discharge manipulation due to dam operation. The obtained hydrographs display some hints about the effect of dam operation. It does not distinctly indicate hydrograph attenuation even though recession parts are widened in observed hydrograph. To explain these behaviors more specifically, it needs further studies. If the discharge variations are due to effects of dam operation, then it will give a strong support to verify the suitability of GAME reanalysis product in hydrological modeling processes.

Channel routing model

For river discharge simulation of large-scale catchments, the effect of channel routing has a dominant role on forming a hydrograph. Thereby it is quite important to incorporate a channel routing model into an entire hydrologic simulation model. To build a river routing model, channel network data sets having information of locations and connection relationship of channel segments are indispensable.

CONCLUDING REMARKS

In this paper, a development of a macro-scale grid based distributed hydrological model and its application to the Huaihe River basin in China (132,350km2) using HUBEX-IOP EEWB data and GAME reanalysis product were presented. The distributed hydrological model is very sensitive with resolution of forcing data input. HUBEX-IOP EEWB data gave good simulation results for Suiping and Wangjiba basins at Huaihe region. GAME reanalysis 2.5-degree data was not suitable to reproduce the river discharge, however, GAME reanalysis 1.25-degree data gave good simulation results at Bengbu of Huaihe River Basin. The results obtained in this research are summarized as follows:

- Better simulations are achieved while the IC ratio (Input-resolution-Catchment ratio) is more than 1:10.
- Spatial distribution of data has significant effect than the temporal distribution in distributed hydrologic modeling.
- The importance of a channel routing model and incorporation of the effect of dam regulation into a hydrologic model is suggested.

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