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Effect of spatial and temporal resolution of precipitation data on the accuracy of long-term runoff simulation

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Abstract The purpose of this study is to investigate the effect of spatial and temporal resolution of precipitation data on the accuracy of long-term runoff simulation. The Radar-AMeDAS precipitation data are used to represent the spatial and temporal variability of precipitation. The precipitation is averaged over different spatial and temporal scales, and both original and averaged data are used as the input for a hydrological model. A rainfall–runoff simulation is carried out in the Fuji River basin by using the BTOPMC model. The difference between the simulated daily hydrographs using original precipitation and the averaged ones is investigated through the comparison of the Nash efficiency for each simulation. In addition, the same analyses are carried out for hydrographs at other time scales, and the influence of spatial and temporal resolution of precipitation data on the accuracy of the hydrological simulation is identified.

Key words distributed hydrological model; long-term runoff simulation; Radar-AMeDAS

INTRODUCTION

Precipitation is usually dramatically distributed with time and space within a basin. In a physically-based distributed model, precipitation data with rational resolution to represent the variability of precipitation needed for an accurate estimation of river discharge. Ichikawa *et al.* (2002) showed that the spatial variability of precipitation causes a significant difference in the shape of the flood hydrograph. However, it is not yet clear at which time and space scale runoff is well estimated with rational accuracy.

The objective of this study is to identify the effect of spatial and temporal resolution of precipitation data on the accuracy of long-term runoff simulation. Precipitation data with different spatial and temporal resolution are processed as input data for a distributed hydrological model, and rainfall–runoff simulations are conducted using these data. The simulated hydrographs are compared so as to identify the influence of the resolution of precipitation data on runoff simulation.

PRECIPITATION DATA

The Radar-AMeDAS precipitation data provided by the Japan Meteorological Agency (JMA) are used in this study. The data are based on the hourly radar gauged precipitation data calibrated by ground gauged precipitation. The spatial resolution of the data is 0.05° × 0.0625° in latitude/longitude (about 5 × 5 km). The original Radar-AMeDAS data are averaged over different spatial scales: 10 × 10 km, 20 × 20 km, 30 × 30 km area and the whole basin area. The temporal averaging is also performed for 1 day, 5 days, 10 days, and 30 days. The precipitation data used in this study are listed in Table 1. Figure 1 shows the precipitation data with different spatial resolution and averaging period.

DISTRIBUTED RAINFALL–RUNOFF MODEL

A rainfall–runoff simulation is carried out using the Block-wise TOPMODEL with Muskingum-Cunge method (BTOPMC). The BTOPMC is a grid-base distributed rainfall–runoff model developed by Ao *et al.* (1999a).

Table 1 Precipitation data with different time and space scales used in the study.

Data	Resolution	
	Spatial	Temporal
S05T00	5 km	1 hour
S10T00	10 km	
S20T00	20 km	
S30T00	30 km	
S60T00	Basin ave	
S05T01	5 km	1 day
S10T01	10 km	
S20T01	20 km	
S30T01	30 km	
S60T01	Basin ave	
S05T05	5 km	5 days
S10T05	10 km	
S20T05	20 km	
S30T05	30km	
S60T05	Basin ave	
S05T30	5 km	10 days
S10T30	10km	
S20T30	20km	
S30T30	30 km	
S60T30	Basin ave	
S05T30	5 km	30 days
S10T30	10 km	
S20T30	20 km	
S30T30	30 km	
S60T30	Basin ave	

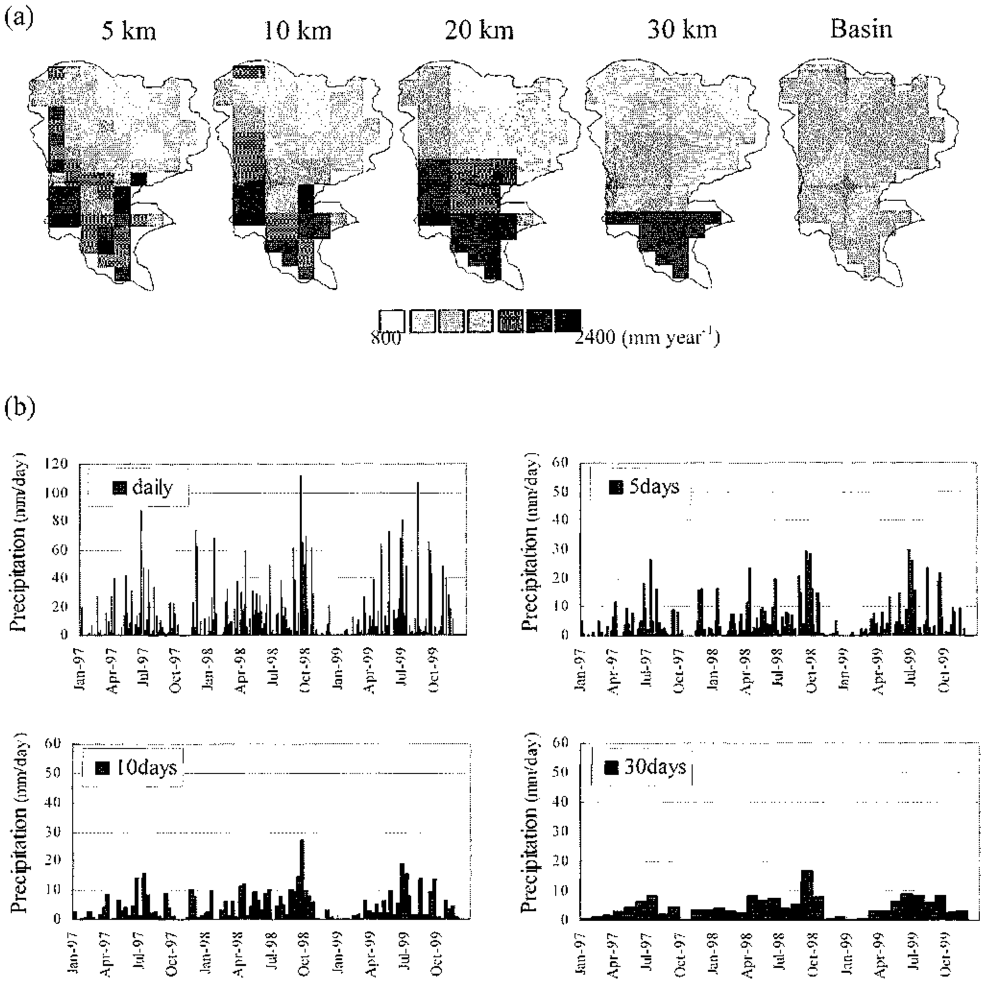


Fig. 1 (a) Spatial distribution of annual precipitation with different spatial resolution. (b) Precipitation data with different averaging period at the Fuji River basin, 1997–1999.

In this model, runoff generation at each grid cell is estimated on the basis of the TOPMODEL concept (Beven & Kirkby, 1979). A river basin is divided into blocks by referencing land cover, soil type and the basin scale, and model parameters are subsequently identified for each block rather than for the whole basin. The average saturation deficit at each time step and the average soil-topographic index are also thereby calculated for each block of the basin. The Muskingum-Cunge method is used for flow routing. This is useful for a large stream network since it can express the flood wave diffusion and propagation. The parameters for river reach (i.e. width and roughness coefficient of river segments) are distributed according to the topography (Ao *et al.*, 1999a; Lu *et al.*, 1989). For more details, see Takeuchi *et al.* (1999) and Ao *et al.* (1999b).

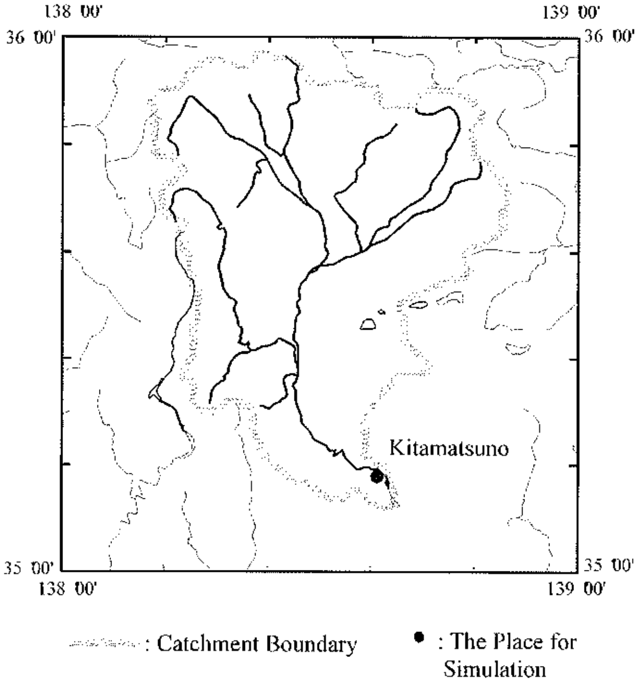
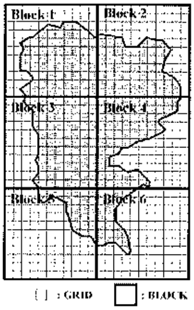


Fig. 2 The Fuji River basin.

Table 2 Model parameters of BTOPMC for the Fuji River basin.

	T_0 (m^2 h^{-1})	m (m)	Sr_{max} (m)	S_{bar0} (m)	n_0
Block 1	6.0	0.0235	0.005	0.1200	0.085
Block 2	12.0	0.0235	0.005	0.0500	0.088
Block 3	10.0	0.0235	0.005	0.1290	0.035
Block 4	12.0	0.0235	0.005	0.0500	0.088
Block 5	10.0	0.0235	0.005	0.0345	0.035
Block 6	10.0	0.0235	0.005	0.0345	0.035

T_0 : saturated hydraulic transmissivity of soil,
m: decay factor of T_0,
Sr_{max}: maximum capacity of root zone,
S_{bar0}: initial saturation deficit of soil,
n_0: Manning roughness coefficient at the outlet of the block.



EVALUATION

Using the precipitation data listed in Table 1 and the distributed hydrological model presented above, a rainfall–runoff simulation is conducted in the Fuji River basin (Fig. 2).

The Fuji River with a length of 128 km and basin area of 3570 km^2 is located in the central Honshu Island of Japan. It originates from mountains with a height of 3000 m and flows down to the Pacific Ocean (RSC, 1997). The grid size of the model is 1 × 1 km, and the basin is divided into six blocks. The model parameters are calibrated by trial-and-error approach. The original Radar AMeDAS precipitation (S05T00 in Table 1) is used as the input data for the calibrations. The identified parameters are listed in Table 2. The simulation is carried out for three years (1997–1999).

The difference between the hydrographs of each simulation is evaluated through the Nash efficiency, E_f, defined as follows:

$$E_f = \left\{1 - \left(\sum_{i=1}^{n} (Q_r(i) - Q_c(i))^2 / \sum_{i=1}^{n} \left(Q_r(i) - \overline{Q_r}\right)^2 \right)\right\} \times 100 \quad (\%) \tag{1}$$

where Q_r(i) is referred discharge, $Q_c(i)$ is the compared discharge, $\overline{Q_r}$ is the average of $Q_r(i)$, n is the number of data. A higher value of E_f indicates good agreement between $Q_r(i)$ and $Q_c(i)$, and E_f = 100% means the simulated hydrographs agree with the observed ones in terms of the variance.

Table 3 Results of case studies for Experiments 1 and 2.

	Case	Precipitation:: Data	Spatial	Temporal	Evaluation Time (T_e)	Nash efficiency (E
Experiment 1:	C1-1*	S05T00	5 km	1 hour	1 day	100.0
	C1-2	S10T00	10 km			99.6
	C1-3	S20T00	20 km			98.6
	C1-4	S30T00	30 km			95.7
	C1-5	S60T00	Basin ave			94.7
Experiment 2:	C2-1*	S05T01	5 km	1 day	1 day	100.0
	C2-2	S10T01	10 km			99.7
	C2-3	S20T01	20 km			98.9
	C2-4	S30T01	30 km			97.1
	C2-5	S60T01	Basin ave			96.4
	C2-6	S05T05	5 km	5 days	5 days	80.3
	C2-7	S10T05	10 km			77.2
	C2-8	S20T05	20 km			75.3
	C2-9	S30T05	30 km			70.8
	C2-10	S60T05	Basin ave			71.7
	C2-11	S05T10	5 km	10 days	10 days	61.1
	C2-12	S10T10	10 km			57.1
	C2-13	S20T10	20 km			55.1
	C2-14	S30T10	30 km			50.5
	C2-15	S60T10	Basin ave			52.3
	C2-16	S05T30	5 km	30 days	30 days	13.2
	C2-17	S10T30	10 km			6.9
	C2-18	S20T30	20 km			4.9
	C2-19	S30T30	30 km			−2.4
	C2-20	S60T30	Basin ave			−1.8

*The estimated discharge from this data is used as reference discharge $Q_r(i)$.

CASE STUDIES

In this study, two different kinds of experiments are designed. Experiment 1 is designed to understand the effect of spatial scale of precipitation data on the runoff. The estimated discharge from the original precipitation data (5 × 5 km, hourly) is used as the reference discharge $Q_r(i)$, and the Nash efficiency E_f is calculated for each hydrograph simulated from the spatially-averaged precipitation. The evaluation time T_e, the time scale for calculation of Nash efficiency E_f is taken as one day. Experiment 2 is designed to show the effect of both spatial and temporal scale of precipitation data on runoff. The calculated discharge simulated by using daily precipitation with original spatial resolution (5 × 5 km) is used as the reference discharge Q_r(i), and the Nash efficiency E_f is calculated for each hydrograph simulated by using the spatially- and temporally-averaged precipitation. The evaluation time T_e is the same with the temporal averaging time for precipitation. For example, the Nash efficiency is calculated by using 10 days averaged discharge when precipitation data are averaged over 10 days.

RESULTS AND DISCUSSION

Figure 3 shows the simulated hydrograph using the precipitation data at different spatial scales. The differences between each hydrograph are not significant except the peak discharge. The change in E_f is approximately 5% even when precipitation is averaged over the basin. In this application, spatial resolution of precipitation does not significantly influence the accuracy of long-term runoff simulation. It is noted that the

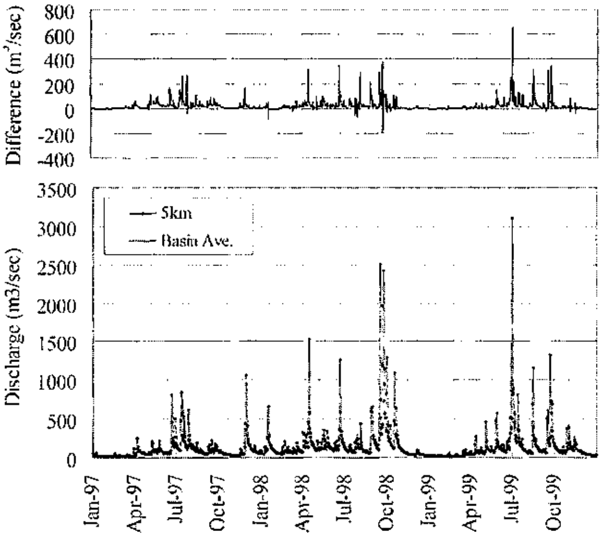


Fig. 3 Simulated hydrograph using precipitation with different spatial scales. In the figure, 5 km denote the simulated discharge using original Radar-AMeDAS data, Basin Ave. denote the simulated discharge using basin averaged precipitation, and the difference between these hydrographs are shown.

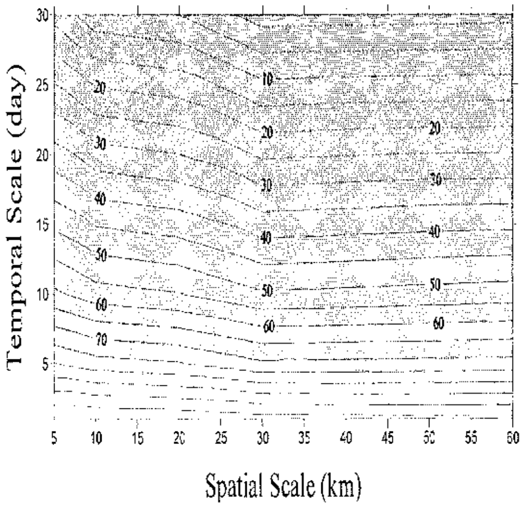


Fig. 4 Change in the Nash efficiency due to spatial and temporal averaging of the precipitation. The spatial scale for "basin average" is represented as 60 km.

results show less influence of the spatial distribution of the precipitation on long-term runoff simulation if the areally-averaged precipitation is accurately observed in the basin. The adequate resolution to detect the basin average precipitation is still problematic.

Figure 4 shows the results of Experiment 2, where the changes in E_f due to spatial and temporal averaging of the precipitation is displayed. It can be seen that the temporal averaging will cause significant difference for long-term hydrological simulation compared with spatial averaging. For example, the difference between daily precipitation with resolution of 5 km and overall basin is 4.6%. On the other hand, the difference between E_f using daily precipitation and monthly averaged precipitation with 5 km resolution is more than 85%. One of the reasons for this large discrepancy is considered to be the change in simulated evaporation. In the case of using temporally-averaged precipitation, the soil layer will be kept in wet conditions due to the longer precipitation duration, and this will cause increasing evaporation from the land surface. For the long-term runoff simulation, the calculation scheme of evaporation within the model should also be changed according to the temporal scale of precipitation. In addition, if the precipitation data are temporally averaged, direct runoff will decrease due to the smaller precipitation rate. This will result in a change in partitioning of the runoff into surface flow and baseflow at each grid cell, and the shape of the resulting hydrograph.

CONCLUSIONS

The influence of spatial and temporal resolution of precipitation data on the accuracy of long-term hydrological simulation is investigated. The result is as follows: the spatial resolution of precipitation dose not show significant influence on the accuracy of long-term runoff simulation, when the areally-averaged precipitation is accurately observed for the basin. However, the adequate resolution to observe the basin-average precipitation is still problematic.

The temporal resolution of precipitation data is sensitive for the long-term hydrological simulation.

Presently, the study of the Prediction in Ungauged Basins (PUB) is planned. PUB is an IAHS decadal initiative to provide hydrological data in ungauged or information-poor basins. It is a scientific endeavor to assemble, promote and build the science and technology capacity to predict and estimate the hydrological phenomena without depending on calibration data. The runoff simulation by using physically-based distributed hydrological models is one of the key components of PUB. For the hydrological simulation in PUB, it is necessary to clarify at which time and space scale runoff is well estimated with rational accuracy. In this study, the impact of spatial and temporal scale of precipitation is investigated. Further studies would be needed for different scales of basins.

REFERENCES

Ao, T. Q., Ishidaira, H. & Takeuchi. K. (1999a) Study of distributed runoff simulation model based on block type TOPMODEL and Muskingum-Cunge method. *Ann. J. Hydraul. Engng JSCE* **43**, 7–12.(In Japanese).

Ao, T. Q., Takeuchi, K., Ishidaira, H., Kazuhiko, F. & Kaneki, M. (1999b) The Naka River floods analyses by BTOPMC method. In: Proc. Int. Symp. Floods and Droughts (October 1999, Nanjing), 414–420. China.

Beven, K. J. & Kirkby, M. J. (1979) A physically based, variable contributing area model of hydrology. *Hydrol. Sci. Bull.* **24**(1), 43–69.

Ichikawa, Y., Tachikawa Y., Hori, T., Takara, K. & Shiiba, M. (2002) Investigation on the scale of rainfall spatial variability to be considered in runoff simulation. *Ann. J. Hydraul. Engng JSCE* **46**, 133–138 (In Japanese).

Lu, M., Koike, T. & Hayakawa, N. (1989) A rainfall–runoff model using distributed data of radar rain and altitude (in Japanese). *Proc. JSCE* **411**(11-12), 135–140.

RSC (1995) *Catalogue of Rivers for Southeast Asia and the Pacific*, vol. I (ed. by K. Takeuchi, A. W. Jayawardena & Y. Takahasi). UNESCO IHP Regional Steering Committee for Southeast Asia and the Pacific (RSC).

Takeuchi, K., Ao, T. Q. & Ishidaira, H. (1999) Introduction of block-wise use of TOPMODEL and Muskingum-Cunge method for the hydro-environmental simulation of a large ungauged basin. *Hydrol. Sci. J.* **44**(4), 633–646.