Appropriate spatial sampling resolution of precipitation for flood forecasting

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Introduction

For the implementation of lumped conceptual models in flood forecasting, point precipitation time series records need to be aggregated into regionally averaged time series. Therefore a question arises: how many rainfall gauges inside a specific river basin are needed to provide sufficient precipitation records for the rainfall-runoff models?

The variability of rainfall recorded at a single spot is generally much larger than that of the discharge recorded at the outlet of the basin considered. This is quite understandable considering the damping effect of the rainfall-runoff transformation process. For a given physics-based hydrological model, the greater the diversity between the input (rainfall) and the output (discharge), the greater difficulty will be encountered in establishing the mapping from the input to the output. Therefore any measures, which can help to decrease the variability of the input, or increase the similarity between the input rainfall, time series and the output discharge time series will promote the performance of a calibrated physical model.

The operation of aggregating the point-sampled rainfall time series into regional-averaged time series has the expected smoothing-out effect. One important aspect that has to be addressed here is that the purpose of the appropriate spatial sampling of rainfall is not to master the regime of the rainfall events as detailed as possible, but to serve the practice of flood forecasting. Therefore the appropriate spatial sampling is defined as that which can possibly lead to accurate forecasting of discharge in the river channel.

The problem is attacked in two steps. The first one is based solely on the statistical analysis of recorded rainfall and discharge data, trying to identify the appropriate amount of rain gages for flood forecasting. The second step is to verify the results obtained in the previous step by running a physical hydrological model: HBV, which is developed by the Swedish Meteorological and Hydrological Institute (SMHI, 2003). Qingjiang river basin in China is adopted as the case studied in this research, and the area upstream of the Yuxiakou flow station is considered here, as shown in Fig.1.

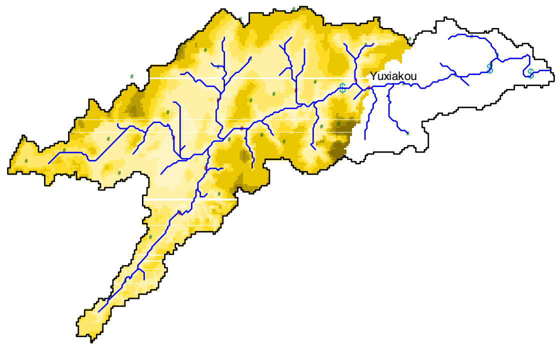

Figure 1. Qingjiang river basin.

Both rainfall and discharge data are measured at 6 hours time interval.

Statistical analysis on rainfall-discharge data

Variances (square of the standard deviation) of rainfall time series give an indication of the variability of rainfall at a location or of a region. The recorded rainfall data on the neighbouring rain gages can be treated as mutually correlated random variables if they are not separated over long distance. The variance of the sum of these individual time series (which is one method of estimating the aerial rainfall) is given by (Osborn & Hulme, 1997):

$$S_n^2 = \overline{s_i^2}\left[\frac{1+(n-1)\bar{r}}{n}\right] \quad (1)$$

where $\overline{s_i^2}$ is the mean of the station variances; s^2_n is the variance of the average of the combination of n station time series; $\bar{r}$ is the mean inter-station correlation between all pairs of stations within the basin which is calculated from Fig. 2; n is the amount of rain gages included in the aggregation.

As can be seen from equation 1, the variance will be reduced with an increasing number of rain stations n involved in averaging. This is proved by the curves in Fig. 3, from which can be seen that the variance is reducing hyperbolically as n increases, but after a certain threshold it levels off, which implies that the effect of smoothing on the variability (variance reduction) is no longer significant when n is greater than about 10.

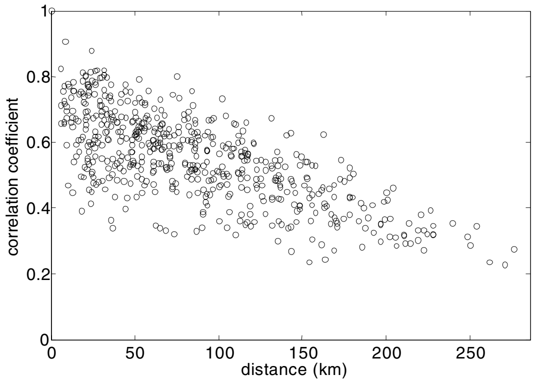

Figure 2. Correlation between pairs of point rainfall time series versus their separation distance for all possible combinations of station pairs in Qingjiang river basin.

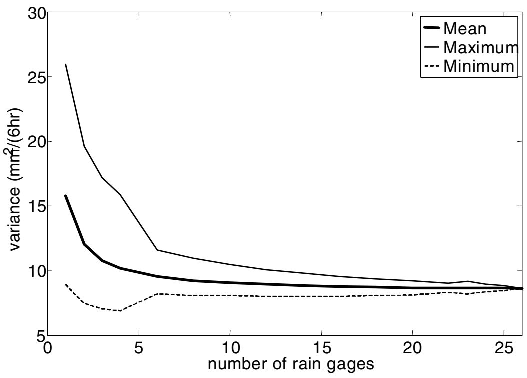

Figure 3. Variance of rainfall time series obtained by averaging n station time series together for different n.

With the decreasing variability of the rainfall, it is expected that the similarity between the rainfall time series and discharge time series will be increased, which will benefit to the rainfall-runoff modelling. This similarity is measured with the maximum cross correlation between rainfall time series (with different n) and discharge time series as shown in Fig. 4.

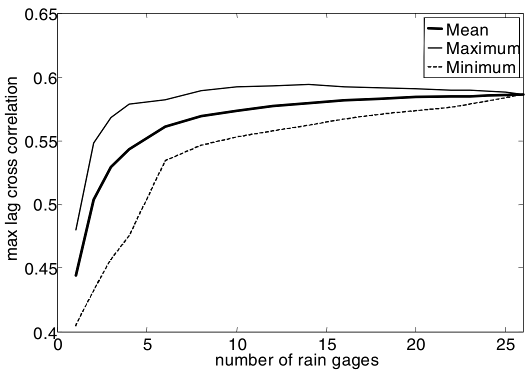

Figure 4. Maximum cross correlation (at time lag 3) versus different values of n.

The use of the concept of maximum cross correlation stems from the fact that the correlation between two time series differs according to different time lags. For the area upstream to Yuxiakou the hydrological response time can be identified as 3 time unites (18 hours) (see Fig. 5).

It is assumed that with the averaged rainfall time series becoming more similar to the discharge time series, as indicated by the increasing values of correlation coefficients in Fig. 4, the performance of a given hydrological model will be increased. Fig. 4 reveals that, when n is increased to 10, the correlation between averaged rainfall time series and discharge time series hardly increases any more, therefore 10 will be identified as the appropriate number of rain gages that determines the appropriate spatial resolution of rainfall sampling for the area upstream to Yuxioakou in Qingjiang river. This result is verified by performing real flood forecasting with HBV model.

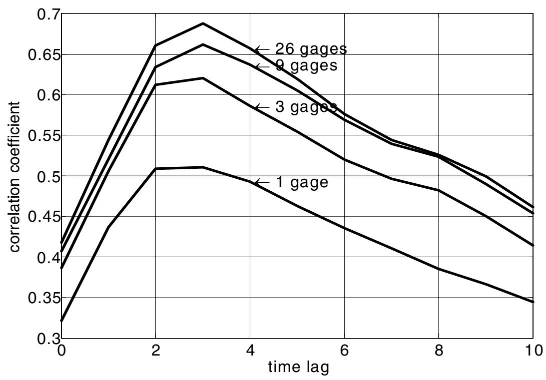

Figure 5. Cross correlation between averaged rainfall time series (with different n) and discharge time series for different time lags.

Verification with HBV model

The area upstream to the Yuxiakou flow station is treated as one sub basin as seen in Fig. 1. The one-sub basin HBV model is calibrated with rainfall, evaporation and discharge data ranging from 1989 to 1996. Then it is validated with data from 1997 to 1999. The effect of the amount of rainfall stations on the forecasting results is shown in Fig. 6, where Nash-Sutcliffe efficiency coefficient R2 and relative accumulated difference between computed and recorded discharge are used as the criteria to judge the performance of forecasting. The validation results compare favourably to the ones obtained in the preceding step.

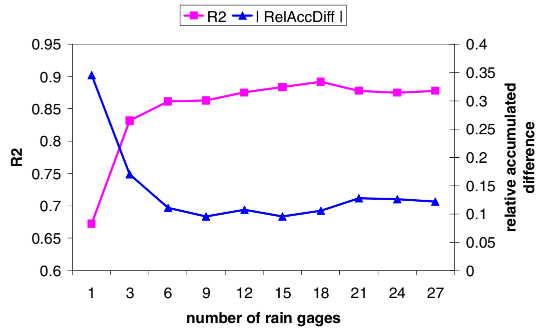

Figure 6. Verification using HBV model.

Conclusions

Among 27 rain gages used in the studied area, 10 are found to be the effective amount for flood forecasting. This is deduced first from the observed rainfall and runoff data, by calculating the variance reduction effect of all combinations of rain gages from one to the total amount of the cluster, and their correlation with discharge time series. The result is further verified by running rainfall-runoff model-HBV, with only one combination for a certain number of rain gages. Although the latter verification process is not as robust as the preceding statistical method (which is not practically possible for running hydrological models), it provides a reasonable prove on the statistical result from a different point of view.

References

Swedish Meteorological and Hydrological Institute (SMHI), 2003. Integrated Hydrological Modelling System (IHMS); Manual version 4.5. Norrköping, Sweden.

Osborn, T.J. & M. Hulme, 1997. Development of a relationship between station and grid-box rainday frequencies for climate model evaluation. Journal of Climate. 10, pp. 1885-1908.