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Appropriate scales for hydro-climatological variables in the Red River basin

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Abstract Decision support systems (DSSs) in water management should preferably consist of appropriate models, which are complex enough to represent important processes at a balanced level, but not unnecessarily refined, taking into account research objectives, data availability and uncertainties. This idea is illustrated by applying a methodology for the determination of appropriate scales to the hydrological part of a DSS. The variability of a relevant variable at the point scale, the discharge at the outlet, is used to determine the appropriate temporal scale. The appropriate spatial scale for precipitation is then determined at this appropriate temporal scale. Results indicate an appropriate temporal scale varying between 12 h for middle-sized upstream areas to 48 h for the complete river basin, accepting an aggregation error of 10%. The appropriate spatial scale for precipitation for the complete river basin is about 80 km. The appropriate scales found are important for the hydrological model set-up and may indicate the requirements for downscaling from climate model to hydrological model scale for climate impact assessments.

Key words appropriateness; decision support system; discharge; precipitation; Red River basin; spatial scales; temporal scales; variance reduction function

INTRODUCTION

In the European-Asian project FLOCODS, a decision support system (DSS) for flood control and water management in the Red River basin in Vietnam and China has been developed (Booij, 2003a). This DSS consists of hydrological, hydraulic and socio-economic models and can be used to evaluate different management options (see Nghia, 2000) under different scenarios (e.g. climate change and economic growth). An important question is how good such a DSS should be in order to support decisions in water management. Preferably, appropriate models should be used, which are complex enough to represent important processes at a balanced level, but not unnecessarily refined, taking into account research objectives, data availability and uncertainties. This idea is illustrated by applying a methodology for the determination of appropriate scales to the hydrological part of the DSS. The appropriate temporal and spatial scales of two hydro-climatological variables (discharge and precipitation) are determined taking into account the modelling objectives. In this study, the modelling objective is to reasonably simulate average discharge behaviour.

The appropriate scales found are important for the hydrological model set-up and may indicate the requirements for downscaling from the global climate model (200–

300 km) to the hydrological model scale (1–100 km, depending on area and objectives) for climate impact assessments. Next, different approaches are available for this downscaling, such as statistical methods to downscale large-scale global climate model variables to local surface variables (e.g. regression methods: Wilby & Wigley, 2000; classification methods: Bardossy & Plate, 1992; and conditional methods: Jothityangkoon *et al.*, 2000) and high-resolution regional climate models nested inside global ones (e.g. Jones *et al.*, 1995).

DATA

Precipitation data from the Vietnamese Hydrometeorological Forecasting Centre and discharge data from the Institute of Mechanics are used in this study. Daily precipitation data from 30 stations in the Red River basin for the period 1960–2000 were employed. On average about 35% of these data were missing; for the worst station 76% and for the best station 3% of the data were missing. Six-hourly discharge data from 19 stations in the Red River basin for the flooding season (1 June–15 October) in the period 1960–2001 and daily discharge data from one station (Son Tay) in the Red River basin for the period 1956–1998, were used.

APPROPRIATE SPATIAL AND TEMPORAL SCALES

Related spatial and temporal scales

Appropriate temporal and spatial scales are related, i.e. the larger the appropriate spatial scale, the larger the appropriate temporal scale (see e.g. Blöschl & Sivapalan, 1995). Consequently, an innumerable number of appropriate combinations may be found. Therefore, one scale actually needs to be fixed to obtain one appropriate combination. This problem is avoided by considering the variability of a relevant variable at the point scale, i.e. the discharge at the outlet. This variable will be used to determine the appropriate temporal scale and then the appropriate spatial scale at this appropriate temporal scale.

Appropriate temporal scales

The temporal variance is an important statistic describing the variability of discharge time series. The variance σ^2 for a variable $Z(t)$ is estimated as:

$$\sigma^2 = \frac{\sum_{t=1}^{n}[Z(t)-\mu]^2}{n-1} \tag{1}$$

where n is the total number of time steps in the temporal domain and μ is the average of $Z(t)$ over n. In general, it applies that the larger the time period over which $Z(t)$ is aggregated, the smaller will be the variance. The relation between the instantaneous variance (subscript i) and the temporally averaged variance (subscript ΔT) can be stated as follows

$$\left(\sigma^2\right)_{\Delta T} = \left(\sigma^2\right)_i \kappa^2 \tag{2}$$

where κ^2 is the variance reduction function decreasing with increasing time period ΔT. Its magnitude depends on the temporal correlation structure of the variable, and the size of the time period. For a stationary isotropic *spatial* random field, Rodriguez-Iturbe & Mejia (1974) showed that κ^2 is the expected value of the correlation coefficient between any two points randomly chosen in this field. Here, it is assumed that this definition can be translated to a stationary isotropic *temporal* random time series, because similar correlation behaviour is observed in both spatial and temporal domains for a particular variable (e.g. precipitation) and both domains are considered to be stationary and isotropic. This results in the following expression for κ^2:

$$\kappa^2 = \int_0^{\Delta T} \rho(\tau) f(\tau)\,\mathrm{d}\tau \tag{3}$$

where τ is the time lag between any two points randomly chosen in the temporal domain, ΔT is the maximum time lag considered in the time period equal to the aggregation interval due to the one-dimensional character of the temporal domain, $\rho(\tau)$ is the temporal correlation function and $f(\tau)$ is the probability density function (pdf) of the random variable τ.

The pdf has been determined as:

$$\begin{aligned} f(\tau) &= \frac{4}{\Delta T^2}\tau & 0 < \tau < \frac{\Delta T}{2} \\ f(\tau) &= \frac{4}{\Delta T}\left(1 - \frac{\tau}{\Delta T}\right) & \frac{\Delta T}{2} < \tau < \Delta T \end{aligned} \tag{4}$$

Assuming an exponential temporal correlation function $\rho(\tau) = \exp(-\tau/\lambda_t)$, where λ_t is the temporal correlation length, the temporal variance associated with an aggregation scale ΔT can be determined from the instantaneous variance. The determination of λ_t is done using correlograms, viz. relations between correlation coefficients and different time lags (τ). Next, correlation functions $\rho(\tau)$ are fitted to the correlograms and λ_t can be determined.

The appropriate temporal scale for a variable is dependent on its correlation structure and the application area studied. Temporal scales should be sufficiently detailed to capture natural variability, but not unnecessarily refined that computation time is wasted. The appropriate temporal scale can be determined by means of the relations above given a specific appropriateness criterion. This criterion is based on the bias allowed in estimating the variance of temporally averaged variables from the variance of instantaneous variables. The higher this permitted bias, the larger the appropriate scale. The determination of the appropriate scale is illustrated in Fig. 1, where the reduction of the variance is given as a function of dimensionless aggregation scale ($\Delta T/\lambda_t$). The dotted line illustrates the determination of the appropriate scale assuming a permitted bias of 10%. This arbitrary bias is assumed to be appropriate in this study and results in an appropriate temporal scale for the variance which is about

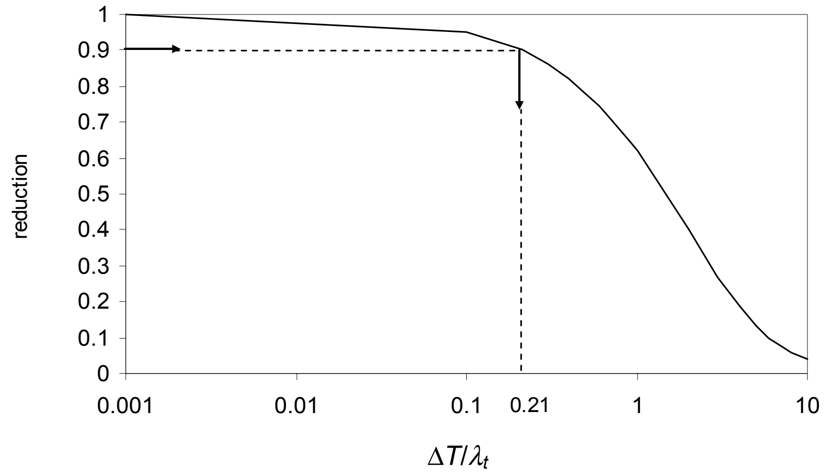

Fig. 1 Determination of the appropriate scale for a variable accepting a 10% bias.

21% of the temporal correlation length. The appropriate (spatial) scale for return values was found to be 25% of the correlation length assuming a bias of 10% (see Booij, 2002). Which fraction of the correlation length represents the appropriate scale for a given bias thus depends on the relevant statistic. This approach may be an attractive solution from the point of view of DSS users, because it allows them to require a certain accuracy (aggregation error) with respect to the relevant output.

Appropriate spatial scales

The appropriate spatial scale for precipitation is then determined at the appropriate temporal scale found. Similarly to the temporal case, equation (3) and the spatial correlation length of precipitation at the appropriate temporal scale can be used to achieve this. Instead of equation (4), the pdf of Ghosh (1951) for two points randomly chosen at a specific distance in a square grid box is used. This has been applied by, e.g. Booij (2003b) and is not shown here. The resulting variance reduction function looks similar to the one shown in Fig. 1 and can be used to estimate the appropriate scale assuming a permitted bias of 10%. This results in an appropriate spatial scale for the variance of about 21% of the spatial correlation length similarly to the temporal case. The variance reduction function and the appropriate spatial scale are used to scale the temporal variance of precipitation from an arbitrary (climate model) scale to the appropriate scale. This information can be used in, e.g. stochastic precipitation models, to generate precipitation at the appropriate scales for current and changed climate.

RESULTS

Appropriate temporal scales

Figure 2 shows the temporal correlation coefficient as a function of time lag for six-hourly and daily discharge series at Son Tay, a measuring station close to Hanoi with an upstream basin area of about 150 000 km^2. Obviously, temporal correlation

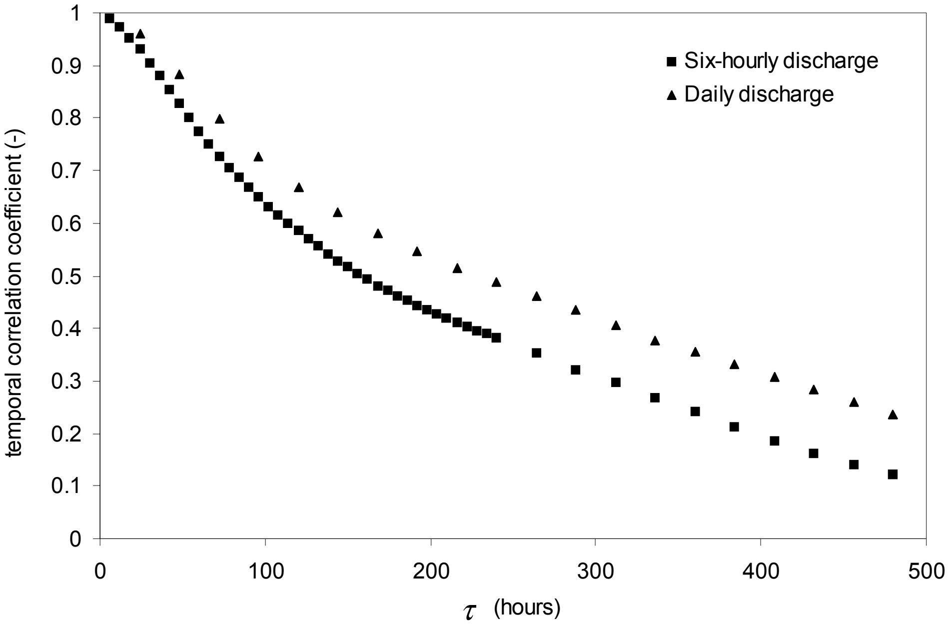

Fig. 2 Temporal correlation coefficient as a function of time lag τ in hours for six-hourly and daily discharge series at Son Tay.

coefficients for daily discharges are larger than for six-hourly data at the same time lags due to a similar averaging effect as described by equation (2). Exponential correlation functions could be well fitted to these data and resulted in temporal correlation lengths of 250 h for six-hourly data and 350 h for daily discharge. Six-hourly data will be used to estimate the temporal correlation lengths, because these mostly approximate instantaneous data (ideally) necessary to determine correlation lengths, similarly to point values in the spatial case.

Figure 3 shows the temporal correlation length λ_t as a function of the spatial scale of the upstream basin area for 15 out of the 19 discharge stations (for four stations no

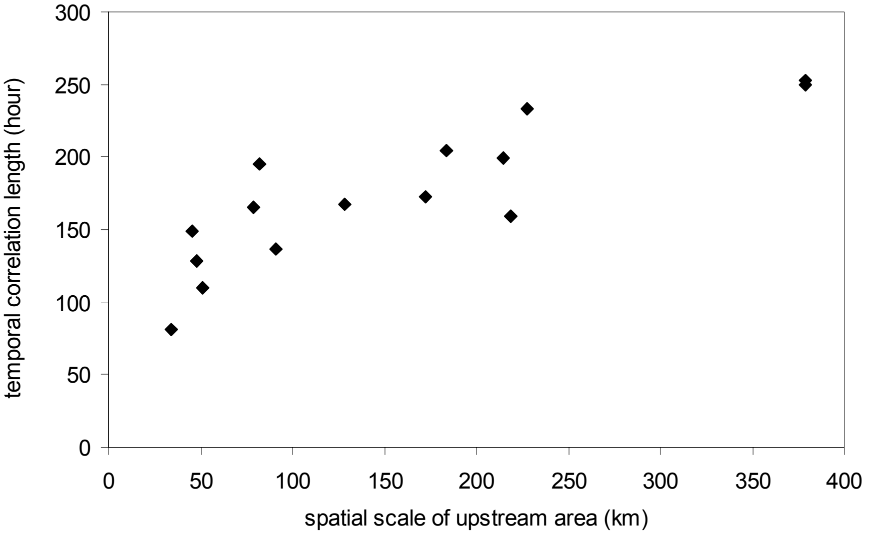

Fig. 3 Temporal correlation length in hours as a function of the spatial scale of the upstream basin area (square root of surface area) in km for 15 sub-basins.

upstream areas are available). The figure shows temporal correlation lengths increasing with spatial scales. This trend is caused by the larger dampening effect of the rainfall–runoff relationships in large sub-basins relative to small sub-basins. This results in less discharge variability (and more temporal correlation) for large sub-basins compared to small sub-basins.

The temporal correlation lengths in Fig. 3 vary between 60 and 250 h resulting in an appropriate temporal scale for discharge varying between 12 h for middle-sized upstream areas (~2500 km^2) to 48 h for the complete Red River basin upstream of Hanoi and Son Tay (~150 000 km^2) accepting an aggregation error of 10%. Because the discharge of the complete basin upstream of the delta (Son Tay) is of interest in the hydrological model in the DSS, the appropriate temporal scale for Son Tay of 48 h is chosen as the appropriate temporal model scale. This implies an appropriate temporal scale for precipitation of 48 h as well.

Appropriate spatial scales

The appropriate spatial scale for precipitation, as input in the hydrological model, has been determined at the appropriate temporal scale found. Figure 4 shows the spatial correlation coefficient as a function of inter-station distance resulting from 30 precipitation series. An exponential correlation function could be roughly fitted to this figure and resulted in a spatial correlation length of about 375 km for 48-hourly precipitation. The spatial correlation length for daily precipitation was about 330 km and compared well with the ones found by Osborn & Hulme (1997) for Europe in summer (200 km) and winter (300 km) and Booij (2002) for Western Europe (300 km). However, one would expect more spatial variability and thus less spatial correlation in a sub-tropical basin such as the Red River basin compared to European areas. Therefore, further study of the spatial correlation behaviour of precipitation, particularly in sub-tropical basins such as the Red River basin, is recommended.

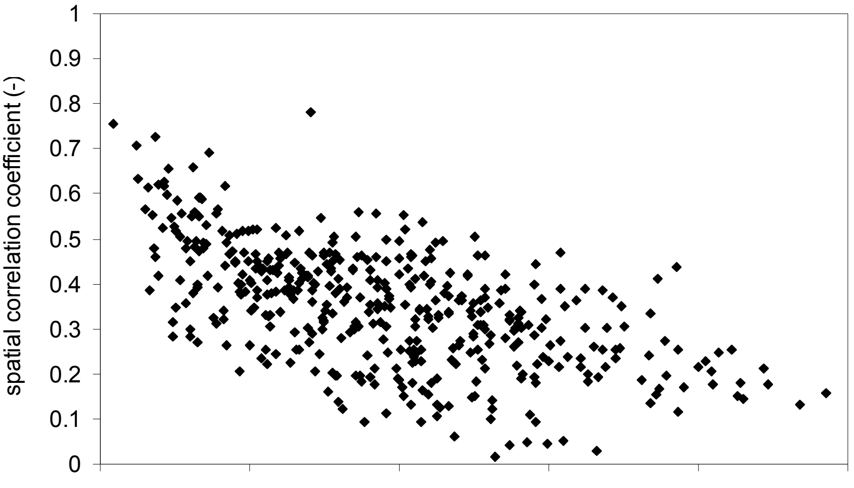

Fig. 4 Spatial correlation coefficient as a function of inter-station distance *h* in km resulting from 30 precipitation series.

The appropriate spatial scale for precipitation at an appropriate temporal scale of 48 h is finally estimated to be 80 km accepting an aggregation error of 10%. This appropriate scale is much larger than the one found by Booij (2002) for Western Europe (20 km), because the latter study focussed on extreme precipitation instead of the current study focussing on average discharge and precipitation behaviour.

CONCLUSIONS

The appropriate temporal and spatial scales of the variables discharge and precipitation were determined for the Red River basin in Vietnam and China taking into account the modelling objective to reasonably simulate average discharge behaviour with a hydrological model. This hydrological model is part of a decision support system for water management and flood control. The appropriate temporal scale for discharge at the outlet of the river basin was found to be 48 h accepting an aggregation error of 10%. The associated appropriate spatial scale for precipitation was about 80 km accepting the same error. This appropriate spatial scale for precipitation would mean a total number of 25 sub-basins in the hydrological model set-up, assuming the spatial variability of precipitation is determining the appropriate model scale. Furthermore, downscaling from climate model scales to hydrological model scales for climate impact assessments seems to be a relatively easy task when considering average discharge behaviour.

Obviously, other appropriate scale combinations may be found when other hydrological behaviour is of interest. For example, it may be expected that, for modelling flood behaviour, smaller temporal and spatial scales are required than the scales found in this study. Analyses similar to those described here can be done to estimate these appropriate scales depending on the research area and modelling objectives.

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