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Evaluating critical rainfall and catchment scale influence on hydrological response in urban areas

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Abstract

Rainfall spatial and temporal variability are key points in the prediction of hydrological response. At the same time, catchment scale and characteristics also play important roles, especially in urban areas, where the high level of imperviousness combined with intense and localised rainfall causes fast responses (Ochoa-Rodriguez et al., 2015). New instruments such as weather radars have been developed in recent decades able to better capture the spatial and temporal variability of storm events. At the same time, large improvements have been made to create high-resolution hydrological models that are able to represent the catchment with a high level of detail. However, the interactions between rainfall and catchment variability and their effects on the hydrological response remains poorly understood. In this work, we aim to evaluate the critical space and time scales that characterize rainfall variability and catchment characteristics in relation to hydrological response in urban areas. Critical scales based on dimensionless parameters developed in a previous work (Cristiano et al, 2018) will be evaluated for two urban areas in different climatological regions, one in Europe and one in the US.

The first catchment is Cranbrook, a small urban area (7 km^2), situated close to London UK (see Cristiano et al. 2018 for more details about the study case). The Little Sugar Creek basin (110 km^2), located in the Charlotte metropolitan area (North Carolina, USA) was chosen as second study case. For this area, local streamflow measurements were available for four locations at temporal resolution of 5 min. The physically - based, fully distributed Gridded Surface Subsurface Hydrologic Analysis (GSSHA) model developed by Wright et al. (2014) was used to simulate the hydrological response. 25 storm events were selected from a 15–year (2001-2016) radar data set, measured at a resolution of 1km^2–15 min resolution by the S-Band radars of the National Weather Service (NWS) Next Generation Radar network (NEXRAD). Rainfall events were then aggregated in space (to 3 km^2 and 6 km^2) and in time (to 30 min and 60 min), to generate 9 combinations of spatial and temporal resolutions. These events were used as input for the hydrological model to obtain the simulated hydrological response corresponding to coarser resolutions.

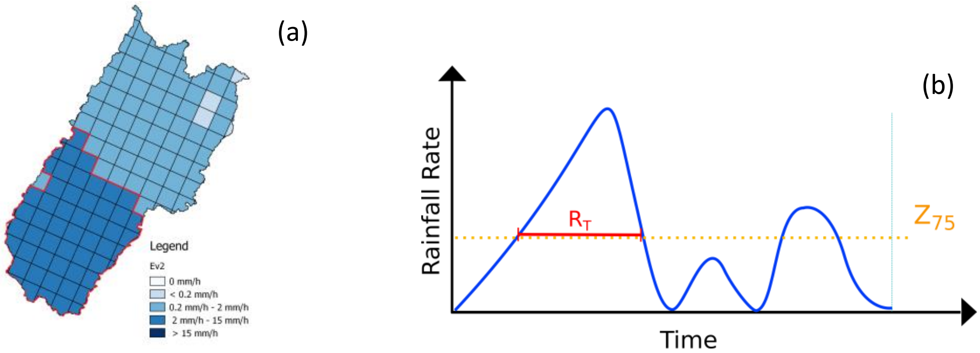

Fig 1: Schematization of spatial (a) and temporal (b) rainfall classification using the cluster identification.

To classify spatial and temporal variability of rainfall, the cluster classification approach proposed by Cristiano et al. (2018) was applied to the selected events. This method, schematized in Fig. 1, considers the 75th percentile of the rainfall intensity of the selected events as threshold and identifies for each time step the main cluster of pixels over the basin above the selected threshold. The cluster dimension at each time step is then averaged over the total event duration. The averaged cluster dimension R_S represents the core of the storm event and gives a good estimate of the spatial variability of the rainfall event. To classify the temporal variability of the storm event, the maximum duration T_w of the storm with an intensity higher than the 75th percentile threshold is considered.

Three dimensionless scaling factors [α_1, α_2, α_3], proposed by Cristiano et al. (2018) are here applied at a larger scale and validated with local measurements. The scaling factors combine spatial and temporal rainfall and catchment scale in relation with the resolution used to measure rainfall. The scaling factor α_1 focuses on spatial variability and relates rainfall spatial scale R_s (square root of the cluster dimension) and catchment scale C_s (square root of the drainage area) to the spatial rainfall resolution Δs. The parameter α_2 relates spatial rainfall scale R_s and temporal catchment scale C_t (estimated using the lag time) to the spatial rainfall resolution Δs and to the temporal rainfall resolution Δt, respectively. The last scaling factor α_3 combines spatial and temporal rainfall scale (R_s and R_t) and spatial and temporal catchment scale (C_s and C_t) to spatial and temporal rainfall resolution (Δs and Δt).

$$\alpha_1 = \frac{R_s}{\Delta s}\frac{C_s}{\Delta s} \qquad \alpha_2 = \frac{R_s}{\Delta s}\frac{C_t}{\Delta t} \qquad \alpha_3 = \frac{R_s C_s}{\Delta s^2}\frac{R_t C_t}{\Delta t^2}$$

Figure 2 shows preliminary results, where the scaling factors are compared to the coefficient of determination R^2. The plots enable identification of thresholds for scaling factor values associated with level of performance given a specific combination of rainfall input resolution. For instance, for values of α_2 larger than 35, a coefficient of determination higher than 0.9 is expected, suggesting a good level of approximation of the hydrological response.

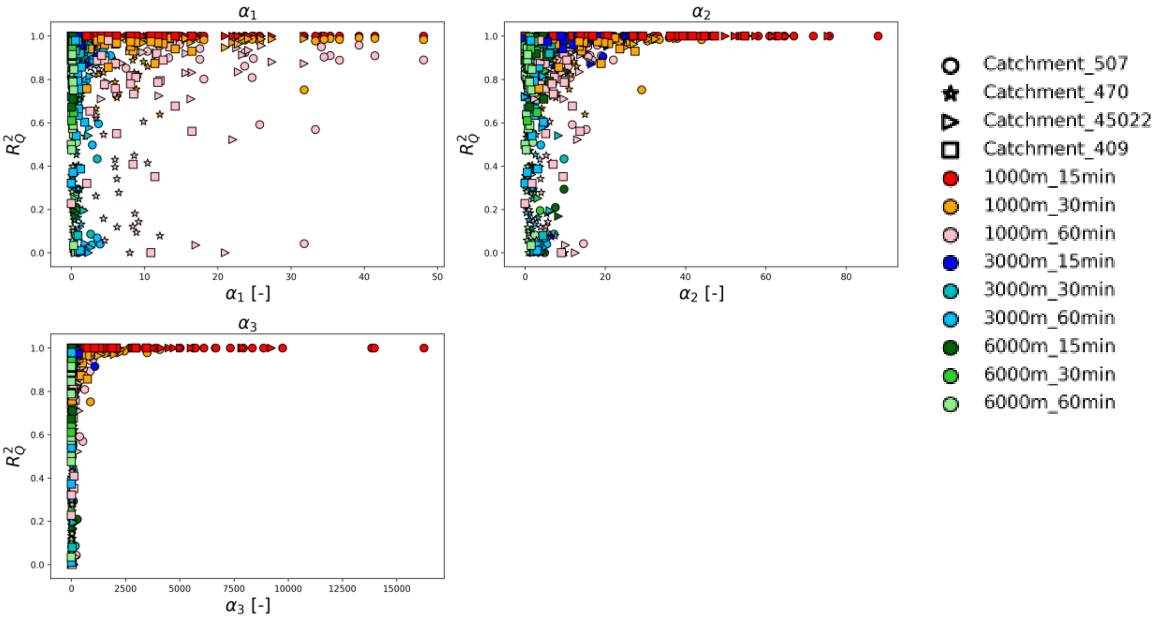

Fig 2: Scaling factors in relation with the coefficient of determination R^2

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