A stochastic spatial-temporal rainfall generator for urban hydrological applications

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Abstract

Traditionally, spatially-uniform rainfall input was largely used in urban hydrological applications. However, recent studies have suggested that the impact of the spatial variability of rainfall on urban catchments should not be neglected, in particular when the drainage area is small. In this sense, the generation of stochastic rainfall details with realistic spatial and temporal characteristics can provide a better basis for urban-scale applications, such as urban pluvial flood risk mapping and urban drainage design.

For this purpose, the development of a stochastic spatial-temporal rainfall generator for urban hydrological applications is proposed in this work. The proposed generator is an extension of the conceptual rainfall model proposed by Willems (2001), which was intended for small-scale applications. The basic idea of Willems' conceptual model is to characterise rain storms with a number of physically-meaningful features (e.g. storm direction and velocity, rain cell extent, peak intensity and so on), and then to describe the statistical properties of each of them with a specific probability distribution. Based upon this, design rainfall with spatial variability can be simulated by firstly sampling a number of rainfall cell clusters over a 'simulation area', and then by moving the overall simulation area across the 'catchment' area with a given speed and direction. However, three main aspects where the model could be potentially improved can be identified:

- The parameters of Willems' model were primarily calibrated based upon point rain gauge data, which could be insufficient to capture the real structure of rain storms and cells.
- The rain cells were conceptualised using bi-variate Gaussian model, which might oversimplify the real structures of small-scale rain cells and consequently smooth off the rain cell peaks.
- The temporal variability of the rain field was due to merely (stationary) field advection, so the temporal evolution of the field itself was not taken into account in Willems' model. This will lead to the 'unrealistic' isotropy in the spatial and temporal scaling behaviours of simulated storms (Seed et al. 1999).

To tackle these deficiencies, the following strategies have been implemented:

- High-resolution radar images (provided by the Royal Meteorological Institute of Belgium) were used to better capture the spatial and temporal characteristics of rainfall fields. However, the use of radar images made the storm cell identification and tracking more challenging, in particular for small-scale rainfall details. To cope with this, a multi-threshold technique based upon the hierarchical threshold segmentation (HTS) method (Peak and Tag, 1994), together with an enhanced version of the TITAN algorithm (Dixon et al., 1993; Muñoz et al., 2015) were developed in this work. With this enhancement, adjacent storm cell clusters at small scales could be better identified, isolated and tracked.
- A multi-layer conceptual model based upon the superposition of different rainfall entities (including high intensity peaks, rainfall cells, and small and large storm scales areas) was adopted. The 'simulation areas' were built by overlapping high intensity peaks within rain cells, which, in turn, were embedded in small mesoscales areas (Fig 1). Rain cells were still modelled using a bivariate Gaussian model. Small mesoscales areas were fitted as ellipses with constant intensity by averaging the whole areal intensity without considering the rain cell singularities.

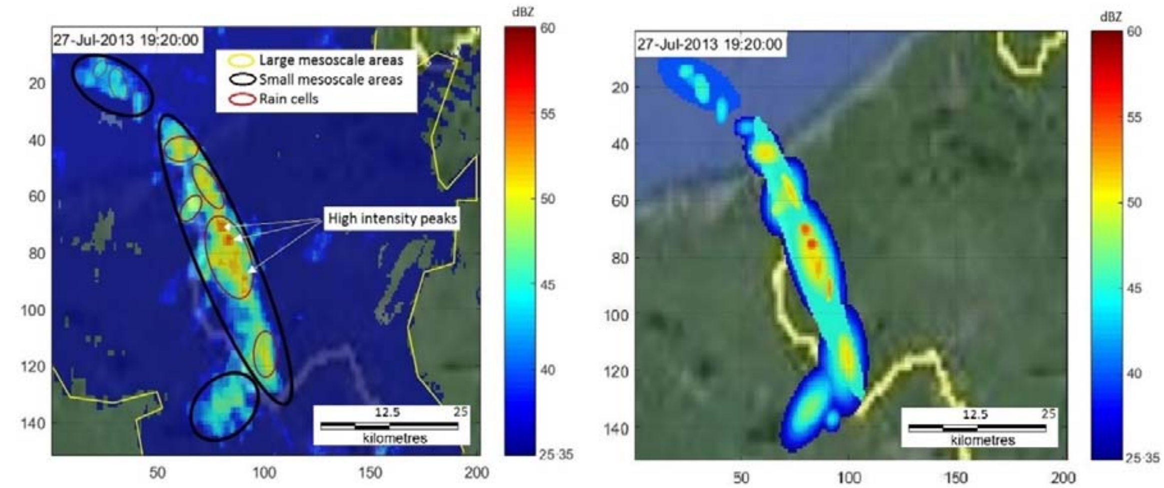

Fig 1: The original radar rainfall image (left) and the conceptualised rainfall image (right).

- Temporal evolution of the rainfall entities was explicitly taken into account by including decay and diffusion processes. Parameters describing evolution of the physical features of the storms were also characterised by using the enhanced TITAN tracking algorithm.

The performance of the generator is currently under evaluation. This is done by comparing the statistical properties of the generated long-term series with the ones from rain gauge records within the study area.

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