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Method for generating spatial and temporal synthetic hourly rainfall in the Valley of Mexico

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Hydrological risk analyses require a dense pluviometer network and a long period of records with an adequate time resolution; usually pluviometer networks have short periods of simultaneous records, so it is required to extend the number of records by means of synthetically generated rainfall events. This paper describes the development and implementation of a method based on a daily rainfall disaggregation for generating synthetic rainfall events distributed spatially and temporally. It uses the information recorded in 49 rain-gauge stations in the network of the basin of the Valley of Mexico during the rainy season from 1988 to 2006. Within various methods found in the literature, we consider that this one provides a greater simplicity for a practical implementation. The tests carried out showed that rainfall events generated with this method properly reproduce the statistical parameters of the historical records, including those that are not implicitly incorporated in the model, as is the case of the synthetic hourly rainfall, whose statistical values are virtually identical to the historical ones despite that the proposed method only uses the probability distribution of maximum daily rainfall.

1. Introduction

Urban hydrology studies for designing drainage systems are based on the analysis of extreme rainfall events (Onof and Arnbjerg-Nielsen, 2009). It is desirable that the design of urban drainage networks be made from an analysis which considers many scenarios, instead of using only one design storm (Molnar and Burlando, 2005); however, in many cases the simultaneous records in rainfall stations are for short periods of time and they are insufficient for a proper analysis of extreme events. In such cases, it is appropriate to extend the records by generating synthetic series, which must satisfy two basic conditions: first, the series should be statistically consistent with the historical ones (Hingray and Ben Haha, 2005), and second, they should have the temporal and spatial resolution required for the study. In the case of hydrodynamic simulation of drainage systems, it is necessary to generate rainfall events with short time intervals, at multiple sites simultaneously covering the region of study (Licznar et al., 2011).

There are several methods for generating synthetic rainfall events described in the literature, which are differentiated by the hypothesis considered; this implies using different sets of parameters, which causes the models to vary in the complexity for their use due to the effort required for processing such parameters; also some of the models may be hyperparametrized as remarked by Bernadara et al. (2007). The time resolution of synthetic data depends usually on the available historical data. Some authors have done a classification of the rainfall generation methods; Arnaud and Lavabre (1999) and Arnaud et al. (2007) specifically addressed the hourly generation models, and grouped them into five categories: 1) daily disaggregation models, 2) models based on the aggregation process, 3) models based on the description of the patterns of

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dimensionless storm intensity, 4) models based on multiplicative cascade processes, 5) and other types of stochastic models. Another type of classification is based on the area covered: 1) rain generators for one site, as proposed by Cernesson et al. (1996) or Arnaud and Lavabre (1999) and 2) multi-site generators, which generate fields of rain simultaneously in multiple sites covering a given area; examples of these models are Mehrotra et al. (2006) and Frost et al. (2011). Vischel et al. (2009) presented a classification similar to Arnaud et al. (2007) based on the hypothesis considered by the models: 1) rain cell models (e.g. Rodriguez-Iturbe and Eagleson, 1987; Salson and Garcia-Bartual, 2003), 2) invariant scale models, as the cascade disaggregation processes proposed by Molnar and Burlando (2005) and Licznar et al. (2011), 3) rainfall multi-site models (e.g. Mehrotra et al., 2006) and 4) meta-Gaussian models (e.g. Bouvier et al., 2003). Vischel et al. (2009) suggest that each model has advantages and disadvantages that must be considered in order to define which of them to use.

Because of interest in this research is focused on the generation of rainfall episodes that can be used for the design and the analysis of the operation of drainage networks, we analyze in more detail the results obtained by Arnaud et al. (1999, 2007), Mehrotra et al. (2006) and by Bouvier et al. (2003), which are oriented to such problems.

Arnaud and Lavabre (1999) and Arnaud et al. (2007) focuses on hyetographs of rainfall episodes selected from daily criteria. From these selected daily episodes, hourly hyetographs were generated based on nine descriptive variables assumed to be independent (average number of episodes per year, number of storms in a rainy period, duration of each storm, average intensity, dry period between successive storms, etc.). The authors found that compared with the Gumbel distribution function fitted to the observed data the model overestimate maximum annual rainfall for return periods over 10 years, particularly for the 24 h rainfall. They consider that this discrepancy is primarily due to the persistence modeling of storms within an episode. In our opinion, the principal flaw of the method is that the events generated do not take in to account the spatial dependency of the rain at the 50 stations considered, this is an important aspect as is discussed in Section 4, were we show the correlation of rain as a function of the distance.

Mehrotra et al. (2006) compares three models to generate continuous simultaneous daily rainfalls in 30 stations. They found that the Wilks (1998) model was the best of the three models, based on the overall performance, time calculation and the simplicity of its structure. Unfortunately they only evaluate the spatial dependence for rainfall occurrence at each pair of stations, but not for the corresponding magnitudes.

Bouvier et al. (2003) performed a principal component analysis of the historical daily rainfall fields in order to separate its temporal distribution and the spatial correlation. Their method reproduces quite well the characteristics of the fields which did not serve as input of the model, as the cumulative distribution function of the local rainfall depths, surfaces covered by isohyets 10, 20, 30 mm, etc. Although the study was done for daily rainfall, the model can be applied to different duration intervals, lower or larger than a day. The reason this method cannot be utilized for detailed hydrological analyses is because it is not designed to simulate the continuous series of rainfall that preserve a similar spatial–temporal variation as historical storms. A measurement of this characteristic is the autocorrelation between rainfall depths at consecutive hours for every rain-gauge station, which is not well reproduced by Bouvier et al. (2003) method.

The aim of the research presented, is to extend to the case of hourly scale rainfall events a method for generating synthetic daily rainfall first introduced by Dominguez-Mora et al. (2013). We utilize a disaggregation method of daily rainfall based on the spatial and temporal distribution of historical rainfall fields recorded in resolution more frequent than daily. The proposed method assumes that the generated synthetic rainfall has the same temporal resolution as historical records (1 h for this analysis, but this method can be applied to any other time interval, if there is historical information available). Subsequently we verify whether the synthetic rainfall generated is statistically equivalent to the records of historical rainfall and, if this goal is not properly reached, to make appropriate modifications for obtaining the statistical equivalence for the set of historical storms and synthetic ones.

The structure is as follows, Section 2 describes the rain database and the criteria for selecting storms to be utilized in the study. The method for generating synthetic rainfall with a daily scale and its disaggregation in hourly rainfall is presented in Section 3 where it is also demonstrated that when the original approach of dividing the set of historical rainfall into two subsets as proposed by Dominguez-Mora et al. (2013) was extended to the hourly scale the results shown some shortcomings, and the modification to the method is described. In Section 4 a discussion of the results is done. Conclusions are presented in Section 5.

2. Rain data

Rainfall data is obtained from 49 automated rain-gauges located in the area of Mexico City, as shown in Fig. 1. This zone has an average elevation of 2240 m.a.s.l. and is surrounded by mountains with peaks higher than 3000 m. The network consists on typing bucket rain-gauges located within a rectangle 55 km high and 45 wide, which has been utilized in other studies (Bouvier et al., 2003); it has an average density of one rain-gauge every 50 km^2. Gauges operate continuously; their power is provided by the network and they have back up batteries in the case of network electricity interruptions. The rain is mainly concentrated in the months from July to October, when near 80% of annual rainfall occurs. Most of the storms are of convective type, very concentrated in time and space, but some ones cover all the area with durations of several hours. Hourly rainfall data is collected since 1988, when the network started to operate with some issues; it is after 1993 when the network operates properly, and that is the reason why the continuous data considered for the study starts that year; however, the event with maximum precipitation ever recorded in the area occurred during 1988, data obtained from the automated rain-gauges was considered also for the study and validated with measurements recorded by an older, non-automated network.

The storms for years 1988 and 1993–2006 selected for analysis satisfy any of the following conditions:

1. The daily rainfall in any of the 49 stations is greater than 60 mm.