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Publication Date:
2019

Permanent Link:
https://doi.org/10.3929/ethz-b-000347606

Reproducing extreme statistics of hourly and sub-hourly rainfall with Bartlett-Lewis models: Some tips and new developments

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Abstract

Stochastic rainfall modelling with a Bartlett-Lewis (BL) process has been widely used to generate long rainfall times series for hydrological applications. However, as highlighed in the literature, it still remains challenging for this type of models to well preserve extreme rainfall statistics, particually at hourly and sub-hourly timescales (Verhoest et al., 2010). This limits its use for hydrological applications that require high-resolution rainfall input, such as urban drainage design. Many developments have been proposed to address the above issue since the basic BL model proposed in 1987 (Rodriguez-Iturbe et al., 1987). These developments mainly focused upon improving the way BL models are fitted and their fundemental model structrue.

In terms of model fitting, it has been found crucial to include the coefficient of skewness (or 3rd-order moment) of rainfall depths at relevant timescales into the objective function for modelling fitting (Cowpertwait, 1998). In addition, the way of estimating the selected statistics from data for model fitting was found to have a great impact on the models' ability to preserve extreme statistics (Cross et al., 2018; Wang et al., 2018). For example, Cross et al. (2018) demonstrated that BL models' capacity of preserving fine-scale extremes can be effectively improved through a censored approach which restricts part of the rainfall signal that is modelled prior to statistics estimation.

In terms of model structure, a number of research works have focused upon testing other probability distributions (e.g. Gamma and Generalised Pareto distributions), different from the exponential distribution used in the basic BL model, for rain cell intensity modelling (Onof and Wheater, 1994; Cameron et al., 2000). This has proven to partially improve BL models' performance in preserving extreme statistics. The second group of research works focused upon adjusting the characterisation of rainfall cells in these models (Cowpertwait et al., 2007; Kaczmarska et al., 2014; Ramesh et al., 2017). For example, Kaczmarska et al. (2014) adjusted the original rectangular pulse rain cell model by allowing mean cell intensity to vary in proportion to the cell duration parameter. This simple yet effective adjustment has proven to largely improve BL models' ability to reproduce fine-scale rainfall structures.

In addition to testing and further exploring some of the above-mentioned recent developments, in this paper we would like to draw the attention to a comment made in the original publication of the randomised BL (RBL) model but ignored in the subsequent research. That is, an erroneous assessment of the mathematically feasible limits of a BL model parameter has potentially led to many sub-optimal parameters in past publications. Addressing this issue properly may improve the reproduction of extremes. More specifically, we re-assess the convergence condition of integrals needed to obtain the key theoretical statistical properties (e.g. mean, co-variance and skewness) for BL models: their convergence conditions determine the degree of 'flexibility' of BL models.

In this paper we show that the integrals' domain of convergence is somewhat larger than originally appears to be the case, although different expressions are required to enable this relaxation of the convergence conditions. We then apply this new development to the RBL model proposed by Kaczmarska et al. (2014) (denoted as RBLx) and prove that the original convergence condition can

be relaxed. Five-minute rainfall data from a total of 3 rain gauges in Germany – Bochum (69 years), Nettebach (49 years) and Aplerbeck (49 years) – are used to test this new constraint. The results suggest that the proposed changes can improve RBLx model's ability to reproduce hourly and sub-hourly extreme statistics obtained from the observed rainfall records (see Fig 1).

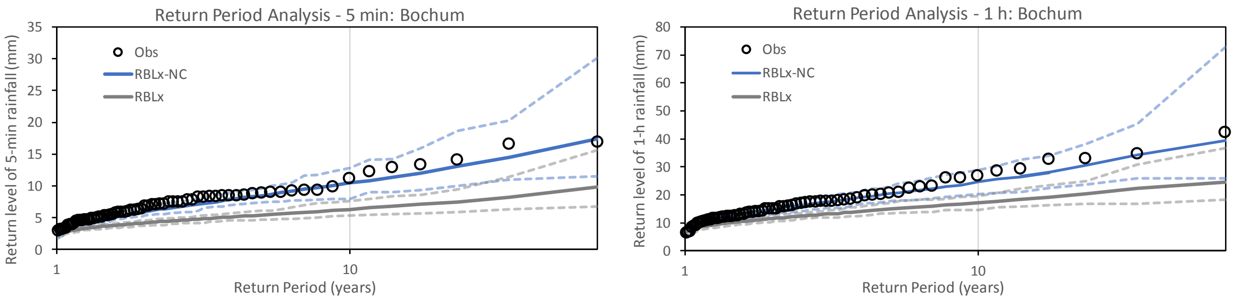

Fig 1: Observed (circle markers) and simulated (grey and blue lines) rainfall extremes at 5-min (left) and 1-h (right) at Bochum, where RBLx represents Kaczmarska's model and RBLx_NC represents RBLx model with new constraint. The solid and dashed lines are the means and the maxima/minima of 100 simulations, each of 69-years.

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