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Investigating the variation and non-stationarity in precipitation extremes based on the concept of event-based extreme precipitation

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ABSTRACT

Extreme precipitations (EP) could induce a series of social, environmental and ecological problems. Traditional EP analysis usually investigated the characteristics based on a fixed time scale and therefore ignored the continuity of EP occurrence. As a result, a comprehensive assessment on the influence and consequence of the EP occurring during consecutive time periods were largely eliminated. On the other hand, the characteristics of EP, including variables such as frequency, intensity and extreme volume, were commonly defined without sufficient consideration of the local tolerance capacity (which can be represented by a threshold level of EP) and therefore would sometimes be inappropriate. In this study, we proposed a concept of event-based extreme precipitation (EEP) by considering the continuity of EP and defined the statistical variables for the characteristics of an EEP event by taking account of local tolerance capacity. An EEP was identified as a collection of precipitation data over the consecutive time period in which all the precipitation amounts are above the pre-defined threshold, and EEP events are separated by at least one time step (e.g., day or hour) with precipitation amount below the threshold. As a case study which in fact motivated our proposal, we investigated the changes and variations of EEP with the consideration of potential non-stationarity in the Hanjiang River Basin of China (HJRB) during the time period of 1960–2013. Results showed that the concept of EEP, which could reflect the impact of continuity of EP occurrence and mirror the differences of local tolerance capacity, was more appropriate than the traditional method in the EP analysis.

1. Introduction

The analysis of extreme precipitation (EP) has received considerable attention, mainly due to its implications for hazard assessment and risk management (Easterling et al., 2000; Beguería et al., 2011). As shown by both observations and climate model simulations, EP increased under a warming climate (Zhai et al., 2005; Goswami et al., 2006; Mishra et al., 2012; Ali et al., 2014). The projections of precipitation patterns by the Intergovernmental Panel on Climate Change (IPCC) Fifth report, resulting from climate change, usually suggested that the intensity of EP would increase with atmospheric temperature at a faster rate (~7% °C^{-1}) than average precipitation (1–3% °C^{-1}) at the global scale (Stocker et al., 2013; Rajah et al., 2014).

A precipitation event is defined as an EP when its amount exceeds a certain threshold (Bell et al., 2004). The determination of threshold is a key factor in the generation of EP series. Du et al. (2013) grouped the methods of threshold determination into three categories: the fixed value method, the standard deviation method and the percentile-based method. In practice, the percentile-based method were widely used in many regions over the world because of its efficiency and simplicity (Bell et al., 2004; Wang and Zhou, 2005; Du et al., 2013). In most cases, the EP was based on the 90th (Gemmer et al., 2011), 95th (Bell et al., 2004; Zhai et al., 2005), 97.5th (Wang and Zhou, 2005) or 99th (Gemmer et al., 2011) percentiles of daily precipitation data, which represent moderate to extremely unusual events and were

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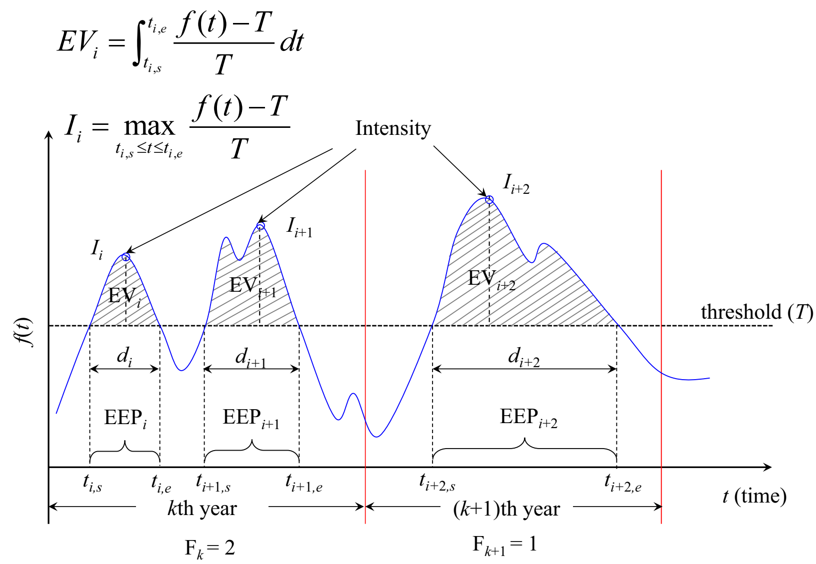

Fig. 1. The illustration of the EEP concept. The $f(t)$ represents for the precipitation amount at time t. The definition of frequency (F), intensity (I), extreme volume (EV) of event-based extreme precipitation (EEP) events. (Note: d_i represents the duration of a single EEP, which corresponds to the time interval of EEP event.)

demonstrated to be appropriate in various regions (Alexander et al., 2006; Ghosh et al., 2012; Vittal et al., 2013). Three indicators, i.e., frequency (F), intensity (I) and extreme volume (EV), are often used to describe the characteristics and detect the trends of EP. Usually, frequency is defined as the number of EP per year, intensity is referred to the peak precipitation amount. However, Du et al. (2013) argued that the commonly used intensity definition would be inappropriate sometimes, and hence proposed a modified intensity index by considering the local tolerance capacity (i.e., threshold), which was defined as the value of the precipitation amount exceeding the threshold divided by the corresponding threshold. They expected that, by comparing the EP events with different thresholds and precipitation amount, the modified index was more suitable than the usually used one.

On the other hand, the continuity and duration of EP should also be addressed in the definition of the characteristics of EP. For example, consider two EP events with the same total precipitation amount under the threshold of 70 mm and assume that the first event has EP occurring in a single day with precipitation amount of 240 mm and the second event has EP occurring in three consecutive days with precipitation amount of 80 mm in each day. In general, the first event might cause a flash flood, while the second one may also induce a heavy flood through the cumulative runoff generation. In most studies, the EP was considered only on the single daily scale, and the event like the second one was commonly treated separately as three single EP events and, as a result, its impact might be neglected or weakened because the daily precipitation amounts are not so large when the continuity of EP occurrence is ignored. Vittal et al. (2013) defined the EP in term of clusters, i.e., a cluster of EP was identified as successive days when daily precipitation was above the respective threshold, and clusters were separated when there was at least a single day between them with precipitation amount below the threshold. However, the intensity and extreme volume in their study still did not consider the influence of local tolerance capacity and the volume is not sufficiently considered. Therefore, the characteristics of EP should be better defined with the consideration of the local tolerance capacity (i.e., threshold) and also the continuity of EP event period.

With respect to the frequency analysis for extreme characteristics, various distributions were used in modelling extreme hydroclimatological extreme series such as extreme value distributions (Moberg and Jones, 2005; Alexander et al., 2006; Xia et al., 2011), Extended Burr XII distribution (Shao et al., 2004) and Pearson III distributions (Griffis and Stedinger, 2007). As the EEP was determined by a threshold, the generalized Pareto distribution, as a peak-over-threshold distribution, was selected in analyzing the EPP characteristics in the case study of this paper.

The stationarity, i.e. the statistical properties of a process not changing over time, was implicitly assumed in frequency analysis (Beguería et al., 2011). However, in the context of climate change, such stationarity would no longer hold and the results by traditional frequency analysis would become doubtful (Khaliq et al., 2006; El Adlouni et al., 2007). Therefore, the traditional frequency analysis under the stationarity assumption, which implies the absence of trends, shift and periodicities (Villarini et al., 2010), might not be appropriate to simulate the extreme series under a changing statistical characteristics (e.g., mean and variance) over time.

To deal with the underlying non-stationary effect, some studies made the distributional parameters to be time-dependent by using the time as a covariate (Kharin and Zwiers, 2005; Towler et al., 2010). However, the functional relationships between parameters and the time need to be specified as a priori, and such information might not be available or persistent over time due to the complexity of climate system (Kao and Ganguly, 2011; Ghosh et al., 2012). Alternatively, the distributional parameters were estimated separately for a series of Y-years moving window, rather than for the entire extreme series (Kao and Ganguly, 2011; Ghosh et al., 2012; Vittal et al., 2013). A choice of 30 years of window size was recommended by Kao and Ganguly (2011) considering that it was expected to smooth out the effects of most multi-decadal climate oscillators and providing more confidence for low frequency extremes (Kharin et al., 2007). This method has been proved to be an effective way to cope with the potential nonstationarity probably existed in the extreme series.

In this paper, we proposed the concept of event-based extreme precipitation (EEP) to eliminate the influence of local tolerance capacity (i.e., threshold) and simultaneously consider the continuity of EP occurrence in the EP analysis. The thresholds of EEP in each station were determined by the percentiles method. We would also define the characteristics of EEP (i.e. the variables of frequency, intensity and extreme volume) in this paper, and detect