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Extreme rainfall events: Learning from raingauge time series

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Summary This study analyzes the historical records of annual rainfall maxima recorded in Northern Italy, cumulated over time windows (durations) of 1 and 24 h and considered paradigmatic descriptions of storms of both short and long duration. Three large areas are studied: Liguria, Piedmont and Triveneto (Triveneto includes the Regions of Veneto, Trentino Alto Adige and Friuli Venezia Giulia). A regional frequency analysis of annual rainfall maxima is carried out through the Two Components Extreme Value (TCEV) distribution. A hierarchical approach is used to define statistically homogeneous areas so that the definition of a regional distribution becomes possible. Thanks to the peculiar nature of the TCEV distribution, a frequency-based threshold criterion is proposed. Such criterion allows to distinguish the observed ordinary values from the observed extra-ordinary values of annual rainfall maxima.

A second step of this study focuses on the analysis of the probability of occurrence of extra-ordinary events over a period of one year. Results show the existence of a four month dominant season that maximizes the number of occurrences of annual rainfall maxima. Such results also show how the seasonality of extra-ordinary events changes whenever a different duration of events is considered.

The joint probability of occurrence of extreme storms of short and long duration is also analyzed. Such analysis demonstrates how the joint probability of occurrence significantly changes when all rainfall maxima or only extra-ordinary maxima are used.

All results undergo a critical discussion. Such discussion seems to lead to the point that the identified statistical characteristics might represent the landmark of those mechanisms causing heavy precipitation in the analyzed regions.

Introduction

In regions characterized by complex orography, topographic forms can trigger rain storms by extracting atmospheric

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moisture through orographic precipitation mechanisms (Smith and Barstad, 2004). Therefore, it is not surprising how the monitoring and the analysis of precipitation, intended to get a better understanding of the underlying physical processes, have always been central to meteorology and climatology in areas with complex orography (e.g., Buzzi and Foschini, 2000; Garrido et al., 1994; Obled et al., 2002). So far literature has highlighted how, despite the fact that local regions are close to one another when compared to the scale of the synoptic domain, differences exist in the large-scale circulation, interacting with the meso-scale local features, thus triggering heavy precipitation events (Mamassis and Koutsoyiannis, 1996; Rotunno and Ferretti, 2001; Rudari et al., 2004, 2005). Such consideration seems to suggest that different forcing mechanisms can influence the statistical properties of extreme rainfall obtainable from raingauge records.

At the beginning of this study there is the assumption that the ground effects, produced by a rainfall event, is strongly related to its observed frequency (Siccardi et al., 2005). The distinction between ordinary and extra-ordinary rainfall events cannot be based only on their absolute magnitude but also on the probability of exceedence of the observed values.

Moving from such consideration this study focuses on the statistical analysis of maximum value H_d of the series of rainfall depths cumulated over different durations, d, recorded in a given period of time (in this study case one year). The main problem in studies focusing on rainfall extremes is the identification of objective and statistically significant methods able to restrict the analysis to the events of interest. The most common approach is to analyse those events with recorded tangible impacts on the social community, or events characterized by a particular interest either in their synoptic development or in their spatial and temporal extension (e.g., Buzzi et al., 1998; Doswell et al., 1998; Rotunno and Ferretti, 2001). Therefore, the analysis is usually confined to a very limited set of events, hardly suitable to infer general characteristics. However, the extension of the database is possible. Such extension can be carried out by identifying all the events that objectively belong to one particular class, i.e., extra-ordinary rainfall events.

The first task of the study is to identify an objective criterion that can effectively separate ordinary from extra-ordinary events. The use of the Two Components Extreme Value (TCEV) distribution as Cumulative Distribution Function (CDF) for H_d is suggested. This allows the definition of a frequency-based criterion to single out extra-ordinary events, where ''event'' takes from now on the meaning of ''occurrence of H_d'', for at least one of the durations d considered. In fact, the derivation theory of the TCEV distribution (see Rossi et al., 1984) is based on the analytical evaluation of the probability that H_d belongs to the ordinary or to the extra-ordinary component of the distribution.

The second task is to carry out specific analysis on the identified extra-ordinary events. Two aspects are especially analyzed in this study. The first regards the seasonality of extra-ordinary H_d values. If the probability of H_d to be extra-ordinary changes with statistical significance in a particular period of the year, it becomes possible to infer that one specific 'ingredient' or 'mix of ingredients', necessary to produce such events, are available more frequently in that period for that specific area. The second regards the joint probability of occurrence of short- (d = 1 h) and long-duration (d = 24 h) H_d.

A first result is that, for the analyzed region, statistically significant differences in the probability of exceedence of extra-ordinary H_d can be observed during different seasons of the year. This could help the scientific community to identify a set of conditions leading to extreme events and to the relative importance each single meteorological 'ingredient' has in determining extreme precipitation over each individual region, thus improving the predictability of extreme events.

A second significant result is that, when an extra-ordinary H_d occurs for at least one of the durations d, the joint probability of occurrence of one or more H_d for other durations d during the same day, is significantly higher than when an ordinary H_d occurs. When statistically significant low or high joint probabilities of occurrence are found, they can lead to physical considerations about the different or similar nature of these two classes of events, which often cause dramatically different effects from the hydrological point of view.

The paper is organized as follows: second section introduces the methods used in the analysis, third section describes the analyzed area and the data sets used in the study. In fourth and fifth sections the results are presented and discussed. sixth section draws up the conclusion of the study.

Methods for data analysis

According to Rosso and Burlando (1996), the definition of rainfall annual maxima H_d and some statistical tools useful for their analysis are introduced in a rigorous mathematical framework.

Consider $X(t)$ a random variable describing a continuous process of point precipitation, such as the rainfall rate at time t measured at a point in space through a raingauge station.

The cumulated rainfall recorded over a given time interval can be defined as:

$$X_d(t) = \int_{t-\frac{d}{2}}^{t+\frac{d}{2}} X(\xi)\, \mathrm{d}\xi \tag{1}$$

In the present case $X_d(t)$ represents the rainfall depth measured by the raingauge station over a duration d and depends on both the duration d and location t along the time axis. Since the stress is on the statistical characterization of extreme storms on annual basis, the maximum depth of rainfall which is recorded in a given period of time τ = 1 year must be considered:

$$H_d = \max[X_d(t) : t_0 < t < t_0 + \tau] \tag{2}$$

This random variable H_d represents the recorded maximum of annual rainfall depth and it is parameterized by the examined duration d.

As previously mentioned, the Random Variable ''maximum rainfall depth over a duration d recorded during one year'' is hereinafter referred to by using capital H_d. The