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An exploratory study of spatial annual maximum of monthly precipitation in the northern region of Portugal

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ABSTRACT

Adequately analyzing and modeling the extreme rainfall events is of great importance because of the effects that their magnitude and frequency can have on human life, agricultural productivity and economic aspects, among others. A single extreme event may affect several locations, and their spatial dependence has to be appropriately taken into account. Classical geostatistics is a well-developed field for dealing with location referenced data, but it is largely based on Gaussian processes and distributions, that are not appropriate for extremes. In this paper, an exploratory study of the annual maximum of monthly precipitation recorded in the northern area of Portugal from 1941 to 2006 at 32 locations is performed. The aim of this paper is to apply max-stable processes, a natural extension of multivariate extremes to the spatial set-up, to briefly describe the models considered and to estimate the required parameters to simulate prediction maps.

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1. Introduction

Taking into consideration extreme rainfall events on a regional basis is of upmost importance for various purposes such as planning and predicting floods and other disasters. For the farmers as well as the population in general it is important to be aware of the risks associated with a given extreme event in that region. The electricity producers are another sector that could benefit with this knowledge since it allows an optimum operation of hydro-electric structures or water reservoirs.

Quantifying and characterizing the behavior of environmental phenomena such as precipitation levels, wind speed, or daily temperatures, when data is collected in specific locations, is a topic of enormous importance. A single extreme event may affect several locations, and their spatial dependence has to be appropriately taken into account. In light of recent concerns over climate change, the use of robust mathematical and statistical methods for such analyses has grown in importance. Statistics of extreme events for spatial settings has shown a great development in recent years with an increasing number of studies, see Brown and Resnick (1977), Davison et al. (2012), Kabluchko et al. (2009), Olinda et al. (2014), Reich and Shaby (2012), Schlather (2002) and Smith (1990), to mention only a few.

Classical geostatistics, mostly based on multivariate normal distributions, is inappropriate for modeling tail behavior. Extending well-developed tools of univariate extremes to model spatial extreme data is an active area of research. One of the challenging issues in spatial extreme value modeling is the need for using spatial extreme value techniques in high dimensions. Several statistical tools, among which we will only refer to the spatial max-stable processes, have been used in the most recent decades for modeling spatial extreme data. Max-stable processes appeared as natural models for spatial extremes. Different spectral characterizations of max-stable processes exist, namely those by de Haan (1984) and Schlather (2002).

The purpose of this work is to initiate the study of a real data set of annual maximum of monthly precipitation data, collected from 1941 to 2006 in several locations of northern Portugal, the region where extreme values of precipitation need to be careful studied because of the associated risks. Applications to rainfall data have been done recently by Smith and Stephenson (2009), Padoan et al. (2010) and Davison et al. (2012), to mention only a few.

In the region of Portugal chosen for this study a few studies have appeared from which we would like to mention a large study, Belo-

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Pereira et al. (2011), comparing four global gridded data sets. Ordinary kriging have been applied and the spatial distribution of the mean annual precipitation was captured. Our interest here is to model and to predict extreme precipitation, so the Gaussian approach used in that study and other similar ones, is not adequate because the interest is on the tail of the distribution.

We begin with an exploratory analysis highlighting some of the peculiarities of the data, a brief theoretical bases for the max-stable Schlather (2002) and Smith (1990) processes is sketched and an application of the theoretical procedures is performed in Section 3 to extreme precipitation data. Predicted simulated maxima values in the region under study are displayed.

2. Material and methods

2.1. The study area and the available data

Portugal is located on the southwesterly part of the Iberian Peninsula and is influenced by the Atlantic and Mediterranean climatic zones. It shows different spatial precipitation distribution along its territory. The mean annual precipitation varies from more than 2800 mm, in the northwestern region, to less than 400 mm, in the southern region, following a complex spatial pattern (N–S/E–W) (Fig. 1-left), in close connection with the relief, far beyond the most determinant factor of the precipitation pattern (Santos et al., 2010).

In a previous study by Moreira et al. (2014) three clusters were defined in Portugal regarding precipitation variability as a result of applying a Principal Component Analysis (PCA) to the Standardized Precipitation Index (SPI) followed by a K-means clustering of the Principal Components (PCs) loadings provided by the PCA. From the PCA, two PCs were retained, which were submitted to the varimax rotation. The first component, with the highest loadings in the north, explains 46% of the total variance and the second one, related to the south, explains 37.3%. Both components explain 83.3% of the total variance (Martins et al., 2012). The K-means clustering of the loadings of these two PCs shows three significantly different regions within Portugal relative to precipitation variability, thus separating the north from the center and the south sub-regions, see Fig. 1.

In that classification, cluster 1 is the region of Portugal showing the highest precipitation values caused by the ocean influence and mountainous characteristics. It is very important to adequately modeling the spatial pattern of the maximum rainfall values in order to help populations for being prepared for the risks associated to natural disasters caused by those extreme rainfall events. There exist 32 meteorological and rainfall stations identified in Fig. 1, well covering the whole region under study, so it just makes sense to perform a spatial extreme analysis of the maximum precipitations values, collected in those stations.

The data are compiled from the Portuguese Institute of Ocean and Atmosphere and the National System of Water Resources Information, managed by the Portuguese Institute for Water database. At those 32 stations in cluster 1, the total monthly precipitation is available from 1941 to 2006 (actually we would prefer to deal with daily precipitation but these data are not available). So in each year and location we will consider the annual maximum of total monthly precipitation. Our data set is then a matrix of 66×32 values. Fig. 2 and Table 1, identify the stations where data have been collected. In Fig. 2 the stations are enumerated in its respective locations, (long, lat). Fig. 2 was prepared to be used again in Section 3 to define a grid for the simulations.

In a previous paper, Neves and Gomes (2011) presented a preliminary study of the annual maximum of daily rainfall in the same region. However only a few locations and years were available for that study, surprisingly there are many missing daily records in more recent years and several stations. So in this work we decided to use other information available, i.e., the total monthly amount recorded during 66 years in a larger number of stations.

All the analysis will be performed in the R environment through some available functions in packages for extreme value theory and spatial extreme analysis, mainly *evd*, *ismev* and *SpatialExtremes* packages. *SpatialExtremes* (Ribatet et al., 2013), includes now the most used max-stable models and several functions that allow the associated analysis.

2.2. A brief theoretical background on spatial extreme models

The analysis of spatial extreme data lies at the intersection of two branches of statistics: extreme value analysis and geostatiscs. Let us mention a couple of books in each field, which present very good overviews. For extreme value theory we refer to Coles (2001),

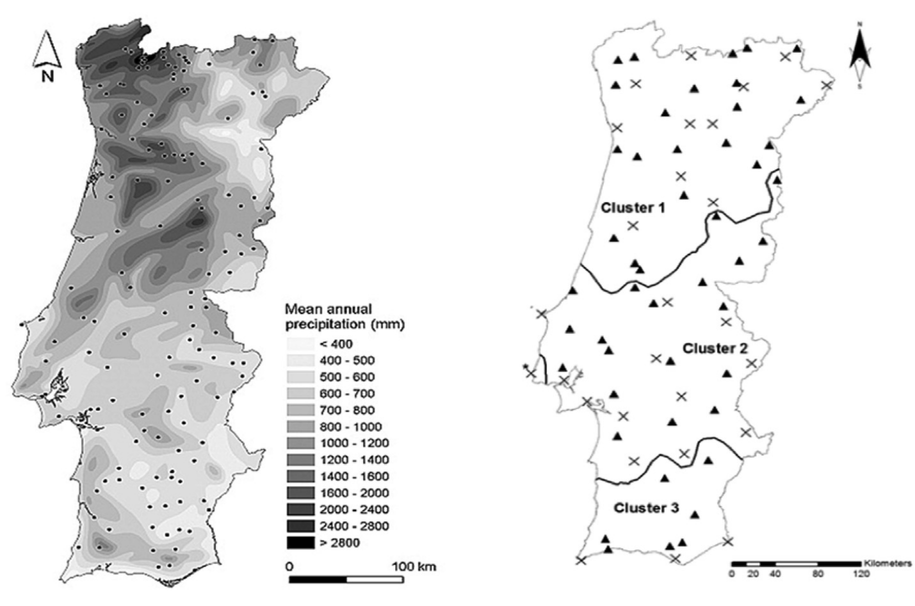

Fig. 1. Mean annual precipitation in Portugal mainland (left), from Santos et al. (2010) and clusters of precipitation variability (right), from Moreira et al. (2014).

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