



European dry spell regimes (1951–2000): Clustering process and time trends



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ABSTRACT

Aiming to improve the knowledge of droughts in Europe, three indices related to dry spells, DS, regime have been analysed: the number of DS per year, N ; the longest annual DS, L_{\max} ; and the mean DS length per year, L , for different daily rainfall thresholds (0.1, 1.0, 5.0 and 10.0 mm/day) at annual and seasonal scales. The database consists of daily records from 267 rain gauges, along the years 1951–2000. First, the mean values at annual and seasonal scales of these three indices are represented for the four thresholds. For 0.1 and 1.0 mm/day, spatial patterns suggest a strong N–S gradient for latitudes south of 45°N, especially at annual scale and in summer season. For 5.0 and 10.0 mm/day, the patterns are different, with a strong gradient in the Scandinavian Peninsula and the largest L_{\max} and L at NE Europe, except for summer. Second, a principal component analysis, PCA, is applied to the 60 variables (three indices at five time scales and four thresholds) characterising the DS regime of every gauge. A clustering process leads to a classification of the 267 rain gauges into 20 spatial clusters, on the basis of five selected principal components replacing the original variables. Most of clusters are spatially coherent, with greater spatial variability on DS regimes towards the south and west than to the north and east of Europe. And third, time trends on the three indices are quantified by the Kendall-tau algorithm, and statistical significances at 95% confidence level are assessed by the Mann–Kendall test. For all thresholds and seasons, there is a clear predominance of significant negative trends for N . Specifically, the highest number of rain gauges with significant negative trends corresponds to summer and winter, with average percentages from -2.7 to -8.1% per decade. In summer, significant negative trends are observed in Western Europe at 40°–60°N and between 10°W and 20°E. In annual and winter periods, negative trends are detected also at Western Europe for 0.1 and 1.0 mm/day and at latitudes south of 45°N for the two highest thresholds. Spring, and especially autumn, are characterised by a low number of negative trends, particularly for 1.0, 5.0 and 10.0 mm/day. In summer, L_{\max} depicts remarkable positive trends in Western Europe, at 40°N–60°N and between 0°E and 20°E, with high average values close to $+10\%$ per decade. Positive trends on L are dominant at annual scale and winter for 0.1 mm/day, and in summer for 0.1 and 1.0 mm/day, with average trends ranging from $+4.8$ to $+8.1\%$ per decade. Spring and autumn are characterised by numerous negative trends on L for all thresholds.

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1. Introduction

Water resource management is a key factor to achieve the success on the economy and development of a country, intending to mitigate the effects of severe droughts. As a result

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of the increase in anthropogenic greenhouse gas concentrations, numerous studies on climate change have found an important tendency towards a global warming in the last decades (Trenberth et al., 2007), with changes in precipitation regimes (Zhang et al., 2007; Min et al., 2011) as also in storm tracks (Pinto et al., 2007; Ulbrich et al., 2009). As a main consequence, more frequent droughts affecting wider areas of the world are to be expected in the next future (Trenberth et al., 2007; Helldén and Tottrup, 2008; Mishra and Singh, 2010). Nowadays, droughts and associated food crises are already a serious problem in many places of the world. As an example, close to 14 million people in Ethiopia, Kenya, Somalia and Uganda have been affected in 2011 by these severe environmental problems, and drought episodes, even without considering collateral effects, concerned 3 million people in Niger (Balint and Mutua, 2011; Guha-Sapir et al., 2012; Dutra et al., 2012; Viste et al., 2012).

Several methodologies have been developed and applied to study droughts along the last decades, as summarised by Serra et al. (2013) and references therein. Some of these methodologies have been applied to drought analyses for Europe (Lloyd-Hughes and Saunders, 2002; Klein Tank and Können, 2003; Bordi et al., 2009; Serra et al., 2013) and particularly for the Mediterranean region, where droughts are nowadays frequent and severe (Douguédroit, 1991; Anagnostopoulou et al., 2003; Brunetti et al., 2004; Serra et al., 2006; Vicente-Serrano, 2006a,b; Livada and Assimakopoulos, 2007; Lana et al., 2006, 2008a,b; Diodato and Bellocchi, 2008; Nastos and Zerefos, 2009; García-Ruiz et al., 2011, among others). The change on frequency and spatial extent of droughts is also projected along this century, with more detectable variations in their extremes than in their means (Sheffield and Wood, 2008). Detailed projections for Europe and the Mediterranean region confirm this worldwide estimate (Lehner et al., 2006; Kundzewicz et al., 2006; Beniston et al., 2007; Giorgi and Lionello, 2008; Hertig and Jacobeit, 2008; Heinrich and Gobiet, 2012). The identification of the most vulnerable zones to future droughts should allow the application of the right policies in order to improve water management, to prevent hydrological stress on the environment and permit development of human activities.

The objective of this study is to analyse the spatial and temporal behaviour of dry spells, DS, in Europe, bearing in mind that long DS may induce drought. A DS is defined as a set of consecutive days with daily precipitation amounts below a threshold. Three indices are evaluated: the number, N , the maximum length, L_{\max} , and the average length, L , of DS for four different thresholds and at annual and seasonal scales. The mean values of these magnitudes are spatially represented to detect regions with the driest conditions. In order to summarise all the information given by these variables, a principal component analysis, PCA, is applied, and a clustering process permits deriving a regionalization of the rain gauges according to their DS patterns. An analysis of time trends on these magnitudes establishes the European regions with more significant DS trends, for a period (1951–2000) with evident signs of changes in precipitation behaviour (Goodess and Jones, 2002; Frich et al., 2002; Haylock, 2003; Xoplaki et al., 2004; Zolina et al., 2010).

Since the 80s, several analyses of DS regime have been conducted in different regions, as the Iberian Peninsula

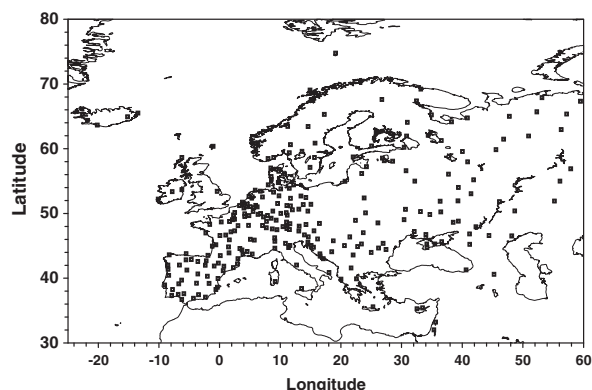


Fig. 1. Rain gauge network.

(Martín-Vide and Gómez, 1999; Serra et al., 2006; Lana et al., 2008b), Greece (Anagnostopoulou et al., 2003; Nastos and Zerefos, 2009), Croatia (Cindrić et al., 2010), Eastern Mediterranean (Kostopoulou and Jones, 2005), Italy (Brunetti et al., 2002), Switzerland (Schmidli and Frei, 2005), France (Galloy et al., 1982; Douguédroit, 1987), Belgium (Berger and Goossens, 1983), Norway (Perzyna, 1994), and Brazil (Carvalho et al., 2013), among others. A thorough view is difficult to be obtained due to the different variables, methodologies and recording periods. The main goal of this paper is to produce a unified and detailed study of the DS behaviour in Europe at annual and seasonal scales for different thresholds with the additional intention of detecting regions with more risk of persistent DS at present and in the immediate future.

2. Database, magnitudes, and methodology

European daily precipitation data for the years 1951–2000 have been compiled from 267 rain gauges. Most of these series (236) come from the European Climate Assessment and Dataset, ECA&D (<http://eca.knmi.nl/>). All these series are public and non-blended and their quality has been analysed

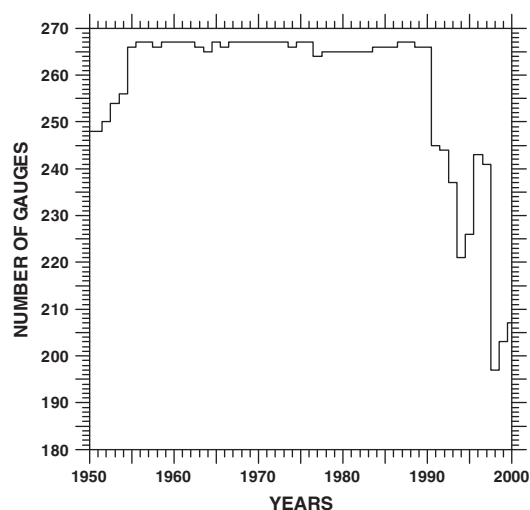


Fig. 2. Number of available rain gauges by year.

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