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Assessing the role of drought events on wildfires in the Iberian Peninsula

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ABSTRACT

Southern European countries are particularly affected by summer wildfires and drought events. The occurrence of extreme meteorological conditions during preceding and contemporaneous months amplifies the risk of summer wildfires.

The main scope of this study was to investigate the impact of drought periods on burned areas in the Iberian Peninsula. This will be achieved through the comparison of time series of two widely used multi-scalar drought indices (SPI and SPEI) calculated for each province and then associated with the time series of the standardized logarithm of normalized burned areas during the fire summer season. The SPI and SPEI were both calculated for the time scales spanning between 2 to 12 months and for each month from January to August, between 1980 and 2005. Based on the regression analysis between drought indicators and burned areas, the months that present lowest errors were identified for each province. From the obtained results two main conclusions were reached: (i) the association between drought and fires is a local scale process and should be analyzed at the province or sub-province level rather than at the country or continental level; (ii) the relation between wildfires and drought is better explained by the influence of the spring precipitation on the central sector and by the influence of temperature and precipitation during summer on most of the Portuguese provinces.

1. Introduction

Wildfire has a major role in the dynamics of a variety of terrestrial ecosystems, in particular the Mediterranean ones (Bastos et al., 2011), affecting both biodiversity and human activities. It is now widely accepted that the main drivers of fire ignition and propagation are (1) the presence of fuel (i.e. biomass/vegetation) (Flannigan et al., 2009; Gouveia et al., 2012); (2) favorable weather patterns often amplified by appropriate climate conditions preceding the fire season (Flannigan et al., 2009; Pereira et al., 2011); (3) socioeconomic conditions that affect land use/land cover patterns, fire-prevention and fire-fighting capacity (Flannigan et al., 2009; Pereira et al., 2011) and (4) the local topography (Pereira et al., 2011).

Mediterranean ecosystems are prone to forest fires (Salis et al., 2014) and over the last decades there has been an increase in the number of extremely large fires as well as in the extent of wildfires in some Mediterranean regions (e.g. Pereira et al., 2011; Pausas and Fernández-Muñoz, 2012; Salis et al., 2014). These fires caused extensive economic and ecological losses, and even human casualties (Salis et al., 2014).

Mediterranean Europe is a region particularly susceptible to climate change (Giorgi and Lionello, 2008) and some of the changes associated with global warming (e.g. reduction of precipitation, increased temperature and increased frequency of extreme events such as droughts and heat waves) have strong implications on the fire regimes (Pausas and Fernández-Muñoz, 2012; Koutsias et al., 2013; Salis et al., 2014; Sousa et al., 2015). Mediterranean European fire regimes are sensitive to changes in human behavior and in land use patterns (Bastos et al., 2011; Salis et al., 2014) either as part of agro pastoralism, accidental ignitions, criminal intent or even land abandonment (Salis et al., 2014).

During the last decades the western Iberian Peninsula (IP) has been particularly affected by summer wildfires, namely in Portugal, where the years 2003 and 2005 were especially outstanding (Trigo et al., 2013a). The above mentioned fire-seasons were both particularly exceptional registering, in 2003, the maximal burnt area

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since 1980 and, in 2005, the highest number of fire occurrences in Portugal and the second largest number in Spain since 1980 (Pereira et al., 2011). The 2005 fire season occurred simultaneously with one of the most severe droughts of the recent history (Gouveia et al., 2009), which greatly affected Portugal and Spain for more than 9 months. This strong negative impact on vegetation dynamics, which coincided with the period of greatest vegetation activity (Gouveia et al., 2012), might be associated with the amplified tree death during 2005 and 2006 (Catry et al., 2010).

The marked increase in wildfires extremely distresses the composition of Mediterranean ecosystems, namely in soil impoverishment through loss of nutrients during fire events (Knicker et al., 2006) or by runoff (Shakesby and Doerr, 2006); by the loss of plant cover and consequent erosion (Bastos et al., 2011); or indirectly through the effects of changes to the soil and vegetation on hydrological and geomorphological processes (Shakesby and Doerr, 2006). Although some Mediterranean vegetation species are adapted to wildfires, not all Mediterranean species are able to recover afterwards (Bastos et al., 2011). Moreover, the occurrence of strong or frequent droughts increases water stress during species' regeneration which, if associated with the occurrence of more concentrated rainfall events, may intensify erosion and nutrient loss (Bastos et al., 2011).

The response of ecosystems to water deficit occurs over different temporal scales, making necessary to resort to tools that are susceptible to incorporate this temporal feature. A considerable amount of studies were undertaken in recent years using multi-scale drought indicators, such as the Standardized Precipitation Index (SPI) (McKee et al., 1993) and the Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al., 2010a,b). The application of multi-scalar indices allows identifying whether a certain region is in hydric stress (Vicente-Serrano et al., 2010a,b). Although there are still large uncertainties regarding observed global-scale trends in droughts with no statistically significant changes in observed drought conditions in Europe (IPCC, 2012), several studies pointed out that drought frequency is increasing in the Mediterranean basin (Sousa et al., 2011; Hoerling et al., 2012; Vicente-Serrano et al., 2014), in particular over the IP (Xoplaki et al., 2012; Trigo et al., 2013b). In this sense, it is crucial to assess the spatial and temporal variability of drought, paying special attention to the role they play in increasing the risk of large wildfires (Sousa et al., 2015). In addition, the environmental, ecological and socio-economic impacts of large fires pose the question about what we can learn from the past that may reduce future impacts of forest fires.

This study focus on the IP, which encloses continental Portugal and Spain (with the exception of Ceuta, Fig. 1) and is characterized by scarce and highly variable precipitation and recurrent drought episodes (Vicente-Serrano et al., 2014). Drought events and their resulting impacts have been thoroughly studied (e.g. Moreira et al., 2012), namely the association between the occurrence of forest fires and droughts (e.g. Riley et al., 2013; Urbieta et al., 2015). Moreover, global warming processes may have a significant impact on drought occurrence (Vicente-Serrano et al., 2011), as a result of precipitation shortages and warmer conditions. As a result, continental IP, which is an area highly sensitive to current and future climate change (Giorgi and Lionello, 2008) is very likely to be highly affected, in accordance with changes observed in the last decades towards a drier climate already associated with anthropogenic emissions (Hoerling et al., 2012; Trigo et al., 2013b). Thus, the main goal of this study is to assess the role played by droughts on the occurrence of fire events in the IP. In order to achieve this goal, time series of two drought indices, namely SPI and SPEI, will be computed for each province in IP and then related with time series of burned areas during the fire summer season through regression analysis. The role of drought events on fire occurrence will then be assessed based on the magnitude of the root mean square errors obtained from the regression analysis. The relative importance of the roles played by temperature and precipitation in the fire regime will then finally be evaluated by comparing the differences obtained in the values of the magnitude of the errors when using SPI and SPEI.

2. Data and methodology

2.1. Drought assessment

Drought events were characterized through the computation of two multi-scale drought indices, SPI and SPEI, over the IP for the time scales ranging from 1 to 12 months. These indices are based on observed climate information and their computation allows the identification of the beginning and end of drought episodes as well as the quantification of their magnitude and spatial extent (Vicente-Serrano et al., 2014). The SPI is based on a probabilistic approach to precipitation (McKee et al., 1993), whereas the SPEI is based on water balance, incorporating evapotranspiration that has an important role in the incidence of droughts (Vicente-Serrano et al., 2010a). Spatial and temporal drought patterns were investigated in prior studies using SPI covering Portugal, Spain or the entire IP (e.g. Vicente-Serrano et al., 2011, 2014; Moreira et al., 2012; Raziei et al., 2014). On the other hand, SPEI has also been used to characterize drought events in the IP (Vicente-Serrano et al., 2011, 2014), and results compared to those obtained with SPI. Moreover, and as shown by Bedia et al. (2014a) and by Urbieta et al. (2015), drought indexes and SPEI in particular, contribute positively to the adequate modelling of inter-annual burned area series as they bear some sort of "memory" on the antecedent conditions.

Both SPI and SPEI hold the advantage over other widely used drought indices such as PDSI, of having a temporal multi-scalar character. The application of multi-scalar indices to high spatial-resolution datasets allows associating a given temporal scale of drought to the occurrence of a given phenomenon or event (e.g. desertification, forest fires). Additionally, SPEI revealed to be more sensitive to global warming (Vicente-Serrano et al., 2010a) and has also shown to be better associated with hydrological drought in Iberia than SPI or PDSI (Vicente-Serrano et al., 2014). More detailed explanations on both SPI and SPEI, as well as on the meaning of the different drought time scales, can be found in McKee et al. (1993) and Vicente-Serrano et al. (2010a,b, 2014).

The climatic dataset used to compute both SPI and SPEI was produced by a dynamic downscaling process with a climate version of the MM5 model with high spatial resolution (10 km) (Jerez et al., 2011). The dataset has been extensively used and validated in the framework of very diverse applications, from renewable energies (e.g. Jerez et al., 2013; Jerez and Trigo, 2013) to climatic reconstructions (Hernandez et al., 2015). Each drought indicator was computed for the period between 1980 and 2005 and for the 12 time-scales for each IP province (Fig. 1), based on the respective average values of temperature and precipitation. Although the results are aggregated by province, the high spatial-resolution character of the source data is worth being emphasized. To the best of our knowledge, apart from the works of Bedia et al. (2014b), Abatzoglou and Kolden (2013), Riley et al. (2013) and Parks et al. (2015), high spatial resolution weather data have not been commonly used for drought assessment.

The SPI was computed using monthly precipitation records, through the fitting of a gamma probability distribution with a rectangular adjustment. The reference evapotranspiration (ET_0) was determined based on the Hargreaves equation (Hargreaves and Samani, 1985). SPEI was computed through the fitting of a log-logistic probability distribution with a rectangular adjustment, and