Assessing the association of drought indicators to impacts. The results for areas burned by wildfires in Portugal

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Abstract
In the FP7 European project "DROUGHT-R&SPI - Fostering European Drought Research and Science-Policy Interfacing" CEABN works together with partners from other eight countries on monitoring and prediction tools to manage drought impacts at different scales.
The wildfire extent was one of the impacts studied in relation to recent drought events in Portugal. The identification of specific periods where shortage of water is relevant to the extent of wildfires is of prime importance to counteract drought impacts. Meteorological droughts can be characterized using indices such as SPI (Standardized Precipitation Index). In this study we explored the links between area burned by wildfires and meteorological drought indicators using data series from mainland Portugal. Significant correlations were found between wildfire burned area and drought indices (SPIs 1, 3 and 6), which can be useful to understand and manage the risk of forest fires.

Keywords: Portugal, drought, SPI, forest fires

1. Introduction

Drought is a recurrent climatic event occurring worldwide and intensively perceived by the Mediterranean countries (Pereira *et al.*, 2009). Projections indicate an increased in the observed trend (Sousa *et al*., 2011) towards drier conditions for this region (Van Lanen *et al.*, 2013) with substantial foreseen impacts that need to be properly addressed (EEA, 2012).
"DROUGHT-R&SPI - Fostering European Drought Research and Science-Policy Interfacing" is a FP7 European project aiming at improving drought preparedness across Europe (http://www.eu-drought.org). In this framework, Portugal, along with eight other countries, works on monitoring and prediction tools to manage drought impacts at different scales (from pan-European to sub-national or river basin level).
Meteorological droughts can be characterized using indices such as SPI, Standardized Precipitation Index (Moreira *et al.*, 2008). They calculate anomalies in precipitation, accumulated over several periods: 1, 2, 3, 6, 9, 12, 24 months, compared with its multiyear average (Zargar *et al.*, 2011). In the last 70 years there were ten major drought events in mainland Portugal: 1944-45 (extreme), 1948-49, 1964-65, 1974-76, 1980-83, 1990-92, 1994-95, 1998-99, 2004-2005 (extreme) and 2012 (extreme). The drought episode of 2004-2005 can be considered the most severe in terms of meteorological data, extent of the area affected, and impacts on different socio-economic and environmental sectors (Comissão para Seca 2005, 2006). The wildfire extent was one of the most important impacts of recent drought events in Portugal (MAMAOT, 2013). In fact, precipitation deficits, by reducing soil and fuel moisture, ease up the ignition and spread of forest fires (Shoennagel *et al.*, 2004; Gouveia *et al.*, 2009; Jurdao *et al.*, 2012). The identification of specific periods where the shortage of water is crucial to maximise wildfire extent is of prime importance for counteract drought impacts. However, although the climate drivers of area burned have been extensively studied, both in Portugal (Viegas & Viegas, 1994; Pereira *et al.* 2005; *Trigo et al.*, 2006) and elsewhere (e.g., Flannigan & Harrington, 1988;

Pausas, 2004; Littel *et al.,* 2009), the links between drought indices and wildfire extent have only recently been modeled (e.g., Stagge *et al*., 2014).
The objective of this study is thus to explore the link between area burned by wildfires and meteorological drought indicators using long-term data series (fire and climate) from Portugal analysed at sub-national level (NUTS2).

2. **Methods**

2.1. The **Standardized Precipitation Index (SPI) as a** drought indicator

The Standardized Precipitation Index (SPI) (McKee *et al.* 1993) is a probability index that was developed to give a representation of abnormal wetness and dryness, and compares precipitation with its multiyear average. It is essentially a seasonally normalized, backwards-looking moving average of precipitation. SPI overcomes the difficulty of comparing sites with different climate and highly variable precipitation distributions by transforming the precipitation distribution record to a normal distribution (Paulo & Pereira, 2006). The first step in calculating the SPI is to determine a probability density function that describes the long term time series of precipitation observations. The series can be for any time duration (typically for total precipitation of 1, 2, 3, 6, 9, 12, 24 months). Once the probability density function is determined, the cumulative probability of an observed precipitation amount is computed. The inverse normal Gaussian function, with mean zero and variance one, is then applied to the cumulative probability. The result is the SPI (Guttman, 1999).
Positive SPI values indicate a wetter than typical period, i.e. accumulated precipitation greater than the median, while negative SPI values indicate a dryer period with less precipitation than normal. A value of zero corresponds to the median accumulated precipitation. The magnitude of the departure from zero is a probabilistic measure of the severity of a wet or dry event that can be used for risk assessment (Paulo *et al.,* 2012). The time series of the SPI can be used for drought monitoring. Accumulated values of the SPI time series are used to analyze drought severity. Threshold values of the SPI define drought beginning and ending (Moreira *et al*., 2008). If SPI reaches a value of -1 or less a drought is said to have occurred. Different duration of SPI reflected different phenomena (Zargar *et al*., 2011). One month SPI (SPI1) is related to short-term conditions as short-term soil moisture and vegetation stress during growing season. Three months SPI (SPI3) is related to short/medium-term conditions, roughly approximating seasons, while the six-month SPI (SPI6) shows the precipitation across distinct seasons. When the nine months SPI (SPI9) is less than -1.5 substantial impacts occur in agriculture and other sectors, one year SPI (SPI12) is tied to evolution of streamflows and reservoir and groundwater levels (Paulo & Pereira, 2006).

To explore correlations of drought with the areas burned by forest fires in Portugal we used monthly SPIs of different duration: SPI1, SPI2, SPI3, SPI6, SPI9 and SPI12. These SPI values were calculated on the basis of long-term series of monthly precipitation (1979-2009) based on the WFDEI (Watch Forcing Data ERA-Interim) for each NUTS2 (Nomenclature of Territorial Units for Statistics level 2) area of the Portuguese mainland (Norte, Centro, Lisboa, Alentejo and Algarve).

2.2. **Proportional change to standardize continuous variables as crop or forest fire in long-term data series**

Monthly SPIs were used as candidate explanatory variables to model wildfire extent, defined by area burned. Annual area burned by wildfires in Portugal (1985-2010) is the dependent variable, extracted at the NUTS2 level from the European Fire Database (compiled by the EU JRC) and used after log-transformation to rescale the data.

Data from long-term series as areas burned by wildfires typically do not fluctuate around a constant mean. Therefore, in order to detect the signal of drought in wildfire areas, it is important to remove these multi-annual trends that are not related to drought. This was accomplished by using moving averages, whose length was determined by the structure of the time series data as detected by autocorrelation analyses. Burned area anomaly was defined as:

$$\text{Log(fire area)}_{\text{anomaly}} = \text{Log(fire area)}_{\text{observed}} - \text{Log(fire area)}_{\text{mov.average}}$$

The standardization was accomplished by a proportional change as:

$$\text{Log(fire area)}_{\text{proportional change}} =$$
$$= (\text{Log(fire area)}_{\text{observed}} - \text{Log(fire area)}_{\text{mov.average}}) / \text{Log(fire area)}_{\text{mov.average}}$$

Proportional change has a minimum value of -1 (when there is no burned area in that year), zero when the observed burned area is equal to the expected value (the moving average), and greater than 0 when the observed burned area is higher than expected.

Once defined the moving average period, we performed a correlation analysis (Pearson r) to detect the most significant links between monthly SPIs (of the current year and the last 3 months of the previous year) and the proportional change of log-transformed annual burned area. This later variable was in turn modelled using a multiple regression model (stepwise method) with all the SPIs as candidate independent variables (Draper & Smith, 1998). Correlation values and regression coefficients were considered statistically significant for $p<0.05$.

3. **Results and discussion**

The analyses of long-term series for burned areas (log transformed) in Portugal indicated that statistically significant partial autocorrelations of these data exist for lags 1 and 2 years. These results suggested that four year moving average (2 previous years and 2 following years) was adequate to smooth these data in order to better detect the annual anomaly and calculate the proportional changes in log-transformed burned areas. Figure 1 represents burned area by wildfires in the five NUTS2 for mainland Portugal (1985 - 2009), whereas its log-transformed and standardized trends are depicted in figure 2.

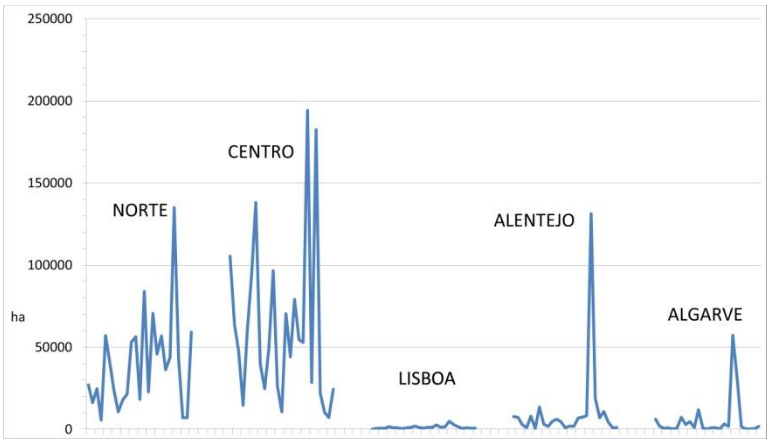

Figure 1. Burned area (ha) by wildfires in mainland Portugal (1985 - 2009) by NUTS2. The x-axis corresponds to the sampling years for each NUTS2.

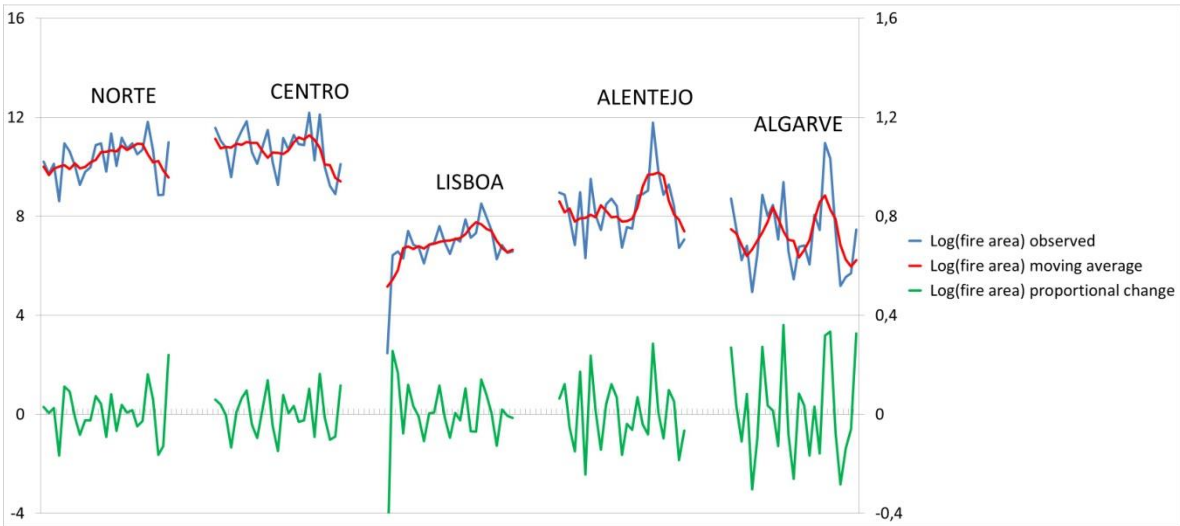

Figure 2. Log(fire area) observed, Log(fire area) moving average and Log(fire area) proportional change, by NUTS2 in mainland Portugal (1985 - 2009). The x-axis corresponds to the sampling years for each NUTS2; the left y-axis correspond to observed and moving average of Log(fire area), the right y-axis to Log(fire area) proportional change.

Investigating the correlations between short-term SPI1 and Proportional Change of log-transformed burned area we found two significant correlations (Figure 3). For short-term meteorological droughts, measured by SPI1, the most significant is the negative correlation occurring in May (R=-0.271). A negative correlation suggests that as meteorological drought severity increases (SPI becomes more negative), the wildfire area burned increases. It can be also speculated that, larger precipitation values in May result in lower areas burned, probably due to higher moisture in soil and vegetation before the summer (Dias *et al.* 2006). While statistically non-significant, all months from Abril to August show negative correlations, with the same interpretation as before.

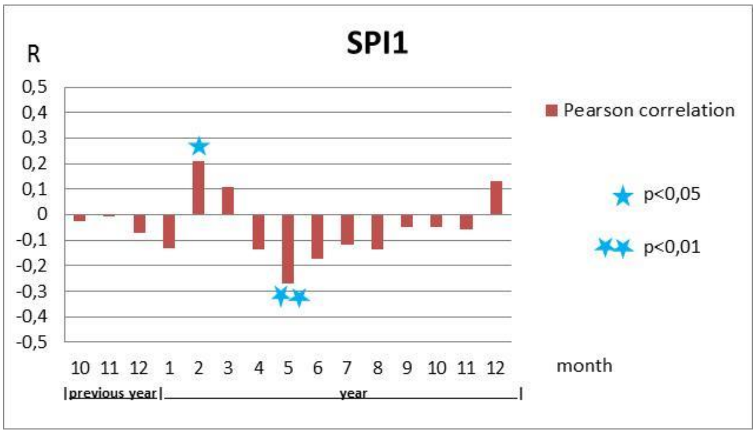

Figure 3. Correlations between Proportional Change of log (fire area) and monthly SPI1

The results also showed a positive (R=0.208) significant correlation, with SPI1 of February, meaning that extensive wildfire burned area is correlated with higher than average precipitation in February. In a Mediterranean country such as Portugal, a water surplus by the end of winter benefits fuel accumulation, namely the biomass of the herbaceous layer, which is easy to burn during the summer (Schoennagel *et al.* 2004; Gouveia *et al.* 2009). A similar explanation, in line with those provided by Viegas & Viegas (1994), can be used for March, even if the correlation is not statistically significant.

SPI3 involves the total rainfall of the current month and of the two previous months. In this case (Figure 4) the significant negative correlations for SPI3 are found between May and August, with highest values for June (R=-0.348) and July (R=-0.367). Thus according to our results, accumulated deficit of precipitation from May to July is a good candidate for predicting larger annual wildfire area. A significant positive effect of summer drought (especially when evaluated by SPEI) in wildfire extent, was also found by Stagge *et al.* (2014) for several European regions.

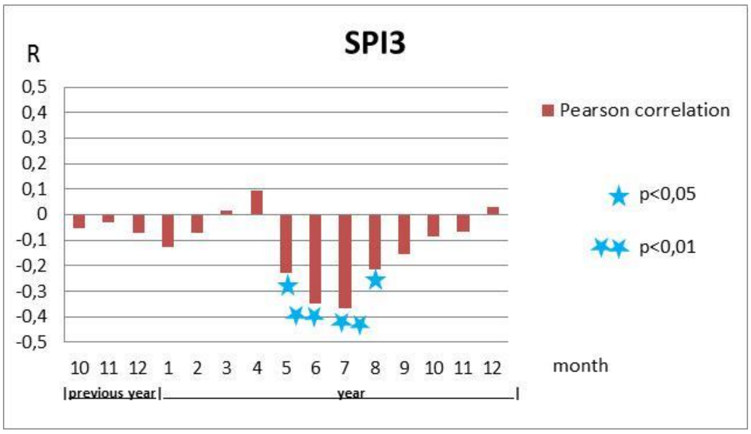

Figure 4. Correlations between Proportional Change of log (fire area) and monthly SPI3

Medium-term SPI6, commonly used to indicate drought impacts in rainfed agriculture, (Zargar, 2011) was also well correlated with burned area. SPI6 involves precipitation of the current month and of the previous five. The highest negative correlations were found from August to October (Figure 5).

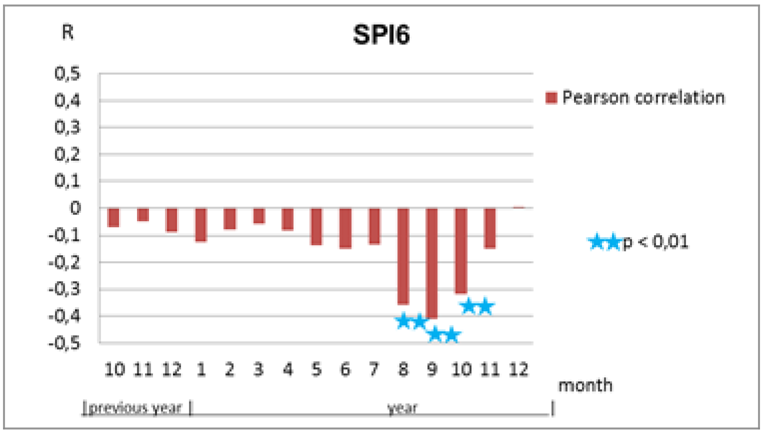

Figure 5. Correlations between Proportional Change of log (fire area) and monthly SP6

The highest negative correlation (R=-0.412) in this study was found for the SPI6 in September. This means that accumulated precipitation deficits from April to September correspond to accumulated dryness of soil, litter and vegetation (Dias *et al.*, 2006; Pellizzaro *et al.*, 2007), therefore triggering larger burned areas (Canyameres *et al.*, 2006; Jurdao *et al.*, 2012).

Though this correlation does not allow for a detailed analysis of the process, it can be useful in making the general association between drought and wildfire extent. In fact, we found that SPI6 of September was the first and only independent variable selected by the multiple regression model where all possible linear combinations of SPI1, SPI2, SPI3, SPI6, and SPI9 were used as explanatory candidates of the proportional change of area burned (log-transformed) in mainland Portugal:

$$Y_{LogFireChange} = -0.047 \times SPI6_{September},\ R = 0.412,\ p<0.001,\ n=125.$$

This indicates that it is possible to establish a solid negative association between cumulative precipitation deficits in late spring and summer months and wildfire extent, and that this association summarizes well the relationship between drought and burned area for mainland Portugal.

4. Conclusions

Climate scenarios estimate a significant increase in the forest fire danger (Bedia *et al.*, 2014) and in the total burned area (>66%, Amatulli *et al.*, 2013) for the EU-Mediterranean countries by the end of the 21st century. The identified link between meteorological drought and fire impact can be a step towards the improvement of an early-warning system for seasonal wildfire severity for both Portugal and other countries sharing the same climatic conditions.

The medium-term drought index, SPI6, in September provided the best explanation for burned areas in an interpretable way. Accumulated precipitation deficit results in low moisture content in forest fuels and therefore in larger areas burned due to more intense wildfires.

Short-term (SPI1 of May) and short-medium-term indices (SPI3 of May, June, July and August) can be used in real-time, giving some forecast lead time, to evaluate for possible major risk of forest fires and to engage field measures to implement in the forthcoming months.

The assessment of the SPI1 of February can provide important warning information when deciding whether to enact measures, in the four months ahead, to reduce herbaceous biomass, which may increase risk of wildfires.

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