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Synoptic weather conditions and changing fire regimes in a Mediterranean environment

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ABSTRACT

Analysis of global change effects on fire regimes requires evaluations of key processes explaining fire activity at the appropriate spatial and temporal scales. Classifications of the weather conditions prevailing at large continental scales (called "Synoptic Weather Types", SWT) offer convenient potential proxies for integrating weather-related factors into our understanding of fire regime attributes at regional scales. Here we establish a methodology for identifying the major SWT that lead to wildfires and assessing their influence on fire regime in interaction with other global drivers such as drought events or fire suppression policies. Based on days with fires larger than 50 ha that occurred in Catalonia, a region located in the western Mediterranean Basin, we propose a clustering methodology using data of temperature at 850 hPa, sea level pressure and winds at 925 hPa from the NCEP/NCAR reanalysis dataset covering the whole of western Europe (25–70°N and 20°W–40°E). Our classification method proposes 6 SWT: three that were characterized by synoptic conditions leading to strong winds in the region, two that led to 'hot and dry' environments, and one that was not characterized by any strong weather determinants. Fires under 'hot and dry' conditions, such as the South intrusion SWT, triggered the bulk of fires and burnt area in the region. Spatial analyses of fire distribution under each SWT revealed markedly different fire-prone locations, opening the possibility for strategic planning of fire management based on local fire regimes. Fires occurring during mild years (wet spring conditions) and under 'hot-and-dry' SWTs have been eradicated from the region thanks to enhanced firefighting capability, and fire sizes in dry years have strongly reduced. In contrast, fires occurring under windy situations have not followed the same course of change and have not diminished in incidence over time, and seem to be more difficult to control using current fire suppression strategies. The role of SWT on determining fire regimes and its interaction with fire suppression strategies has a huge potential to help researchers and managers develop better fire analyses based on sound physical grounds and serve to understand and eventually regulate the adverse impacts of fire regime changes in a global change context.

1. Introduction

Weather plays a critical role in large wildfire (LWF) event occurrence (Flannigan et al., 2000; Pausas, 2004; Piñol et al., 1998; Pyne et al., 1996). Vegetation susceptibility to fire is directly affected by the cumulative impact on plant moisture content of weather conditions prior to a fire event in relation to average climatic conditions (Barbero et al., 2015). Weather conditions on the same day of a fire determine dead-fuel moisture conditions and directly influence ignitability and fire propagation (Pyne et al., 1996). Short-term weather conditions linked to fire events are usually associated to high-temperature, low-humidity and windy days (Piñol et al., 1998; Schroeder and Buck, 1970).

There have been various attempts to characterize the weather conditions that lead to fire events (Amraoui et al., 2015; Paschalidou and Kassomenos, 2016; Ruffault et al., 2016a; Schroeder and Buck, 1970). Synoptic climatology focuses on large-scale weather patterns defining general atmospheric conditions at a continental scale. Depictions of large-scale weather conditions aggregate a large amount of weather variables at a continental scale – temperature, precipitation, wind, atmospheric pressure – and usually better forecast and explain key environmental processes than any of these variables considered individually (Fernández-Martínez et al., 2016; Millan et al., 1998). The synoptic weather conditions affecting LWF occurrence can serve to

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characterize and classify these specific conditions into general groups, named Synoptic Weather Types (SWT). Research pioneered by Schroeder et al. (1964) and picked up later by others like Taklel et al. (1994) in the USA, Millan et al. (1998) in Spain, Pereira et al. (2005) in Portugal, Paschalidou and Kassomenos (2016) in Greece and Ruffault et al. (2016b) in France, among others, shows that SWT are regarded as a potential framework to derive, or describe, homogeneous fire-prone weather conditions. Furthermore, SWT offer a sound physical basis for the development of fire risk indexes, as they are easy to simulate by global and regional circulation models (Taklel et al., 1994; Trigo and Palutikof, 2001).

Each SWT might drive different fire-regime attributes (fire frequency, size, etc.). In this regard, Jin et al. (2014) revealed that fires occurring under Santa Ana winds in California were usually larger and less frequent than fires not occurring under these conditions. Synoptic weather typification was also shown to predict how a wildfire will spread in a specific relief (Duane et al., 2016), and has thus proven useful in operational fire-suppression strategies (Castellnou et al., 2009; Lázaro et al., 2016). SWT could thus become essential descriptors of fire activity and a key foundation for understanding fire regime attributes such as fire spread, size, location and frequency. In today's climate change context, SWT characterization can become a crucial piece of information for predicting fire regime evolution, beyond classical temperature-increase assessments (Batllori et al., 2013; Terrier et al., 2013).

Nevertheless, the effect of SWT on fire regimes can become modulated by other fire drivers such as drought conditions prior to the fire season or the efficiency of human fire suppression efforts. The dryness of a year has been shown as a determinant of final burnt area in many ecosystems, since it predisposes vegetation available to burn (Pausas and Paula, 2012). On the other hand, several studies (Brotons et al., 2013; Minnich, 1983; Piñol et al., 2007) have argued for effects of fire suppression practices on final size of fires. However, nothing is known about how a specific SWT influences fire activity under particular drought or suppression conditions.

SWT have been proposed in many countries worldwide, but there is still a lack of any deeper understanding of the specific differences in the effects of these SWT on a broad range of fire regime attributes such as frequency, location, size and temporal evolution. Furthermore, the science on the interaction of SWT with other fire regime drivers is only in its early stages (Fernandes et al., 2016; Pereira et al., 2005), and further research is needed to unravel the key processes at work behind fire activity.

This study aimed to classify LWF-days into SWT for fire occurrences in Catalonia (NE Spain), a Mediterranean environment, for the period 1980–2015 according to general weather conditions in Western Europe. In Mediterranean environments from European countries with highly anthropogenic landscapes, evaluating the use of synoptic classifications to derive knowledge on the fire regime attributes is critical to our understanding of the fire phenomenon and will significantly contribute to our capacity to enhance wildfire prediction accuracy. Our objective was thus to develop a novel methodology allowing to distinguish different weather situations leading to LWF and classify them into general synoptic patterns using data from the NCEP/NCAR reanalysis (Kalnay et al., 1996). Working up from this analysis, our main aim was to investigate fire regime attributes for each SWT and correlate them to other fire drivers to try to understand the past, present and potential futures of fire regimes according to these SWT. We evaluated temporal trends on the number of days of each resulting SWT, unraveled the spatial probability of fires occurring under each SWT, and finally analyzed fire size distributions within each SWT according to drought conditions and fire suppression effects.

2. Climate and fire regime in the study area

Mediterranean environments are marked by hot and dry summers and strong seasonality (Olson et al., 2001). Cool wet winters promote biomass growth and extended summer drought favors the regular occurrence of wildfire (Batllori et al., 2013). In the Mediterranean Basin, macroclimate mainly results from the seasonal alternation between frontal cyclones associated with polar air masses during winter, and sub-tropical high-pressure systems from subsiding maritime and continental tropical air masses during summer (Tatli and Türkeş, 2013). In fact, during summer, two large semi-permanent weather systems located at each end of the Mediterranean Basin dominate its meteorological processes. At the western edge is the Azores high, and over the eastern borders is the low-pressure monsoon system that extends from the Middle East to the whole of southwestern Asia (Millan et al., 1998). The Mediterranean Basin has a complex orography that includes extensive coastal areas mostly backed by relatively high mountain ranges (Lionello et al., 2006), and it also favors the formation of deep convective cells and thermal lows over the major peninsulas (Hoinka and Castro, 2003). Other thermally driven systems subordinated to larger weather structures thus develop during day and can strongly modify the regional flows (Millan et al., 1998).

Catalonia is located in the NE Iberian Peninsula and covers an area of approximately 32,000 km^2 (Serra et al., 1999). Climate is Mediterranean, with hot dry summers, rainy springs and falls, and cold winters (Albentosa, 1980). Continental and Pyrenean influences are found, with precipitation and temperature variations related to distance-to-sea and altitude (Lana et al., 2001). Traveling depressions and blocking anticyclones characterize precipitation, temperature, and moisture variability, and the relative location of highs and troughs determines atmospheric wind (Martín-Vide et al., 2008; Millan et al., 1998). In summer, the presence of thermal lows due to terrestrial warming distinguish a fair proportion of days (Lionello et al., 2006), along with the prevalence of local winds (i.e. sea breezes; Grimalt et al., 2013). Catalonia has a complex relief that greatly affects weather dynamics. Most of the mountain ranges are orientated east-west, while some mountain chains near the sea follow the coastal south-west to north-east direction. The Pyrenees, the major east-west-oriented mountain range in the North of the region, strongly affects climate variability (Soriano et al., 2006). There are also flat areas near big river basins located in the West and South. The coast with the Mediterranean Sea outlines the eastern part of the region, and this proximity to the sea generates milder conditions in summer and winter than in more continental areas.

In the period 1970–2010, more than 9000 fire events greater than 0.5 ha occurred in Catalonia, and total burnt area was about 400,000 ha (Turco et al., 2013). Mean annual area burnt was 8000 ha/year, corresponding to 0.75% of Catalan wildland area. Catalonia is characterized by a quite low fire return interval (between 60 and 400 years for homogeneous fire regions of about 45,000 ha; Pique et al., 2011) with very large and intense wildfires. Burnt annual area shows strong annual variation, with two peaks in 1986 and 1994 burning 65,000 and 75,000 ha, respectively. Most of the burnt area is caused by a few large fires (González-Olabarria and Pukkala, 2007), and most of the fires occur in the summer season (June–September; Piñol et al., 1998). Stand-replacing fires appear to be the most common in the area, with a large proportion of the burnt area being affected by crown fires (> 85%; Rodrigo et al., 2004). The dominant fire management strategy in Catalonia is fire suppression, with investments increased six-fold since the early 1980s. There is a general downtrend in the number and size of fires since the big fires of 1986 and 1994, which is mainly explained by increased effort on fire prevention and suppression (Brotons et al., 2013; Turco et al., 2013). However, in Catalonia the specific role of fire suppression efforts in determining fire regimes is still under debate (Brotons et al., 2013; Otero and Nielsen, 2017; Piñol et al., 2007).