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Atmospheric conditions associated with extreme fire activity in the Western Mediterranean region

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HIGHLIGHTS

- West Iberia (WI) and North Africa are the sub-regions most affected by fires.
- Fire annual cycle has a main peak in August and secondary peak in March over WI.
- Extreme fire activity episodes are identified in both summer and winter seasons.
- Extreme fire episodes occur in 5% of days but represent 22% of total fire pixels.
- Fire occurs under similar weather conditions but different circulation patterns.

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ABSTRACT

Active fire information provided by TERRA and AQUA instruments on-board sun-synchronous polar MODIS platform is used to describe fire activity in the Western Mediterranean and to identify and characterize the synoptic patterns of several meteorological fields associated with the occurrence of extreme fire activity episodes (EEs). The spatial distribution of the fire pixels during the period of 2003–2012 leads to the identification of two most affected sub-regions, namely the Northern and Western parts of the Iberian Peninsula (NWIP) and Northern Africa (NAFR). The temporal distribution of the fire pixels in these two sub-regions is characterized by: (*i*) high and non-concurrent inter- and intra-annual variability with maximum values during the summer of 2003 and 2005 in NWIP and 2007 and 2012 in NAFR; and, (*ii*) high intra-annual variability dominated by a prominent annual cycle with a main peak centred in August in both sub-regions and a less pronounced secondary peak in March only evident in NWIP region. The 34 EEs identified were grouped according to the location, period of occurrence and spatial configuration of the associated synoptic patterns into 3 clusters (NWIP-summer, NWIP-winter and NAFR-summer). Results from the composite analysis reveal similar fire weather conditions (statistically significant positive anomalies of air temperature and negative anomalies of air relative humidity) but associated with different circulation patterns at lower and mid-levels of the atmosphere associated with the occurrence of EEs in each cluster of the Western Mediterranean region.

1. Introduction

Vegetation fires are an ecological disturbance occurring worldwide with climatological, social and economic impacts at the global, regional and local scales (Le Page et al., 2008; Oom and Pereira, 2013). Fire disturbance was classified as an “essential climate variable” by the Global Climate Observing System that has highlighted the need for long data time series to quantify the links between climate and fire (GCOS-107, 2006).

In terms of accuracy and reliability, satellite information is an especially appropriate tool to monitor fire activity at the global level (Justice and Korontzi, 2001). This is mainly due to the spatial and temporal homogeneity of remote-sensed data and to its independence from fire policies of the different countries (Pereira et al., 2011; Amraoui et al., 2013).

During the last decades several fire detection algorithms were developed using remote sensed data obtained from different sensors on board polar orbiters (Dwyer et al., 2000; Stroppiana et al., 2000; Justice et al., 2002; Giglio et al., 2003; Arino et al., 2005) or geostationary satellites (Prins and Menzel, 1992; Calle et al., 2006; Roberts and

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Wooster, 2008; Amraoui et al., 2010). In this context, the MODIS active fire product (Justice et al., 2002) is especially appropriate in climatological studies since it provides consistent daily information about fire activity, at 1 km resolution over a period of 10 years (2003–2012) (Csiszar et al., 2005; Oom and Pereira, 2013).

The Mediterranean basin is struck by a large number of devastating fire events that burn hundreds of thousands of hectares of forests, shrub and grasslands every year (Barbosa et al., 2007), with dramatic consequences for ecosystems and population (Pereira, 1999). The western part of the Mediterranean basin which includes the Iberian Peninsula, Southern France and Sardinia in Europe and Northern parts of Morocco, Algeria and Tunisia in North Africa has been the most affected by vegetation fires in the last decades (Schmuck et al., 2013). In the Mediterranean region fire ignition is strongly conditioned by human behaviour and socioeconomic activities (Costa et al., 2010) but natural factors like the morphology of the landscape, land use, land cover, and meteorological conditions have also to be taken into account (Amraoui et al., 2013). In particular, weather and climate have a profound influence at all stages of biomass burning from ignition, spread and behaviour up to severity and effects (Benson et al., 2009). The vast majority of burned area in Mediterranean regions is due to a reduced number of extreme events that occur during a short period of time, and are associated with several atmospheric processes interacting at different temporal and spatial scales (Pereira et al., 2005). Particular attention is therefore to be devoted to fire activity associated with extreme events and to the roles played by climate and weather on such extreme events.

In two previous studies, the authors used composite analysis of meteorological fields to identify and characterize the synoptic patterns associated with large fire episodes. The first study (Pereira et al., 2005) focused on summer fire activity in Portugal in 1980–2000 and relied on the official Portuguese database of burned area based on in situ observations. The second study (Amraoui et al., 2013) focused on Italy and Greece in summer 2007–2009 and was based on active fire detections by Meteosat-8, a geostationary satellite operated by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

As mentioned above, these two studies focused on the extreme fire activity events that occurred only during the summer season. In addition and regarding to the first case, the study relied on the largest fire database in Europe based on ground observations which is not usually available for several regions around the Mediterranean basin, while the second study is based on geostationary remote sensing data which present low spatial resolution over the region (Pereira et al., 2011; Amraoui et al., 2013). In this sense, the novelty of this study is to (*i*) extend the similar rationale to the detection and characterization of extreme fire episodes throughout the year and to expand the analysis to North Africa; and, (*ii*) use the MODIS dataset which is particularly useful to characterize fire activity at the regional scale (Western Mediterranean basin) thanks to its highest spatial resolution and relatively long-term database.

In this context, the specific aims of the study are to (*i*) characterize the spatial and temporal distribution of fire pixels over Western Mediterranean during the 2003–2012 period including the identification of extreme fire episodes throughout the year; and, (*ii*) assess the meteorological conditions associated with identified extreme episodes based on the analysis of the atmospheric fields of mean sea level pressure, geopotential, wind, air temperature and relative humidity.

2. Data and methods

2.1. Fire and meteorological data

Information about active fires was extracted from the MCD14ML Collection 5 active fire product which relies on MODIS imagery data (Justice et al., 2002). The dataset covers the 10-year study period, from January 2003 to December 2012. Fire detection is performed using a contextual algorithm that exploits the strong emission of mid-infrared radiation from fires and is based on brightness temperatures derived from the 3.9 and 10.5 μm channels (Giglio et al., 2003).

Meteorological information was derived from the ERA-Interim dataset, the most recent global atmospheric re-analysis product of the European Centre for Medium-Range Weather Forecasts (ECMWF). Detailed information about the product may be found in Dee et al. (2011). Extracted information covers the 30-year period (1983–2012) and consists of daily fields at 12 UTC, with a spatial resolution of 0.75° × 0.75° lat-lon, over the Western Mediterranean sector (30°W–20°E, 20°N–60°N) of the following meteorological variables:

- mean sea level pressure (hereafter MSLP);
- air temperature at 2 m height (hereafter T2m);
- wind speed and direction at 10 m (hereafter W10m);
- air temperature, geopotential height and relative humidity at 850 hPa which corresponds to about 1500 m of altitude (hereafter T850, Z850 and RH850, respectively);
- geopotential height at 500 hPa, in the mid atmosphere, at about 5 000 m of altitude (hereafter Z500).

2.2. Analysis of extreme fire activity episodes

The identification of a given extreme episode (hereafter referred to as EE) of fire activity in a given region is defined based on the following criteria: the episode should consist of at least 3 consecutive days, each day having a minimum of 10 fire pixels over the region and each day ranking first in number of fires among the respective 10 records for that day of observations (covering the study period 2003–2012).

The role played by the meteorological conditions during EEs over a given region is assessed by analysing the associated patterns of meteorological fields at different levels. Analysed patterns are anomaly composites, consisting of arithmetic means (performed over all days associated with EEs) of daily departures of 12 UTC meteorological fields from the respective average for that day over the reference period (1983–2012).

The statistical significance (*p-value*) of obtained anomalies in each grid point was evaluated by bootstrapping (Efron and Tibshirani, 1993). Anomaly fields are plotted only when statistically significant at 0.999 level, i.e. when values are higher (lower) than the 99.9th (0.1th) percentile if positive (negative).

3. Results

3.1. Fire activity in the Western Mediterranean region

During the 10-year study period (2003–2012), a grand total of 126 887 fire pixels (all data used) were detected over the study area (Fig. 1). The spatial distribution of fire pixels suggests defining two sub-regions of high fire activity. The first sub-region (hereafter referred to as NWIP) covers the Northern and Western parts of the Iberian Peninsula and accounts for 57% of the grand total of fire pixels. The second region (hereafter referred to as NAFR) spreads over Northern Africa and South-Eastern Iberia and contributes to 40% of the grand total. The vast majority of fire pixels occur from May to October, and account for 82% and 91% of the total number observed in NWIP and NAFR, respectively.

The temporal distribution of fire pixels reveals high inter-annual variability (Fig. 2, upper panel), with 43% of the total number occurring in three years, i.e. 13% in 2003, 15% in 2005 and 15% in 2012; 2008 is the year with the lowest fire activity, representing just 5% of the grand total. The contribution of NWIP to the grand total is larger than that of NAFR in seven out of the 10 years analysed. The contribution of NWIP to the total fire pixels each year is especially high in 2003 and 2005, reaching