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The outstanding synergy between drought, heatwaves and fuel on the 2007 Southern Greece exceptional fire season

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ABSTRACT

The fire season of 2007 was particularly devastating for Greece, achieving the new all-time record of estimated burnt area (225,734 ha) since 1980. The season was remarkably severe in Peloponnese Peninsula, in southern continental Greece, being considered the most extreme natural disaster in the recent history of Greece. Moreover during the hydrological year of 2007, Peloponnese was struck by a severe winter drought that corresponds to the second lowest annual accumulated value since 1951. However, the subsequent spring was very wet partially attenuating the effect of the previous drought. Additionally, the region was stricken by three heat heaves during summer, being the number of hot nights especially noticeable, surpassing more than 35 nights over the Southern Greece. Here we show that the central and Northern sector of Peloponnese Peninsula become the most susceptible to wildfires due to the combined effect of the two extreme meteorological events, drought and heatwaves which was confirmed by the location of the main burnt areas of 2007 fire season. Additionally, the analysis showed that during the extreme days of fire activity in 2007, strong northerly advection of very hot and dry air over the region, favored fire occurrence.

The study attempts to bring new light to the synergistic effect between fuel availability and weather conditions that created extraordinary conditions for fire propagation. We focused on the largest burnt areas and the respective NDVI behavior is assessed throughout the pre fire periods. We found that vegetation dynamics are related to the extreme climatic events that occurred in these periods. Moreover, our results confirm that the higher fire incidence in areas with higher vegetation activity and density seems to indicate that the large burnt areas of 2007 fires season in Peloponnese Peninsula appear to be more sensitive to fuel availability and vegetation density than to vegetation dryness.

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1. Introduction

Drought episodes in Mediterranean region are responsible for negative impacts on the vegetation that result in significant crop yield losses (Rodriíguez-Puebla et al., 2007; Schillinger et al., 2008), increased risk of forest fires (Pellizzaro et al., 2007) and forest decline (Vicente Serrano et al., 2010; Besson et al., 2014). The Mediterranean region is prone to frequent drought episodes, as a consequence of the large intra and inter-annual variability of precipitation. Very intense drought episodes are relatively common, with prolonged periods without precipitation (Vicente Serrano and Beguería, 2003). The dependence of vegetation dynamics on water accessibility in the Mediterranean regions has been extensively documented (Udelhoven et al., 2009; Gouveia et al., 2009; Vicente Serrano, 2007; Lindner et al., 2010; Koutsias et al., 2013).

Fire regimes in the Europe, namely in Southern Mediterranean areas have been changing in the last decades, mainly due to land-use changes and climate driven factors (Fried et al., 2004; Pausas and Fernández-Muñoz, 2012), such as increasing temperatures and extreme events such as droughts and heatwaves. Dimitrakopoulos et al. (2011) used a well-known drought indicator, the Standard Precipitation index (SPI) and found a positive correlation between burned areas in Southern and Central Greece and summer droughts (drier and warmer regions), for the period 1961–1997. Moreover,

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the study showed a significant increase of burned area and drought episodes in regions (Northern and Western Greece) characterized by higher annual precipitation and lower mean temperatures. The other regions of the country did not show any significant change in drought episodes although presenting always high fire activity. Koutsias et al. (2013) and Xystrakis et al. (2014) emphasized the opposite role of spring and summer precipitation in fire occurrence in Greece over the last century, being the summer precipitation associated with negative values of burned area whereas the high spring precipitation matches years large burned areas. Good et al. (2008) and Dimitrakopoulos et al. (2011) pointed out to an obvious outperformance of precipitation related variables in comparison with temperature related variables. Similarly, an assessment of the impact of dryness conditions in Mt. Taygetos, Southern Greece, showed that the drivers of the recent fires in 1998 and 2007 were both low precipitation and high temperature in summer, which enhanced the synergy between climate and fuel availability and consequently led to intense fires (Sarris et al., 2013).

The fire season of 2007 in Greece was catastrophic by most accounts. The authorities reported more than 60 human fatalities, more than 100 villages spoiled (Boschetti et al., 2008; Gitas et al., 2008; Koutsias et al., 2012) and, additionally, the new record of estimated burnt area (225,734 ha), since 1980. The fire season was especially severe in the Peloponnese Peninsula, in southern continental Greece, with 189,952 ha burnt area (ca. 1.5% of Greek land surface; 117,188 ha of forests and forested areas burnt), and considered to be the most extreme natural disaster in the recent history of Greece (Koutsias et al., 2012). Albeit the main forest fires are the result of arson and negligence, several studies attempted to assess the causes for this exceptional fire season, with a focus on climatic factors (Founda and Giannakopoulos, 2009; Amraoui et al., 2013; Koutsias et al., 2012; Sarris and Koutsias, 2014), but also highlighting a synergy of land use changes and climate (Koutsias et al., 2012).

The year of 2007 was warmer than the average conditions, with a strong effect in Southern Europe and the Middle East. Surface air temperature anomalies were 1–2 °C above the 1961–1990 average over most of the continent and, according to Luterbacher et al. (2007) and the winter of 2006–2007 was probably the warmest of the last 500 years. The temperature anomalies in January reached more than 11 °C in Eastern Europe. Moreover, Greece suffered three exceptional heatwaves in June, July and August of 2007 that represented the highest maximum temperatures of the last six to seven decades (Tolika et al., 2009). The prevailing synoptic situation during the heatwaves of summer 2007 corresponded to the occurrence of a long wave ridge with axis oriented from SW to NE, at 500 hPa, along with the horizontal advection of dry and warm air masses from north-western Africa to the central and eastern Mediterranean and further north to the Balkans (Founda and Giannakopoulos, 2009). On the other hand, according to Amraoui et al. (2013), the air masses were further heated by adiabatic compression associated to strong subsidence in the layer 800–500 hPa. Additionally, at the surface there was strong northerly advection of very hot and dry air over the region, favoring the occurrence of severe wildfire episodes. These authors show that the unusually large and severe fires occurred in Peloponnese, particularly in August, are located in the area of higher values and stronger positive anomalies of FWI (Fire Weather Index that is part of the Canadian Forest Fire Weather Index System). The comparison with future projections obtained using regional climate models shows that these extreme high temperature values have more than 50% of probability to happen by the end of the 21st century (Founda and Giannakopoulos, 2009; Tolika et al., 2009).

The impact of extreme drought events and heatwaves on vegetation has been widely assessed by means of remote sensing data (Kogan, 1997; Gouveia et al., 2009, 2012; Vicente-Serrano et al., 2013; Gobron et al., 2005; Lobo et al., 2003). Several vegetation indices have been used to analyze the behavior of vegetation, been the Normalized Difference Vegetation Index (NDVI) the most commonly used (Stöckli and Vidale, 2004; Julien et al., 2006; Gouveia et al., 2008; Vicente-Serrano et al., 2013).

Several authors have stressed that one extreme climatic event or a conjugation of two extreme climate events do not always imply an extreme ecological response of the ecosystem (e.g. Kreyling et al., 2008; Smith, 2011; Jentsch et al., 2011). Considering these limitations Smith (2011) proposed a variety of approaches to broaden our knowledge on the vulnerability of ecosystems to climate extremes. In this context, the main goals of this work are the following:

1. To characterize drought and heatwave events of 2007;
2. To evaluate the relationship of drought, heatwaves and wildfires during 2007 fire season;
3. To evaluate the impact of drought on vegetation dynamics on the months preceding the fire season using NDVI.

2. Data and methodology

2.1. NDVI

Vegetation dynamics was assessed using Normalized Difference Vegetation Index (NDVI) data as obtained by the VEGETATION sensor on board of SPOT4 and SPOT5 satellites. VEGETATION provides daily high quality global monitoring data since 1998, in four channels at 1 km^2 resolution (Hagolle et al., 2005).

We extracted NDVI data from S10 products of VITO database (http://free.vgt.vito.be). The 10-day composites were obtained after applying the Maximum Value Composite method (MVC) which allows removing pixels with clouds (Holben, 1986). The selected period for the data spans from September 1998 to August 2009 for the area of interest: 34°N to 44°N and 17°E to 27°E. MVC-NDVI data were already corrected for atmospheric and radiometric effects and calibrated geometrically (Maisongrande et al., 2004). With the aim to create a consistent dataset of vegetation dynamics, we further corrected the yearly time-series of MVC-NDVI using the approach described in Stöckli and Vidale (2004) and Gouveia et al. (2009).

We obtained the large burnt areas for 2007 with *K*-means clustering of monthly MVC-NDVI anomalies over each hydrological year (Gouveia et al., 2010). The method aims to detect mainly large burned areas and, in this study, we used an improved version that is applicable to broader areas such as the entire Iberian Peninsula (Bastos et al., 2011; Gouveia et al., 2012). The method was applied to MVC-NDVI anomalies for 2007 over Greece and a set of six large burnt scars over Peloponnese, hereafter referred to as A1 to A6 (Fig. 1). Then we used some of those areas to monitor the respective NDVI behavior. Monthly means and anomalies of NDVI from September to August were computed over the period of 1999–2009. Drought persistence was evaluated by adding up (for each pixel) the number of months between November 2006 and July 2007 with NDVI anomalies lower than −0.010 (Gouveia et al., 2009, 2012; Trigo et al., 2010).

Vegetation behavior of the main vegetation types over the study area was also assessed by means of a cluster analysis on the monthly NDVI means. Seven main clusters corresponded to the main vegetation communities over the studied area. The relationship between these clusters and the main land cover types was performed using the Global Land Cover 2000 (GLC2000) classification for the studied area.

2.2. Meteorological data

With the aim of visualizing the spatial extent of the 2007 drought we used the monthly precipitation dataset from GPCC

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