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The rainfall factor in lightning-ignited wildfires in Catalonia

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ABSTRACT

Wildland fires originated by lightning in Catalonia (NE Spain) are systematically examined through the use of lightning and precipitation data. The region of study, with a Mediterranean climate, is prone to summer wildfires. Despite being mainly anthropogenic, lightning-ignited fires (10%) are relevant as they can trigger large fires. Given that the lightning efficiency in Catalonia is of 1/1400 fires per lightning, the ability to identify potential ignition candidates among the whole lightning population would be of great value to forest protection agencies. Literature reveals that lightning characteristics such as polarity or multiplicity has proven to be of limited value as predictors. Therefore, another approach is necessary to set a probability of wildfire ignition to each lightning. In this regard, the aim of this study was to explore the relationship between lightning-ignited wildfires and precipitation, as lightning-ignited wildfires in the region are often attributed to 'dry' lightning (lightning accompanied with little or no precipitation). Results revealed that 25% of the lightning strokes related to wildfire ignitions had no associated precipitation at all, 40% had less than 2 mm of precipitation and 90% had less than 10 mm. Results also revealed that holdover fires (ignitions with delayed arrivals) are rare in the region. Finally, results suggest that there is no apparent link between the amount of precipitation and the holdover duration, indicating that the survival phase of lightning-ignitions is mainly driven by the daily cycle of solar heating. All in all, adding information on the precipitation associated to each lightning may help focusing attention on a reduced sample of strokes and provide fire managers with valuable information about potential lightning-caused wildfires.

1. Introduction

Lightning is the main natural cause of ignition in woodlands all over the world (Komarek, 1964; Pyne et al., 1996). In Europe, forest fires mostly affect the Mediterranean countries where, on average, 85% of the annual burned area is recorded (San Miguel and Camia, 2010). Forest fires in the Mediterranean are mainly anthropogenic (56% deliberate action, 33% negligence, 6% to accident) and only 5% have a natural origin (European Fire Database, Camia et al., 2010). This is probably the reason why not much attention has been paid to natural caused fires, in comparison to boreal forests where lightning is the main cause of ignition (Johnson, 1992).

Notwithstanding the foregoing, lightning fires are relevant in Mediterranean-climate regions as they can trigger large fires (e.g. Portugal summer 2003 outbreak, San-Miguel-Ayanz et al., 2013). The reason is twofold: firstly, storm systems can cause multiple, relatively simultaneous lightning-ignited fires in remote areas that may overwhelm fire management crews with limited suppression resources and result in longer response times (Podur et al., 2003; Wotton and Martell, 2005; Morin et al., 2015); and secondly, they are frequently associated to extreme meteorological conditions with dry thunderstorms and strong winds, which makes difficult the use of aerial extinction resources (Vélez, 2000; Garcia-Ortega et al., 2011; Nieto et al., 2012). Besides, fire hazard is increasing over large areas of the Mediterranean Europe. The combination of rural exodus with fire suppression policies have created, over the last decades, landscapes of high combustibility, through increasing significantly the availability and continuity of fuel loads (Moreira et al., 2011). Moreover, temperature increases and future drier conditions projected for the Mediterranean (Beniston et al., 2007; Gonçalves et al., 2013; Barrera-Escoda et al., 2013) could lead to an increase in extreme events (Nikulin et al., 2011).

The physical process involved in a lightning-caused fire occurrence has been subject of study for some years (e.g. Kourtz and Todd, 1991; Anderson et al., 2000). This process can be divided into three distinct stages (Anderson, 2002): ignition, survival and arrival. First, a lightning flash bearing continuing current triggers an

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ignition within the forest floor, tree or snag. The ignition then acts as a source for a smouldering fire within the duff layers, capable for surviving for several days. Finally, if fire weather conditions are conductive, the smouldering fire bursts into flaming combustion and the fire is considered to arrive. In the following, the characteristics of the three stages of lightning-caused fires are further developed.

1.1. Lightning-caused fire physical process

1.1.1. Ignition phase

The ignition phase can be defined as the process in which a fire, smouldering or flaming, is started in forest fuels. The likelihood of a lightning flash triggering an ignition is determined by the characteristics of the lightning flash, fuel type and moisture conditions. Regarding lightning, it is generally accepted that long continuing current (LCC) following some return strokes is the source of ignition in forest fuels (Fuquay, 1980). Continuing current is a slow varying current that immediately follows a return stroke and typically lasts for tens to hundreds of milliseconds (Rakov and Uman, 2003). LCC has been defined as having durations longer than 40 ms, the value accepted as the time of a typical interstroke interval (Kitagawa et al., 1962; Brook et al., 1962). Unfortunately, little was known about LCC before the advent of high-speed video cameras with GPS timing. With these cameras it is possible to record and analyse the luminous properties of lighting, LCC among them (e.g. Ballarotti et al., 2005; Campos et al., 2007; Saba et al., 2010; Montanyà et al., 2012; Pineda et al., 2014). These works with high-speed cameras allowed confirming the presence of LCC in both cloud-to-ground (CG) polarities. Saba et al. (2010) observed that 75% of positive CG flashes contained LCC, as well as 30% of the negative flashes. Saraiva et al. (2010) found LCC in 17.5% of negative CG flashes. Pineda et al. (2014) reported, in the region of the present study, the presence of LCC in 60% of −CG and 66% in +CG. In this case, only negative strokes with peak currents below 20 kA were not followed by LCC. The results are in good agreement with the “exclusion zone” proposed by Saba et al. (2006), which states that, for negative CG strokes, high peak current return strokes followed by LCC do not exist.

Past research has alluded to a possible dependence of lightning ignitions on polarity. Positive strokes were found to be more likely to cause ignition because of their higher peak current and their higher probability of bearing LCC (e.g. Latham and Schlieter, 1989; Kourtz and Todd, 1991; Latham and Williams, 2001; Durden et al., 2004). Nevertheless, later studies found no significant relationship between the occurrence of lightning fires and polarity (e.g. Larjavaara et al., 2005; Hall and Brown, 2006; Nieto et al., 2012; Pineda et al., 2014; Vecín-Arias et al., 2016).

1.1.2. Survival phase (Holdover)

After an ignition, if surface fuels are sufficiently dry and weather conditions are conductive, the fire will begin to spread as an active fire almost immediately. Contrarily, if the fuel moisture content is high but less than the moisture content of extinction, the fire may smoulder as a “holdover fire” (Flannigan and Wotton, 1991). The smouldering fire may survive for several days, until the surface vegetation becomes dry enough to support sustained combustion. The fire may then emerge, emit readily visible smoke and spread through the forest.

1.1.3. Arrival phase

The arrival phase is the final stage of a lightning-caused fire occurrence at which a holdover fire translates into flaming combustion on the surface. Once a fire reaches this stage, it becomes governed by three fire behaviour components: weather, fuel and terrain (Anderson, 2002).

1.2. Main factors for lightning-ignited wildfires

There is some debate and several theories pertaining to what are the factors that play a role in lightning-ignited wildfires (hereafter LIW). Among all the factors (vegetation, fuel moisture, topography, climate, weather conditions, etc.) only those related to the scope of the present study are reviewed in the following.

1.2.1. Vegetation type and structure

Vegetation type and structure play an essential role in determining spatial patterns of LIW, because they affect fuel load, moisture, flammability and rates of combustion (Rothermel, 1983; Vecín-Arias et al., 2016). For example, a greater lightning fire probability associated with conifer stands has been reported in different parts of the world, from boreal Picea ssp stands to mixed coniferous forests in the Alps (e.g. Krawchuk et al., 2006; Reineking et al., 2010; Müller et al., 2013). In comparison to other forest species, conifers are highly flammable, due to a high content in resin and essential oils (e.g. Núñez-Regueira et al., 2000). Besides, Mediterranean-type shrublands are also highly flammable (e.g. Dimitrakopoulos and Papaioannou, 2001; Alessio et al., 2008).

Litter is the surface fuel consisting of freshly fallen leaves, needles, bark or acorns that has undergone little or no decomposition (Pyne et al., 1996). It generally constitutes the ‘receiving’ fuel that may ignite and initiate the fire (Curt et al., 2011). Litter composition usually reflects the composition of the overlying vegetation (Olson, 1963) and one can expect that similar ecosystems would have similar litter flammability (e.g. Behm et al., 2004). Once ignited, litter fuels may propagate fire horizontally and vertically to the upper vegetation layers (Plucinski and Anderson, 2008). Lightning fires may also start in deeper layers at the base of the trees. Indeed, the decomposing vegetative matter making up the forest floor (duff layer) is also affected by or involved in fire. Duff combustion has a slow spread rate but may persist several days and can break into open flame several days after ignition to resume its spread as a surface fire (Hartford, 1993).

1.2.2. Fuel moisture

A lightning strike can ignite a fire; however the ignition, survival and arrival of this fire are heavily dependent on the moisture of the forest fuels (snags and logs, litter and duff layers). The moisture content of the vegetation needs to be low enough for the energy and heat of the lightning strike to cause combustion (van Wagner, 1972; Flannigan and Wotton, 1991; Viegas et al., 1992; Meisner et al., 1993; Morin et al., 2015). The moisture content will affect not only the efficiency of heat absorption, but also the likelihood of fuel temperatures reaching the critical point of ignition from a lightning strike (Hall, 2007). If the forest fuel is damp, but deeper organic layers are dry, the fire may smoulder into the duff layer, as a “holdover fire” (Martell and Sun, 2008). Fuel moisture content is increased by groundwater availability, atmospheric humidity and particularly precipitation (Evett et al., 2008). The relative timing of the lightning strike and precipitation can be critical to determine whether a wildfire is ignited and detected (Hall, 2008).

As noted earlier, weather characteristics such as rainfall, relative humidity and temperature have a bearing on fuel moisture. It is well established that the Mediterranean summer weather conditions (high temperature, prolonged drought periods and strong winds) play a significant role in the Mediterranean fire regime (Ganteaume et al., 2013). Several attempts to link weather factors and fire occurrence can be found in the literature. For example, Vazquez and Moreno (1993) linked fire occurrence with drought, Vasilakos et al. (2008) with rainfall and wind, or Rorig and Ferguson (1999) and Álvarez-Lamata (2005) with the amount of rainfall.