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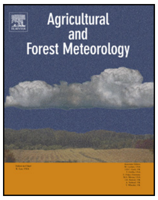

Characteristics of lightnings igniting forest fires in Austria

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ABSTRACT

Besides anthropogenic causes, lightning is the major reason for forest fire ignition worldwide. Information on lightning characteristics and impact points is missing or controversial, due to the difficulty of lightning stroke localization and the relation to single forest fire events. Austria as an Alpine country experiences a high number of thunderstorms and lightnings, which ignite more than one third of forest fires from June to August. With data from the "Austrian Lightning Detection and Information System" (ALDIS) it was possible to link single lightnings and their characteristics to the location and attributes of individual forest fires. Three subsets with lightning data were compiled and analyzed regarding their strength (kA), polarity (positive or negative) and multiplicity (number of re-strokes). Additional data on the time of ignition, burned area, sea level, exposition and burned vegetation were investigated. Two fire weather sub-indices (FFMC – Fine Fuel Moisture Code and BUI – Build Up Index) of the Canadian FWI (Fire Weather Index) were calculated for the location of the impact point of each lightning and over a period of twenty days, including the day of ignition. Positive lightnings were significantly more likely to induce a fire. Both the FFMC and BUI showed a significant mean decrease after the day of ignition. Precipitation was significant lower at those impact points where forest fires were ignited. Burned area was larger when lightnings ignited during day hours. Most lightning fires occurred at higher altitudes with southerly or western exposition, mainly in stands of Norway spruce (*Picea abies* L.). Pine species were four times more often affected than the natural tree species distribution would assume. The study results contribute to the international discussion on lightning fires and will help to provide recommendations for further modelling studies on the forecast of lightning caused forest fires.

1. Introduction

Humans and lightnings account for most forest fires ignitions around the world. Especially in regions with summer droughts combined with convective activity, lightnings can ignite a significant proportion of forest fires up to 40% or more (Anderson, 2002; Hall and Brown, 2006) and may be responsible for more than 90% of the area burned (Wendler et al., 2011). Lightnings occur nearly everywhere and are not linked to the living space of humans. The resulting forest fires are often located in remoted and hardly accessible areas, where they are difficult to combat by fire brigades and may lead to devastating and long living crown fires (Flannigan and Wotton, 1991; Kourtz and Todd, 1991; Stocks et al., 2002). Also lightnings may ignite during night time, which hampers firefighting and may increase burned area and fire severity. Moreover, lightning fires have the potential to smoulder undetected over a long time period and burst into flames when weather conditions are suitable for ignition (Conedera et al., 2006; Wendler et al., 2011).

Although lightning fires are frequent in temperate zones with large forested areas, like Canada, the US or some regions in Europe and Asia, information on lightning characteristics and conditions at the impact point is often missing or controversial due to the random nature of lightnings. It is general accepted in scientific literature, that lightnings with long continuing current ignite most fires (Pineda et al., 2014). Other lightning characteristics like the role of positive lightnings, current strength and lightning multiplicity are not that clear. For instance older studies like Fuquay (1980) showed that positive lightnings are more likely to induce forest fires than negatives ones, due to higher current amplitudes, greater probability of a long continuing current and less accompanying precipitation. While some newer studies (e.g. Wendler et al., 2011; Wotton and Martell, 2005) agree with this finding, most research results from the last years found no higher ignition probability of positive lightnings (e.g. Flannigan and Wotton, 1991; Larjavaara et al., 2005; Pineda et al., 2014). Further uncertainties include the role of fuel moisture at the point of lightning impact, as relatively wet conditions may not prevent initial ignition (Dowdy and Mills,

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2012). One reason for the uncertainties related to fire ignition is the difficulty of lightning stroke localization and linkage to single forest fire events. In case that the individual strokes cannot be analyzed, the driving factors are hard to identify. A first attempt on this issue was done by Larjavaara et al. (2005). However most studies from recent years did not deal with this difficulty. This can lead to a misunderstanding of the role of lightning characteristics, fire weather, determining fuel conditions and of other factors like exposition, topography and ground vegetation.

Central European mountain forests are highly diverse in terms of climate, geology and topography, resulting in various compositions of forest ecosystems and distinct levels of fire susceptibility. Similarly to most regions of the world, anthropogenic forest fire causes are dominating. Nevertheless a high number of thunderstorms and lightnings are observed, which ignite more than 10% of forest fires in regions like southern Switzerland (Conedera et al., 2006), northern Italy (Valese, 2007) and in parts of Spain (Vecín-Arias et al., 2016). In Austria around 15% of annual forest fires and up to 40% in the summer months are ignited by lightning (Müller et al., 2013).

European mountain forests are among the regions which are most affected by climate change (Lindner et al., 2010). For the future an increase in lightning activity is assumed due to global warming (Price 2009; Reeve and Toumi, 1999; Romps et al., 2014). Regional climate models predict an increase in temperature and a reduction of precipitation in summer and autumn, especially in the south and east of Austria (Dankers and Hiederer, 2008; Fischer and Schär, 2010; Lautenschlager et al., 2009; Matulla et al., 2004). In recent years several drought and temperature records occurred in Austria, like the driest July ever recorded in 2013, the very first time temperatures above 40 °C in August 2013 or the largest number of days above 35° in 2015 (ZAMG, 2016). Anomalies in the Austrian forest fire regime were observed as well, which may indicate a shift to more and larger forest fires (Müller et al., 2015).

In this context Austria can serve as a case study for the analysis of lightning caused forest fires in European mountain forests. We want to identify the physical, meteorological and local conditions for lightning caused ignitions to contribute to the discussion on lightning fires and lightning characteristics and to provide recommendations for further modelling studies on the forecast of lightning caused forest fires.

The first aim of the present study was to evaluate the possible impact of polarity, strength and multiplicity of lightnings strokes on the chance of ignition. We hypothesize that currently measurable physical parameters of lightnings are not relevant for ignition and, in particular, that positive lightnings do not ignite more forest fires than negative ones, like recent studies suggest (e.g. Larjavaara et al., 2005; Pineda et al., 2014; Vecín-Arias et al., 2016).

The second aim was to analyze the role of fuel moisture conditions at the point of lightning impact. We hypothesize to find dry conditions at the day of ignition but higher fuel moisture afterwards because of rare dry thunderstorm events in Austria. Precipitation after ignition is therefore assumed to inhibit large lightning fires in Austria, like it was found for other parts of the world (Aldersley et al., 2011; Littell et al., 2009; Nash and Johnson, 1996; Wendler et al., 2011).

Third, the influence of ignition time and ground parameters like altitude, exposition and vegetation are investigated. As southern orientated Norway spruce (*Picea abies*) stands at higher altitudes are primarily affected by lightning fires (Müller et al., 2013) it is assumed that fires on southern to western exposition lead to a larger burned area due to stronger solar radiation and drier fuel conditions in the summer months (Vacik et al., 2011). Also lightnings igniting in the evening or night hours may cause larger burned areas, because of the difficulties of fire suppression.

2. Material and methods

2.1. Forest fire documentation

Within the activities of European (ALP FFIRS) and national (AFFRI, FIRIA) projects the analysis on the occurrence, distribution, causes and characteristics of forest fires were accomplished (Vacik et al., 2011). A wildfire database has been established, as no homogenized and nationwide database on forest fire occurrence existed. The database now includes more than 4000 forest fire incidents from 1540 to 2016, with an almost complete documentation of the last 25 years (Eastaugh and Vacik, 2012). In some cases the collected information was incomplete, for instance the exact time of detection, the cause, the burned area or affected tree species were missing or unknown.

The position, respectively outbreak point, of each forest fire was estimated according to the available information provided by the data source. This information could include maps with marked ignition points, the specification of affected properties, road, valley or mountain names, distances to important local objects like churches, chalets, mountain shelters etc. In some cases it was possible to gain information on the exact outbreak point by using aerial photographs and documenting pictures taken during the firefighting operations. To define the position, WGS84 was chosen as coordinate system. The localization accuracy of each forest fire was estimated by expert judgement in respect of the available information by placing a buffer radius around the assumed ignition point. The highest accuracy can be reached with a resolution of 1" in WGS84, which approximates a buffer of 30 m. The mean localization uncertainty for all recorded forest fires in the Austrian fire database is currently 1500 m, for all records since 1993 it averages at 1350 m and since 2003 the mean localization uncertainty is 1260 m.

Additional information about the forest fires was totally burned area, mainly affected tree species and forest type, altitude and exposition at ignition point. The burned area of lightning fires was investigated in terms of the time of ignition in a 12 h interval, divided in day (06:00 h–18:00 h local time) and night (18:00 h–06:00 h). In this context it has to be remarked that ignition and detection time are not comparable. Ignition time indicates the time of the lighting stroke that caused the fire, while detection time is associated with the time when the forest fire is first observed. Smouldering and undetected fires after lightning ignition may last a couple of days (Conedera et al., 2006; Rorig and Ferguson, 1999; Wendler et al., 2011).

Burned area sizes were also analyzed regarding a possible correlation with the exposition, whereby larger burned areas were assumed to occur from SE to W exposition (against NW to E). Exposition was classified according to south, southwest, west, northwest, north, northeast, east, southeast and flat terrain.

Full information for each record was not always available or could not be acquired. Therefore the number of analyzed forest fires had to be reduced for the current analysis. An estimation of burned area was available for 248 cases (71%). Information on tree species could be collected for 258 fires (74%), data on forest types for 312 events (89%). Altitude and exposition were evaluated for all cases.

2.2. Lightning detection

The Austrian Lightning Detection and Information System (ALDIS) detects thunderstorm activity in and around of Austria. The detection efficiency of cloud to ground (CG) lightnings is well above 90% since 1999, with an estimated efficiency of 98% from 2006 onwards (Diendorfer, 2007; Schulz et al., 2005). This makes ALDIS one of the best performing lightning detection systems worldwide (ALDIS, 2009; Biagi et al., 2007; Castedo-Dorado et al., 2011;