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Asynchronous lightning and Santa Ana winds highlight human role in southern California fire regimes

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Abstract

Southern California's most extreme fire weather is caused by offshore Santa Ana winds, which commonly occur later in the year than the lightning which provides natural ignition. Examination of the specific dates of both lightning and Santa Ana winds over 25 years shows that Santa Ana winds are very rare during or even within ten days of lightning strikes. The median lag between the two phenomena is 52 days, and on those occasions when lightning does occur shortly before Santa Ana winds, the actual density of strikes is very low. The rarity of lightning as ignition for Santa Ana-driven fires suggests that the current fire regime dominated by such fires is largely a product of the abundance of human-caused ignition.

1. Introduction

In southern California, the Mediterranean-type climate, flammable chaparral scrub vegetation, and steep terrain allow for frequent and severe wildfires that have extensive impacts on both human and ecological communities (Pyne 1982, Keeley and Davis 2007). The ongoing expansion of housing into the naturally fire-prone wildlands of the region has contributed to rates of losses of life and property that are the highest in the United States (Safford 2007, Keeley *et al* 2009). In the decade 2007–2016, about 15% (468 269) of the ~3 million hectares that burned in the state were in five southern California counties, and Jin *et al* (2015) calculated that between 1990–2009 the housing value destroyed annually in the region was almost $195 million, and that annual suppression costs exceeded $90 million.

Within the southern California region, foehn-type Santa Ana winds are typically responsible for the largest and most destructive wildfires (Keeley and Fotheringham 2001, Jin *et al* 2014, 2015). These easterly and northeasterly winds emanating from high pressure in the interior western United States warm adiabatically and their relative humidity drops as they descend over the Transverse and Peninsular ranges, so that they dry and heat fuels in addition to driving the flame front (Westerling *et al* 2004). As a result, fires driven by Santa Ana winds spread faster, across a wider variety of fuel types than those that are not, contributing disproportionately to loss of lives, structures, and dollars in the region; housing value destroyed per fire is more than 13-fold higher for fires driven by Santa Ana winds than for those that are not (Jin *et al* 2015). The difficulty in controlling fires driven by these winds (and their dangers) derive in large part from the rapid rate at which they may spread. The 2003 Cedar Fire, for example, grew from 200 ha to 12 500 ha in just four hours (Westerling *et al* 2004).

The timing of Santa Ana wind-driven fires presents something of a climatological conundrum. Santa Ana conditions occur most frequently in the winter, but this is when winter precipitation in the Mediterranean climate of the region dampens fuels, reducing the likelihood of fire. Consequently, Santa Ana fires are generally thought of as an autumnal phenomenon, when fuels are still dry from summer drought, but Santa Ana conditions have begun to occur (Jin *et al* 2014). Absent human ignition, the timing would be further complicated by the fact that lightning in the region generally occurs during the summer months.

Discussions of pre-EuroAmerican fire regimes in the region have therefore focused on the possible role of ignitions by Native Americans, and on assumptions that lightning-ignited fires must have smoldered locally until Santa Ana conditions occurred, and then flared up into conflagrations. With regard to the role of Native Americans, views have been mixed, with Lewis (1973) arguing that anthropogenic fire was central to the very evolution of chaparral, whereas Bendix (2002) concluded that its impact was spatially limited to population centers and ecotones, and Keeley (2002) suggested that while chaparral may have been maintained by lightning fire, the presence of extensive herbaceous patches as well as chaparral in the landscape reflected frequent burning by native peoples. Without anthropogenic ignition, lightning is the only realistic source for fire, and this is where timing becomes more problematic. While multiple authors have suggested that summer lightning fires could have occasionally smoldered until the autumnal Santa Ana winds began (Minnich 1987, Bendix 2002, Keeley and Fotheringham 2001, Keeley 2002), the actual instances in which this seems to have been documented (Minnich 1987) are as rare as they are dramatic. Keeley and Fotheringham (2001) note the rarity with which such holdover is likely to have happened, while emphasizing the large conflagrations that could result when it did.

Those discussions have been guided by understanding of the general climatology of the region, but have not included data on the actual occurrence of lightning relative to Santa Ana conditions. The details of such occurrences are critical to the likelihood of natural Santa Ana-related fires. While it is possible for fires to smolder until winds rise, the probability decreases with the passage of time.

In this paper, we use 25 years of data for the dates of lightning strikes and the dates on which Santa Ana conditions occurred to quantify the lag between the two. Specifically, we examine (i) the number of days experiencing both lightning and Santa Ana winds, (ii) for lightning days without Santa Ana winds, the number of days until Santa Ana winds occurred, (iii) the density of lightning strikes on days during or shortly before Santa Ana winds, (iv) seasonal variation in the lag between lightning and Santa Ana winds, and (v) whether large fires have actually resulted from coincident lightning and Santa Ana winds.

2. Methods

2.1. Lightning data

We identified lightning dates using the publically available lightning strike data from the National Climate Data Center (www.ncdc.noaa.gov/data-access/severe-weather/lightning-products-a). The data are segregated by county, and we analyzed those from the five southern California counties that are consistently affected by Santa Ana winds (Keeley 2004): Los Angeles, Orange, Riverside, San Bernardino, and San Diego (figure 1).

2.2. Santa Ana wind data

We used a published compilation of days on which regional Santa Ana conditions prevailed, based on synoptic scale reanalyses of sea level pressure gradients and lower tropospheric advection (Abatzoglou *et al* 2013). The overlap of the data available for lightning (starting 1986) and Santa Ana winds (ending 2010) determined the timespan we analyzed, 1986–2010.

2.3. Fire data

We determined the starting date of large wildfires from California's Fire and Resource Assessment Program (FRAP). We follow Westerling *et al* (2006, 2016) in using 400 ha as the cutoff size for large fires. There were 261 such fires in the region during the timespan analyzed. The FRAP database includes fire perimeters and relevant data (fire alarm date, fire containment date, fire cause, fire size), based on records from Federal, State, and local agencies (http://frap.fire.ca.gov/projects/fire_data/fire_perimeters_methods). Although there are some concerns regarding completeness of the FRAP record, those concerns arise primarily for fires smaller than those we examined, and for fires earlier than the period we analyzed (Keeley 2004). For 72 of the fires, fire cause was listed as 'unknown/unidentified,' for these we checked the fire start date against the dates of lightning strikes, to consider the possibility that they may have been lightning-caused. Two of the entries for fires we analyzed had missing data for the starting date; for those we inferred dates based on contemporary newspaper accounts.

2.4. Data analyses

We merged the data for dates of lightning, Santa Ana winds, and large fires to determine the extent to which they coincided. For every date on which lightning struck within the five-county region, we determined (a) whether Santa Ana winds had prevailed on that day, or (b) how many days elapsed before the occurrence of Santa Ana winds. Because the often extreme lag following spring lightning skews the data, we report median rather than mean number of days from lightning to Santa Ana winds. For calculation of density of lightning strikes, we used the land area of each county as reported by the US Census Bureau.

3. Results and discussion

Days with both lightning strikes and Santa Ana winds were exceedingly rare (table 1), with fewer than one per year overall. The occurrence of those days is not coincident across the region, so that no single county had less than a two year mean recurrence interval between lightning-Santa Ana wind days. Los Angeles County experienced none during the 25 year period, and Orange County experienced only one.

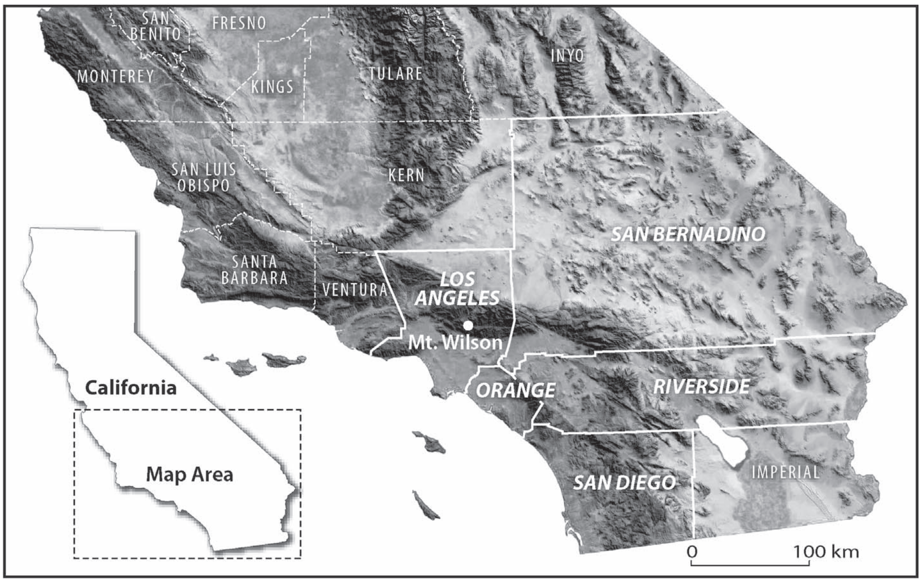

Figure 1. Location of the five counties (in bold) included in the study. Mt. Wilson is the location for the precipitation data used in figure 3.

Table 1. Frequency and timing of lightning relative to Santa Ana winds (SAW) in southern California counties, 1986–2010.

County	Mean lightning strikes/1000 km^2 day^{-1}	Median lag (days) from lightning to SAW	Mean number of days/year with both lightning and SAW	Mean lightning strikes/1000 km^2 day^{-1} on days with both lightning and SAW	Mean number of lightning days/year with SAW within 10 days	Mean lightning strikes/1000 km^2 day^{-1} on days followed by SAW within 10 days	Number of lightning-ignited fires[a] affected by SAW within 10 days
Los Angeles	0.3	43	0	–	4.5	2.5	0
Orange	0.1	30	0.04	0.5	2.1	4.9	0
Riverside	0.6	54	0.36	0.6	4.9	2.4	0
San Bernardino	1.1	55	0.48	0.1	8.5	3.2	0
San Diego	0.4	55	0.48	0.6	3.4	2.5	0
OVERALL	0.8	52	0.88	.2	12.1	1.7	0

[a] Data are for fires > 400 ha.

The virtual absence of lightning on Santa Ana days means that any lightning-ignited Santa Ana fires must indeed smolder for some length of time before the winds rise. The length of that lag is therefore highly relevant to the probability of this occurring. We found that across our 25 year sample, the median lag from a day with lightning to a day with Santa Ana winds was 52 days. This lag was notably shorter in Orange County (table 1, figure 2) at 30 days, but that is also the county which experiences the least lightning, at 0.1 strikes/1000 km^2 day^{-1}.

Although the preponderance of lightning strikes occur weeks before any Santa Ana winds, the variance shown in figure 2 indicates that the lag is sometimes shorter, suggesting the potential to start occasional conflagrations that would involve Santa Ana conditions. We therefore focused on strikes that were followed within ten days by Santa Ana winds, as those that might most plausibly ignite fires that would last long enough to be affected by the subsequent winds. An average of 12.1 days year^{-1} have lightning that is followed within 10 days by Santa Ana winds. Again, however, the strikes on those days are quite sparse, with only 1.7 strikes/1000 km^2 day^{-1}. This is because short lag times are seasonally concentrated in the November–January period when lightning is particularly rare (figure 3). These are also months when precipitation is generally high across the region (figure 3), so that moist fuels decrease the chance for lightning to ignite fire, or for fire to smolder for lengthy periods.

All of these factors reduce the probability of lightning-caused fires being affected by Santa Ana winds, and the fire records bear this out. During the period we examined, there were only 14 large ($\geq$ 400 ha) lightning-caused fires (out of the total of 261 large fires in the five counties), and none of these were ignited within ten days before Santa Ana conditions. There were an additional nine for which the fire cause was recorded as 'unknown' but which started on days during which lightning strikes had occurred in the same county so that it is possible that they too were caused by lightning; again, none of these began on, or were followed within ten days by, Santa Ana winds. It remains likely that over much longer time periods

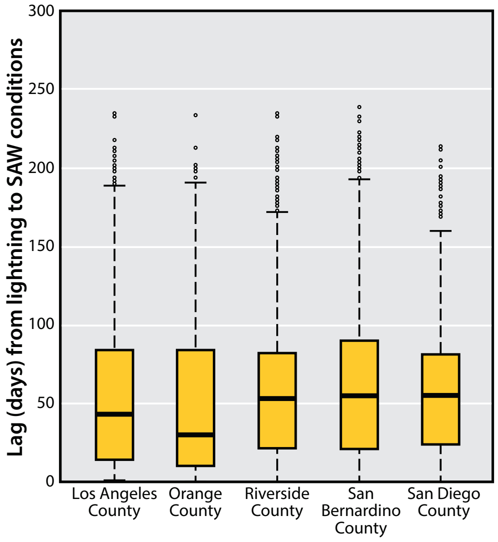

Figure 2. Lag between lightning strikes and Santa Ana wind (SAW) conditions in southern California counties. Heavy horizontal lines show the median, yellow boxes extend from the first to third quartiles, whiskers are at 1.5x the interquartile range, and dots represent outliers.

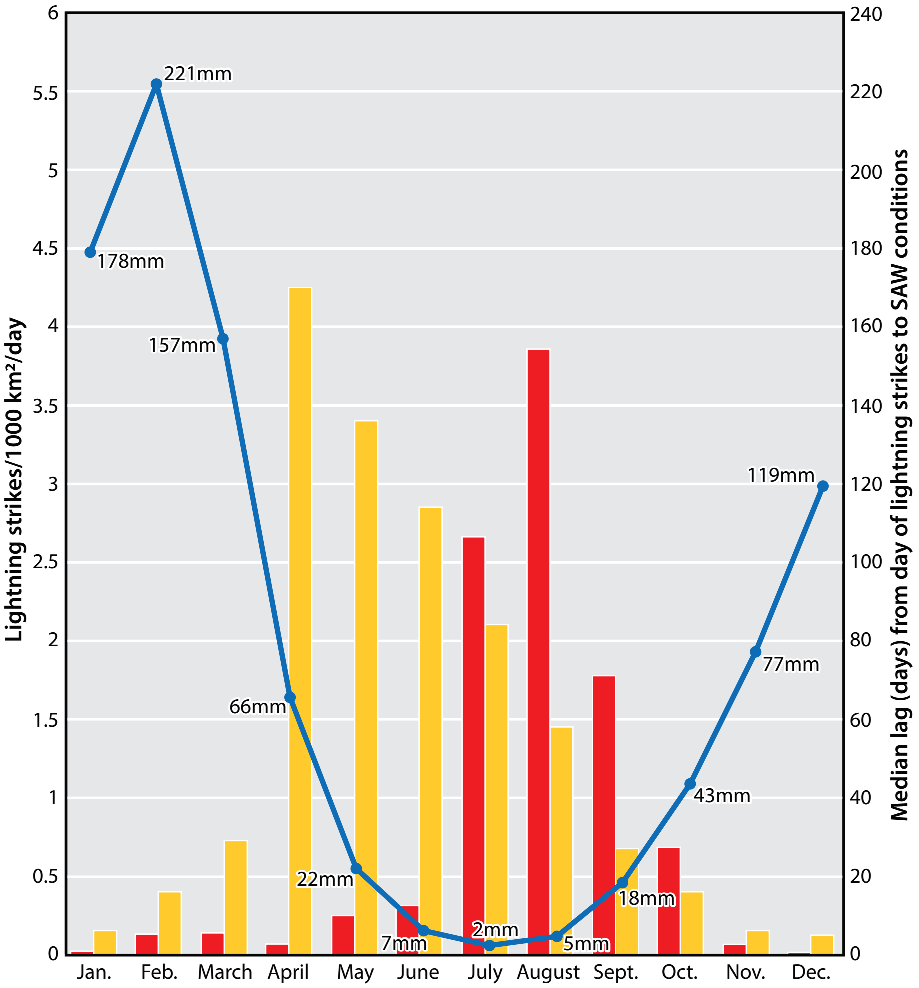

Figure 3. Seasonality of lightning, lag between lightning and SAW, and precipitation in southern California. Red bars denote density of lightning strikes, yellow bars represent the lag, and the blue line shows mean monthly precipitation at Mt. Wilson, which is representative of general seasonal patterns in the region (precipitation data from www.ncdc.noaa.gov/cdo-web/datatools/normals).

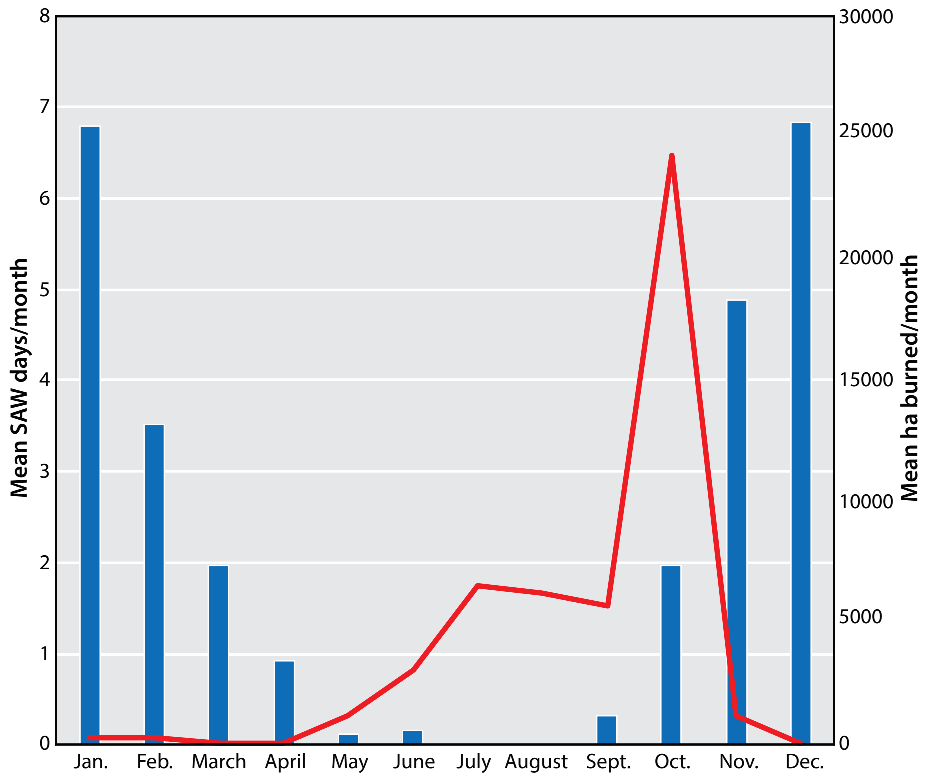

Figure 4. Seasonality of Santa Ana wind days and area burned in study area. Blue bars denote mean number of Santa Ana wind days per month and the red line shows the mean area burned per month (in fires > 400 ha). Data are for the period 1986–2010.

lightning fires might occasionally last long enough to be fanned by Santa Ana winds (Keeley and Fotheringham 2001, 2003), but our data suggest it would only be a rare occurrence. It is instructive to contrast this with the FRAP data for large human-caused fires over the same 25 year period: 39 out of 169 of these began on Santa Ana wind days. While that amounts to only 23%, those 39 accounted for 47% of the area burned by human-caused fires (412 157 ha of 892 159). These figures dwarf the area burned by lightning-caused fires, which totaled only 97 784 ha (these numbers exclude the fires of unknown causation).

The seasonality of burning over the timespan we studied reflects what is currently understood to be the classic pattern for the region: the most extensive burning occurs in autumn during the overlap between summer-dried fuels and winter Santa Ana winds (figure 4). The substantial lag between lightning and Santa Ana winds (table 1, figures 2 and 3) suggests that this pattern might be rather different in the absence of human ignition sources.

4. Conclusions

The rarity of natural (lightning) fires during Santa Ana conditions has significant implications regarding past, present, and future human impacts on southern California fire regimes. There has been debate over the impact of Native Americans on fire in the area prior to EuroAmerican settlement (Timbrook *et al* 1982, Bendix 2002, Keeley 2002); the lack of natural fires during Santa Ana conditions may support the argument that anthropogenic ignition was necessary to account for the apparent occurrence of presettlement Santa Ana fires (Mensing *et al* 1999). There has also been considerable debate regarding the extent to which fire suppression may have facilitated large fires by allowing chaparral fuels to age over the past century (Minnich 1983, 2001, Minnich and Chou 1997, Minnich and Franco-Vizcaíno 1999, Keeley *et al* 1999, Keeley and Fotheringham 2003, Keeley and Zedler 2009). Our findings suggest that plentiful human ignition may have been a more important factor, as it is non-seasonal, and makes ignition during Santa Ana conditions commonplace rather than rare. There has recently been recognition of how human ignition expands the 'seasonal niche' of wildfire (Balch *et al* 2017); our data represent an example in which the niche is expanded into the most severe fire weather conditions—weather which paradoxically would rarely coincide with fire, absent the human role. Finally, as anthropogenic climate change leads to higher temperatures and evapotranspiration rates (Cayan *et al* 2008) and potentially to drought (AghaKouchak *et al* 2014), fuels may in the future be drier during the winter months when the lag between lightning and Santa Ana winds is minimized, making the rare winter lightning a more likely ignition source for Santa Ana fires than it has been in the past.

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