Geophysical Research Letters

COMMENTARY
10.1029/2021GL092843

A Shorter, Sharper Rainy Season Amplifies California Wildfire Risk

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Key Points:

- California autumn precipitation of outsized importance from ecological and wildfire risk perspectives
- An observed decrease in autumn precipitation and delay in rainy season onset have contributed to an increase in peak seasonal wildfire risk
- Sharpening precipitation seasonality reported by Luković et al. (2021) is consistent with climate model projections in a warming climate

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Citation:

Swain, D. L. (2021). A shorter, sharper rainy season amplifies California wildfire risk. *Geophysical Research Letters*, *48*, e2021GL092843. https://doi.org/10.1029/2021GL092843

Received 4 FEB 2021
Accepted 11 FEB 2021

Abstract California has experienced increasingly severe autumn wildfires over the past several decades, which have exacted a rising human and environmental toll. Recent fire and climate science research has demonstrated a clear link between worsening California wildfires and climate change, mainly though the vegetation-drying effect of rising temperatures and shifting precipitation seasonality. New work by Luković et al. (2021) explores observed changes in California's autumn precipitation in greater detail, finding that the rainy season has indeed become progressively delayed and that the "sharpness" of California precipitation seasonality has increased. These precipitation shifts have important implications for the region's ecology and wildfire risk, as they increase the degree of temporal overlap between extremely dry vegetation conditions and fire-promoting downslope winds in late autumn. Both of these observed shifts are consistent with climate model projections for the region's future, suggesting that recent trends may offer an early preview of larger changes to come.

1. Introduction

California is a land famous for its predictably long, dry summers and mild, wet winters—both hallmarks of its temperate "Mediterranean" climate. But these same climatological characteristics predispose the region to periodic water scarcity: if precipitation-bearing storms fail to materialize during the relatively brief wet season that peaks from November to March, there is little opportunity to make up for accumulated deficits during the rest of the calendar year (Swain et al., 2016). This reality understandably focuses climatological and hydrological investigations primarily on the core rainy season months in winter. Yet despite the relatively modest contributions to total annual precipitation during the autumn and spring, these so-called "shoulder seasons" are of outsized importance from an ecological perspective.

Because California's dry season coincides with its warm season, during which potential evaporation greatly exceeds precipitation for a sustained multi-month period, the period of time between the wet season termination in spring and its subsequent onset in autumn effectively set the bounds of the region's wildfire season (as well as its agricultural irrigation season) (Berghuijs et al., 2014). In a typical year, the region's vegetation begins to dry out by the late spring or early summer as soil moisture decreases, reaching peak dryness by late summer or early autumn. Autumn also heralds the arrival of "offshore wind" season, characterized by occasional bursts of land-to-sea winds (locally termed "Santa Ana" winds in southern California and "Diablo" winds near the San Francisco Bay Area) that represent a conspicuous reversal of the typically moist onshore (west-to-east) flow across coastal California. Offshore winds tend to occur during autumn and early winter, rather than summer (Abatzoglou et al., 2021), as they are primarily driven by strong surface pressure gradients arising from early season cold air masses over the Great Basin (Guzman-Morales et al., 2016). These sometimes violent winds can result in dramatic drying and warming of the airmass as they descend the western slopes of California's mountains from the interior desert plateau toward the Pacific Ocean. California's wildfire season is therefore usually "back-weighted": the greatest risk of severe fires often occurs in autumn, rather than during the hotter summer (Abatzoglou et al., 2018), due to the temporal coincidence of maximal annual vegetation dryness and desiccating offshore windstorms (Nauslar et al., 2018).

2. An Even Shorter, Sharper Seasonal Cycle in California

(Luković et al., 2021), in a recent analysis, offer compelling evidence that California's already narrow wet season is becoming even shorter and sharper. Using station-based precipitation observations between 1960 and 2019, the authors report a substantial and statistically significant decrease in autumn (September–November) precipitation. This autumn precipitation decline is primarily driven by November precipitation decreases, which is historically the wettest autumn month in California, with relatively smaller contributions by decreases in September and October. Notably, this autumn drying trend is detected across the full latitudinal extent of the state, and is robust across both northern and southern California. Luković et al. (2021) further find that the average onset of California's rainy season has become progressively delayed by nearly a full month (~27 days) over the past 6 decades, and that the California's overall annual precipitation has become increasingly concentrated into its core rainy season months (December–March) and the expense of the shoulder seasons (primarily autumn). From a large-scale atmospheric perspective, this progressively delayed wet season onset is linked to a delayed strengthening of the semi-permanent Aleutian Low and subsequent southward shift in the mid-latitude storm track—in other words, an extension of "summer-like" atmospheric conditions into October and November.

3. Increased Confluence of Dry Vegetation and Offshore Winds Amplifies Risk

This observed lengthening of California's dry season through decreasing and delayed autumn precipitation has substantial implications for the region's ecology, as well as wildfire risk. The addition of 1–2 months each year during which net water balances are strongly negative acts to decrease the moisture level in dead and dormant vegetation, which includes California's seasonal grasses and increasingly extensive regions of drought and bark beetle-induced forest mortality (Goulden & Bales, 2019). In some cases, such prolonged moisture deficits can begin to stress even living vegetation as water in the soil column becomes depleted toward the end of the dry season. Collectively, these shifts increase the overall flammability of California's vegetation at precisely the time of year when it is already at its driest—an effect compounded by California's observed warming trend, which further increases atmospheric water demand and subsequent moisture deficits (Goss et al., 2020; Williams et al., 2019).

In addition to the direct effect of increasing peak seasonal vegetation flammability, the delay in California's rainy season also increases the temporal overlap between "summer-like" vegetation dryness and the offshore wind season. Offshore winds in California actually exhibit phase-shifted peaks from north to south in autumn and winter, respectively, with "Diablo" winds across northern and central California most common around October and "Santa Ana" winds across southern California most common around December or January (Abatzoglou et al., 2021; Guzman-Morales et al., 2016, Figure 1a). The onset of the rainy season from north to south across California exhibits a similar seasonality, beginning 1–2 months earlier in the north than across the south. Historically, precipitation would usually (but not always) occur in California slightly prior to the peak of offshore wind season in each region (September or October in the north; October or November in the south). As small an increment as 2%–5% of the annual average precipitation, received in a timely manner, is often sufficient to dampen fire season substantially and reduce the fire-fanning potential of these winds. Early season precipitation is thus critical from a wildfire risk mitigation perspective, despite its small fractional contribution to the annual total. But with the observed ~1 month delay in rainy season onset described by Luković et al. (2021), precipitation is increasingly arriving during or after the offshore wind peak, increasing the confluence between extremely dry vegetation and strong wind conditions (Figure 1b).

4. Observed Trends Are Consistent with Long-Term Climate Projections

The observed decrease in autumn precipitation reported by Luković et al. (2021) is broadly consistent with climate model projections for a warming California. Previous work has shown that decreases in "shoulder season" precipitation (including autumn) would most likely emerge at some point during the first half of the 21st century as a result of increased anthropogenic forcing, and this general result has been robust across a wide range of multi-model ensembles (including the CMIP5 [Dong et al., 2019], CESM Large Ensemble [Swain et al., 2018], and NA-CORDEX [Mahoney et al., 2021] experiments). These same analyses

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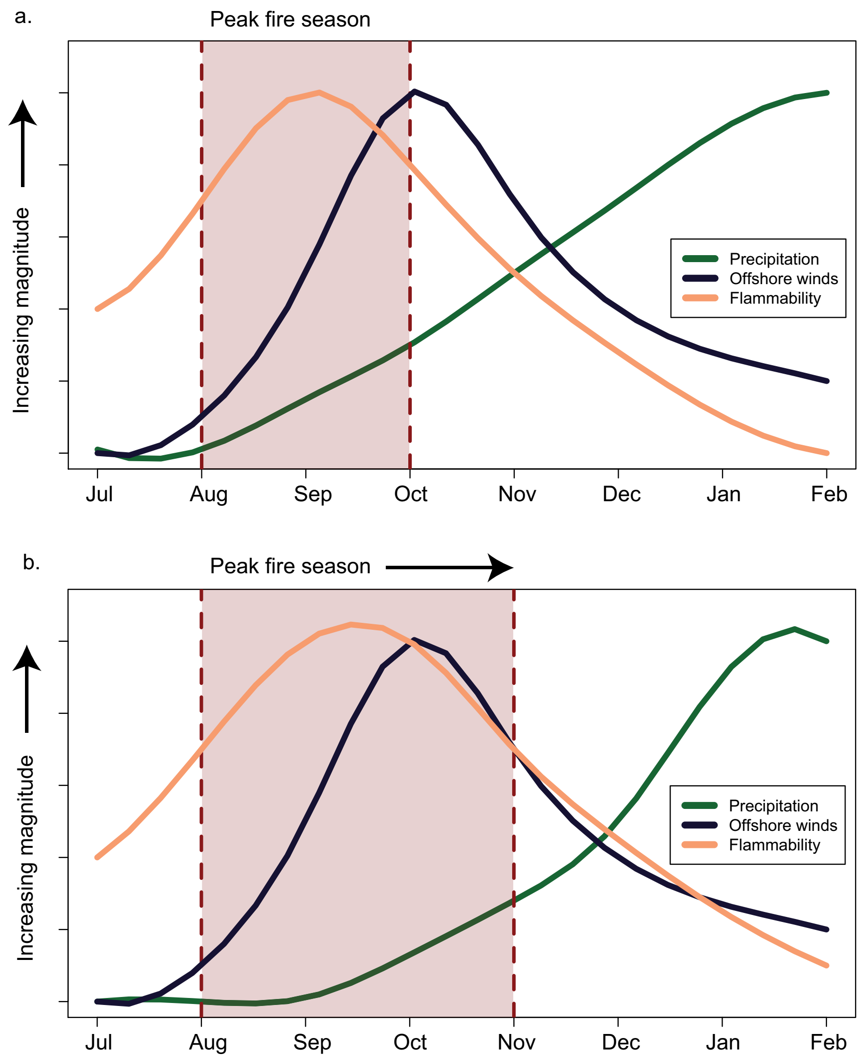

Figure 1. Delayed wet season onset increases autumn wildfire risk. Schematic figure qualitatively depicting (a) the seasonality of California precipitation, offshore winds, and vegetation flammability (b) how a delay in autumn precipitation onset can increase the temporal overlap between dry vegetation and peak offshore wind conditions, increasing the duration and severity of peak fire season. In both (a) and (b), the duration of peak fire season (from a vegetation flammability perspective) is represented by the width of the red rectangle. Schematic represents seasonality in northern California, where peak offshore winds and seasonal precipitation onset occur about 2 months earlier than in southern California.

have additionally emphasized projected increases in "seasonal sharpness", the rising fraction of California's overall annual precipitation that is expected to occur during its core winter rainy season months of December-March at the expense of the autumn and spring. Luković et al. (2021) indeed report a modest degree of seasonal sharpening between 1960 and 2019, perhaps offering an early preview of further sharpening to come.

This particular aspect of California's shifting precipitation seasonality may be doubly significant from a wildfire risk perspective, as it has at least two distinct potential effects on vegetation conditions. First, future precipitation decreases in both autumn and spring will increase the duration of vegetation soil moisture drying that occurs each year, delaying and increasing the peak intensity of autumn burning conditions. Second, projected increases in the amount of mid-winter precipitation (as well as the increased occurrence of individual extremely wet winters [Berg & Hall, 2015; Swain et al., 2018]) may promote increased growth of fast-responding vegetation such as grasses and light brush (known as "fine fuels" in the wildland firefighting community) in spring, which will inevitably dry out during the long, dry summer that follows. Indeed, in certain California ecological regions characterized primarily by grass and brush (as opposed to forests), some of the worst historical wildfire conditions have actually occurred following wet (vs. dry) winters (Abatzoglou et al., 2018; Williams et al., 2019). In this sense, the observed and projected sharpening of California's precipitation seasonality offers the "worst of both worlds": greatly increased vegetation flammability during the dry season, but also plenty of water to encourage the growth of grass and brush following increasingly intense winter precipitation.

To be clear, the high inter-annual variability of California seasonal precipitation has previously presented a challenging signal-to-noise problem, thus far making formal climate change attribution of observed trends difficult (Williams et al., 2019). Nevertheless, the growing correspondence between observations (as demonstrated by Luković et al., 2021) and climate model projections for these key California precipitation seasonality metrics increasingly suggests these trends are unlikely to have arisen by random chance, and will likely continue in the future with further climate warming. While there is some evidence that the early season frequency of Santa Ana winds in southern California may decrease in a warming climate, there is little indication that their peak magnitudes will weaken (Guzman-Morales & Gershunov, 2019), meaning that these ongoing precipitation shifts will likely contribute to further amplification of California's autumn wildfire risk (Goss et al., 2020).

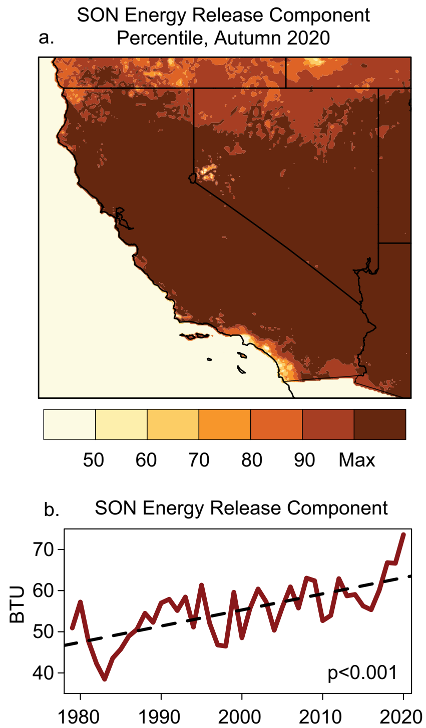

Figure 2. Increasing autumn vegetation flammability across California, 1979–2020. (a) Map depicts historical percentile of vegetation flammability as quantified using the Energy Release Component (ERC) in autumn (September–November) 2020. Dark brown colors ("Max") represent regions where autumn 2020 ERC was the highest in the 41-year record. (b) Time series depicts historical values of California statewide ERC (September–November 1979–2020); trend line is result of a simple linear regression (trend is statistically significant at $p < 0.001$). Data from the GridMET database, obtained via climateengine.org.

5. Challenges and Opportunities for Fire Management

The escalating challenge of an increasingly prolonged and severe fire season in California has unfortunately been vividly illustrated by recent catastrophic autumn fires. Over just four years between 2017 and 2020, nearly 200 lives were lost and over 45,000 structures were destroyed in California wildfires, with the health and livelihoods of millions more adversely affected by extreme air pollution episodes caused by prolonged intervals of dense smoke (Burke et al., 2021). The historically unprecedented level of vegetation dryness during 2020 (Higuera & Abatzoglou, 2021) and other recent autumns in California (Figure 2) has co-occurred with both record warm temperatures and anomalously low precipitation, and a rapidly growing body of evidence suggests this is not a coincidence. Not only have extreme autumn "fire weather" conditions more than doubled since the late 1970s in California (Goss et al., 2020), but these increases have been primarily attributed to increased vegetation flammability (rather than to shifts in the offshore wind patterns that often accelerate these fires [McEvoy et al., 2020]). The combined effects of warming summer and autumn temperatures during fire season (Williams et al., 2019), as well as decreases in autumn precipitation (e.g., [Luković et al., 2021] and others), have yielded an increasingly pronounced risk of dangerous peak season fires. Moreover: the expansion of fire season into historically unusual calendar months has begun to severely tax wildland firefighting resources, as many relevant state and federal agencies maintain only skeleton staffing levels during "non-peak" fire season months. And climate model projections strongly suggest that these challenges will only increase as the climate warms further in the coming decades as California's autumn fire season becomes warmer and drier still (Goss et al., 2020, McEvoy et al., 2020, Williams et al., 2019, Westerling, 2018).

Yet the news is not all bad. One of the most promising tools for managing increasing wildfire risk is the use of prescribed fire to more closely mimic optimal fire regimes. To reverse the harmful legacy of total fire exclusion policies of the 20th century, which prevented beneficial lower intensity fires from maintaining healthy forest density and ultimately increased wildfire risk in the long run (Steel et al., 2015), and to partially offset the rising risk posed by a changing climate, many ecologists and fire scientists have argued for a much more comprehensive program of targeted fire treatments (Kolden, 2019; Miller et al., 2020). This includes cultural burning practices that have been an important part of life among the indigenous peoples of California for thousands of years (Eriksen & Hankins, 2014; Lake et al., 2017), and which sometimes take place during dry spells early in the wet season. While there is clear evidence that autumn drying in California is increasing the risk of extreme fire conditions, drier conditions during the early portion of the wet season may also offer increased opportunities for ecologically and societally beneficial managed fire when wind conditions permit, perhaps expanding opportunities to reduce wildfire-related hazards in the long run.

Data Availability Statement

Energy Release Component (ERC) data are obtained from the GridMET database, and may be obtained via the Climate Engine portal at www.climateengine.org.

Acknowledgments
D.L. Swain was supported by a joint collaboration between the Institute of the Environment and Sustainability at the University of California, Los Angeles; the Center for Climate and Weather Extremes at the National Center for Atmospheric Research; and the Nature Conservancy of California as well as NSF PREEVENTS grant 1854761. D.L. Swain thanks GRL Editor Alessandra Giannini for the invitation to write this commentary.

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