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SCIENCE BEHIND THE NEWS

Increasing Hydroclimatic Whiplash Can Amplify Wildfire Risk in a Warming Climate

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On January 7 and 8, 2025, a series of wind-driven wildfires occurred in Los Angeles County in Southern California. Two of these fires ignited in dense woody chaparral shrubland and immediately burned into adjacent populated areas–the Palisades Fire on the coastal slopes of the Santa Monica Mountains and the Eaton fire in the foothills of the San Gabriel Mountains. Both fires ultimately eclipsed the traditionally-defined "wildland-urban interface" boundaries by burning structure-to-structure as an urban conflagration. The scope of the devastation is staggering; at the time of writing, the fires have together killed at least 29 people, destroyed over 16,000 structures (Helsel 2025), and are expected to become the costliest global wildfire disaster on record.

The chaparral ecosystems that prevail across coastal southern California (CSC) evolved with frequent wildfire. Regions with Mediterranean climates (like CSC) are characterized by cool, wet winters and hot, dry summers. Vegetation typically becomes progressively drier, with corresponding landscape-level flammability rising, from spring through summer and peaking in early autumn prior to the onset of the rainy season sometime between October and December. The region is also susceptible to strong, downslope "Santa Ana" windstorms during autumn and winter, which cause air to warm and dry as it accelerates and descends steep mountain slopes, further desiccating vegetation. Thus, the autumn (and, increasingly, early winter) months bring episodic periods of elevated wildfire risk across CSC; a majority of the region's fastest-moving and most historically destructive fires have occurred during this window of overlap between critically dry vegetation and strong downslope winds (Abatzoglou et al. 2023).

The catastrophic January 2025 fires were propelled by an especially extreme combination of these two recognized risk factors: (1) downslope wind gusts over 80 mph (35 m/s) and (2) exceptionally dry vegetation following a historically dry start to the rainy season and unusually warm antecedent temperatures driving a prolonged episode of elevated atmospheric evaporative demand. But there was also a third contributor: two consecutive anomalously wet winters (in 2022–2023 and 2023–2024), which led to abundant growth of herbaceous vegetation across CSC. This remarkable wet-to-dry sequence (Figure 1A), therefore, set the stage for the CSC wildfire disasters to unfold by first facilitating prodigious fuel accumulation during the previous growing seasons (Keeley 2004), then subsequently drying vegetation to produce exceptional

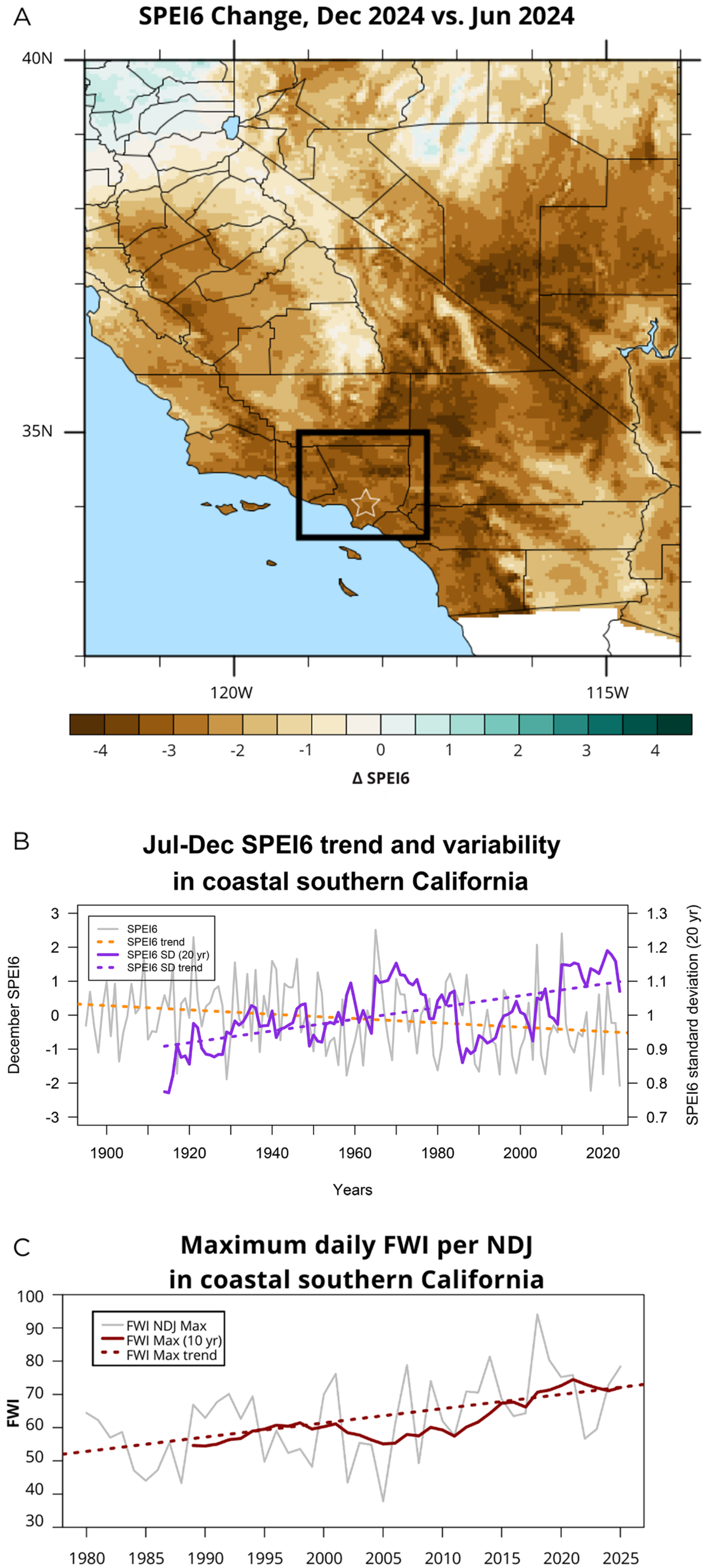

FIGURE 1 | Legend on next page.

FIGURE 1 | Overview of 2024–2025 wet-to-dry "whiplash" event in southern California and associated hydroclimate/fire weather trends. (A) Map depicting the geographic scope and magnitude of the June 2024–December 2024 wet-to-dry hydroclimate whiplash event in southern California as measured using 6-month Standardized Precipitation and Evaporation Index (SPEI6) differences. The black rectangle region encompasses the region that experienced the most extreme fire weather conditions on January 7-8 2025, and the white open star depicts the approximate location of Los Angeles, CA. (B) Time series of observed SPEI6 (ending in December; grey line). Also shown are the SPEI6 linear trend from 1895 to 2024 (dashed orange line; cumulative decrease of −0.94 units over the 129 year record; $p < 0.01$) and the 20-year running mean variability (standard deviation; dark purple line) and its linear trend from 1915 to 2024 (dashed purple line; cumulative increase of ~0.22 units or ~25% over the 129 year record; $p < 0.01$). (C) Time series of observed maximum daily Fire Weather Index (FWI; unitless; grey line) within each November–January period, as well as the 10-year running mean (dark red solid line) and its linear trend (red dashed line) from 1980 to 2025 (inclusive through January 10, 2025; cumulative increase of 18.8 units or ~36% over the 44 period of record; $p < 0.01$). Data in (b) and (c) are for the Mediterranean South Coast Ecoregion (Level 3); SPEI data are computed from PRISM and FWI data are calculated from gridMET.

flammability unusually far into winter (when Santa Ana winds are common).

Globally, climate change has increased wildfire potential primarily through greater aridity (Jain et al. 2022). In CSC, hotter summer and autumn seasons drive this aridity by increasing evaporative demand (i.e., atmospheric "thirst"), subsequently drying out vegetation. This, in conjunction with an increasingly delayed onset of the rainy season (Goss et al. 2020), may also be increasing temporal overlap between critically dry vegetation and Santa Ana winds (Swain 2021). As the events of January 2025 vividly illustrate, however, transitions from anomalously wet to anomalously dry conditions may further amplify these risks by exacerbating fuel accumulation and desiccation cycles. Indeed, in fire regimes (including CSC) where fire occurrence varies strongly with inter-annual variations in biomass (Swetnam et al. 2016), increased hydroclimate volatility is causally linked to increased wildfire activity.

In a recent review, we reported that rapid swings between unusually wet and dry conditions (and vice versa)–what we term "hydroclimate whiplash"–will broadly increase due to climate change (Swain et al. 2025). This increased volatility stems primarily from thermodynamically-driven increases in the atmosphere's water vapor-holding and water-evaporating capacity, which raise the intensity ceiling on both extreme precipitation and evaporative demand, respectively. Therein, we quantified a projected more than doubling in terrestrial hydroclimate whiplash events at a global warming level of 3°C. In CSC, a ~25% increase in late-season moisture variability (July–December SPEI) has occurred concurrent with a mean drying trend over 1895–2024 (Figure 1B), and also coincided with a ~36% increase in the maximum amplitude of extreme fire weather conditions during peak offshore wind season (November–January) between 1980 and 2025 (Figure 1C). We suggest, therefore, that an increasingly volatile hydroclimate may further amplify the risk of extreme wildfires in many regions as rapid shifts from an unusually wet growing season to an usually dry fire season become more frequent–and that recent events in CSC offer a clear example of the potential consequences.

While climate change amplifies increasingly severe wildfires globally (Jones et al. 2022), non-climatic factors contribute substantially to wildfire disasters. Population-level wildfire exposure has ballooned as urban and peri-urban areas expand rapidly in fire-adapted regions (Rao et al. 2022). Land use decisions, expanding extent of invasive grasses, agricultural abandonment, and historical fire suppression all contribute to the growing wildfire crisis to varying degrees, depending on local context (Jones et al. 2022). Accordingly, the interventions with the greatest demonstrated near-term benefit are generally those implemented locally. These include strengthening building codes to encourage or mandate fire-resistant structures, reducing fuel around homes and communities, minimizing human-caused ignitions during extreme fire weather conditions, increasing public education and improving communication technologies to facilitate effective emergency response, fire-aware land use planning, and leveraging increasingly skillful predictions of extreme fire weather conditions to strategically allocate firefighting personnel and equipment (Bowman et al. 2020).

Increasing hydroclimate whiplash, in conjunction with other well-established impacts of climate change on fire activity (Jones et al. 2022), will accelerate increases in wildfire disaster risk at regional-to-global scales. Humans, however, are capable agents of landscape-level changeand it is not only possible, but necessary, to stem the tide of increasingly disastrous wildfires by offsetting greater climatological fire potential via extensive and sustained risk-reducing interventions that increase the fire resilience of communities.

Author Contributions

Daniel L. Swain: conceptualization, data curation, formal analysis, investigation, methodology, project administration, software, visualization, writing – original draft, writing – review and editing. **John T. Abatzoglou:** conceptualization, data curation, formal analysis, investigation, methodology, writing – review and editing. **Christine M. Albano:** conceptualization, writing – review and editing. **Manuela I. Brunner:** conceptualization, writing – review and editing. **Noah S. Diffenbaugh:** conceptualization, writing – review and editing. **Crystal Kolden:** conceptualization, writing – review and editing. **Andreas F. Prein:** conceptualization, writing – review and editing. **Deepti Singh:** conceptualization, writing – review and editing. **Christopher B. Skinner:** writing – review and editing; conceptualization, data curation, software, visualization. **Thomas W. Swetnam:** conceptualization, writing – review and editing. **Danielle Touma:** conceptualization, writing – review and editing.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All data used to calculate SPEI and its trends from the PRISM dataset (accessible via: https://prism.oregonstate.edu) and all data used to calculate the FWI and its trends are from the GridMET dataset (accessible via various options at: https://www.climatologylab.org/gridmet.html).

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