FIRE WEATHER

Heat, dryness, and wind are driving wildfires in the Western U.S.

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Research brief by
Climate Central

CLIMATE CENTRAL

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INTRODUCTION

Climate change is worsening wildfires across forested land and lengthening wildfire seasons in the Western United States. Warming from heat-trapping pollution is drying out forests, grasslands and other landscapes, increasing the likelihood that destructive fires will erupt and spread. And warming is also affecting day-to-day weather in ways that this analysis shows are increasing the frequency of fire weather days.

To explore changes in weather conditions that increase the spread of fire, Climate Central analyzed data from weather stations in 225 locations across 17 states going back to 1973. This review of historical trends in fire weather—a combination of high heat, low humidity, and strong winds—aims to investigate how climate change is affecting wildfire risk throughout the American West.

Long-term warming trends lead to accelerated evaporation from soils and plants, creating drier conditions. Our analysis of the U.S. West shows that this drying has been driving increases in the frequency of fire weather days, affecting states from the Pacific Coast to the western Great Plains and from the Canadian to the Mexican borders. In addition to increasing the risk of fire to communities throughout these states, these extreme conditions are also causing problems even when fires don't ignite. In response to high-risk fire weather conditions, and in the hopes of avoiding equipment-related ignitions, power companies are shutting off electricity to millions of people, creating health risks to those who depend on power for refrigeration of medications and to stay cool during heat waves.

Cover photo: AP Photo/Noah Berger

WHAT IS 'FIRE WEATHER?'

Three factors influence fire behavior: weather, fuels, and topography. Changes to the weather element can affect fire behavior and increase fire risks, regardless of the nature of the fuels present or the natural contours of the land.

Fire weather generally refers to meteorological conditions that promote the spread of wildfires, although definitions of fire weather can vary. Variables such as temperature, relative humidity, wind, precipitation, and atmospheric instability all affect fire behavior. This analysis focuses on three meteorological elements fundamental to fire weather—temperature, relative humidity, and wind. When these three elements converge in particular ways, the stage is set for wildfire growth.

Relative humidity is a measure of how close the air is to being saturated by water vapor. When humidity levels are very low, the air feels dry and it sucks moisture from the land, leaving vegetation dry and prone to burning. As temperature increases, relative humidity decreases. Our analysis shows decreasing relative humidity has been a major factor in boosting the number of days each year of wildfire weather for many locations. Thresholds at which low relative humidity can drive fire weather vary depending upon fuel types and local climate. (See more details on relative humidity in the sidebar on page 9).

Hotter temperatures affect humidity and dryness and they also have a direct influence on fire behavior, heating the fuels and making them more likely to ignite.

Wind is critical for several reasons. Wind supplies oxygen to a fire, which leads to the fire burning more rapidly. It also increases evaporation, helping to dry out the land which provides more fuel for the fire. Wind also carries embers, which help a fire spread. Changes in wind speed or direction can cause a fire to shift, and can increase the rate of spread and intensity of the fire.

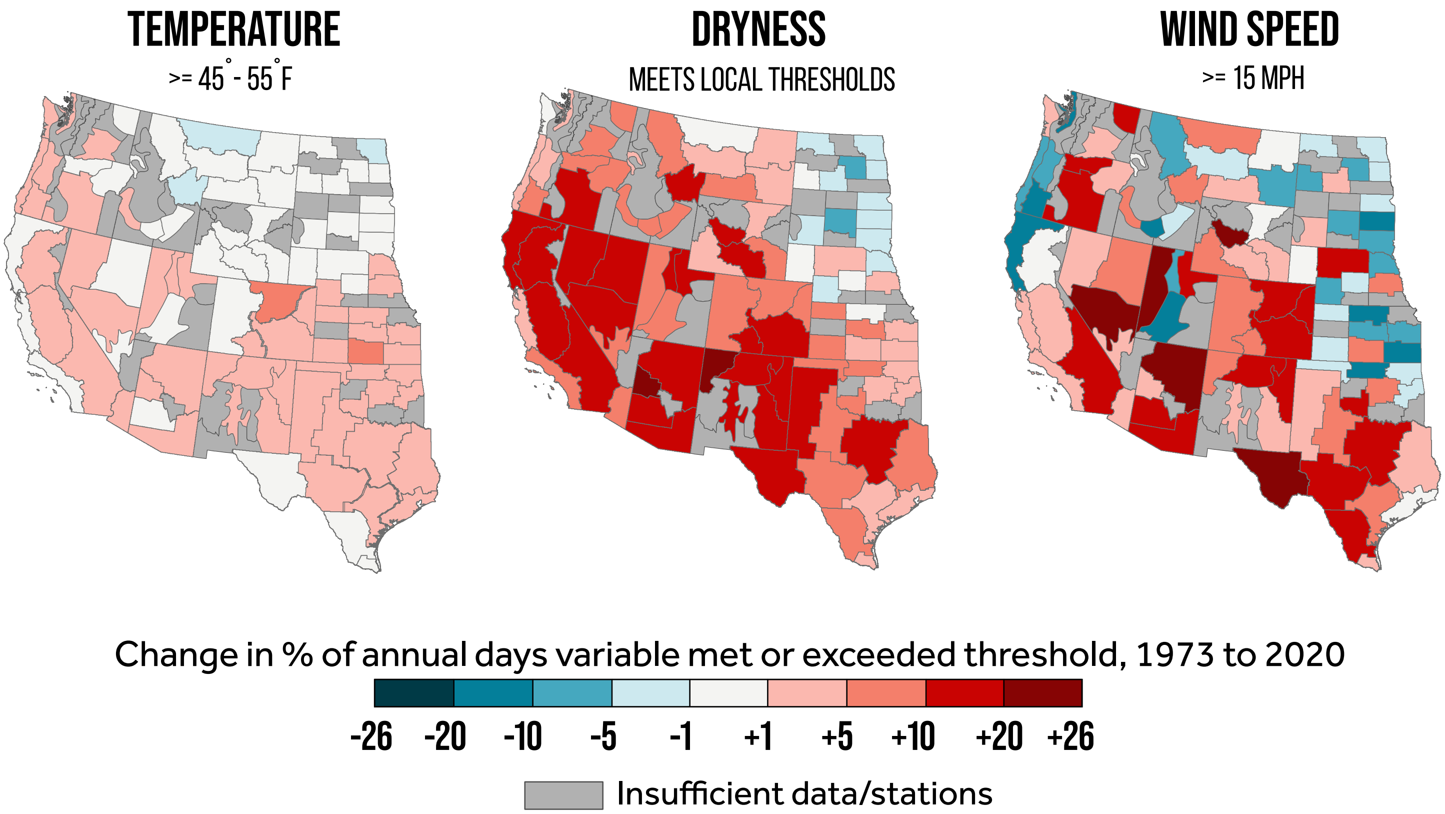
To be considered a fire weather day, these three elements must co-occur at or above certain levels, producing dangerous weather conditions that increase the risk of wildfire. While the critical relative humidity values for fire weather vary across the country, our analysis shows decreasing relative humidity has been a major factor in boosting the number of days each year of wildfire weather for many locations.

WHAT ELSE IS FUELING MODERN WILDFIRES?

Fire weather is an important factor for wildfire, but it's just one part of the story. Humans play a key role in influencing the amount of fuel available. We also play a role in igniting fires through a variety of activities. Additional human-induced forces include:

- The legacy of generations of firefighting efforts and the loss of indigenous approaches to land management have both led to buildups of fuels in places where fire was always a natural part of the environment.
- The arrival and spread of invasive grasses and other exotic species are creating more combustible and fire-prone environments.
- The ongoing urbanization of forests, forest edges and other areas where fires are prone to burn puts more residents in harm's way and forces firefighting agencies to allocate greater resources toward protecting homes.
- Urban development causes more wildfire ignitions. Discarded cigarettes, sparks from cars, fireworks, and other human activities can start fires at times of year when lightning is uncommon and fires would naturally be rare.
- Rising temperatures contribute to tree mortality caused by beetles, causing a buildup of dead trees that some scientists worry will lead to larger and worse wildfires.
- As firefighting agencies try to respond to larger and more numerous fires, their resources are being stretched thin, forcing them to make difficult decisions about responding to some fires while allowing others to burn unchecked.

Figure 1. What's driving increases in fire weather?



Source: NOAA/NCEI's Local Climatological Data, Climate Central analysis

When temperature, low relative humidity, and wind converge in particular ways, they set the stage for rapid wildfire growth. Climate change is driving an increase in days when temperatures and low relative humidity reach dangerous thresholds.

CLIMATE CENTRAL FINDINGS: FIRE WEATHER TRENDS

As explained in the methodology section of this report, Climate Central analyzed data from individual weather stations and then aggregated them by climate division when possible. These climate divisions are defined by the National Oceanic and Atmospheric Administration (NOAA).

The analysis shows strong increases since the 1970s in both the total number of annual fire weather days and in the percentage increases in the number of fire weather days experienced every year. These results are consistent with findings from previously published research.

Parts of New Mexico, Texas, and Southern California have experienced some of the greatest increases in fire weather days each year, with parts of New Mexico now seeing two more months of fire weather than was the case nearly a half century ago. Some of the climate divisions in Texas, California, Oregon, and Washington are experiencing fire weather more than twice as often now than in the early 1970s.

Increases in fire weather days were higher in the interior regions compared to coastal regions. Living along the coast typically means higher humidity levels, so it's harder for these areas to reach the low relative humidity threshold used in the analysis. While there are still relatively few days per year when the fire weather conditions occur in these coastal areas, the analysis shows an increase in these conditions over time (see maps on pages 7 & 8).

By contrast, some parts of North Dakota, South Dakota, Kansas, and Nebraska experienced a decline in the frequency of fire weather days. This is part of a region where springs and summers have been cooling slightly while much of the rest of the country and world has been warming. This cooling is expected to be temporary and may be influenced by the cooling effects of agricultural development, crop irrigation, and natural variation.

This analysis is intended to provide a greater understanding of the role that changes in day-to-day weather are playing in wildfire risks through the American West. Warming and drying trends are also altering the dryness, flammability, and other conditions of vegetation that promote larger and more intense wildfires.

MORE FIRE FUNDAMENTALS AND RESOURCES

When the wind is blowing hot, dry air, it's fire weather, which affects fire ignition, behavior and suppression. While 80% of wildfires are started by humans, there are also a number of other elements that can raise the risk and danger of fire:

- Dry lightning is cloud-to-ground lightning without any accompanying rainfall nearby and is the lightning type most likely to cause wildland fires.
- Fuels are any combustible material that can feed a fire, including grass, leaves, ground litter, plants, shrubs, trees and other vegetation.
- Topography can cause dramatic shifts in fire behavior. Slope steepness and direction, elevation, barriers, and land configuration all play a role.
- Climate change is a major contributor to the severe and persistent droughts in southwestern North America in recent decades.

You can find daily fire reports at the National Interagency Fire Center. There are fire and smoke maps at AirNow, the San Francisco Chronicle CA Fire Map and the California Smoke Information Map. The weekly U.S. Drought Monitor map shows parts of the U.S. that are in varying levels of drought. The National Wildfire Coordinating Group has a glossary of wildfire terms. And check out the Society for Professional Journalists' toolbox on covering fires.

Figure 2. Fire weather trends in Western U.S. climate divisions (1973-2020)

TOP 10 FIRE WEATHER ANNUAL AVERAGE DAYS

1	**Nevada - 95** CD4 - Extreme Southern (Las Vegas)	6	**New Mexico - 72** CD5 - Central Valley (Albuquerque)
2	**Nevada - 93** CD3 - South Central (Tonopah, Goldfield)	7	**New Mexico - 70** CD7 - Southeast Plains (Roswell, Carlsbad)
3	**California - 85** CD7 - Southeast Desert (Palm Springs)	8	**New Mexico - 70** CD3 - Northeast Plains (Mosquero, Clayton)
4	**New Mexico - 74** CD2 - Northern Mountains (Santa Fe, Taos)	9	**New Mexico - 68** CD1 - Northwest Plateau (Gallup, Aztec)
5	**Utah - 74** CD4 - South Central (Beaver, Kanab)	10	**Wyoming - 68** CD3 - Green & Bear Drainage (Evanston, Kemmerer)

TOP 10 INCREASE IN TOTAL FIRE WEATHER DAYS (# OF DAYS)

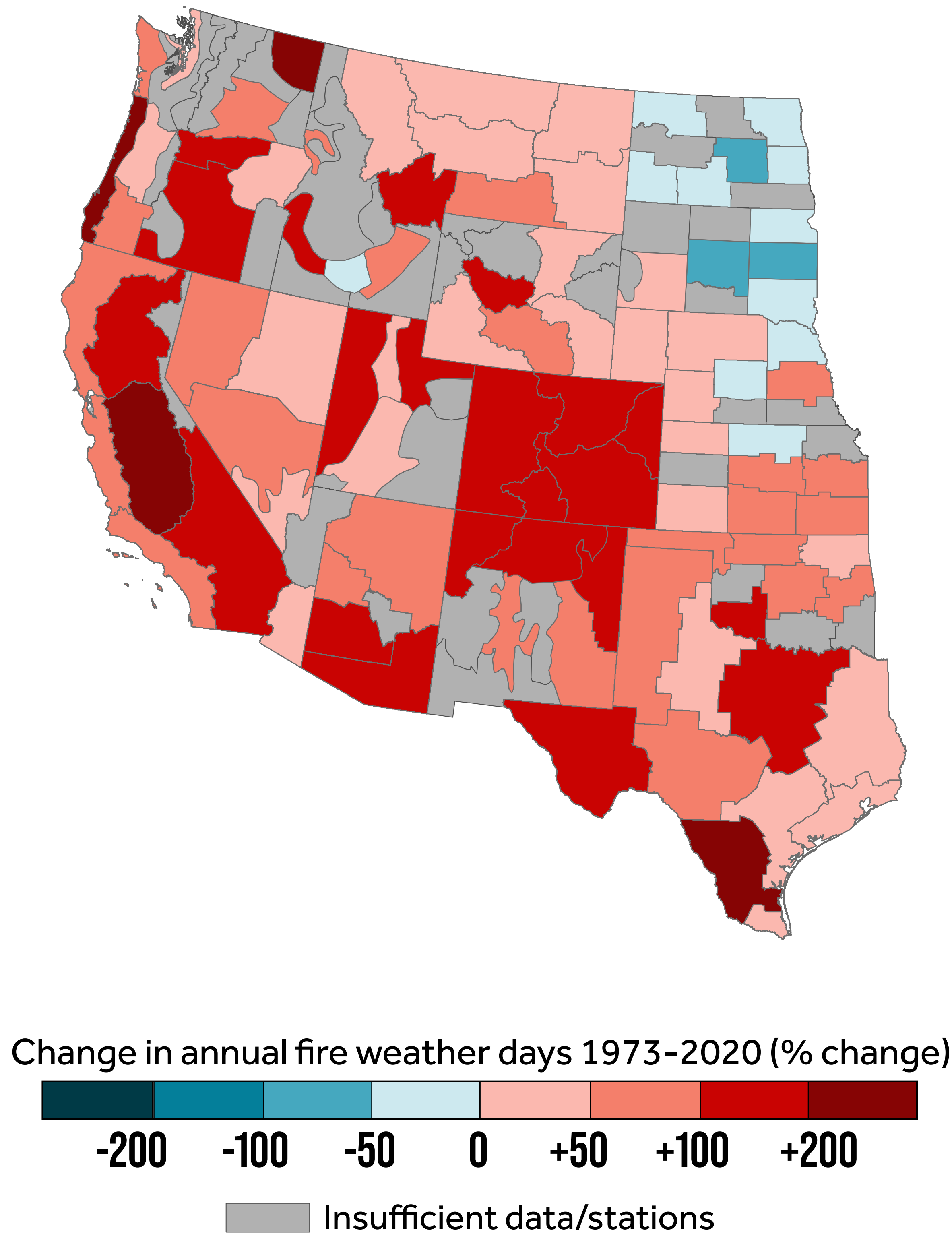
1	**New Mexico - 60** CD2 - Northern Mountains (Santa Fe, Taos)	6	**Nevada - 55** CD3 - South Central (Tonopah, Goldfield)
2	**New Mexico - 59** CD1 - Northwest Plateau (Gallup, Aztec)	7	**Arizona - 51** CD7 - Southeast (Tucson)
3	**California - 59** CD7 - Southeast Desert (Palm Springs, San Bernardino)	8	**Arizona - 43** CD2 - Northeast (Flagstaff, Holbrook)
4	**Texas - 56** CD5 - Trans Pecos (El Paso)	9	**Colorado - 43** CD1 - Arkansas Drainage (Colorado Springs, Pueblo)
5	**New Mexico - 55** CD3 - Northeast Plains (Mosquero, Clayton)	10	**Colorado - 42** CD5 - Rio Grande Drainage Basin (Alamosa, Del Norte)

TOP 10 INCREASE IN FIRE WEATHER DAYS (% CHANGE)

1	**Texas - 284** CD9 - Southern (Laredo, Asherton)	6	**Idaho - 173** CD5 - Southwestern Valleys (Boise)
2	**California - 269** CD5 - San Joaquin (Bakersfield, Merced)	7	**California - 173** CD2 - Sacramento Drainage (Sacramento, Paradise)
3	**Oregon - 253** CD1 - Coastal area (Astoria, Gold Beach)	8	**Oklahoma - 169** CD7 - Southwest (Hollis, Mountain View)
4	**Washington - 236** CD9 - Northeastern (Spokane)	9	**Colorado 161** CD4 - Platte Drainage Basin (Denver, Boulder, Ft. Collins)
5	**Arizona - 186** CD6 - South Central (Phoenix, Scottsdale)	10	**Utah - 158** CD1 - Western (Knolls, Lakeside)

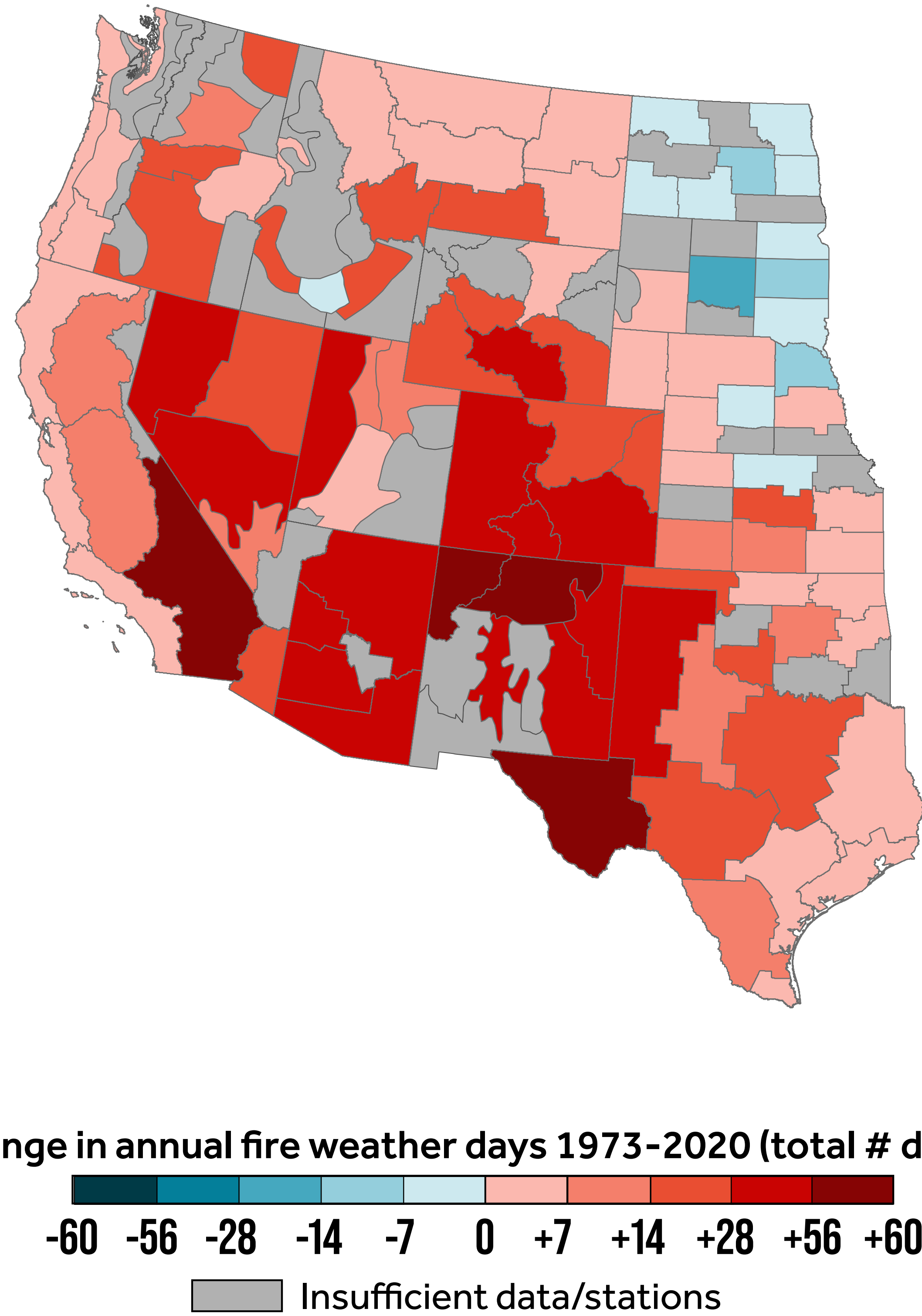
Source: NOAA/NCEI's Local Climatological Data, Climate Central analysis

Figure 3. Fire weather season is lengthening across the West



Source: NOAA/NCEI's Local Climatological Data, Climate Central analysis

Figure 4. Fire weather days are increasing across the West



Source: NOAA/NCEI's Local Climatological Data, Climate Central analysis

WHY DOES FIRE WEATHER MATTER?

As wildfire weather becomes more prevalent, there are more days when extreme conditions can blow small blazes up into big ones or fuel the continued growth of large wildfires. That's creating greater risks to public health, property, and local and regional economies from flames and smoke. Smoke is a dangerous pollutant that can contribute to a variety of health problems, increasing susceptibility to asthma and asthma attacks. It can also make one more susceptible to influenza and other viruses like COVID-19, and poses especially high risks to those with other health problems, particularly among seniors and others with weakened lung health. And fire weather conditions restrict firefighters' ability to put out existing wildfires. With climate change, nights have warmed significantly, even more so than days. This has decreased the overnight relative humidity that once helped firefighters gain control over wildfires.

Wildfire weather days are a new challenge for utilities who are laboring to keep up with record power demand during heat waves. California utilities have started shutting down parts of their electrical grids during periods of fire weather to reduce the risks that their power lines will ignite fires during those dangerous times. For decades, utilities have paid compensation to victims of such fires, and this was regarded as a cost of their approach to doing business. But the sheer size and magnitude of the damage caused by fires in recent years has increased compensation costs to levels that bankrupted the Northern California utility Pacific Gas & Electric Corporation. Consequently, policy changes have now resulted in frequent rolling blackouts across large parts of the state.

Research led by scientists at the University of California in Merced and published last year showed that the daily power needs for 12 million people were unavailable in Northern California in 2019 because of these public safety power shutoffs" (PSPSs). PSPSs had an estimated economic impact of around $10 billion. Reducing these impacts at a time of escalating fire dangers could involve replacing long-distance power transmission with localized grids comprised of renewable energy generators and advanced battery systems. PG&E recently proposed spending upward of $15 billion burying overhead power lines.

There are solutions to mitigating risk in the face of longer and more extreme wildfire seasons. These include increased use of land management techniques that eliminate excessive fuels, such as prescribed burns, forest thinning to remove young trees and bushes, and allowing small fires to burn themselves out when it's safe to do so.

HOW SCIENTISTS MEASURE DRY CONDITIONS FOR RISK OF FIRE

As the air warms, more water vapor is required before the air reaches saturation. Effectively, this means warmer air holds more water, allowing more rain and snow to fall.

But in an arid climate like the Western United States, there is limited ground moisture to evaporate into the atmosphere. As a result, warming temperatures are drying out the air. Scientists are now calling these conditions "hot droughts." This low relative humidity accelerates evaporation from vegetation already in place, like leaves, brush, or dead trees, increasing the risk of intense fires.

Relative humidity (RH) is a measure of how close air is to saturation, expressed as a percentage--it's the ratio of the amount of moisture in the air to the amount of moisture needed to saturate the air. Relative humidity is lowest during the afternoon when air temperatures are highest. The Storm Prediction Center (SPC) defines regional relative humidity thresholds for fire weather based on local climate.

Vapor pressure deficit (VPD) is another way to monitor surface dryness, or aridity. The more water vapor in the air, the greater the pressure (i.e. vapor pressure) it exerts at the surface. The greater the difference between the vapor pressure and the vapor pressure at saturation, the greater the evaporation potential from the ground. As VPD increases (meaning the air is further away from saturation), plants must draw more moisture from their roots, which can lead to the plants drying out or dying. Like relative humidity, VPD has been linked to burned forest areas in the Western United States.

The above steps would help adapt western regions in the United States to the dangers of increasing fire-weather conditions. Adaptation is a short-term and expensive solution. In the long-term, fire weather conditions will increase around the world as the planet warms. Reducing carbon pollution to net zero by 2050 by aggressively switching away from fossil fuels would limit global warming and stabilize climate conditions.

METHODOLOGY

This study defines a fire weather day as one where the following three conditions are met in the same hour at least twice in one calendar day::

RH: WITHIN 5% OF REGIONAL THRESHOLDS	TEMP: >= 45˚-55˚F DEPENDING ON SEASON	SUSTAINED WIND: >= 15MPH

Definitions of a "fire weather day" vary from one place to the next. For our analysis we selected thresholds based on (although not exactly the same as) criteria from NOAA's Storm Prediction Center for an elevated fire weather forecast, which is the lowest risk category they use. Additionally, our thresholds are consistent with criteria used by various western utility companies for a Public Safety Power Shutoff (PSPS), including PG&E and Pacific Power as well as in research like Abatzoglou et al. 2020. Our criteria was chosen in order to identify not only the days we could expect a fire to break out but days where the combined meteorological conditions pose a threat to people and infrastructure. Our analysis is based on criteria that uses relative humidity to represent the amount of moisture in the air. Scientists are also moving towards using vapor pressure deficit (VPD) as another method for measuring atmospheric moisture.

This analysis defines a "fire weather day" as one where the temperature, relative humidity, and wind speed all meet or exceed the following criteria in at least two hourly measurements:

- Relative humidity within 5% of regional thresholds defined by NOAA's Storm Prediction Center (based on predominant fuel type and local climate)
- Temperature at least 45-55°F, depending on the season (winter: 45°F; summer: 55°F; spring and fall: 50°F)
- Sustained wind speeds of 15 mph or greater

Using hourly observations from NOAA/NCEI's Local Climatological Data (LCD) dataset, we selected weather stations in the western half of the contiguous United States that met the following conditions:

- At least 40 years of data, beginning in 1973 (which is the start of the period of record for most stations in the LCD dataset).
- Each year must have data for at least 50% of the days, and a daily average of at least 12 hours of data with at least 4 of those hours occurring between noon and 6 pm (this is around the time we see maximum temperature, minimum relative humidity, and high wind speeds). Since our analysis spans many states, this is a general range. The actual time of day that is the hottest, driest, and windiest will depend on your location.
- Had no more than four years missing in either the first (1973-1982) or last decade (2011-2020) of the analysis as data at the end of time series have a larger impact on the overall trend).
- An average of at least one fire weather day per year.

We mapped our results to each station's NOAA climate division. For climate divisions with multiple stations, we averaged the annual fire weather days across these stations. For each climate division, we used linear regression to calculate the total change and percent change in average annual fire days from 1973 to 2020. Some climate divisions only had one weather station inside its boundary. While confidence in our results increase with additional stations, our results are consistent with recent findings (for example, here and here).

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