

CLIMATE AND WILDFIRE IN THE WESTERN UNITED STATES

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Regional patterns in western U.S. wildfire regimes' response to climate variability allow forecasts of wildfire season severity up to a year in advance.

The number and extent of wildfires in the western United States each season are driven by natural factors such as fuel availability, temperature, precipitation, wind, humidity, and the location of lightning strikes, as well as anthropogenic factors. It is well known that climate fluctuations significantly affect these natural factors, and thus the severity of the western wildfire season, at a variety of temporal and spatial scales. Previous studies (Simard et al. 1985; Swetnam and Betancourt 1990; Jones et al. 1999) have demonstrated that large-scale climate patterns in conjunction with El Niño affect the frequency and extent

of wildfires that occur in particular regions of the United States. Swetnam and Betancourt (1998) and Balling et al. (1992) have found relationships between the Palmer Drought Severity Index (PDSI) and fire season severity. Our study differs from earlier work in its resolution, comprehensiveness, and regional scale.

Until now, the lack of a comprehensive fire climatology has hampered detailed studies of climate–fire relationships. Some previous studies (e.g., Simard et al. 1985; Swetnam and Betancourt 1998; Mote et al. 1999) have looked at wildfires by state or larger regions, aggregating fire statistics for many different fuel types and climates, with the result that relationships between climate, fuel type, and fire severity may be obscured. Others have focused on climate influences upon wildfires aggregated at the level of the forest or stand (e.g., Swetnam and Betancourt 1998; Balling et al. 1992)—a finer resolution than pursued here—for smaller regions. Our study is the first to consider the larger picture of wildfire for the entire western United States, including fire histories from several federal agencies whose territories span a diverse array of ecosystems. The quality of the location data for some of these fire histories constrains a comprehensive, regional-scale analysis to a 1° grid resolution. This level of aggregation obscures some of the rich detail of wildfire variability related to the enormous variability in vegetation within the western United States. However, at the same time it provides a common fire history with comprehensive coverage over

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a large region to study patterns of spatial variability in wildfire. As will be shown, this scale is commensurate with that of some important climate variations and still allows us to make comparisons across diverse ecosystems.

Currently, 20–30 years of digitized data on wildfire activity are available from the U.S. Department of Agriculture’s Forest Service (USFS) and from the U.S. Department of the Interior’s Bureau of Land Management (BLM), National Park Service (NPS), and Bureau of Indian Affairs (BIA). Longer historical records for specific sites, especially some USFS- and NPS-managed areas, are available but limited in spatial representation. Results shown here indicate that, despite their foibles, an amalgamation of these datasets yields a spatial and temporal history that is of sufficient quality, spatial resolution, and duration to resolve regional characteristics of the wildfire season, and that these characteristics are related to modes of interannual climate variability. We report here results of our analysis of wildfire frequency and acres burned for the contiguous western United States based on these data. The next sections review the data, describe the seasonality of wildfire, and describe relationships between the PDSI and anomalous fire season severity. Finally, these relationships are used to predict fire season severity at lead times of one season to one year in advance of the fire season in regions with diverse fuels and climates.

DATA. Over 410,000 fire reports from the USFS, BLM, NPS, and BIA were compiled and combined in a dataset of monthly fire-start counts and acres burned on a $1^\circ \times 1^\circ$ grid. A $1^\circ \times 1^\circ$ grid was the finest resolution practical given the quality of the location data in many fire reports. Digitized fire reports are available from USFS beginning in 1970, from NPS before 1970 in some places, from BIA starting in 1972, and from BLM in 1964, but because of data quality concerns pre-1980 BLM fire reports are not included in this analysis. The longest common dataset encompasses approximately 300,000 fires for the region from 31° to 49°N and 101° to 125°W for the period 1980–2000. In many locations, however, the coverage could be extended 8–10 yr using an additional 110,000 USFS, NPS, and BIA fire reports.

While these data do not record every wildland fire ignition for the past 21 yr, they provide a comprehensive representation of wildfire activity in the region. The four source agencies own roughly half the land in the western United States, and the area under their protection accounts for an even larger share of western wildlands. Fires recorded by these four agencies

on federal, state, and private lands regularly account for over 90% of the wildland fire area burned reported by state and federal sources for the western United States. Spot fires that burn out naturally or are quickly put out by personnel at the scene do not appear in these data, so the number of wildfires reported by federal and state agencies is less than actually occur. The effect on area-burned statistics for this analysis is minimal, however, since a small number of large fires account for most of the annual area burned. Moreover, the climate variables we focus on—moisture available in fuels and for fine fuel production—are more likely to influence factors controlling the tendency of a fire, once ignited, to grow to a large size than to determine the timing and location of ignition events themselves.

In much of the western United States, USFS manages lands that have heavier fuel types (e.g., pine, slash), while, in general, BLM manages lands with finer fuels such as grasses and shrubs, though there is some overlap for both agencies. Since these fuel types are well correlated to topography, the USFS data used here are typically for fires at higher elevations than those in the BLM data. An issue concerning fuels and using 1° grid cells is that, over such a distance, vegetation type can vary dramatically. For this analysis, it is assumed that there is a dominant fuel type in each grid cell that can be classified as either heavy or fine for general descriptive purposes.

Older USFS, NPS, and BIA fire reports are geolocated using the Public Land Survey System of township, range, and meridian. Wherever possible, these have been converted to the latitude and longitude at the midpoint of each township. Obvious topographical errors in dates and locations have been corrected to the extent practical given the size and diversity of the datasets. In the case of the NPS and BIA data, fires were located on the grid using park or reservation land boundaries when other location data were unavailable. Where these lands crossed grid cell boundaries, fires without location data were allocated to the grid cell accounting for the majority of historical fires from the same source. In the resulting series, less than 1% of the USFS, NPS, and BIA data and less than 3% of the BLM data are excluded for lack of proper location information or dates.

The fire reports used in this analysis are for those fires that were considered wildfires, required suppression resources to achieve control, and were located on or adjacent to lands under the protection responsibility of one of the federal agencies cited above.

SEASONALITY OF WILDFIRE. Even though roughly half the fires included in this analysis are hu-

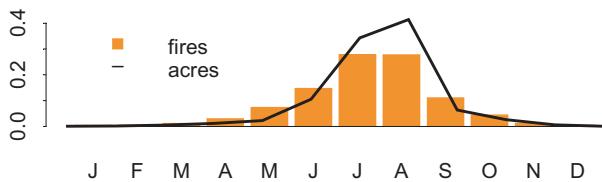


FIG. 1. Percentage of regional annual fire starts (bars) and area burned (line) by month.

man-caused rather than “natural” in origin, Figs. 1–3 clearly show western wildfire to be a process largely governed by climate. Wildfire in the West is strongly seasonal, with 94% of fires and 98% of area burned occurring between May and October. Shown in Fig. 1 are mean monthly percentages of total fire starts and acres burned for this period. Wildfire seasonality closely follows the mid-latitude annual cycle of temperature, yielding a peak of fire starts and acres burned when temperatures are warmest, during July and August. It should be kept in mind that, depending on location, most of the western United States is characterized by summer dryness, with 50%–80% of annual precipitation occurring between October and March. Therefore, it is not surprising that the peak of the fire season occurs during the hottest and driest portion of the climatological annual cycle.

Within the general tendency for peak fire activity in summer, there is a noteworthy regional progression in the locus of fire activity, as portrayed in Fig. 2. Here, the percentage of the average annual number of fire starts occurring for each grid cell is depicted by month (May–October). Fire-start activity begins its seasonal increase somewhat sooner in Arizona and New Mexico than elsewhere, commencing as early as May and June, when precipitation and mountain snowpack there diminish considerably, and ends earliest there as well, in August. This pattern is consistent with the dry spring and early summer that precedes the heaviest monsoon rains in July and August. Monsoonal lightning strikes produce numerous fire starts in June

and July, before the height of the monsoon rains wet the fuel (Swetnam and Betancourt 1998). The start of the fire season spreads north and west through July and August. To the north, in northern Idaho and western Montana, the fire season is more concentrated toward the later part of the summer, with roughly 50% of annual fire starts occurring in the warmest month, August. In many parts of California the fire season peaks in August and September, aggravated by hot, dry conditions that build through the summer season before rains begin in fall.

The greatest number of reported wildfires occurs in July and August in central Arizona and in the Si-

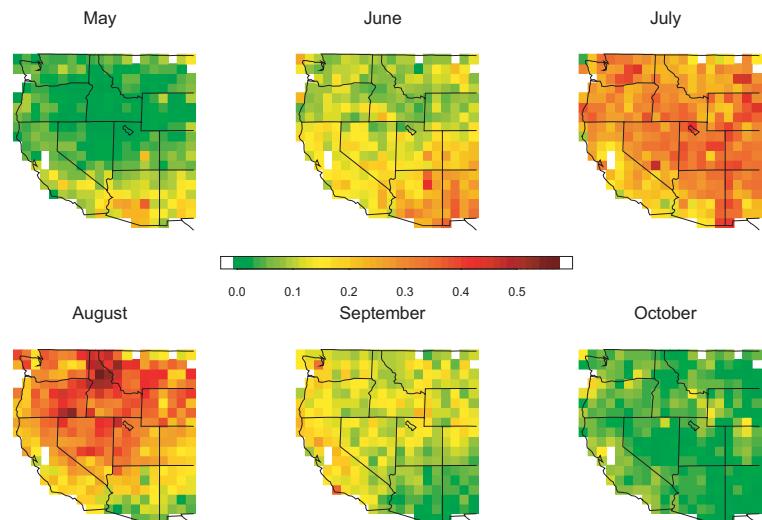


FIG. 2. Percentage of annual fire starts by month for each grid cell. Darker red shading indicates the higher percentage of fires that occur in that month. White areas indicate no available data.

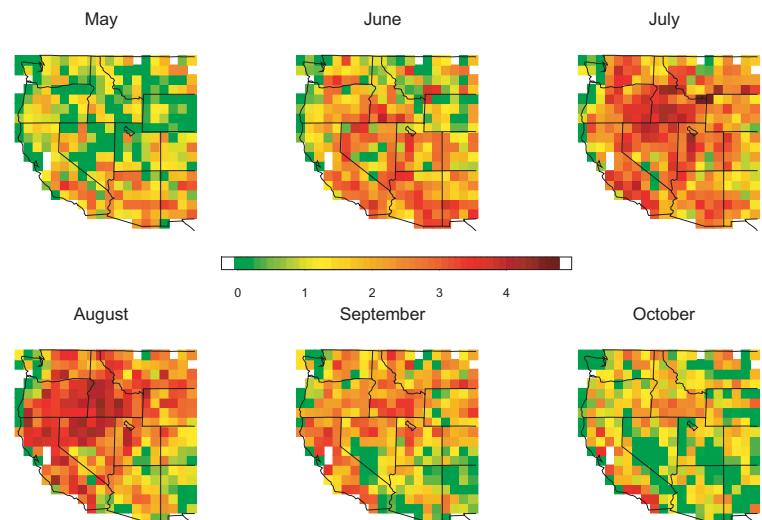


FIG. 3. Average \log_{10} acres burned by month for each grid cell. White areas indicate no available data.

erras, Cascades, and Rocky Mountains. In conjunction with the hottest and driest time of year, monthly mean acres burned (Fig. 3) also peak in July and August, but show somewhat different spatial features than do fire starts. Bailey et al.'s (1994) classification of the U.S. ecosystem by gross characteristics of climate, elevation, and vegetation (Fig. 4) provides a convenient point of reference. Red, orange, and yellow areas in Fig. 4 denote regions characterized by dry grass and shrub lands or chaparral. Light and dark green areas in Fig. 4 denote mountain and plateau ecosystems with extensive forested zones. Areas with the largest number of acres burned tend to be in regions of finer fuel types (e.g., grasses, shrubs, chaparral), though not exclusively. Finer fuels typically lose moisture more rapidly than heavier fuels, increasing their fire-consumption potential. In addition, predominantly fine-fueled regions climatologically tend to be windy areas, such that once a fire starts, the combination of fuel factors and wind cause rapid spread. Moreover, the presence of fine fuels within a region may also give rise to higher monthly mean acres burned, because fine fuels—grasses specially—regenerate faster than heavy fuels, shortening the interval between burns. Finally, the tendency for area burned to be greater in areas characterized by fine fuel types is strongest early in the fire season (June), and may simply reflect the earlier arrival of warm, dry summer conditions at lower elevations. Forested areas in the western United States tend to be at higher elevations.

PDSI AND ANOMALOUS FIRE ACTIVITY.

On seasonal to interannual scales, moisture availability in fuels and for finer fuel production plays a critical role in modulating wildfire activity. In order to quantify this seemingly simple observation and to identify potential predictive relationships, we investigated lagged associations between the PDSI and seasonal acres burned in western wildfires. Despite limitations of the index, especially in the West (Alley 1984; Karl and Knight 1985), the PDSI is in common usage and has been used before in studies of climate–fire relationships (e.g., Balling et al. 1992; Larsen and

MacDonald 1994; Swetnam and Betancourt 1998). The PDSI, which is an autoregressive measure of combined precipitation, evapotranspiration, and soil moisture conditions, represents accumulated precipitation

anomalies and to a very small extent temperature anomalies (Alley 1985; Guttman 1991). It is negative when inferred soil moisture is below average for a location, and positive when it is above average.

The linkage between antecedent moisture and fire varies considerably across the West. Pearson's correlations between antecedent divisional PDSI values for the 48 months ending in August, at the peak of the wildfire season, and transformed seasonal acres burned are shown in Fig. 5 for several areas. These correlations were calculated between local lagged monthly PDSI and standardized logarithms of acres burned. The logarithm of acres burned was used to normalize the time series. Local PDSI values are the

average of values interpolated from U.S. climate divisions for the grid cells within each area.

Acres burned appear to respond to a few characteristic patterns in climate consistent with dominant vegetation types in many areas of the West. In the Idaho Rockies, in an area characterized by closed-canopy coniferous forests, the dominant relationship is a negative correlation, reflecting an association between deficit moisture at the height of the fire season, August, and greater acres burned (Fig. 5b). Balling et al. (1992) found a similar relationship for PDSI and acres burned within Yellowstone National Park. Correlations with local PDSI for the 2 yr preceding the fire season are negative and insignificant, and do not appear to yield strong predictive potential. However, as shown below, when this examination is broadened to consider regional patterns in PDSI over the 2 yr preceding the wildfire season, some useful predictive skill emerges in the northern Rockies area. This area also shows a weak positive association between PDSI 3 yr prior to the fire season and area burned.

Areas in the Colorado Rockies and Sierra Nevada (*D* and *F* in Fig. 5a), characterized by open coniferous forest intermixed with zones of grass and shrubs,

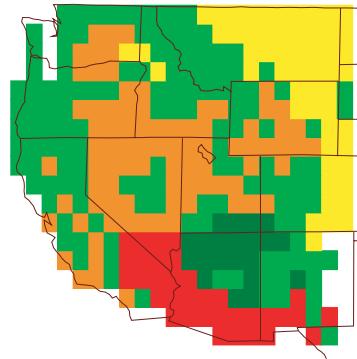


Fig. 4. Projection of Bailey's ecosystem divisions for the western United States onto a 1° × 1° lat–lon grid. Light green areas correspond to mountain divisions; dark green is the Colorado Plateau. Orange areas are temperate desert or Mediterranean divisions; yellow are temperate steppe; red are sub-tropical desert.

contain a different seasonal linkage between anomalous moisture and acres burned. These areas show an earlier reversal in the relationship between acres burned and PDSI, such that the sign of the correlation changes from positive a year before to negative immediately prior to and during the fire season (Figs. 5d,f). In spring and summer, similar to Idaho, deficit moisture appears to be associated with greater anomalous acres burned during the fire season. Winter PDSI is less important but, during the previous year's spring and summer from 11 to 20 months earlier, the correlations are actually positive, reflecting a link between increased moisture and increased acres burned. We hypothesize that in these areas during the spring and summer of the previous year, anomalous moist conditions are conducive to the growth of some fine fuels, while in the nearer term (winter–summer), anomalous dryness increases fuel flammability.

Predominantly dry brush and grassland areas such as in the Great Basin and Mojave Desert (Figs. 5c,e) exhibit a much stronger, positive relationship between above-normal moisture in the spring and summer a year earlier and fire season severity, but no association between fire season severity and moisture conditions immediately prior to or during the season itself. The lack of a contemporaneous link may seem surprising, but it is important to note that spring and summer in these areas are climatologically dry (Osmond et al. 1990). Much of the region is composed of brush and grasses, which follow an annual growth and curing cycle providing a readily available fuel source for fire. Consequently, an anomalous precipitation deficit might have little impact on fuel flammability (e.g., Brown and Hall 2000), while the seasonal growth and development of these fuels are strongly affected by precipitation anomalies. Large, positive correlations with

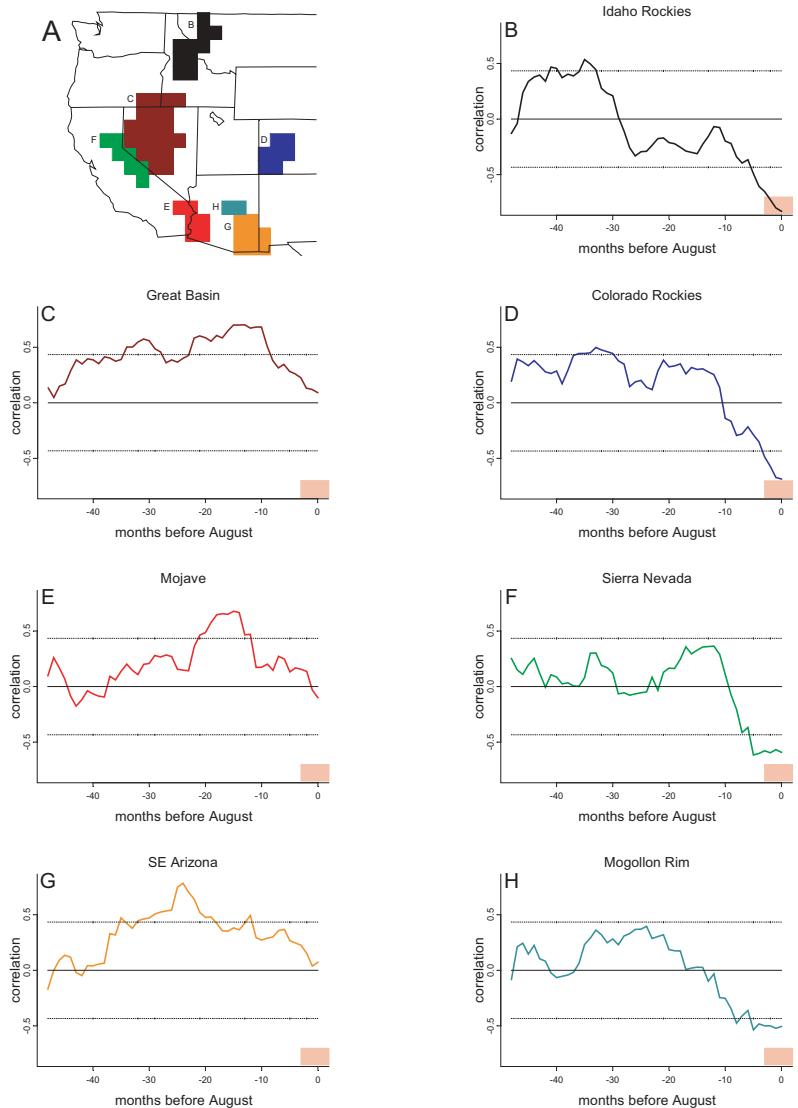


FIG. 5. (a) Pearson's correlations between monthly PDSI 0 to 48 months prior to Aug of the current fire season and normalized \log_{10} total acres burned for the fire season for regions mapped. (b)–(h) Light shading indicates the duration of the current fire season. The 95% confidence interval—indicated by dashed horizontal lines—is calculated for a two-sided *t* test of a correlation coefficient, which assumes that PDSI and \log_{10} area burned are from a bivariate normal distribution (Kanji 1999).

PDSI 12–15 months prior to August (Figs. 5c,e) suggest that anomalous surplus precipitation enhances the previous season's fine fuel production, and thus increases the current season's fuel load.

In dry shrub and grasslands of southeastern Arizona, fire season severity is positively associated with moisture conditions in the years prior to the fire season. Interestingly, the strongest positive correlation there occurs with PDSI 2 yr prior to the fire season. The relationship between acres burned and lagged PDSI in the Mogollon Rim area of southeastern Ari-

zona exhibits the same characteristic sign reversal as in the Sierra Nevada and Colorado Rockies to the north, but the strongest positive correlations are between anomalous acres burned and summer PDSI 2 and 3 yr before the start of the fire season. The switch in the Mogollon Rim from positive to negative correlations occurs a season earlier, in early summer, instead of early fall, a year before the fire season.

The positive correlation between previous years' PDSI and seasonal acres burned is rather higher in the Great Basin, Mojave, and southeast Arizona (Figs. 5c,e,g) than in the Colorado Rockies, Sierra Nevada, and Mogollon Rim (Figs. 5d,f,h). Preceding years' correlations are insignificant in the Idaho Rockies until 3 or more years prior to the fire season (Fig. 5b). Using both fire scar dendrochronologies for 1700–1900 and annual fire statistics by the national forest for 1920–78, Swetnam and Betancourt (1998) found a significant relationship between lagged annual PDSI and fire season severity in open pine forests, but not in mixed conifer forests, in Arizona and New Mexico. They attribute this to the rapid growth of fine fuels in ponderosa forests when conditions are wet, and the relative importance of these fuels in their fire dynamics. They consider fine fuels, in contrast, to be less important in fire dynamics of mixed conifer forests. In our example, fire dynamics and, especially, large-acreage fires, in the Great Basin, Mojave Desert, and southeast Arizona are dominated by fine fuels, whereas the Colorado Rockies, Sierra Nevada, and Mogollon Rim have both fine fuels and heavy fuels. The heavy fuels are slower growing and burn less frequently than those in the grass and shrub lands. This suggests that one year's precipitation is not as important in determining the fuel load in areas with both fine and heavy fuels as it is in areas with predominantly fine fuels.

Similar to Swetnam and Betancourt's (1998) findings for the Southwest, recent work with fire scar chronologies dating from 1700 and a long-term fire history for forests in the Selway Bitterroot Wilderness in Idaho (Kipfmüller and Swetnam 2000), and with fire scar chronologies dating from at least 1600 for forests in the Colorado Front Range (Veblen et al. 2000) and Pike National Forest (Donnegan et al. 2001) in Colorado, found strong associations between current-year moisture deficits and large fire years, and weaker associations with excess moisture 2 to 4 yr prior to large fires years. Our similar findings for larger, coarsely defined forested areas throughout the region using a shorter-duration dataset of recent fires implies that this wet–dry pattern may be commonly associated with above-normal

area burned in forested areas in much of the western United States, for modern managed wildfire regimes as well as for wildfire regimes prior to widespread effective fire suppression.

Fire season severity is not determined solely by climate and vegetation. Despite idiosyncracies in human intervention and recording, however, these data can tell us a great deal about how climate forcing affects fire risk in different locations. Correlations for seasonal acres burned with local August PDSI during, May and August PDSI 1 yr before, and August PDSI 2 yr before the wildfire season are shown in Fig. 6. Strong associations between PDSI 2 yr earlier and fire season severity are concentrated in southeastern Arizona and southern and eastern New Mexico (Fig. 6a). Similar to the Great Basin and Mojave Desert, grass and brush lands in parts of the Southwest, eastern Oregon, and the Wyoming Basin—and to a lesser degree, grasslands throughout much of the West—also show an enhanced fire season in the year following a wet year (vice versa following a dry year), and weak correlations with PDSI during the fire season itself (Figs. 6b,c,d). Recalling that PDSI is nega-

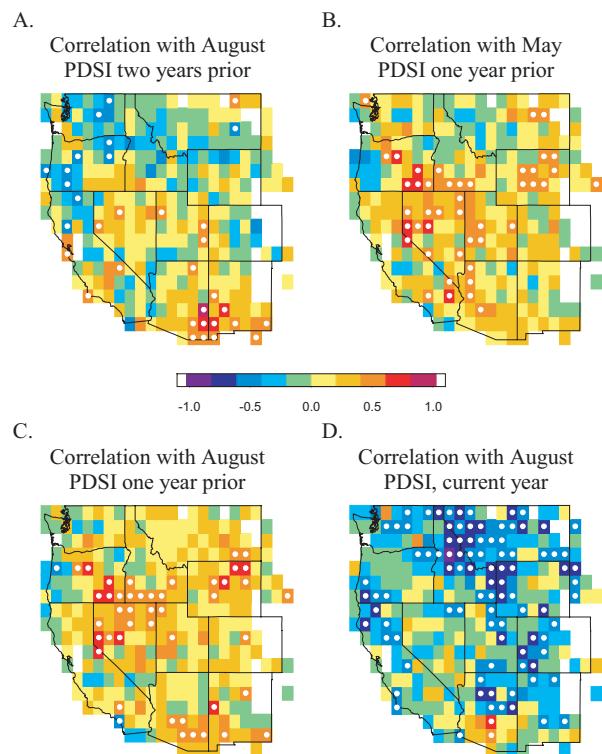


FIG. 6. Correlation between normalized \log_{10} acres burned and (a) Aug PDSI 2 yr prior to, (b) May PDSI 1 yr prior to, (c) Aug PDSI 1 yr prior to, and (d) Aug PDSI during fire season. Cool shades are negative correlations; warm shades positive. White dots indicate correlations that exceed the 95% confidence limits.

tive when conditions are dry, comparing Fig. 6d with Bailey's mountain and Colorado Plateau ecosystems in Fig. 4 reveals that the strong relationship between moisture in the current year and fire severity in the Sierra Nevada and the Rocky Mountains holds for much of the mountainous West.

PREDICTING WILDFIRE SEASON SEVERITY.

The relationship between moisture anomalies in soils and fuels, as proxied by PDSI, and area burned that we described in the previous section provide a basis for forecasting wildfire season severity at months to years in advance. These links between antecedent moisture and fuels are complimentary to traditional forward-looking dynamical or statistical forecast schemes, which predict anomalous climate variability in subsequent seasons. In Fig. 7, we present forecast models for some of the regions identified in the previous section (Fig. 5a). In the first example, transformed acres burned in the Great Basin are estimated in a linear regression model using local values of the PDSI for May 12 months prior to the fire season (Fig. 7a). This single predictor explains 38% of the variance of acres burned in Great Basin, as determined from a cross-validated sequence of models. Cross-validating statistical forecast models is particularly important when confronted with a short time series like the fire data employed here. To avoid an inflated estimate of the skill achieved in this exercise, model diagnostics here are all for results using jackknifed cross validation. That is, for each time step of the model, a forecast is made using model coefficients estimated on the subset of the data excluding that time step. This removes the potential for false statistical skill in the diagnostic measures reported here and in Fig. 7, R^2 and correlation (ρ).

By employing cross validation and by comparing similar models for diverse locations with similar climate and vegetation, we hope to avoid a mistaken reliance on spurious relationships in the data. The

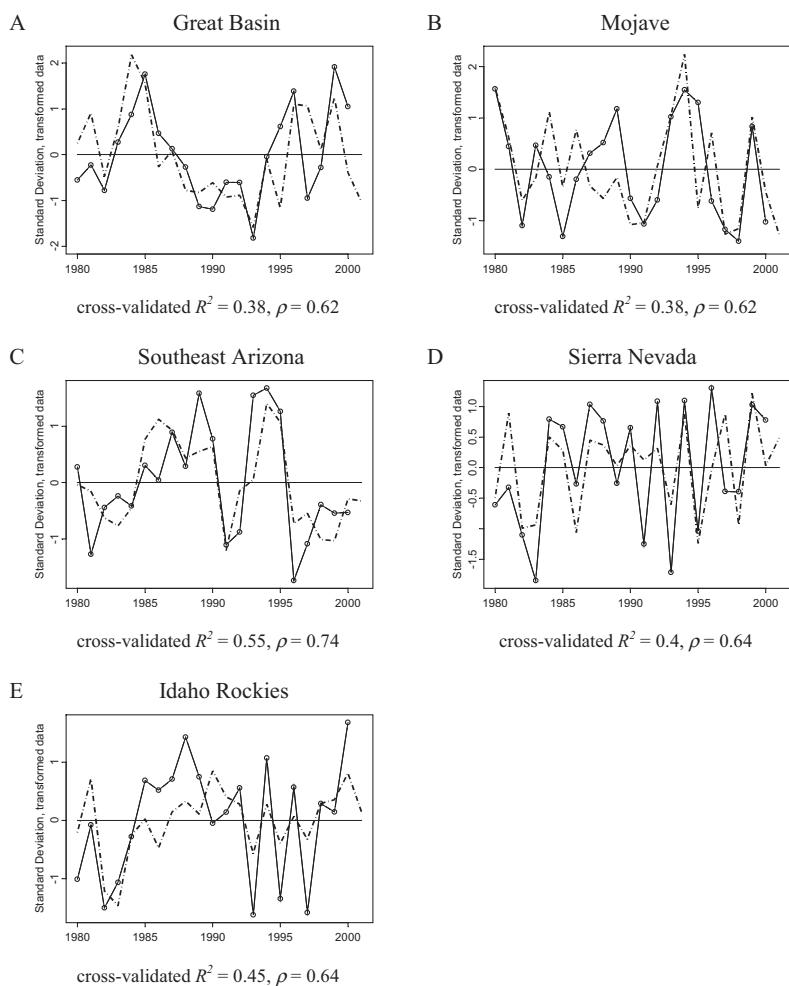


FIG. 7. Forecast models for seasonal normalized \log_{10} acres burned for (a) Great Basin and (b) Mojave using May PDSI 1 yr prior to fire season, (c) southeast Arizona using Aug PDSI 2 yr prior to fire season, (d) Sierra Nevada using Jul PDSI 1 yr prior and Mar PDSI immediately prior to fire season, and (e) Idaho Rockies using fourth, fifth, and sixth principal components of western divisional PDSI. Solid line is observed anomaly; dashed is prediction.

Mojave area identified in Fig. 5 is, like the Great Basin, climatologically dry and shows a strong relationship between anomalous moisture 1 yr prior to the wildfire season and seasonal acres burned. The same cross-validated, one-parameter model as before—May PDSI leading the fire season by 1 yr—also predicts 38% of variance in seasonal acres burned in the Mojave.

For southeastern Arizona, a cross-validated linear regression model using only local values of the PDSI for August 2 yr prior to the fire season accounts for 55% of variation in transformed acres burned. This would appear to be strong predictability, especially considering the 2-yr lead time of the prediction.

In the fourth example, transformed acres burned in the Sierra Nevada are estimated using local PDSI

values from July 1 yr before and March immediately before the fire season, with a cross-validated R^2 of 0.4. Despite weaker correlations with PDSI in the Sierra Nevada than in predominately grass- or brush-covered lands like the Great Basin, Mojave Desert, and southeastern Arizona, useful forecast skill may still be achievable in open woodlands using both the weak, positive relationship between PDSI and fine fuel formation the previous year, and the negative relationship between PDSI and fuel flammability in the current year.

Finally, recalling the lack of strong links between transformed acres burned in the Idaho Rockies and collocated PDSI values in the 2 yr preceding the fire season, we looked for regional patterns in climate reflected in PDSI values for the entire western United States that might offer some predictive skill. Principal components analysis (PCA) is a method for identifying independent patterns across a large number of data series that summarize the modes of variability in the data taken as a whole (Johnson and Wichern 1998). A PCA on seven lags of the 110 western contiguous U.S. climate divisions—January and March immediately preceding, January, March, May, and August 1 yr previous to, and May 2 yr prior to the fire season—yielded three cross-validated indices highly correlated with transformed acres burned in the Idaho Rockies (cf. Westerling et al. 2001). A cross-validated series of linear regression models using the fourth, fifth, and sixth principal components as predictors describes 45% of variance in seasonal acres burned in the Idaho Rockies.

Clearly, there is considerable potential for producing useful forecasts of western wildfire season severity using these data, looking at both simple local forecasts models as well as models that integrate across the broader region. We explore these possibilities elsewhere (Westerling et al. 2001) and in forthcoming work that exploits relationships between nationwide patterns in fire activity and climate indices to predict western wildfire season severity (Westerling et al. 2002). Since we use only PDSI observed prior to the start of the fire season to forecast area burned, it is possible that an approach combining observed climate indices and forecasts of summer precipitation and temperature may offer even greater forecast skill. It is important to note, however, that for the midlatitudes, forecasts for summer precipitation and temperature are at present much less skillful than for winter (Gershunov and Cayan 2002, manuscript submitted to *J. Climate*). Consequently, simple models like those presented here using climate indices observed through the preceding winter to forecast seasonal

wildfire area burned may produce the best forecast skill currently available at a season in advance using climate indices alone as predictors. Forecasts of winter precipitation and temperature might be used, however, to produce longer-range, but less skillful, forecasts for areas like the Sierra Nevada, where area burned is somewhat correlated with spring PDSI values. Since spring PDSI in the Sierra Nevada incorporates the effects of winter precipitation and temperature, this might simply entail replacing observed spring PDSI values with a predictor derived from forecast winter precipitation and temperature. This approach could produce a forecast with a longer lead time, but with less skill than when using observed climate indices.

CONCLUSIONS. A new amalgamated dataset of wildfire starts and acres burned from the BLM, USFS, NPS, and BIA illustrates the seasonal cycle and interannual evolution of fire severity across the western United States over the last 2 decades. While only 21 yr long, and undoubtedly affected by human intervention via wildfire management policy and suppression strategies, these data show important relationships between fire season severity and current and previous years' climate.

Throughout the West, there are links between antecedent moisture anomalies and anomalous summer wildfire activity, which vary regionally and temporally. Acres burned in dry shrub and grasslands—as in the Great Basin, Mojave Desert, southern Arizona and New Mexico, eastern Oregon, and the Wyoming Basin—appear to depend strongly on fuel accumulation governed by climate conditions 10–18 months before the fire season (in addition to fuels accumulating over previous years), and may be relatively unaffected by contemporaneous climate. In the Sierra Nevada and Colorado Rockies, fire season severity is negatively correlated with contemporaneous PDSI and weakly positively correlated with PDSI from the previous summer. This result appears to reflect a trade-off between fuel accumulation and flammability, with wet (dry) conditions the previous year contributing to (inhibiting) fuel accumulation and wet (dry) conditions in the current year suppressing (enhancing) fire activity by moistening (drying) the fuels. In the Idaho Rockies, contemporaneous PDSI is strongly correlated with anomalous wildfire activity, but local conditions over the two preceding years do not appear to be very important.

Our analysis using recent fire records complements similar analyses of much longer fire scar chronologies. While the modern digitized fire record

is much shorter than the fire scar chronologies developed at many sites around the western United States, it is spatially more comprehensive, and can describe the seasonality and interannual variability of wildfire activity in many areas where trees cannot record the local fire history. Furthermore, these data provide a means to confirm that current managed fire regimes still respond to climate signals in ways similar to earlier fire regimes as recorded by fire scar chronologies.

An immediate benefit from these statistical linkages is the ability to produce a seasonal fire forecast. Moderately strong correlations with observed climate anomalies from 2 yr before the fire season up through the preceding spring can provide predictions of wildfire season severity at a season or more in advance. It is commonly assumed that fire season severity depends on precipitation and temperature conditions earlier in the year, as well as during the fire season. The present analysis demonstrates, however, that the importance of antecedent seasons' precipitation for determining fire season severity varies considerably from region to region and from season to season. Given the cross-regional integration of fire-fighting resources in the western United States, the present data provided a valuable resource to gauge regionwide fire season severity and impacts. Furthermore, the long-lead predictability demonstrated here and to be improved in future work raises the possibility that wildfire season severity may be forecast early enough and with sufficient skill to guide fuel management and resource allocation decisions. It is important to emphasize that the predictive methods discussed here look backward to exploit moisture buildup in fuels and anomalous fuels buildup from moisture anomalies. There may also be predictive power from extended weather and climate forecasts, which could add to the skill provided here.

Combining fire histories from many different sources allows for a more comprehensive analysis of regional wildfire season severity. Formal, regional predictions of wildfire season severity achieved through the application of state-of-the-art statistical modeling techniques to comprehensive fire histories may achieve greater and more easily validated skill than what can be achieved with piecemeal or ad hoc approaches. The identification of further links between climate and wildfire activity would greatly benefit from the inclusion of available historical fire data from other federal and state agencies, as well as data from the BLM, USFS, NPS, and BIA from earlier in the last century. A central archive responsible for both historical and ongoing wildfire data management could prove to be an invaluable resource.

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