

The 2000 Fire Season: Lightning-Caused Fires

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ABSTRACT

A large number of lightning-caused fires burned across the western United States during the summer of 2000. In a previous study, the authors determined that a simple index of low-level moisture (85-kPa dewpoint depression) and instability (85–50-kPa temperature difference) from the Spokane, Washington, upper-air soundings was very useful for indicating the likelihood of “dry” lightning (occurring without significant concurrent rainfall) in the Pacific Northwest. This same method was applied to the summer-2000 fire season in the Pacific Northwest and northern Rockies. The mean 85-kPa dewpoint depression at Spokane from 1 May through 20 September was 17.7°C on days when lightning-caused fires occurred and was 12.3°C on days with no lightning-caused fires. Likewise, the mean temperature difference between 85 and 50 kPa was 31.3°C on lightning-fire days, as compared with 28.9°C on non-lightning-fire days. The number of lightning-caused fires corresponded more closely to high instability and high dewpoint depression than to the total number of lightning strikes in the region.

1. Introduction

The summer of 2000 was notable for the number of large wildfires that burned across the western United States. In 2000, more than 122 000 wildfires ignited, burning more than 3.2×10^6 ha. This is in comparison with the annual average for the previous 10 years of about 100 000 fires and 1.5×10^6 ha. Lightning causes most wildfires in the western mountainous states, including Washington, Oregon, California, Nevada, Idaho, Montana, Wyoming, and Utah. A database compiled by the U.S. Department of Agriculture (USDA) Forest Service, including the period of 1986–96 and consisting of locations, dates, and causes of fires, reveals that lightning starts almost 60% of fires on public land in these states (Schmidt et al. 2002). Therefore, there is a need for better forecasts of the dry, unstable conditions that give rise to lightning that ignites fires.

In addition to atmospheric instability, low-level moisture deficit is a key ingredient for “dry” lightning (lightning that strikes the ground with little or no accompanying rainfall). Fire-weather forecasters try to anticipate episodes of dry lightning using existing tools such as traditional stability indices (e.g., lifted index and *K* index) and the Haines index, which is an indicator of fire growth (Haines 1988). The stability indices are effective in predicting periods of convection but were not designed to distinguish between dry and wet thunder-

storms. The Haines index contains a moisture factor in combination with a stability factor to produce a single categorical index used to quantify the risk of wildfire growth. The unstable, dry conditions identified by the Haines index also occur in conjunction with high-based thunderstorms (see below) that produce fire-igniting lightning strikes (Werth and Ochoa 1993), but the usefulness of this index for our purpose is limited because the categories are too coarse.

The problem of estimating the risk of fire from dry lightning is a complicated one. Whether a lightning strike will result in an ignition depends on many factors, including fuel moisture conditions, atmospheric moisture conditions, concurrent rainfall amounts and duration, and fire suppression efforts. In unusually dry years, such as 2000, fires may start despite significant rainfall because fuel moistures are extremely low. In addition, a simple definition of dry lightning itself is somewhat elusive. Lightning can occur without significant precipitation if a thunderstorm is high based, with rainfall evaporating before it reaches the ground; it can occur outside the rain shaft of a “wet” thunderstorm; or it can occur in conjunction with a fast-moving thunderstorm when significant rainfall amounts do not accumulate at any one location. Nevertheless, the importance of dry lightning strikes has long been recognized by the fire-research community. For example, the lightning activity level, a component of the National Fire Danger Rating System, includes a special case for high-based thunderstorms that produce no precipitation at the ground (Fuquay et al. 1979).

The National Centers for Environmental Prediction

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(NCEP) Storm Prediction Center recently began forecasting the potential for dry thunderstorms (those that produce less than 2.5 mm of rain) as part of its Fire Weather Program (Naden 2001). These forecast products include maps that depict convective available potential energy and the average relative humidity in the lowest 6 kPa of the atmosphere (about 600 m above the surface). This product indicates where thunderstorms are expected and where there is a moisture deficit, but there is no indication of how dry and unstable the conditions must be for dry lightning to be of concern to fire-weather forecasters and there is no estimation of risk.

Lightning-strike locations alone cannot be used to estimate risk of fire. Lightning-strike densities do not correlate well with fire start locations for several reasons, including fuel type, fuel condition, and atmospheric conditions (Rorig and Ferguson 1999). This previous study showed an improvement in the ability to estimate risk of fire starts by using separate indicators of stability and moisture from upper-air soundings to discriminate between dry and wet lightning days in the Pacific Northwest. A maximum likelihood discriminant rule was developed using sounding data, precipitation records, and thunderstorm occurrence records from Spokane, Washington, and lightning-strike data from the National Lightning Detection Network (Cummins et al. 1998). The results of the study indicated the 85–50-kPa temperature difference and 85-kPa dewpoint depression were the most useful variables for classifying convective days into dry and wet categories. The discriminant rule was then used to compute a probability of wet or dry lightning in the Pacific Northwest. The purpose of this article is to describe how this simple index, developed from historical data, identified days in the summer of 2000 that had a greater risk of dry convection and, hence, lightning-caused fires.

2. Methods and results

Dates and locations of large (more than 40.5 ha; smaller fires are not included in the database) wildfire ignitions in Washington, Oregon, Idaho, and western Montana were collected for May–September of 2000. The 0000 UTC upper-air soundings and daily precipitation amounts were compiled from Spokane, Boise, Idaho, and Great Falls, Montana, and lightning-strike data (which include location, date, and time) were obtained for the northwestern United States. In addition, daily precipitation data were collected from 11 other National Weather Service (NWS) sites and 108 Remote Automated Weather Station (RAWS) sites located throughout the four-state area from the Cascade Range to the Rocky Mountains. All days were segregated into two groups: days on which lightning-ignited fires started (“fire days”) and days on which there were no fires or on which fires were human caused (“other days”). Between 1 May and 20 September there were 57 fire days

TABLE 1. Mean values of sounding variables ($^{\circ}\text{C}$) at Spokane, WA, for fire and other days, 1 May–20 Sep 2000 (DD is dewpoint depression; TD is temperature difference).

	85-kPa DD	85–50-kPa TD
Fire days	17.7	31.3
Other days	12.3	28.9
t^*	5.34	4.25
$t_{\text{crit}(0.95,140)}^{**}$	3.97	3.12

* t = value of the t statistic.

** $t_{\text{crit}(0.95,140)}$ = critical t value for the 95% significance level with sample size of 140.

and 86 other days. No large fire ignitions were reported after 20 September. Lightning occurred on both fire days and other days (lightning was recorded on 134 of the 143 days somewhere in the four-state region). Therefore, it is important to discriminate those days on which the atmosphere is particularly unstable and dry, leading to a higher risk of fire starts from lightning.

Because Rorig and Ferguson (1999) found the 85-kPa dewpoint depression and 85–50-kPa temperature difference were most useful for discriminating between wet and dry lightning days, the means of these variables were computed at Spokane for fire days and other days (Table 1). The Student's t test was used to test for difference of means. The t test requires independence of the data and is not robust against deviations from this requirement. The daily data used to compute the means are not independent; therefore, an alternative to the conventional t test was used to compensate for autocorrelation in the data (von Storch and Zwiers 1999). The t statistic is computed in the conventional manner and then is compared with a critical value of t that is appropriate for the sample size and the lag-1 autocorrelation coefficient. If t is greater than t_{crit} , then the difference in means is assumed to be significant. Table 1 includes the computed t values and the critical t values for the 95% significance level for each set of means. The means from fire days were significantly higher (drier and more unstable) than those from other days. Tables 2 and 3 include the means for both groups computed from the Boise and Great Falls soundings. The 70-kPa dewpoint depression and 70–50-kPa temperature difference are also included, because the 85-kPa level is closer to ground level at those sites and may be less indicative of conditions above the boundary layer than is the 70-kPa level. Like Spokane, the differences between all the means at Boise (Table 2) and Great Falls (Table 3) are significant at the 95% level or higher, indicating there is less moisture and more instability on fire days than on other days in southern Idaho and Montana, as well as in eastern Washington. The subsequent analysis will use only the Spokane soundings because the sounding variables from Spokane, Boise, and Great Falls are all significantly correlated (correlation coefficients range from 0.61 to 0.74) and because the dis-

TABLE 2. Mean values of sounding variables (°C) at Boise, ID, for fire and other days, 1 May–20 Sep 2000.

	85-kPa DD	85–50-kPa TD	70-kPa DD	70–50-kPa TD
Fire days	27.5	36.0	17.1	20.8
Other days	20.4	32.6	12.1	18.1
t^*	4.97	5.74	4.35	5.36
$t_{\text{crit}(0.95,140)}^{**}$	3.97	2.78	3.55	3.17

* t = value of the t statistic.

** $t_{\text{crit}(0.95,140)}$ = critical t value for the 95% significance level with sample size of 140.

criminant rule used in the analysis was developed from Spokane sounding data.

The discriminant rule developed in Rorig and Ferguson (1999) from the historical thunderstorm database at Spokane was used to assign a probability of dry lightning for all days from 1 May through 20 September based on the values of the discriminating variables (85-kPa dewpoint depression and 85–50-kPa temperature difference). If the probability was greater than 50%, the day was assigned to the dry category, and if it was less than 50%, it was assigned to the wet category. The likelihood that any given day was correctly classified is greater when the probability is closer to the extreme values (0% or 100%). Fifty-one of 57 fire days were grouped into the dry convection category (all 51 days had probabilities greater than 70%), whereas 58 of 86 other days had probabilities greater than 50% and were categorized as dry. Three of the six “misclassified” fire days had reported measurable precipitation at more than 10 locations in the study area, indicating the fuels at potential fire sites may have been sufficiently dry for ignition despite the high levels of atmospheric moisture. The large number of other days categorized as having a high probability of dry convection illustrates the difficulty of using lightning–fire starts to identify dry lightning days. Whether a fire will ignite and spread depends on more than the state of the atmosphere. Even though the atmosphere is dry and unstable, lightning may not strike where fuels are dry, or, if fires do ignite, they may either be controlled or never grow large enough to be included in the fire database.

To understand better the relationship between the sounding variables at Spokane and rainfall amounts in the study area, daily precipitation data were collected from 122 sites (14 NWS stations and 108 RAWS sites) throughout Washington, Oregon, Idaho, and western Montana. Locations west of the Cascade Range crest were not included in the analysis (the air mass west of

the Cascades is typically very different than that in the interior basin), and stations with incomplete periods of record were discarded. Figure 1 shows the time series of the Spokane sounding variables and the daily numbers of lightning strikes, fires, and stations with measurable precipitation in the study area. Inspection of the data reveals that fire starts do not correlate well with large numbers of lightning strikes. There were numerous lightning strikes but very few fire starts in both early to mid-June and early July; in August there were many days with fire starts but relatively fewer lightning strikes. For example, on 1 September there were over 20 000 lightning strikes but no fires. On the other hand, the days with the greatest numbers of fire starts (10 and 24 August) had less than 11 000 lightning strikes. Days with large numbers of fire starts also, with few exceptions, have high 85-kPa dewpoint depressions and 85–50-kPa temperature differences at Spokane, whereas days having many stations recording measurable rainfall occur on days with low dewpoint depression, relatively lower instability, and few (if any) fire starts.

On 10 August, 25 large fires started in eastern Oregon, northern Idaho, and western Montana. Figure 2 shows there was extensive lightning activity in Idaho and western Montana and less in Oregon and Washington. On this day, the 85-kPa dewpoint depression at Spokane (0000 UTC) was 18°C, the 85–50-kPa temperature difference was 33°C, and only 4 of 122 sites in the region recorded greater than 2.5 mm of precipitation. The measurable rainfall occurred in Oregon and western Montana, where fires were not observed. Note the fire in Oregon, where there is no record of lightning strikes in the vicinity on that day. This could have been a “hold-over,” which occurs when lightning strikes but the fire smolders for several days until conditions are right for the fire to grow to a detectable size.

On 24 August (Fig. 3), another 25 large fires started

TABLE 3. Mean values of sounding variables (°C) at Great Falls, MT, for fire and other days, 1 May–20 Sep 2000.

	85-kPa DD	85–50-kPa TD	70-kPa DD	70–50-kPa TD
Fire days	23.4	35.8	12.7	20.5
Other days	17.3	32.7	8.3	18.1
t^*	5.35	5.45	4.78	5.20
$t_{\text{crit}(0.95,140)}^{**}$	3.17	2.87	2.75	2.38

* t = value of the t statistic.

** $t_{\text{crit}(0.95,140)}$ = critical t value for the 95% significance level with sample size of 140.

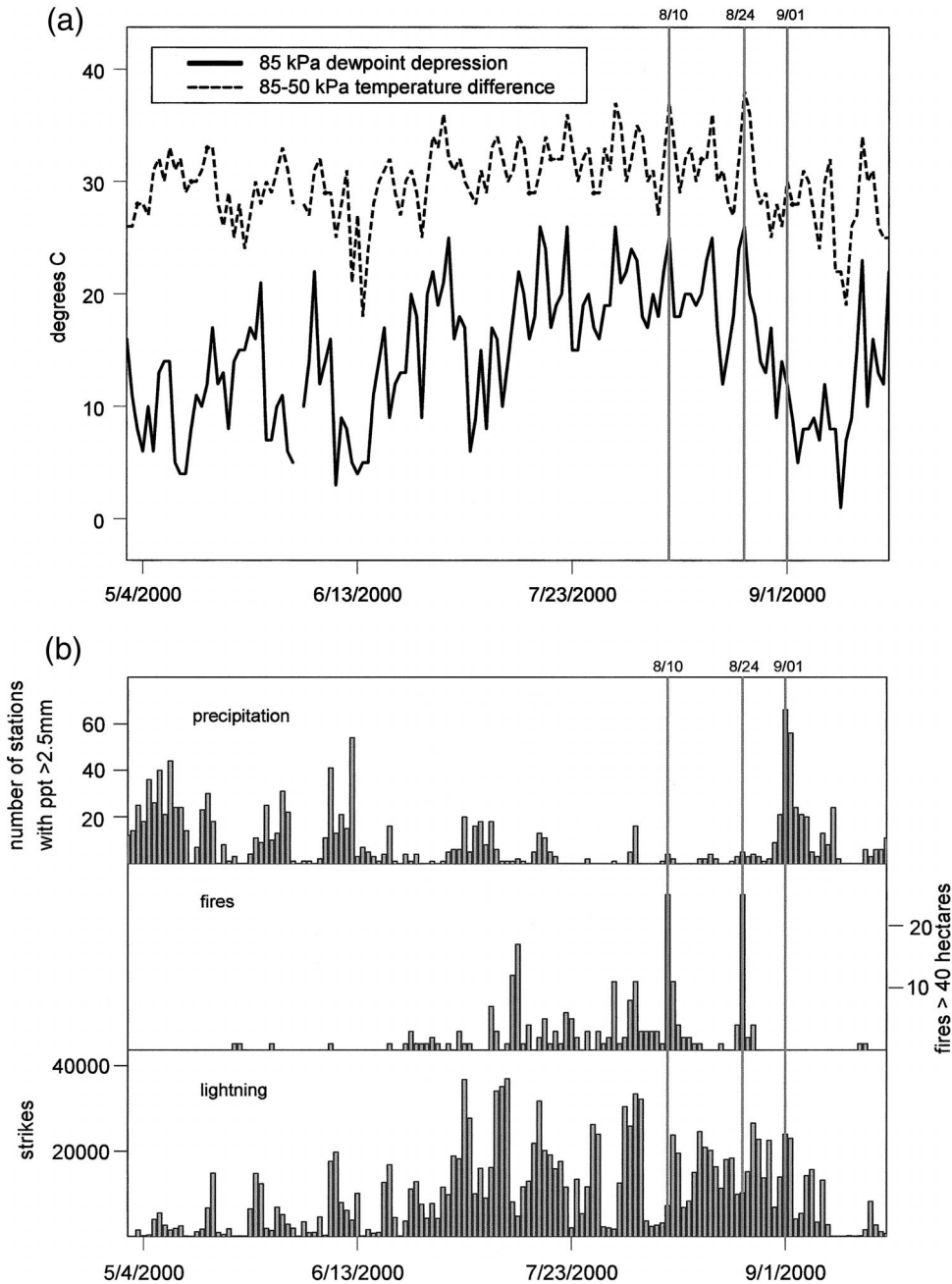


FIG. 1. Time series of (a) daily 85-kPa dewpoint depression and 85-50-kPa temperature difference at Spokane and (b) daily number of lightning strikes, large fire starts, and number of stations with precipitation (ppt) > 2.5 mm within the study area. The vertical lines mark dates used to illustrate lightning and fire patterns in Figs. 2-4.

in Oregon, Idaho, and western Montana. The 0000 UTC 85-kPa dewpoint depression at Spokane was 20°C, and the 85-50-kPa temperature difference was 36°C. Only five observation sites in the region recorded significant rainfall amounts. These sites were located in central Idaho and western Montana, closer to the fires, but precipitation amounts were all less than 5.5 mm.

On the wet day of 1 September there were no fires,

but numerous lightning strikes occurred in Idaho and western Montana, with fewer strikes in eastern Oregon and eastern Washington (Fig. 4). Significant rainfall (substantially greater than 2.5 mm at many locations) was recorded throughout the study area at 66 of the 122 observation sites. The 0000 UTC sounding variables at Spokane indicated conditions were marginally unstable (85-50 kPa difference of 28°C) with an ample supply

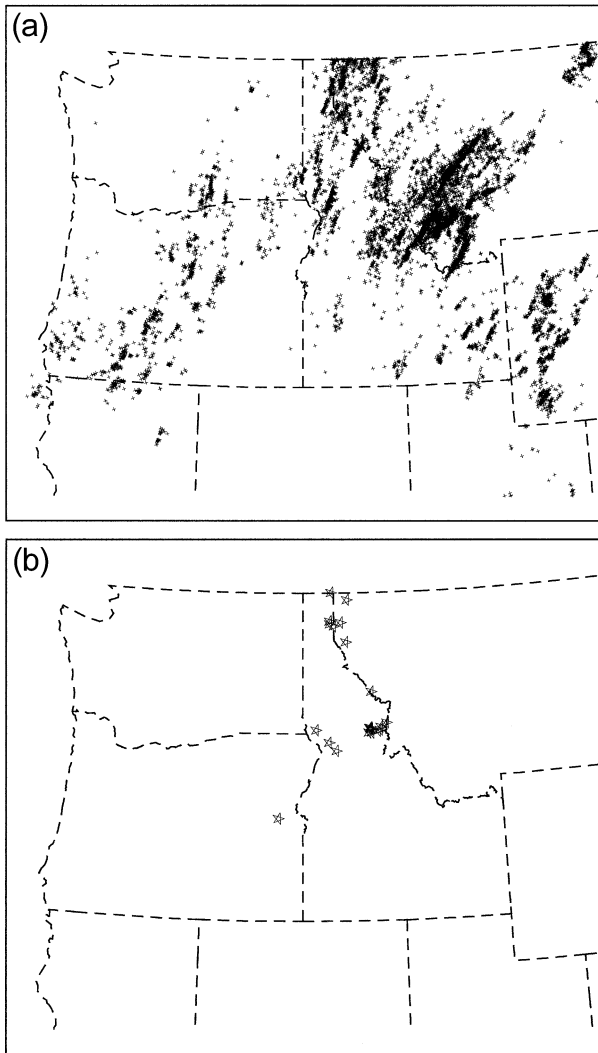


FIG. 2. (a) Lightning strikes and (b) large fires, 10 Aug 2000.

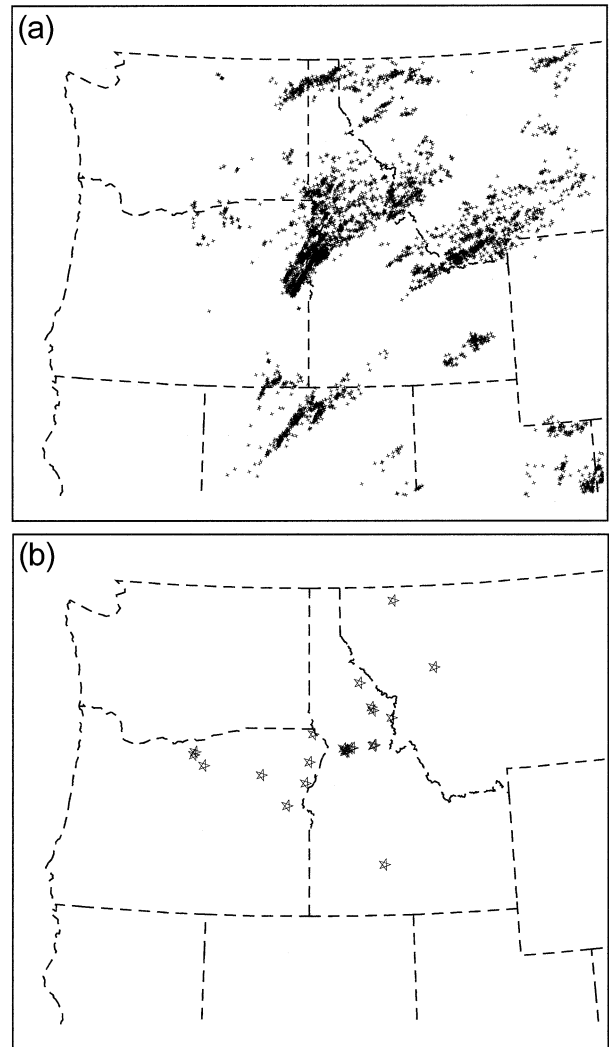


FIG. 3. (a) Lightning strikes and (b) large fires, 24 Aug 2000.

of low-level moisture (85-kPa dewpoint depression of 9°C).

3. Summary

Lightning-caused fires ignited on 57 days in the region encompassing Washington, Oregon, Idaho, and western Montana from 1 May through 20 September 2000. The 85-kPa dewpoint depression and 85–50-kPa temperature difference were significantly different on fire days than on the other days at all three upper-air sounding stations in the region (Spokane, Boise, and Great Falls). On fire days, the atmosphere was drier and more unstable than on other days. Daily precipitation records were obtained for 122 sites in the study area. Very few stations reported significant rainfall amounts (in excess of 2.5 mm) on days when the 85-kPa dewpoint depression at Spokane was high. In converse, on days with numerous lightning strikes and ample low-

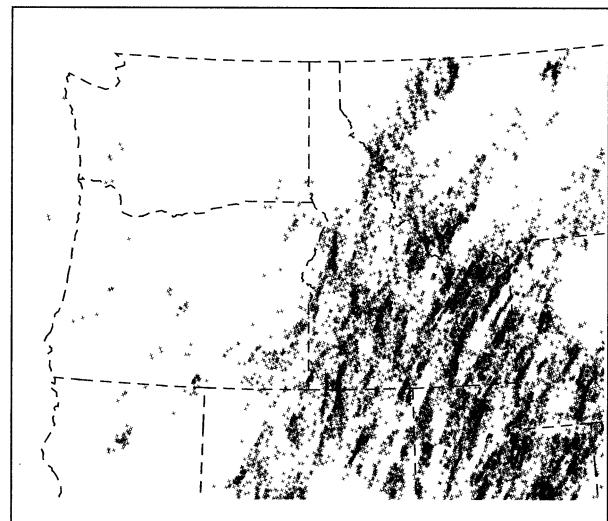


FIG. 4. Lightning strikes, 1 Sep 2000.

level atmospheric moisture, many stations in the study area recorded precipitation, and few (if any) fires started on those days.

These results show that, if convection is expected, lower atmospheric moisture content is an important factor in estimating the risk of dry lightning strikes that result in fire ignitions. The 85-kPa dewpoint depression and the 85–50-kPa temperature difference are easily derived and appear to be successful in discriminating between dry and wet lightning days.

The methodology described here has been developed as a diagnostic tool, but it can easily be applied with data from prognostic models and configured as a predictive tool. Extreme fire seasons like the summer of 2000 occur infrequently, yet even in normal years large numbers of fires burn across the United States. With increasing development in the wildland–urban interface, it is necessary to improve the ability of forecasters to anticipate weather conditions that are conducive to the ignition and spread of wildfires.

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