Program for Climate, Ecosystem and Fire Applications

Climate Analysis of the 2000 Fire Season

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Forward

This report describes the climate factors and associated impacts of the western U.S. 2000 wildfire season. The project was done under Task Order 1422RAH012402 of the Cooperative Assistance Agreement No. 1422RAA000002 between the Bureau of Land Management National Office of Fire and Aviation and the Desert Research Institute Program for Climate, Ecosystem and Fire Applications. For further information regarding this report or project, please contact either:

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by

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Executive Summary

This report provides an assessment of the climate factors associated with the western U.S. 2000 wildfire season. The season was unusual in terms of both its length and spatial extent. Several critical climate factors came together to substantially increase fire danger and fire severity from April through August. These included a persistent pattern of below average precipitation, above average temperature and below average relative humidity across large portions of the West for the entire season. Lightning occurrence was also wide spread throughout the season causing an above average number of natural fire starts. For many of these areas the number of lightning strikes were not unusually high, but the combination of stressed and dry vegetation, large fuel loadings and ample ignition sources generated the most severe fire season in at least 40 years putting substantial stress on geographic area suppression resources. Though the Southwest monsoon began early and strong, it was weak during July and only moderate strength during August that led to continued fire occurrence throughout the Southwest during the summer. There is not strong evidence that La Niña played a significant role in the season's outcome overall. The primary findings of this study are as follows:

- Several areas of the West had undergone one or more years of precipitation deficit leading up to the fire season indicating a longer-term fire danger issue than just seasonal.
- Below average precipitation occurred persistently during the season from April through August across large areas of the West causing in part wide spread fire danger.
- Above average temperature occurred persistently during the season from April through August across large areas of the West; the afternoon maximum temperature departures from average were generally larger than those for nighttime minimum temperatures. Increases in both day and night temperatures contributed to increased fire danger throughout the entire season.
- Below average relative humidity occurred across nearly all areas of the West from April through August; the nighttime maximum anomalies were generally twice as large as daytime minimum values indicating poor overnight fuel moisture recovery and thus sustaining increased fire behavior activity.
- Observed 1000-hour fuel moistures were persistently in the 6-10% range or less from April through September over large portions of the West contributing to increased fire danger.
- Lightning occurrence generally was low in comparison with eleven years (1990-2000) of available climatology data except associated with the southwest monsoon; however, there were a substantial number of days in July and August with wide spread lightning occurrence across the West causing numerous fire starts.

- Even though lightning occurrence was generally low, the number of lightning started fires was above average indicating the efficiency of strikes given high fuel loadings and very dry vegetation.
- The Southwest monsoon had a strong and record early onset in mid-June, but weakened substantially during July and returned moderately in August resulting in extended fire activity in the Southwest.
- It is not readily obvious that La Niña played a significant role in the fire season, though winter and spring (but not summer) observed precipitation patterns in some parts of the U.S. appeared similar to those statistically expected during eastern Pacific cool events.
- There is some predictability at various time scales for the season's most relevant climate factors implying usefulness of climate information and forecasts for strategic planning; however, more applied research will be needed to improve forecast skill, determine more precise relationships between climate and fire danger and fire occurrence, and utilize this information in decision-making.

The intent of this report is to provide a lesson-learned for the 2000 fire season from the perspective of understanding climatic patterns preceding and during a fire season, especially one of such significance. The results should be of interest to both wildfire related decision-makers and fire weather meteorologists. Also, there are general climatology concepts in this report that we recommend be considered when developing long-term assessments such as those produced seasonally by the Geographic Area Coordination Centers.

The results of this report raise several scientific questions on the relationships between climate and fire that would be desirable to address:

- What is the quantitative relationship between precipitation and live fuel moisture?
- To what extent was the spatial occurrence of lightning in 2000 unusual compared to other years?
- Do numerical model diagnostics studies show any impact of La Niña on the fire season?
- What is the predictability of fire climate variables in terms of skill and how can these predictions be better utilized in strategic planning?

The results of this report also highlight the need for four national initiatives:

- The development and implementation of national scale operational climate monitoring for wildfire, prescribed fire and fire use planning.
- The development and implementation of a national consistent ground-based monitoring network for live fuel moisture.
- The implementation of operational year-round Remote Automatic Weather Stations.
- The implementation of an improved and reliable national fire occurrence database.

1. Introduction

The 2000 U.S. wildfire season was the most severe in at least 40 years. According to statistics provided by the National Interagency Fire Center (NIFC 2001) there were nearly 123,000 fire starts nationally during the year, of which over 18,000 were caused by lightning. Consequently, over 8.4 million acres burned, with approximately half of these being attributed to lightning and associated suppression activity. There were over 860 structures burned, over 30,000 firefighters and support personnel involved in suppression, and on one day 86 large fires were burning simultaneously across the western U.S. Using a 10-year (1988-1997) average by cause, the number of lighting started fires during the year was moderately above average (133% of average), but over twice the average number of acres burned (229%). Human caused fire starts were near average (102%), but again the number of acres burned was over twice the 10-year average (227%). In the West, large fire incidents or fires threatening wildland-urban interface areas occurred during nearly every month of 2000.

This report describes climate factors that were most relevant in the outcome of the 2000 wildfire season. Emphasis in this report will be given to the western U.S., though some reference will be made to other parts of the country. Factors including precipitation, temperature, relative humidity and lightning activity are examined, in addition to upper-air wind flow patterns. For a regional annual comparison, a similar type report was prepared in 1999 describing the Nevada climate and wildfire season (Brown and Hall 2000).

2. Data Description

Five primary climate data sets were examined in this study in addition to fuel moisture. A basic description of each data set is provided below.

Precipitation

The precipitation anomalies used in this analysis are based on monthly divisional data produced at the NOAA National Climate Data Center (NCDC). Results are shown in the form of percentiles or percent of average depending upon the analysis. The percentiles represent the percent occurrence of years exceeding the percentile value. For example, a value of 10 means that only 10 percent of the values are as low as this value, or conversely, that 90 percent of the values are higher for the period 1895-2000. The percent of average is simply computed by dividing the monthly value by its respective long-term mean. Data processing tools at both the Western Regional Climate Center (WRCC) and the NOAA-CIRES Climate Diagnostics Center (CDC) were used to produce maps for the precipitation analysis.

Temperature and relative humidity

Remote Automatic Weather Station (RAWS) temperature and relative humidity data analyzed in the study are from the WRCC archive. Hourly values of these two variables for 359 sites were examined to determine maximum and minimum temperature and relative humidity based on hourly values (as opposed to measured maximum and minimum values). Long-term daily station climatologies were developed for each site using a minimum of 8 years data that yields approximately 240 days for each climatological month. At least 18 hours of data for the day had to be present for incorporation into the monthly climatology.

For each station, anomalies were found by computing monthly maximum and minimum values for 2000 for both variables and subtracting from the respective maximum and minimum long-term mean. The anomalies were plotted spatially in order to examine patterns. It is recognized that both large horizontal and vertical (elevation) distances were interpolated between stations. Thus, the anomalies may appear more spatially homogeneous than they actually are. However, based on other types of station data (e.g., ASOS, NWS coop) it is believed that the patterns overall do depict the general sign and magnitude of the anomaly for the region, and will be interpreted as such.

Upper atmosphere variables

Geopotential height and vector winds are two variables considered especially important for assessing the climatology of a fire season. Geopotential height approximates the actual height of a pressure surface above mean sea level. For example, the height above sea level (e.g., in feet or meters) where an atmospheric pressure of 500 mb occurs. In this study monthly 500 mb height anomalies based on the 1970-2000 long-term period are examined to give an indication of large-scale ridge and trough patterns. Monthly vector winds at 500 mb are analyzed using streamlines to show the source regions for upper-level moisture and the overall mean wind flow pattern linked to geopotential height.

Data used for the upper atmosphere analysis (i.e., geopotential height and vector wind) are from the National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) reanalysis global data set (Kalnay 1996). It consists of several derived daily variables on a 2.5 degree spatial grid. While this grid may be considered too coarse for operational meteorological purposes, it provides very useful information for climate analyses based in part because of the consistent manner in which the variables were derived. Reanalysis data for the study were obtained from CDC.

Lightning

Cloud-to-ground lightning strike data were used in this study to assess the extent of lightning activity in relation to wildfire occurrence. Values for 2000 and a climatology period of 1990-2000 are from the National Lightning Detection Network™ maintained by Global Atmospherics, Inc. (GAI). The data set used for the analysis consists of the date, time, latitude, and longitude of the strike. Anomalies of lightning occurrence were assessed by comparing the total detected number of monthly strikes during 2000 to a western U.S. lightning climatology for the period 1990-2000. Because of such a short period of record (11 years), a simple departure from average or percent of average is not appropriate for assessing anomalies. A single thunderstorm over an area could produce an unusually high number of strikes thus influencing the “average” climatology. For this situation we find that simple rankings are most appropriate. First, a 0.5 degree spatial grid for each month January through December was established to develop the climatology. This grid size is somewhat of an arbitrary choice, but it does resolve some coarse terrain features and allows for identifying coherent regions of lightning activity. Second, the number of strikes in each grid cell was counted for each month of each year. Third, annual correction values for 1990-1998 were applied to each monthly grid to improve the climatology counts. These values attempt to correct for known detection efficiency issues across the network during those years based on an algorithm recently developed at GAI (Cummins 2001). Fourth, each grid cell was sorted by year, from the year with the least number of strikes to the most. Finally, the rank of year 2000 for each month was then plotted and examined. A rank of 5 through 7 would be considered an average year, 1 through 4 below average and 8 through 11 above average, though the word "average" is used very loosely here because of the short climatology period.

Fuel moisture

Live and 1000-hour time lag fuel moistures were examined in the study in the context of their potential relationship with climate variables. Live fuel moisture information was taken from the Bureau of Land Management (BLM) Nevada State Office (NSO) live fuel moisture project. NSO provides on their web site pre-processed time series plots of average moisture conditions along with both the past and current year values. Daily maps of 1000-hour time lag fuel moisture were provided by the U.S.D.A. Forest Service (USFS) Wildland Fire Assessment System (WFAS) archives. Also examined in the study and used from the same database were adjective fire danger class maps based on the National Fire Danger Rating System (NFDRS).

3. Results

Several climate variables were analyzed and interpreted within the context of the fire season. Most of these data were examined at monthly time scales, though seasonal precipitation was also used. The results described below clearly indicate that climate conditions played an important role in the 2000 western U.S. wildfire season.

Precipitation

Precipitation at seasonal and longer time scales has a significant impact on vegetation growth and health, and thus influences a fire season. For example, the previous winter and spring precipitation may impact fine fuels green-up and curing dates, whereas it might take an entire year or more of dry conditions to cause stress in certain types of heavy fuels and increase susceptibility to burning.

Divisional precipitation climate data is generated at the National Climatic Data Center (NCDC), and research and data organizations such as CDC and WRCC readily provide this information for inspection and analysis. Divisional data typically cover large areas made up of National Weather Service (NWS) daily cooperative observer (coop) reports. Though specific site observations such as RAWS may not directly correspond to a division's overall monthly pattern, climate division data do provide useful information relevant to spatial fire danger characteristics and other components related to wildfire assessment. Divisional values are also chosen for this particular analysis because year-round data are available and over one hundred years of observations are available, which is not the case with RAWS.

Figure 1 shows divisional precipitation percentile values for the U.S. based on the 1895-1999 historical period. In Figure 1a, percentile values for November 1999 through March 2000 are shown which represents the winter or cool season precipitation. Many of the southwest, south, southeast and midwest portions of the U.S. are shown with percentiles of 20% or less indicating a very dry winter season. Portions of the northern Rockies also fell under this category. This dry pattern persisted during the spring and early summer (April through June) in the Southeast and over much of the West as shown in Figure 1b. During July through September, the anomalous dry pattern continued over the northern Rockies, southwest and southern U.S.

The dry winter pattern set the stage for spring and summer fire occurrence. As the dry conditions persisted, stressed and previously dead vegetation became especially susceptible to ignition with increased fire danger. For those areas with sufficient fine fuel loadings or with non-drought resistant vegetation, only one dry season (or even less) is necessary to increase fire danger substantially. This was especially the case in Oklahoma, Texas and across much of the Great Basin during the summer season. For example, a generally wet winter and/or spring over parts of Oklahoma and Texas may have induced early season fine fuel growth and development, followed by near record dryness during the summer and early fall. The Great Basin had generally average precipitation during the winter, but was followed with a very dry spring. Though summer generally had average precipitation, this region is naturally dry anyway. Thus, the combination of these seasonal precipitation conditions substantially increased the fire risk across this area. The south and southeast U.S. were also affected in a similar manner given the unusually dry winter and spring across these regions.

For those regions with heavy fuel types, several months or seasons might be required to dry out and stress vegetation to a point of increasing fire danger to a level of high risk for large incident occurrence. Conversely, a multi-year wet period plays an important role in vegetation growth and fuel loadings and overall reduction of fire for that period. The two regions during 2000 with the most notable fires were northern New Mexico, northern Idaho and western Montana. Figure 1 shows these areas were generally dry during winter and very dry during spring and summer. In New Mexico, large fires were burning as early as February. The southwest Montana large fires began in late July and continued until early October. To assess the impact of long-term dryness on fire risk, precipitation needs to be examined at longer than seasonal time scales.

A useful tool for assessing precipitation impacts over long time scales is the Standardized Precipitation Index (SPI; Mckee et al. 1993). Monthly precipitation data for a climate division (or station) is statistically transformed to a standard normal cumulative probability distribution. This allows for a scale to be produced ranging from say –4 to +4, where the negative and positive values represent extreme dry or very wet conditions, respectively. Long-term averages are used to compute the anomalies needed in the calculation. The relatively simple statistical transformation of observed data and the computed index allows climate divisions or stations to be compared on equal levels. For example, a +2 value in Oregon has the same meaning as a +2 in Arizona (similar inter-region interpretation cannot be precisely made with the Palmer Drought Severity Index, though it is commonly done and accepted). Equally valuable is the SPI attribute that the index can be integrated over any desired time period, thus yielding the cumulative effect of precipitation. For example, the SPI can be computed for 1-month, 12-months, 72-months or any period of interest. Assigning a descriptive term to index values (e.g., dry, very dry, etc.) is somewhat arbitrary because it depends on the sector being impacted (e.g., agriculture, reservoirs, forest or rangeland health). Schlobohm and Brown (2001) are currently examining the relationship between SPI and wildfire. At least qualitatively for this study, index values below –0.5 can be considered dry, and those of less than one indicate a likely substantial impact on fire danger.

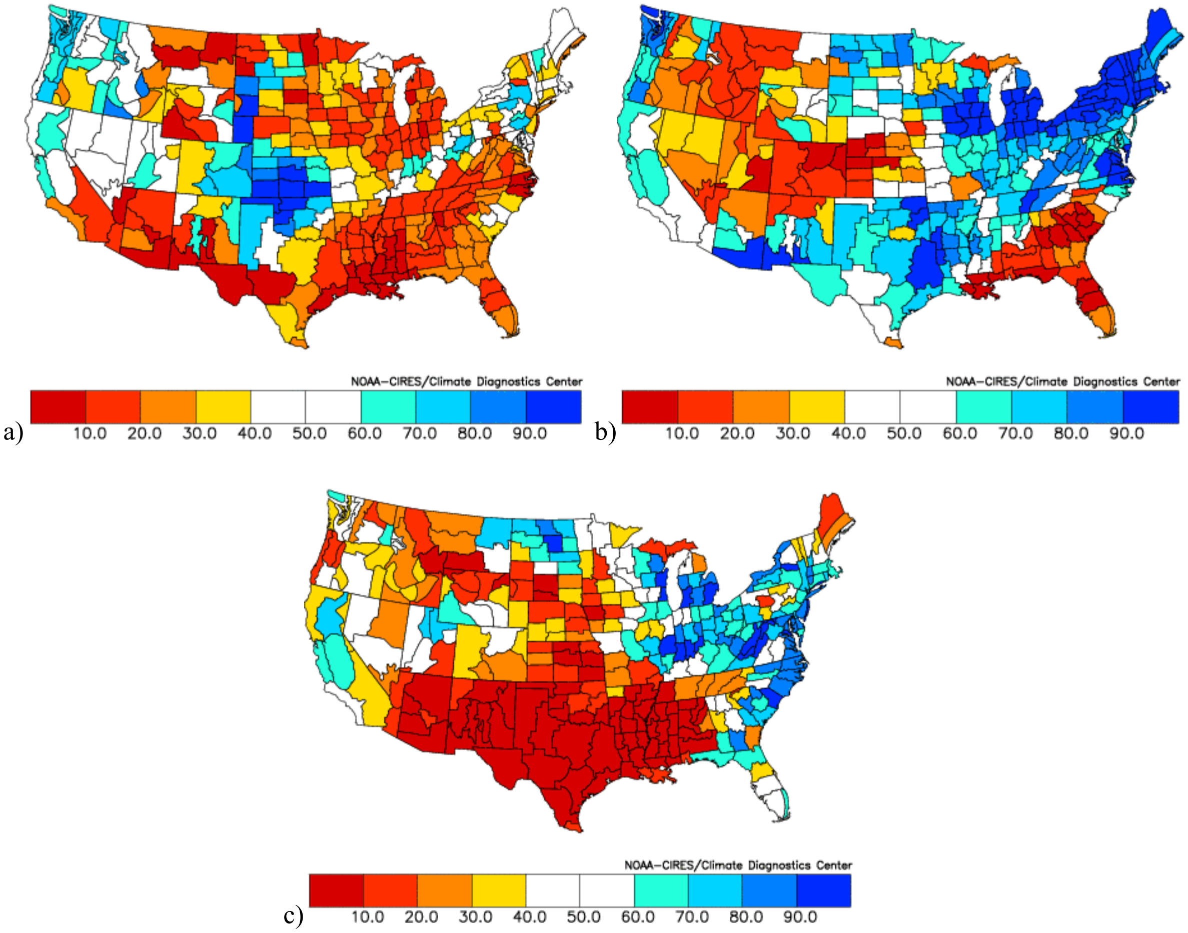
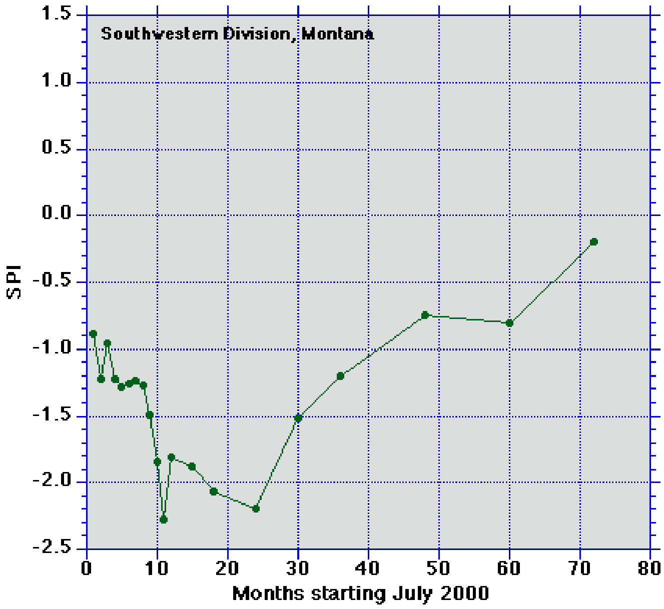


Figure 1. Climate division percentiles based on the period 1895-1999 for a) November 1999 through March 2000, b) April through June 2000, c) July through September 2000. Warm colors (e.g., red) represent dry conditions and cool colors (e.g., blue) represent wet conditions. Map source: NOAA-CIRES Climate Diagnostics Center.

Figure 2 shows the SPI for the Montana southwestern climate division for monthly intervals starting with July 2000 and including several integrated time periods up to 72 months. This division was chosen for its representation of the large fire complexes that occurred from early August through early October. The first point on the plot is for July 2000, yielding a SPI value of nearly –0.9 which is considered dry. The second point on the plot (-1.2) is for June and July combined and indicates a very dry two-month period. The third point combines May through July and has a value of close to –1.0 indicating a very dry three-month period. The series can be followed backward in time up to 72 months on this plot, which shows that basically all six years prior to the large fire incidents were very dry (the period September 1994 through July 2000), with generally extreme below average precipitation during the three-year period September 1997 through July 2000. Thus, a continuous precipitation deficit in this region of heavy fuels has been steadily increasing fire risk during the past six years, and with substantial fuel loadings and ignition sources in place, perhaps the inevitable was to occur. In a situation such as this it is highly unlikely that only a few months of surplus precipitation could overcome such a large deficit; it may require a multi-year wet period to return to generally low wildfire risk.



b)

Figure 2. Standardized precipitation index values for various time steps in the 1 to 72 month range beginning with July 2000, respectively, for the Montana southwest climate division. Data source: Western Regional Climate Center.

Fuel moisture

The live and dead fuel moisture data shown in this section are presented more as ancillary information to the overall discussion of climate impacts on the season rather than as an analysis of the relationship between climate and fuel moisture. For both the western U.S. 1000-hour time lag fuel moisture and Great Basin live fuel moisture presented, there is currently little quantitative information relating their long-term relationship with precipitation indices such as the SPI. Precipitation duration is one of several components used to model time lag fuel moisture, but this is on a daily basis rather than a longer-term climatological scale. However, despite the lack of quantitative information, it is intuitive that an association between fuel moisture and precipitation can be expected. The discussion below generalizes this association and notes potential relationships between climate and vegetation for further study.

The 1000-hour time lag fuel moisture is one component often used for assessments of fire potential. The 1000-hour maps on the Wildland Fire Assessment System (WFAS 2001) are computed from a 7-day average boundary condition composed of day length, precipitation duration, and daily temperature/humidity maximum and minimum values. Because of these other factors, a precipitation anomaly map by itself may not necessarily correspond well to the fuel map. However, if a persistent precipitation anomaly lasting for several weeks or more is occurring, then the two maps may have similar spatial appearance. What will be realized from such a comparison is that lag fuel moisture (LFM) by itself may not be an accurate indicator of fire danger. In other words, an assessment based solely on LFM could be misleading especially during periods of rapid regime change such as occurs with the Southwest monsoon. Of course, this is why other LFM indicators were developed (e.g., 10-hour, 100-hour), in order to capture these faster changes in fuel and more accurately assess fire danger.

Figure 3 shows a single day's snapshot of 1000-hour LFM at mid-month, and after reviewing daily maps, it is found that this day in general represents the conditions throughout most of the month. In April (Figure 3a) the best correspondence between low fuel moisture and dry precipitation anomalies is over the southwest and up through the northern Rockies. Similarity in the spatial pattern between wet anomalies and high fuel moisture could be argued for the eastern and northeast U.S. This correspondence continues in May (Figure 3b) for the southwest and northeast U.S., and there is also some similarity in the Pacific Northwest. In June (Figure 3c) the similarities are reduced substantially with the exceptions of the northern Great Basin, Colorado, Wyoming and the Pacific Northwest. Of particular interest here is the very dry fuel moistures shown in Arizona, but very wet precipitation anomalies. These high percentile values are a result of an early and strong monsoon during the last two weeks in June. These latter two weeks produced the large monthly wet anomaly. But what is particularly curious is that the mid-month fuel moisture pattern seen in Figure 3c persisted more or less in the same manner during each day for the remainder of the month (not shown), despite the fact that temperatures were generally below average and relative humidity above average during the same period based upon RAWS data. This demonstrates the slow response of the 1000-hour moisture, and suggests caution of its sole use as a fire danger indicator in regions especially susceptible to rapid climate regime shifts, such as occurs in conjunction with the Southwest monsoon.

In July (Figure 3d) low fuel moistures are shown across much of the West with corresponding dry precipitation anomalies. The monsoon did not fully develop (see later discussion) and July turned out to be very dry in the Southwest. In August (Figure 3e) dry fuels are shown to be prevalent across most of the West, though this was not necessarily seen in the divisional data. Much of the Southwest and Great Basin are shown with wet precipitation anomalies, though very low fuel moistures were indicated in these same areas throughout the month. However, the low precipitation values and low fuel moistures in the northern Rockies do correspond well, with this being the peak month of the large fire complexes in Idaho and Montana. Substantial precipitation deficits occurred in the Southwest and across Texas in September (Figure 3f) that corresponds well to dry fuel moisture across the region. This dry month combined with the dry July and August led to increased fire activity in Oklahoma and Texas during late summer and early autumn. The wet divisions in Idaho and Montana are a reflection of two or three synoptic storm events that helped suppression crews gain control of the large fire complexes that had been burning for well over a month.

There is not an abundance of live fuel moisture data readily and conveniently available across the West to assess its direct role in the fire season and any relationship with climate factors. Though in a qualitative sense it is easy to relate precipitation deficit with vegetation drying and stress, this has not been quantified in a suitable manner at climate time scales for use in assessing fire danger. For example, what is the specific impact of a –2 PDSI value on fuel model G forest fuels commonly described by NFDRS? Given the importance of live fuel moisture in fire danger, fire behavior and overall vegetation health, it is surprising that monitoring live fuel moisture under a consistent and scientific set of guidelines at the national level has never been implemented.

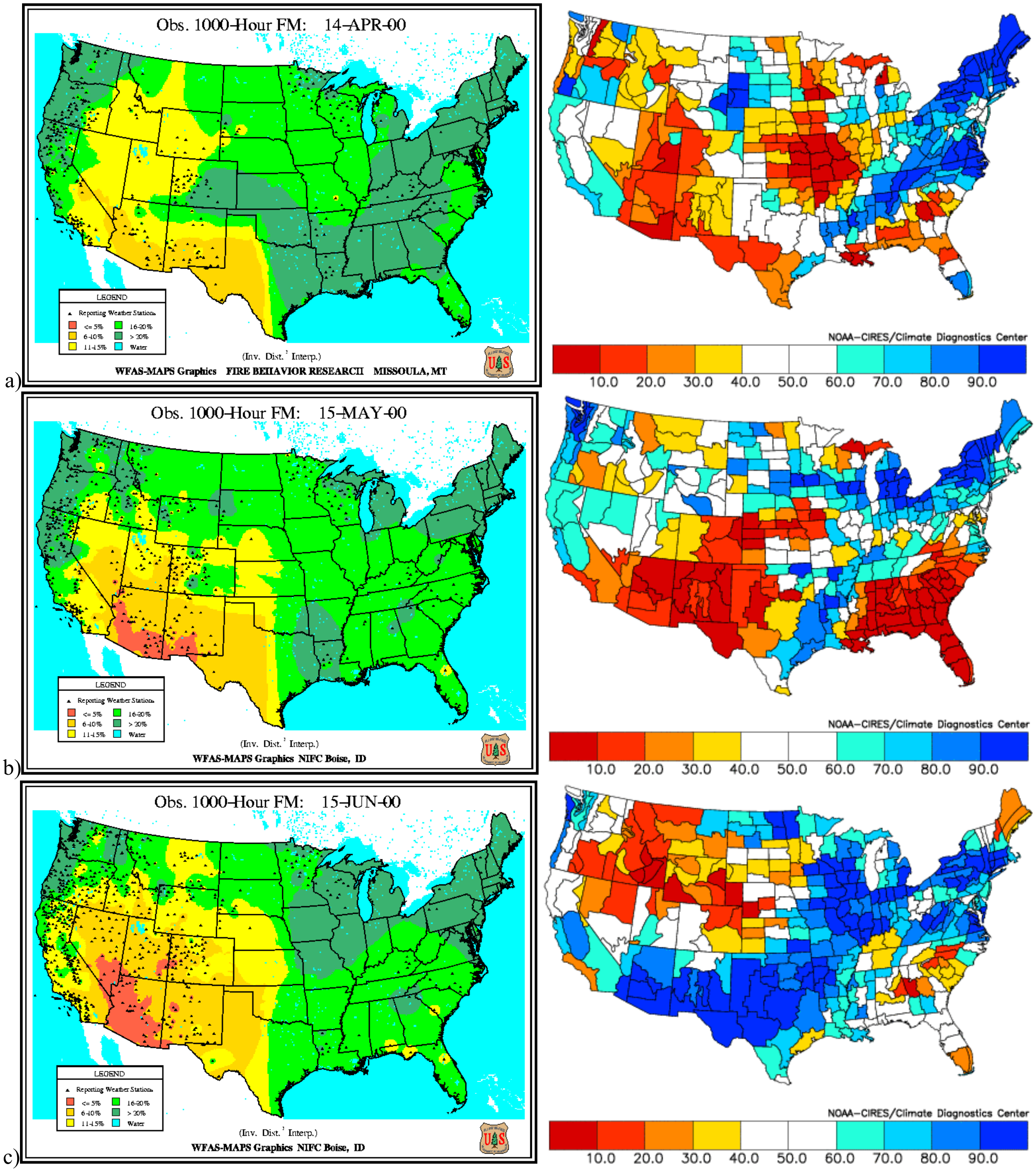


Figure 3. Mid-month observed 1000-hour time-lag fuel moisture for a) April, b) May, and c) June, d) 2000. Also shown are corresponding monthly climate division precipitation percentiles in the same format as Figure 1. Fuel moisture map source: Wildland Fire Assessment System; precipitation map source: NOAA-CIRES Climate Diagnostics Center.

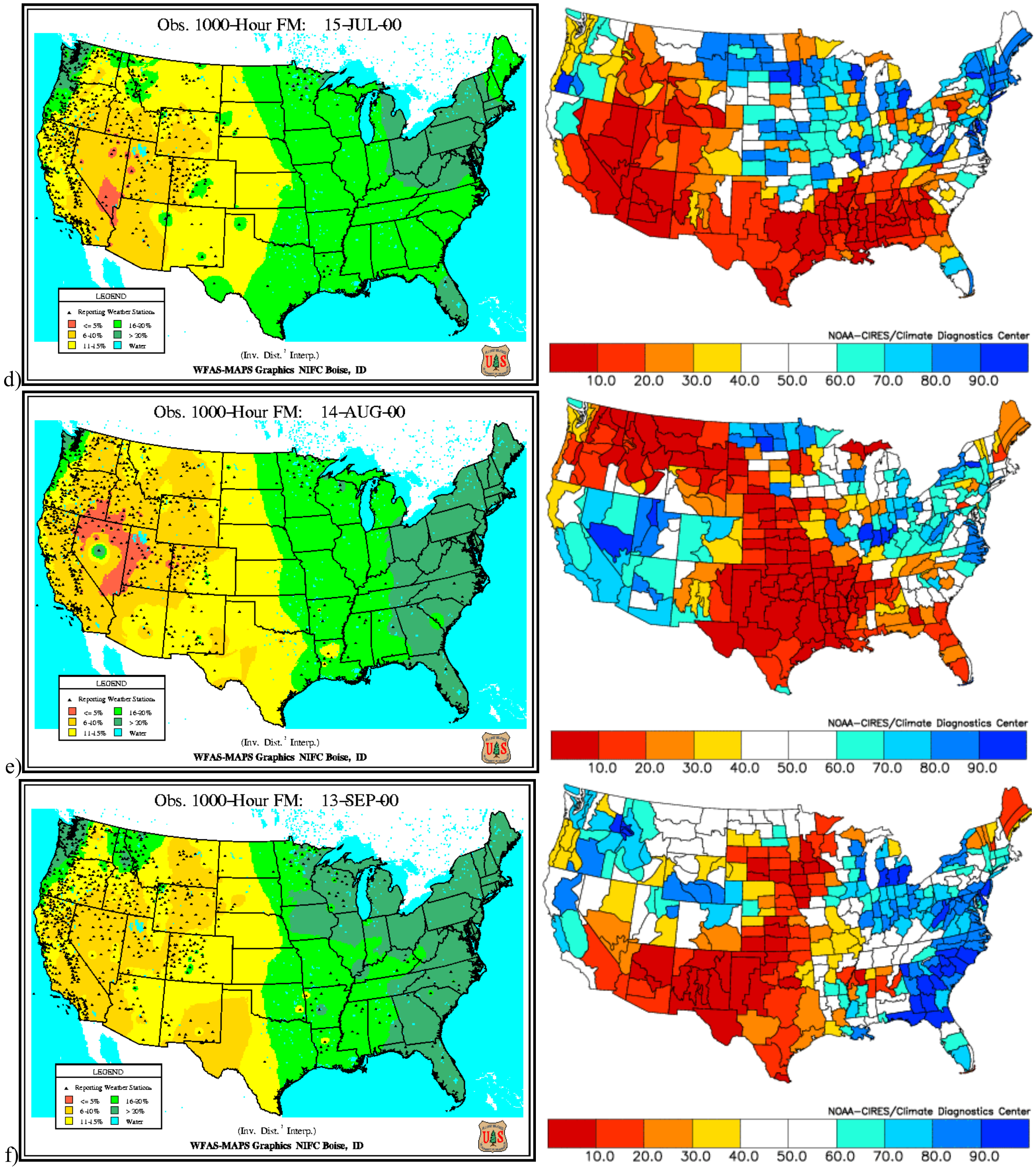


Figure 3. Continued for d) July, e) August, and f) September 2000.

The best regional network currently in place in our view is managed at the BLM Nevada State Office within the Western Great Basin Live Fuel Moisture Project (BLM 2001). Though efforts are underway to improve the timeliness and number of sample sites, this project offers the most consistent methodology and availability of information on a regional scale. Figure 4 shows plots of sagebrush live fuel moisture for two sites in the Great Basin. Each plot shows a bi-weekly long-term average (blue line with triangle symbols), year 2000 values (red line with square symbols), and year 2001 values up to when the graph was included in this report (green line with diamond symbols). The long-term average varies with each station, but for those with longer records the period is typically between 8 and 16 years. The 2001 values are not relevant to the 2000 assessment, but are shown simply because they are included on the plots provided at the BLM web site from where they were copied.

The first plot (Figure 4a) is for East Adobe Creek located in northeast Nevada, and also shown is daily precipitation accumulation for the nearby NWS coop site at Elko, Nevada (Figure 4b). It would be preferable to have precipitation recorded directly within the sampling site radius, but unfortunately this is rarely done. During April 2000 the live fuel moisture was above the sixteen-year average, but starting in the first two weeks of May it fell just below the average. In July the decreasing trend continues and begins to depart further from the average until the sampling stopped in early August. The above average and near average fuel moisture in April and May, respectively, can be seen in correspondence with the Elko plot showing sizeable precipitation events during these two months. The steady decline in fuel moisture during July corresponds well to very little precipitation reported during the month. If 125% fuel moisture is considered roughly the threshold for burning, then in 2000 this occurred during the last half of June and continued through early August. Both fire and large fire occurrence were above average in July in Nevada, but below average in August and through the remainder of the season (WGBCC 2001). The above average precipitation across the state in August (Figure 3e) played a partial role in reducing fire activity.

Figure 4c shows a similar live fuel moisture plot for Kenney Pass, Oregon and daily precipitation accumulation for Vale, Oregon (Figure 4d). Though one sampling period is missing in May, the near average (based on seven years) live fuel moisture through early July seems to correspond with precipitation accumulation. Below average live fuel moisture was reported from the latter half of July through early October. Very little precipitation occurred at Vale in June through August, and if representative of the fuel sampling area, would correspond somewhat with the live fuel moisture pattern during the summer. By the end of October the fuel moisture was back up to a near average value that is likely related to the precipitation occurrence during the month.

The plots and data presented suggest a strong relationship between precipitation and fuel moisture as intuitively would be expected. The direct link between precipitation and vegetation is soil moisture, of which there are some measurements being taken at RAWS sites in Utah. Though beyond the scope of this study, it would be highly desirable to form quantitative links between the three components in a future study.

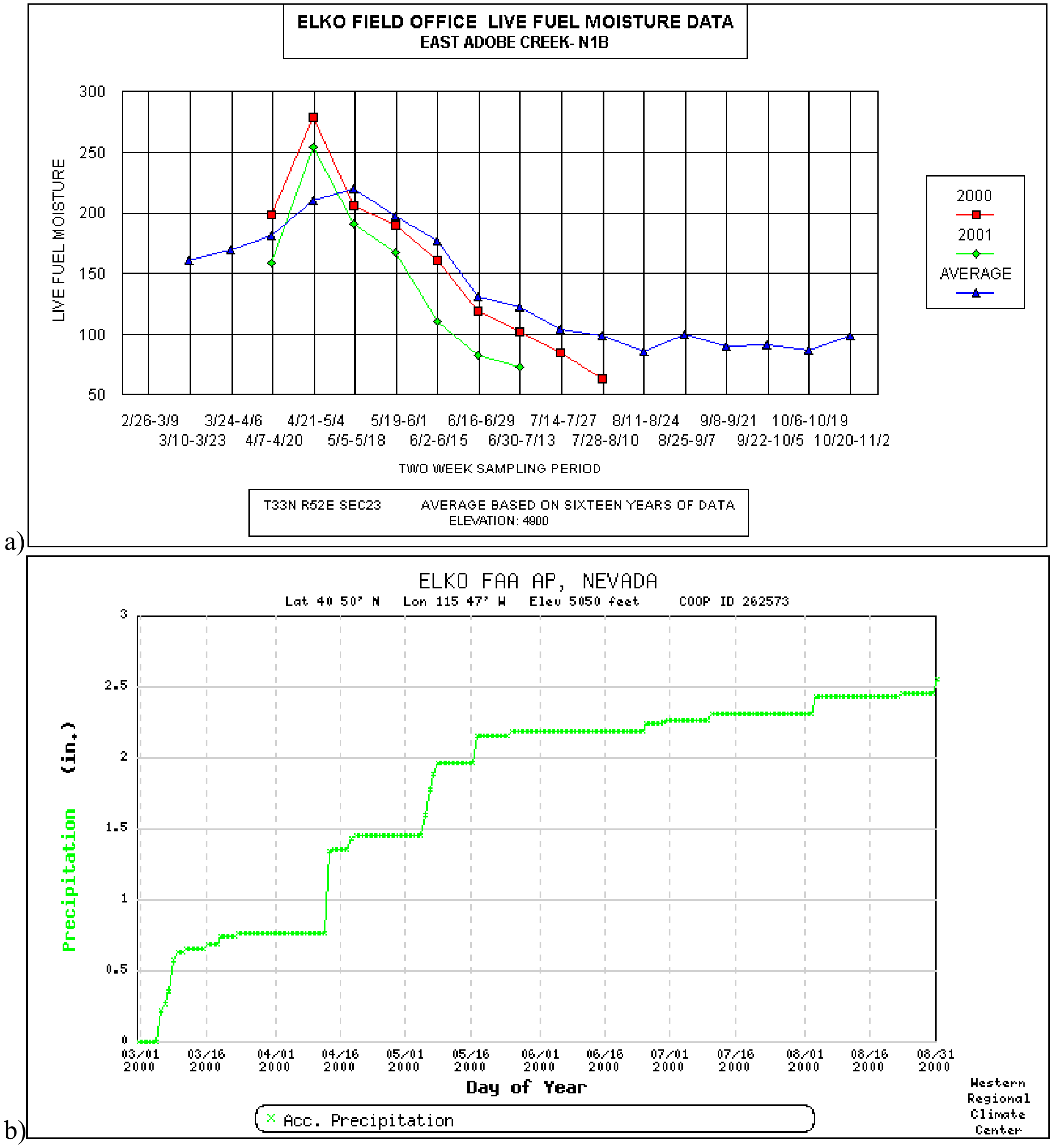


Figure 4. Live fuel moisture observations and long-term climatology for a) East Adobe Creek, NV. Blue line indicates the long-term average, red line observations for 2000 and green line partial observations for 2001. A corresponding plot of daily precipitation accumulation is shown for b) Elko, NV. Live fuel moisture plot source: BLM Nevada State Office; precipitation plot source: Western Regional Climate Center.

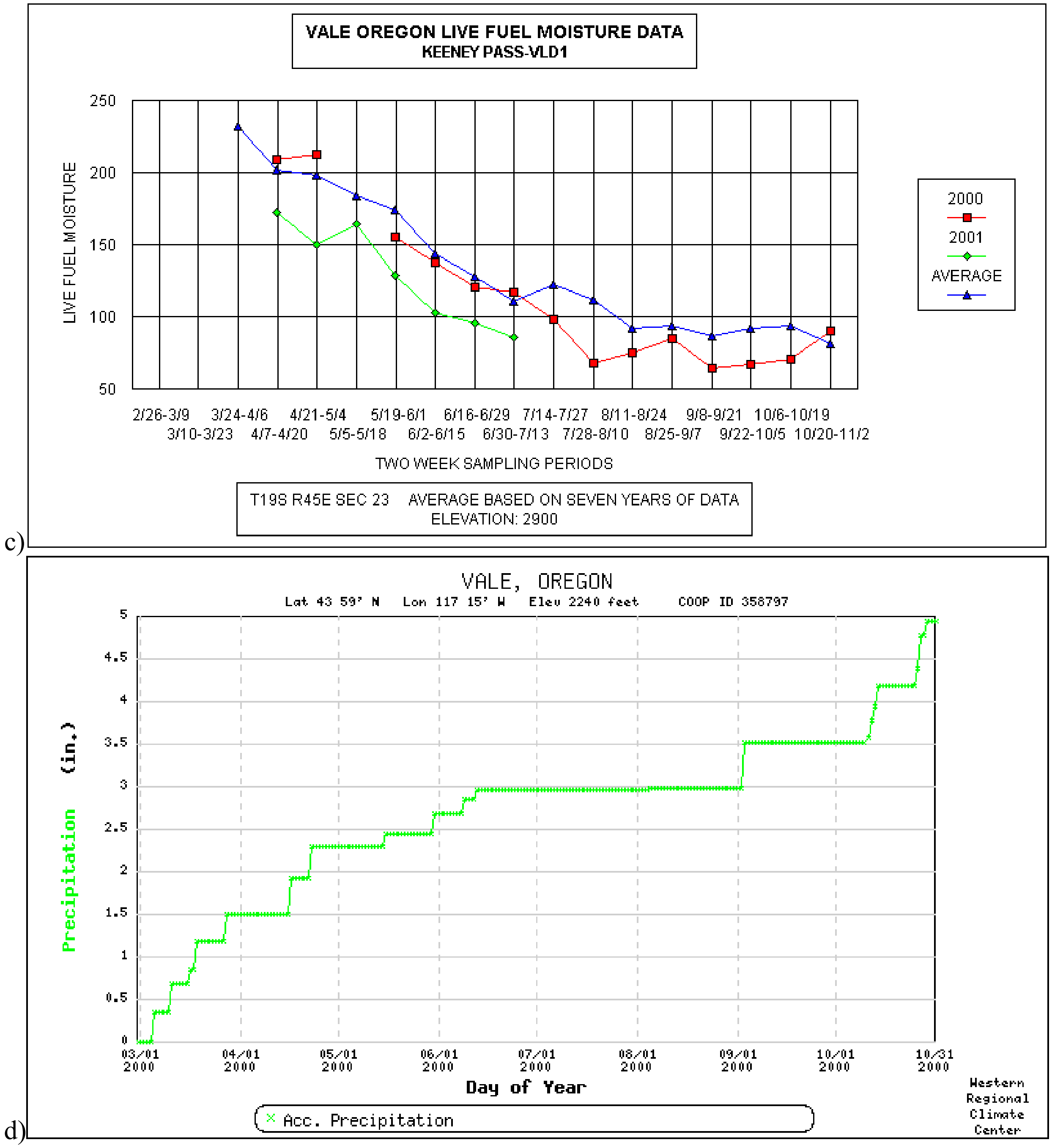


Figure 4. Continued for c) Keeney Pass, OR and d) Vale, OR.

Temperature

Figure 5 shows monthly maximum temperature anomalies based on 359 available RAWS sites for April through September 2000. Anomalies were produced by first computing a climatology of maximum temperature for each month as described earlier. The maximum temperature is determined from hourly data, not the actual observed maximum temperature for the day. Color shading is used to highlight the temperature anomalies, but it is cautioned that much interpolation was used in between RAWS sites to produce a smooth appearing field. However, even with this caveat, other surface temperature observations (e.g., ASOS, NWS coop) generally show anomalies similar to those from RAWS.

Figure 5a shows maximum temperature anomalies for April. Most of the RAWS sites across the West experienced temperatures well above average (> +4°F). The large positive temperature anomalies (> +4°F) also occurred in May, but were confined to mainly the Southwest and Great Basin (Figure 5b). The northwestern and northern states were average to below average (approximately -2°F). Most of the West was again above average (+2°F to +6°F) during June (Figure 5c). For many parts of the West these spring and early summer warm temperatures may have helped induce an early season green-up. However, in conjunction with the below average precipitation over much of the region these warm anomalies may also have induced early vegetation stress and drying. In July (Figure 5d) most of the West except for northern California and the Pacific Northwest was above average (> +2°F). These above average anomalies (> +2°F) persisted through August (Figure 5e) with some exception in the Southwest associated with precipitation occurrence. In September (Figure 5f) the warmest anomalies (> +4°F) were confined to mostly Arizona and New Mexico while the remainder of the West finally cooled off for the season, especially the northern Rockies (< -4°F). As with the dry precipitation anomalies, the persistent warm temperatures throughout both spring and summer were an important factor contributing to increased fire danger throughout virtually the entire season.

Figure 6 shows minimum temperature anomalies derived in the same manner as those in Figure 5. With few exceptions, most of the West from April through September also had above average minimum temperatures, though generally less in magnitude compared to the maximum temperature anomalies. However, the spatial extent of the positive anomalies was not as large as for the maximum temperatures with the possible exception of April and May. In April (Figure 6a) anomalies are generally greater than +2°F for much of the West. This pattern continues into May (Figure 6b) with somewhat less emphasis across the northern Great Basin. In June (Figure 6c) the warmest anomalies (> +2°F) occurred across Arizona, California and Nevada. During July (Figure 6d) the warmest anomalies (> +2°F) shifted mainly east of 114°W. This pattern persisted in a generally similar manner during August (Figure 6e). By September (Figure 6f) only portions of Arizona and New Mexico were having above average temperatures. The above average minimum temperature anomalies contributed to the fire season in at least three ways. First, combined with maximum temperature these anomalies would have increased seasonal fire danger overall. Second, these anomalies basically represent nighttime temperature conditions, and thus for some areas overnight fire activity may have been enhanced instead of reduced due to typical overnight cooling. Third, since temperature is directly related to relative humidity (discussed in the next section) nighttime humidity recovery was also reduced.

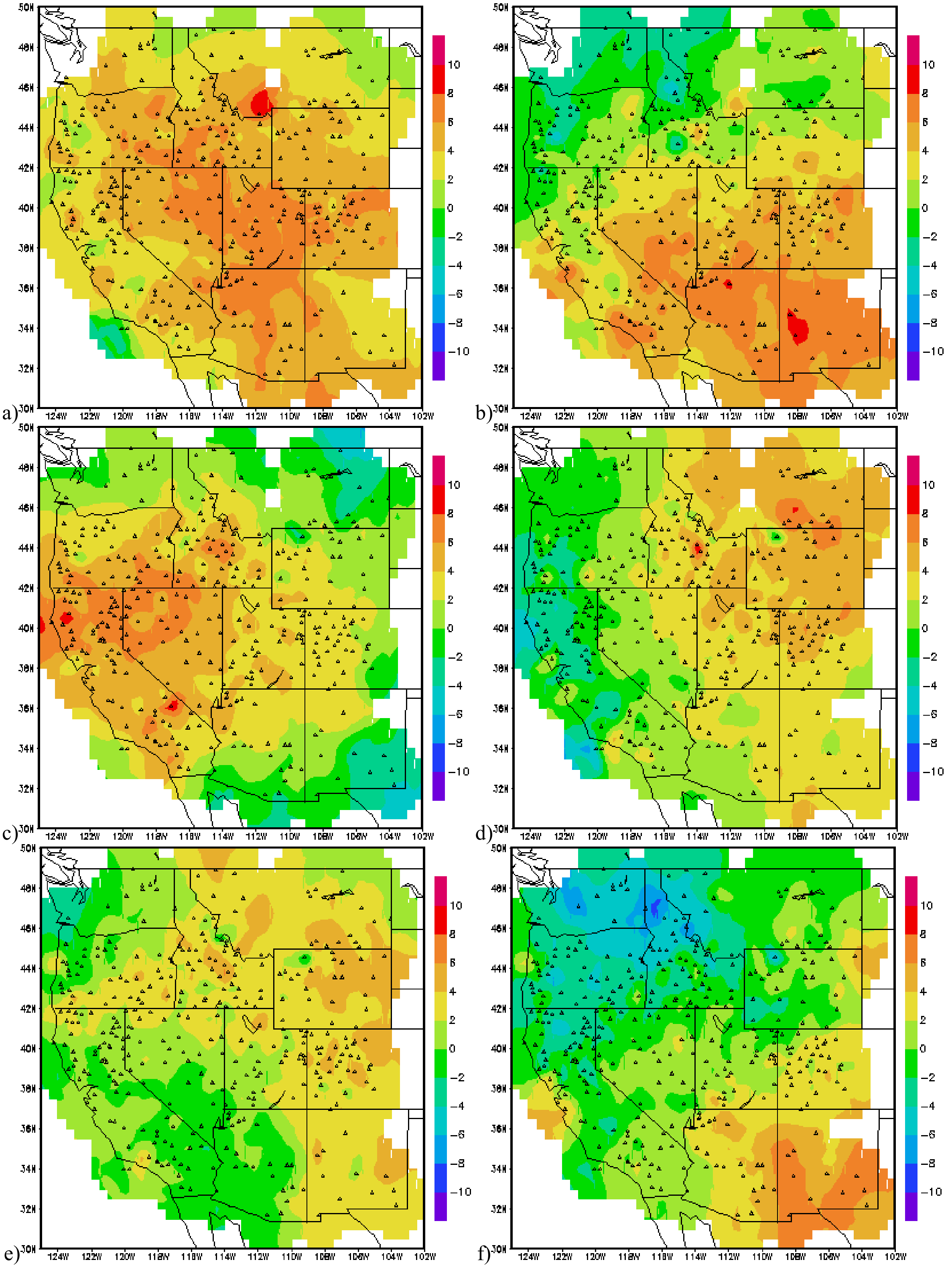


Figure 5. RAWS maximum temperature anomalies (°F) based on hourly values for a) April, b) May, c) June, d) July, e) August and f) September 2000. Warm colors (e.g., red) represent above average temperature anomalies and cool colors (e.g., blue) represent below average temperature anomalies (see color bar). Data source: Western Regional Climate Center.

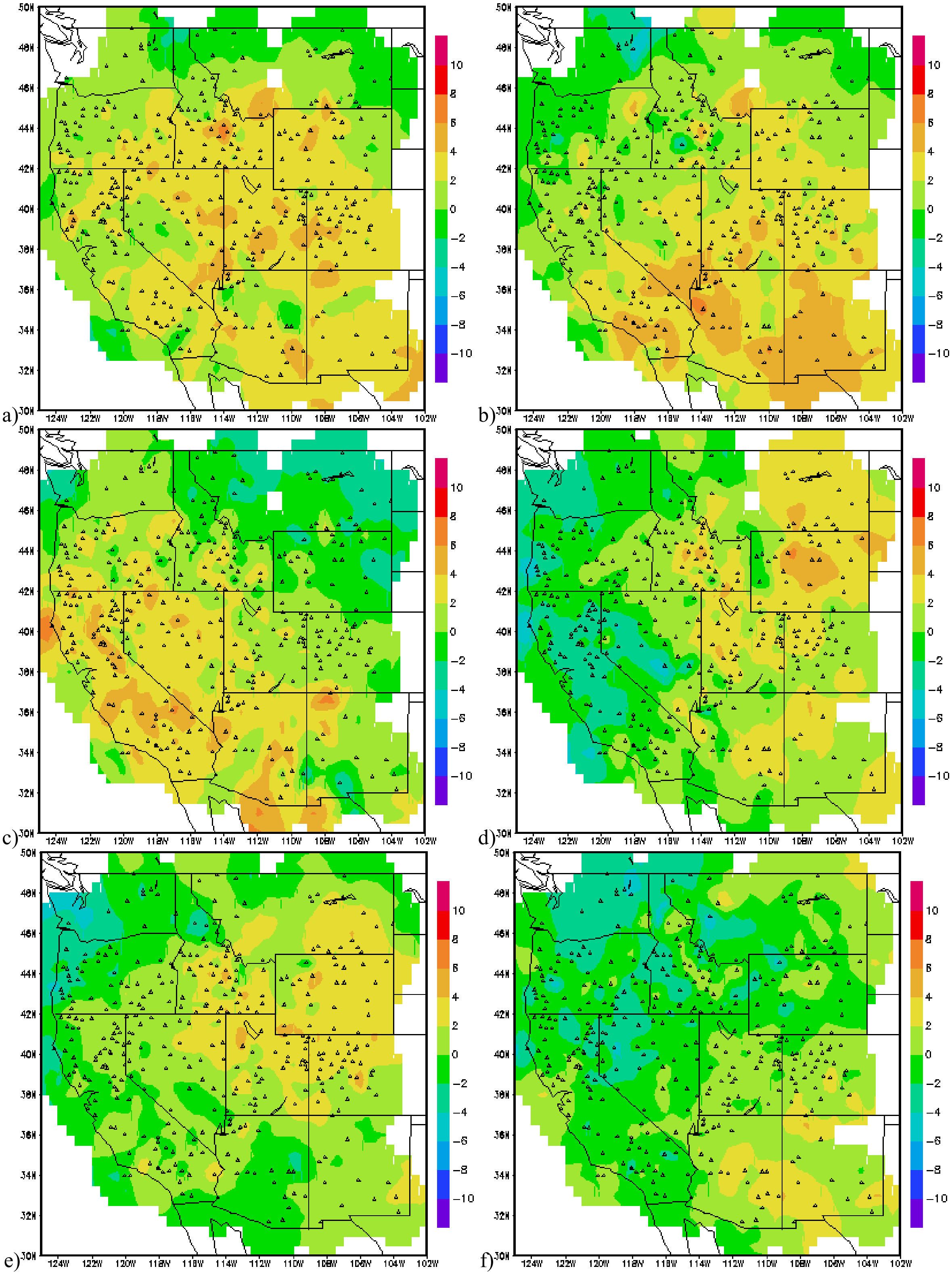


Figure 6. Same format as Figure 5 except for minimum temperature.

Relative Humidity

Figure 7 shows monthly minimum relative humidity anomalies (in percent) using the same set of RAWS sites as for temperature discussed above. The daily minimum relative humidity basically represents the afternoon conditions, or typically the driest time of the day. Most of the West experienced below average minimum relative humidity during the April through September period. In April (Figure 7a) relative humidity was 5% or less below average over much of the West. This pattern persisted through May (Figure 7b). In June (Figure 7c) most of the West remained below average with the exception of southern Arizona and New Mexico where an early onset (mid-June) of the Southwest monsoon brought low-level moisture across the region. During July (Figure 7d) the below average relative humidity pattern continued over most of the West, due in part to a substantial weakening of the Southwest monsoon. In August (Figure 7e) southern Nevada and parts of Arizona experienced an increase of moisture due to increased monsoon activity compared to July, but the rest of the West remained below average. During this month parts of northern Idaho and western Montana experienced anomalies of less than 10% which is quite substantial and a significant impact on fire activity in this region. Finally, in September (Figure 7f) moisture relief occurred across the northern Rockies, but much of the remainder of the West continued with below average relative humidity, especially Arizona and New Mexico. While relative humidity anomalies of 5% would be considered small on a daily basis, averaged over an entire month or season this anomaly magnitude is large, and would substantially increase fire danger as it did during the 2000 season. While the direct influence of the below average relative humidity on live vegetation is not known, it is intuitive that the combination of below average precipitation, above average temperature and below average relative humidity would have had a detrimental impact on virtually all fuel types.

Monthly maximum relative humidity anomalies are shown in Figure 8. These values basically represent the nighttime relative humidity conditions. For the most part, the maximum relative humidity anomalies were larger in magnitude than for the minimum values. In April (Figure 8a) the minimum relative humidity was below average by 5% or more over much of the West, with large areas below average by 10% or more. This pattern continued during May (Figure 8b) with the four corners region having below average of 15% or more. In June (Figure 8c) the driest anomalies shifted to primarily the Great Basin (< -15%). The large positive anomalies (> +5%) in Arizona and New Mexico are due to the Southwest monsoon surge during the last two weeks of the month. The dry pattern over the Great Basin continued to dominate during July (Figure 8d) and expanded to include Arizona and Wyoming. The weak monsoon flow during July is reflected in the negative anomalies over Arizona and New Mexico. In August (Figure 8e) the largest negative anomalies (< -15%) occurred in the northern Rockies, corresponding quite well to the Idaho and Montana large fire activity. The positive anomalies in Arizona and Nevada correspond to monsoon activity. In September (Figure 8d) the pattern reversed in the northern Rockies (positive anomalies > +5%), but Arizona and New Mexico returned to very dry (< -15%). The large positive relative humidity anomalies that occurred during the spring and summer seasons clearly indicate below average nighttime recovery of lag fuel moisture from relative humidity. For many fires this likely inhibited the typical reduction of fire activity during the nighttime hours. Overall, these nighttime anomalies probably had a larger impact on the fire season than did the afternoon values, and strongly contributed to increased seasonal fire danger.

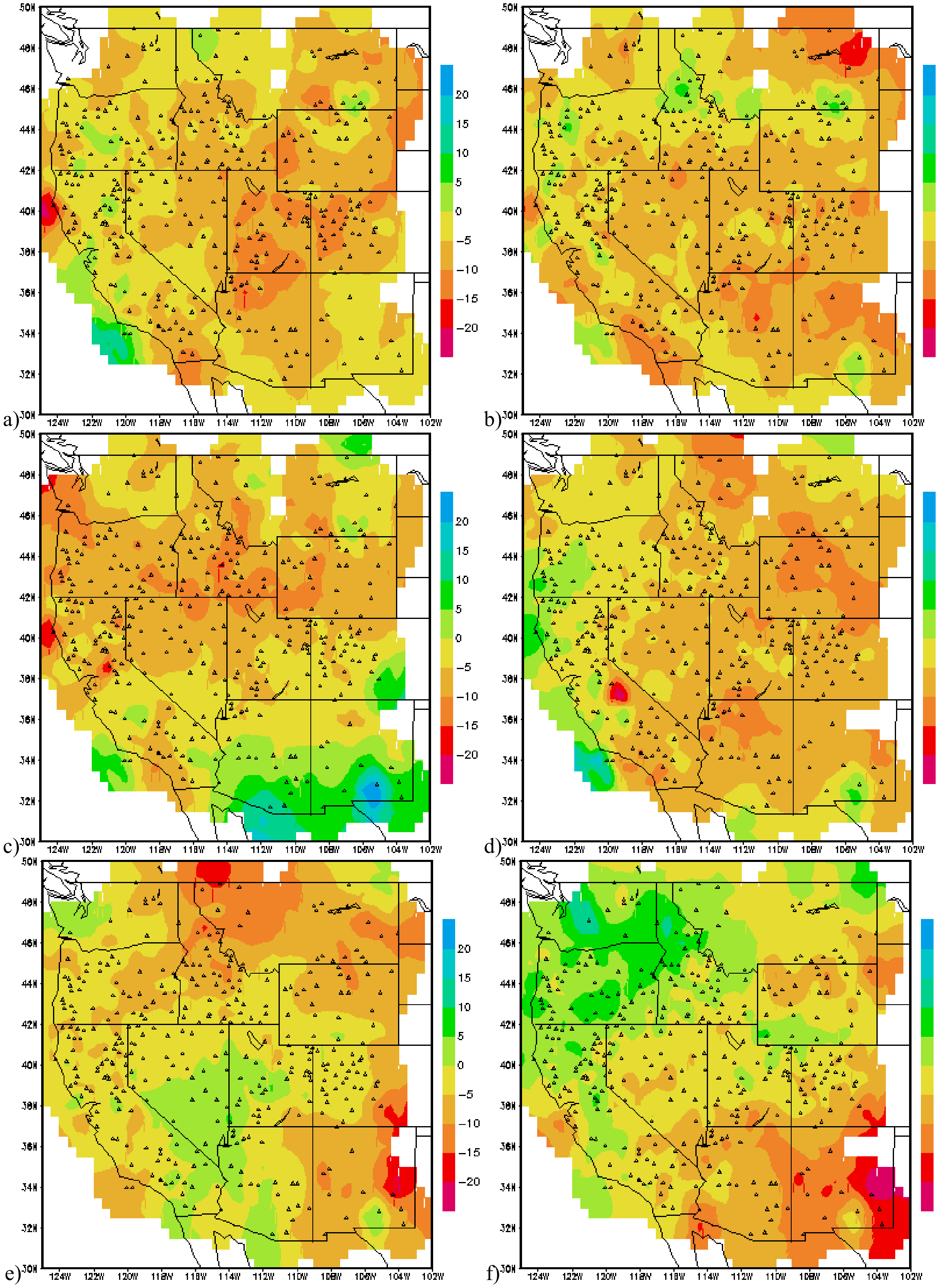


Figure 7. RAWS minimum relative humidity anomalies (%) based on hourly values for a) April, b) May, c) June, d) July, e) August and f) September 2000. Cool colors (e.g., green) represent above average anomalies and warm colors (e.g., red) represent below average anomalies (see color bar). RAWS station locations are indicated by triangle symbols. Data source: Western Regional Climate Center.

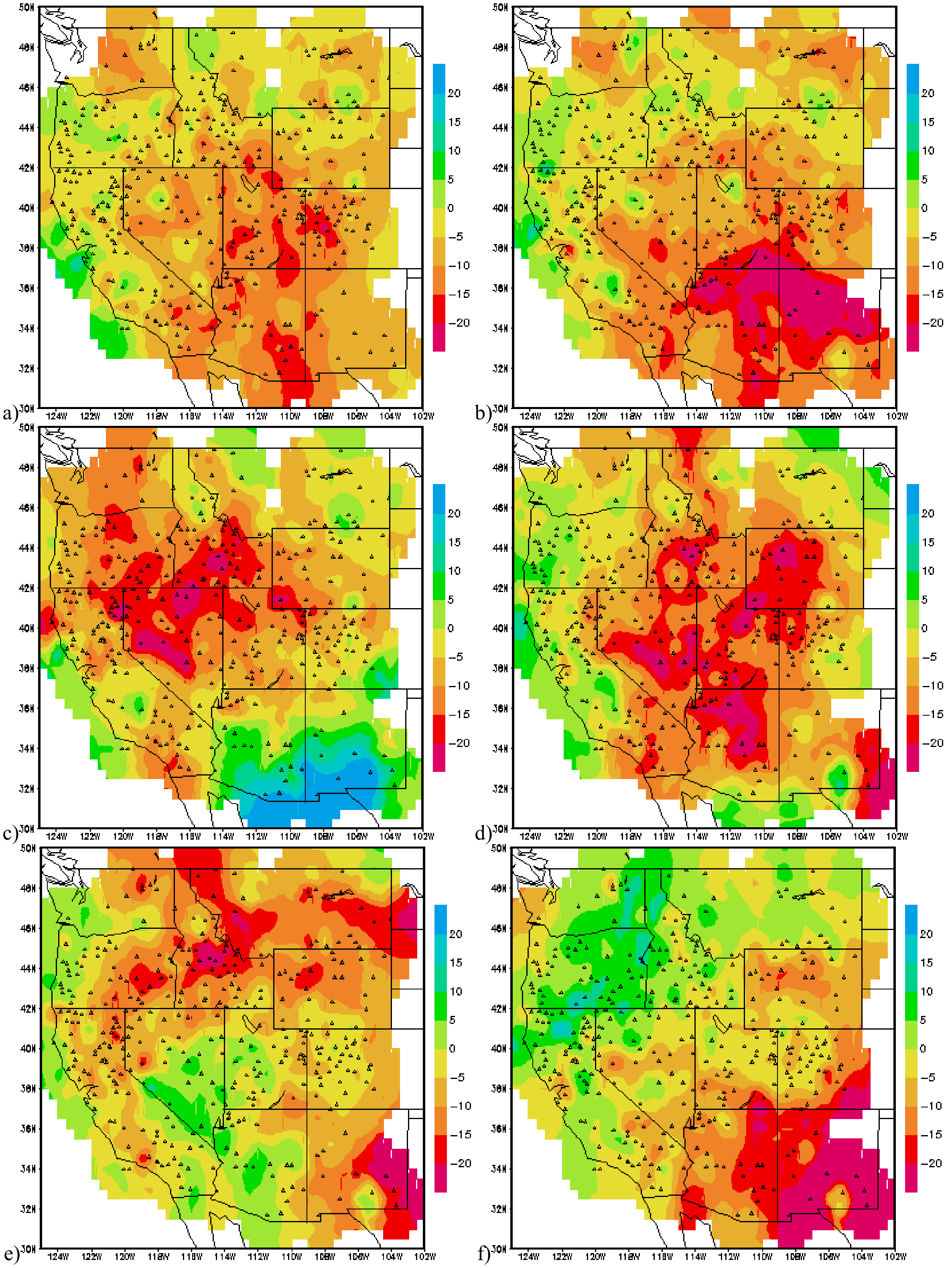


Figure 8. Same format as Figure 7 except for maximum relative humidity.

Upper air

Surface anomalies of temperature, precipitation and relative humidity are a reflection of a broader scale pattern of upper air wind flow. For example, the pressure height level of 500 mb (approximately 18,000 feet) is useful for measuring and monitoring wind, temperature and moisture patterns that strongly influences weather at the ground. Monthly mean values of height anomalies can be examined to assess the dominating features of climate on weather patterns.

Height anomalies (in meters) for the western U.S. at 500 mb are shown in Figure 9, and indicate the presence of anomalous ridges or troughs. The month of April (Figure 9a) was dominated by a large, anomalous ridge pattern (positive height anomalies) across most of the West, yielding the warm and dry conditions discussed earlier. During May (Figure 9b) the positive height anomalies shifted southward to over the southwest U.S. allowing for the continued dry and warm pattern across this region, while in parts of the Pacific Northwest precipitation was above average. In June (Figure 9c) large positive height anomalies are shown over the coast centered over northern California. This pattern kept much of the northern half of the West dry. July (Figure 9d) was dominated by a trough (negative height anomalies) off of the west coast and a ridge (positive height anomalies) over the northern plains. This allowed for generally south-southwesterly flow over much of the West that often can bring thunderstorms across the region, especially the Great Basin. However, the weaker than average monsoon reduced the number of thunderstorms during July. In August (Figure 9e) much of the West was influenced by above average height anomalies, especially over the eastern Great Basin. This pattern was responsible for the above average temperature and below average relative humidity values discussed earlier, and also allowed for moisture flow over the region from the southwest. In September (Figure 9f) a strong high pressure area over New Mexico and western Texas induced anomalous dry conditions in this region, while the anomaly pattern over the Northwest and northern Rockies allowed for two or three frontal systems to bring moisture relief to this area.

Streamlines representing 500 mb wind flow patterns associated with the height anomalies in Figure 9 provide a good indication of moisture sources and where the mean monthly patterns of ridges and troughs are actually located. Figure 10a shows a southwesterly flow across the coast forming a ridge over the central part of the West in April. This ridge appeared as a substantial height anomaly in Figure 9a. The flow pattern in May (Figure 10b) is predominately zonal over the southern half of the West. This pattern in conjunction with the dominating high pressure yielded below average precipitation in this region. There is a slightly more southwesterly component in the flow for the northern half of the West that induced precipitation in some parts of this region. In June (Figure 10c) there is still a predominately zonal flow over the northern half of the West. A trough off of the southern California coast along with an eastern Mexico high combined to start a northward flow of monsoon moisture. In July (Figure 10d) the subtropical high is well established and centered over New Mexico allowing for northward flow of moisture over the Great Basin. While every day had lightning strikes somewhere in the West, the spatial extent of occurrence was limited on many of the days. In August (Figure 10e) the high shifted eastward and was centered over Texas. This feature along with a trough off of the northern coast enhanced moisture flow from the eastern Pacific and monsoon region over all of the Great Basin and up into northern Idaho and Montana. This large-scale pattern allowed for the development of thunderstorms across much of the West. An examination of daily lightning occurrence showed that every day of August had strikes over large spatial areas. The subtropical high continued to dominate the Southwest in September (Figure 10f). However, northward moisture flow and thunderstorm activity across the West was primarily limited to the first week of the month.

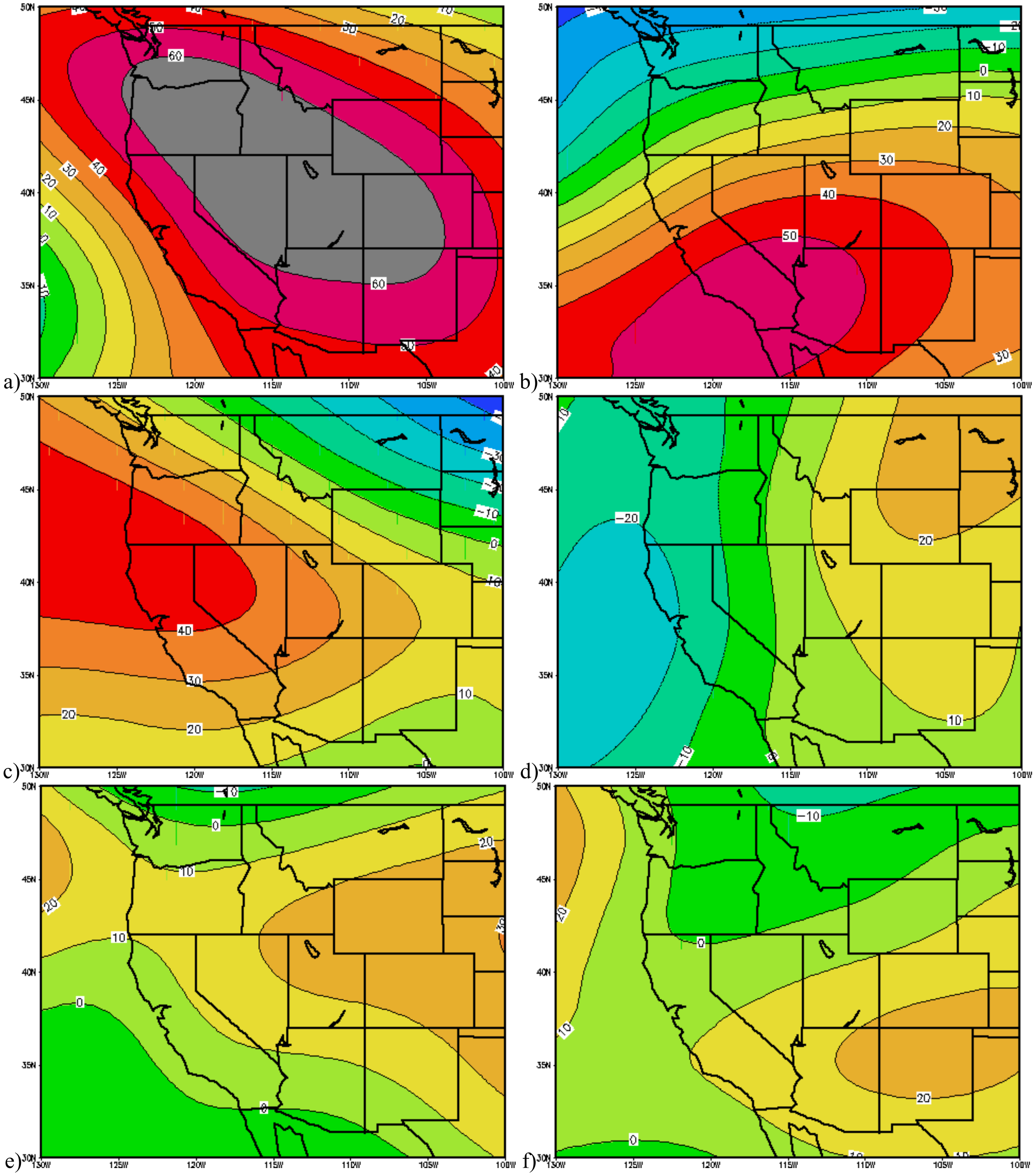


Figure 9. NCEP/NCAR reanalysis 500 mb height anomalies in meters for a) April, b) May, c) June, d) July, e) August, f) September 2000. Data source: NOAA-CIRES Climate Diagnostics Center.

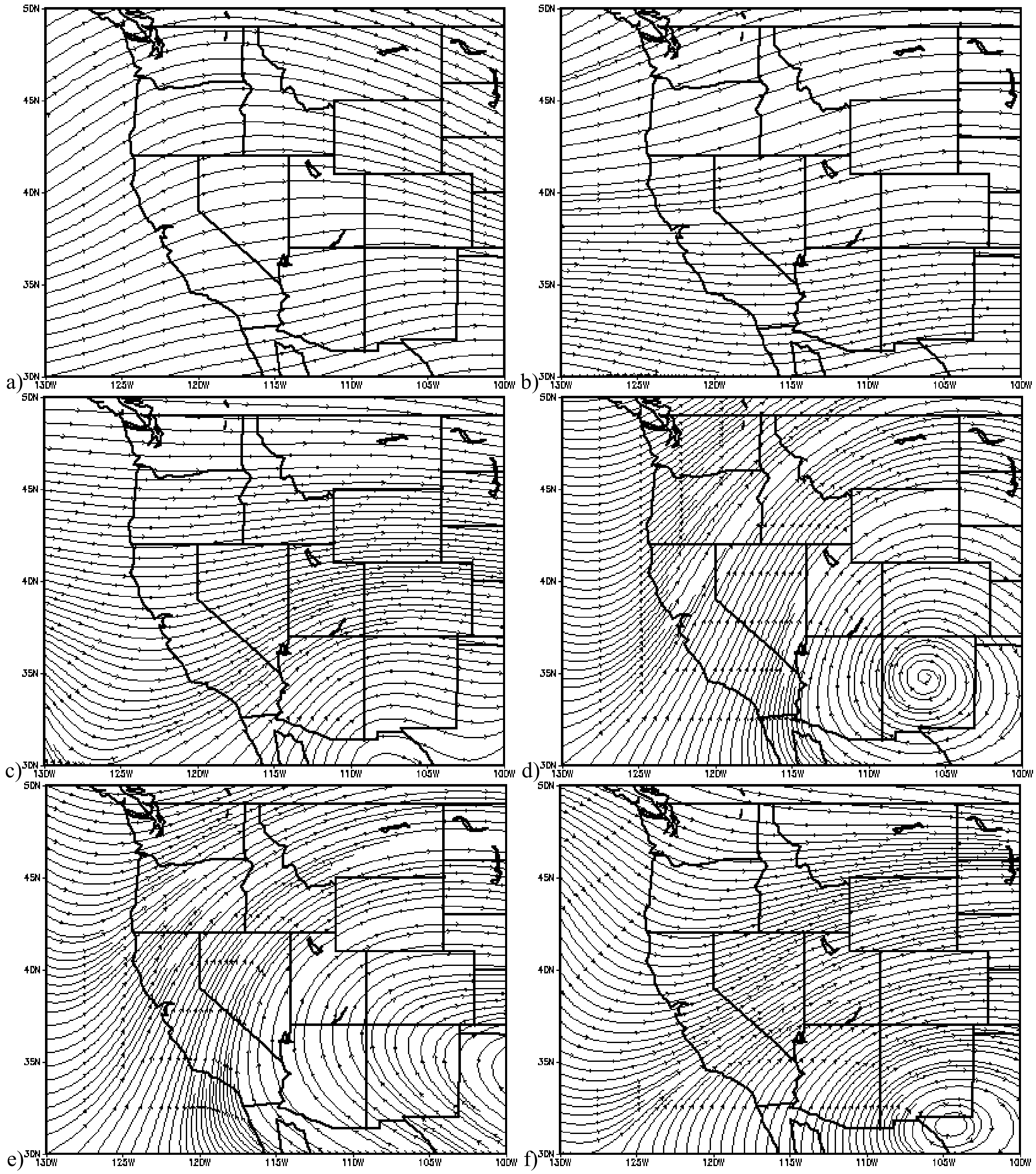


Figure 10. NCEP/NCAR reanalysis monthly average 500 mb vector wind streamlines for a) April, b) May, c) June, d) July, e) August and f) September 2000. Data source: NOAA-CIRES Climate Diagnostics Center.

Lightning

Figure 11 shows the monthly rank of lightning strike counts for 2000 in 0.5 degree grid cells compared to a climatology period of 1990-2000 for the primary western U.S. lightning season (June through September). The lower ranks (fewest number of strikes among the 11 years) are coded with cool colors (e.g., purple) and higher ranks (greatest number of strikes among the 11 years) are coded with warm colors (e.g., red). The area along the U.S. - Canada border has a slight rank bias due to the incorporation of strike data from Canadian lightning sensors during 1998-2000. These data were not available prior to 1998. However, south of approximately 48°N is not affected by the additional data inclusion. In June of 2000 (Figure 11a) much of the southwest had high amounts of lightning activity (ranks 10 and 11). This is largely a result due to the early onset and strength of the southwest monsoon during the last two weeks of the month. For the remainder of the West, strike activity was generally low thus falling in the lower ranks. Strike counts during July (Figure 11b) were typically in the middle to lower ranks across a large portion of the West. However, there are substantial areas with higher ranks in New Mexico, Colorado, Wyoming, Montana and the Pacific Northwest. The Colorado and New Mexico ranks are indicative of an eastward shift of the monsoon flow during the month. In August (Figure 11c) substantial lightning activity associated with the monsoon caused high ranks in the Southwest, while most of the northern portions of the West fell in middle and lower ranks. Middle and lower ranks dominated most of the West in September (Figure 11d) though there are some areas of high ranks especially in Utah, Colorado and Idaho. A large number of fire starts were associated with both areas of high and low ranks. Many of the high rank areas were monsoon related, of which was shown earlier to have below average relative humidity during the season. In the areas with low ranks, the high number of starts indicates that a lot of lightning is not necessary for fire starts given a combination of increased fuel loadings over the years in concert with very dry conditions.

Figure 12 shows four example days during 2000 of natural wildfire start locations (red circle symbols) and lightning strikes across the West (cyan plus symbols). The large Idaho and Montana complexes occurred on July 31 (Figure 12a), however, as seen in the Figure there was minimal lightning occurrence associated with these starts. This is a case where even though lightning occurrence was minimal, it was very efficient in causing fire starts due to the combination of very dry fuels and large fuel loadings. On August 3 (Figure 12b) there was widespread lightning occurrence across the Great Basin with an associated large number of fire starts. August 4 (Figure 12c) was somewhat similar to the previous day except the lightning and fire starts occurred over much larger portions of the West. On August 11 (Figure 12d) there was a large-scale lightning outbreak across Montana and northern Idaho with an associated large number of fire starts. Though strike polarity and amplitude may be important factors in terms of natural fire starts, these issues were not specifically examined for this study. However, the examples presented do show that both large and small numbers of strikes across a region can be associated with a large number of fire starts and subsequent development of large fire incidents. In the former case a high number of strikes over a large area simply increases the probability of a fire start somewhere. The latter case alludes to the efficiency of lightning given dry fuels and sufficient fuel availability. If anything was particularly unusual about the lightning activity during 2000, it was during August and the fact that every day had strike occurrence of varying magnitude over large spatial areas across the West.

The spatial extent of lightning occurrence during the season and its impact on geographic area suppression resource demands can readily be seen in Figure 13 showing the locations of natural fire start occurrence. These locations are based upon reports archived in the National Interagency Fire Management Integrated Database (NIFMID) and the Shared Applications Computer System (SACS), combining 5100-29 and DI-1202 historical data. While this includes much of the federal managed land in the West, it does not include most state reports. All four months (June through September) in the Figure shows widespread occurrence. In June (Figure 13a) most of the occurrence is in the Great Basin and Southwest states, though there are scattered starts north of approximately 42°N latitude. In July (Figure 13b) substantial occurrence can be seen in every western state. August (Figure 13c) looks similar in appearance to July, but with even more occurrence (note the activity especially in northern Idaho and western Montana). In September (Figure 13d) there is still wide spread occurrence, though much reduced in number from the previous months.

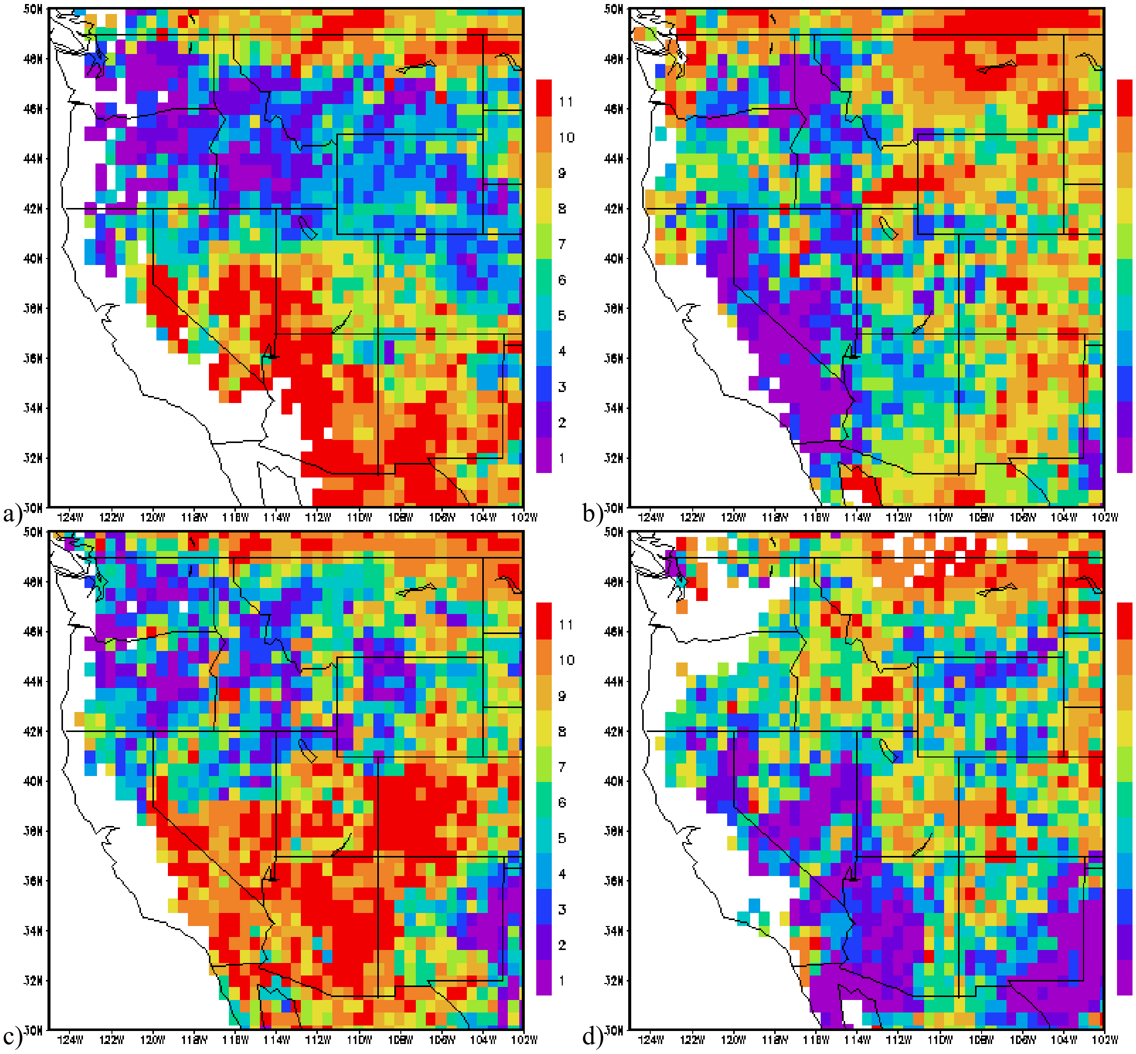


Figure 11. Lightning strike rank 1 (low) through 11 (high) in 0.5 degree grid cells for a) June, b) July, c) August and d) September 2000. Color codes range from cool colors (e.g., blue) for lower ranks to warm colors (e.g., red) for higher ranks. White areas indicate no ranking due too more than 3 years with zero strike counts within the grid cell. Data source: National Lightning Detection Network™, Global Atmospherics, Inc.

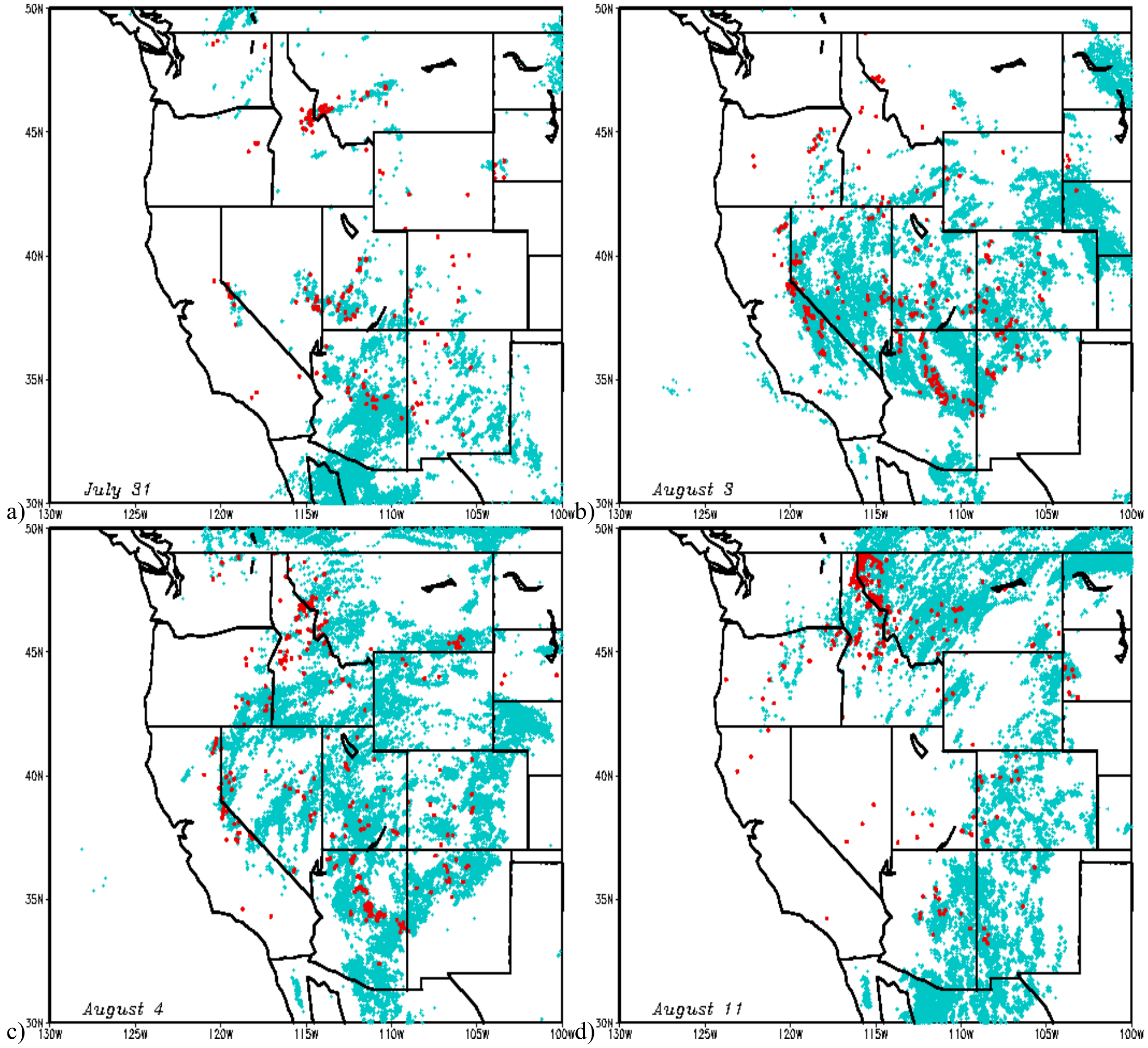


Figure 12. Natural fire start locations (red circle symbols) and lightning strikes (cyan plus symbols) for a) July 31, b) August 3, c) August 4 and d) August 11 2000. Fire start data source: BLM and USFS; lightning data source: National Lightning Detection Network™, Global Atmospherics, Inc.

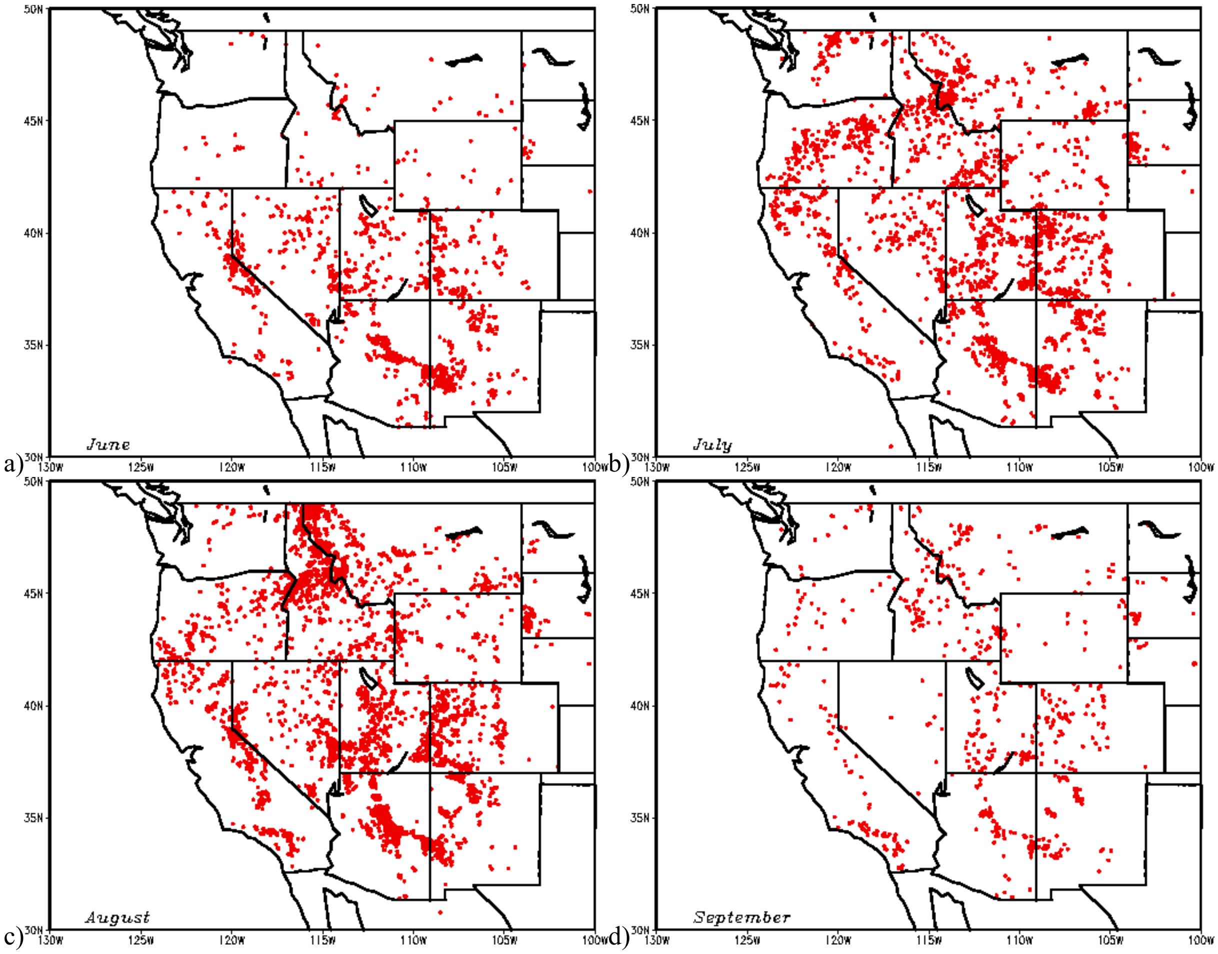


Figure 13. Natural fire start locations (red circle symbols) for a) June, b) July, c) August and d) September 2000. Fire start data source: BLM and USFS.

La Niña

In numerous fire season analyses (and other climate reports) over the past couple of years, La Niña has been prominently mentioned as a possible influence. La Niña refers to (in part) anomalously cool sea surface temperatures (SST) in the eastern equatorial Pacific Ocean. There can be associated global impacts on temperature and precipitation patterns during La Niña events, including in the U.S. Statistically, the southwestern and southeastern U.S. regions are associated with dry precipitation anomalies during La Niña events, and the Pacific Northwest with wet precipitation anomalies. However, there are different intensities of La Niña and thus different impacts. Using other atmospheric variables in addition to SST, the past three years have been dominated by a La Niña pattern (Figure 14). An important question is what impact did La Niña have, if any, on the 2000 fire season?

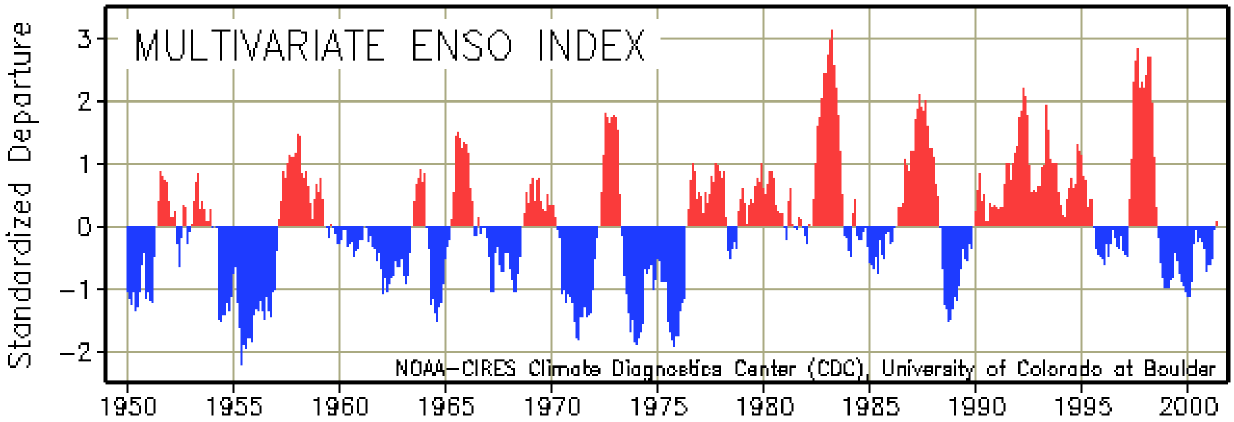


Figure 14. The multivariate ENSO index (Wolter and Timlin 1993) with red lines indicating El Niño and blue lines La Niña conditions. Events are considered strong if they exceed 1 standardized departure. Plot source: NOAA-CIRES Climate Diagnostics Center.

CDC has produced risk maps that indicate the climatological probability of wet or dry precipitation extremes in a climate division relative to chance given a La Niña event concurrent to the season in question. Figure 15a shows the La Niña risk pattern for December through February and the observed climate division precipitation anomalies from WRCC (shown as percent of normal) for the 1999-2000 same winter months. The risk map shows increased dry extremes over portions of the Southwest, with the strongest in New Mexico and Texas. Dry extremes are also shown over portions of the Southeast including virtually all of Florida. Wet extremes are shown in portions of the Northwest and northern Rockies. However, there is no indication of a La Niña precipitation impact over much of the West, including the large areas of California and the Great Basin. During the 1999-2000 winter season there appears to be some correspondence of observed anomalies in relation to the risk pattern. The most obvious areas include the southwestern states, Texas, and a large portion of the Southeast including Florida where dry conditions (negative anomalies) occurred. Much of the West shows above average conditions (positive anomalies), including wet risk correspondence in the northern Rockies region. The risk and observed anomalies in parts of the Pacific Northwest had opposite signs.

Figure 15b shows the similar type maps except for the April through June season. The largest risk of dry extremes is shown in the southwestern states and Great Basin regions. Parts of Texas and the South are also shown to have some dry risk. The observed dry anomalies for the season show some correspondence in the Southwest and Great Basin. A wet June related to the monsoon accounts for the above average anomalies in southern Arizona and New Mexico, and across Texas. The dry anomalies extended up over the northern Rockies and in Florida where the influence of La Niña is considered weak during this season.

Figure 15c shows the same maps except for July through September. Except for wet extremes in the Southeast, there is little large-scale spatial structure in the risk maps, with the possible exception of dry extremes in Utah, Colorado and areas over the central plains. The observed precipitation anomalies are substantially below average near the southeast U.S. coast and along the Ohio River valley. Dry conditions were observed over much of the U.S., especially Texas and the southern states. Qualitatively, there does not appear to be good correspondence between the risk and observed anomalies as one might expect over coherent spatial scales.

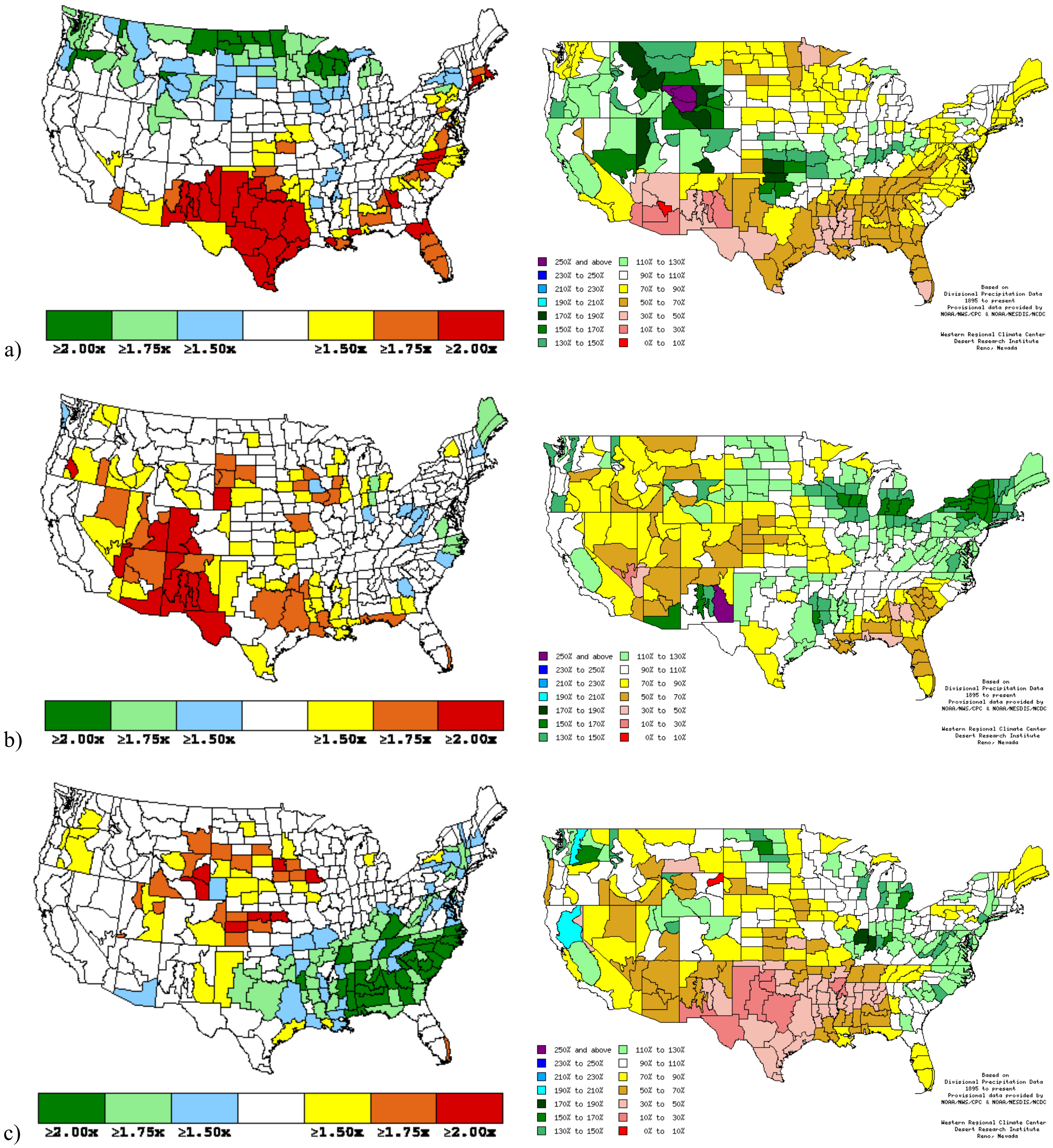


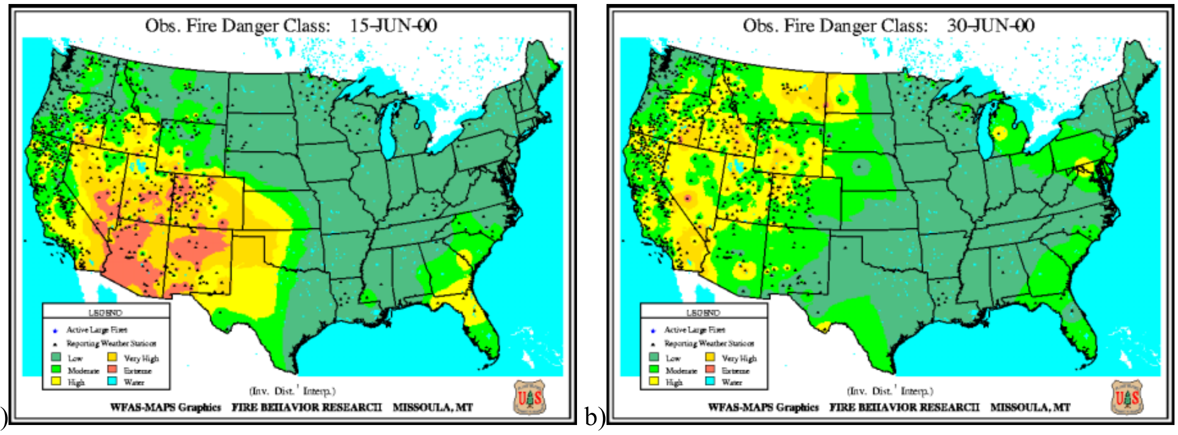
Figure 15. Seasonal risk of wet and dry extremes relative to climatological average risk given a concurrent La Niña event for a) December-February, b) April-June, and c) July-September. Corresponding maps of same season observed divisional precipitation percent of normal values are also shown. Warm colors (e.g., red and orange) and cool colors (e.g., blue and green) indicate dry extremes (anomalies) and wet extremes (anomalies), respectively. Risk map source: NOAA-CIRES Climate Diagnostics Center; precipitation percent of normal map source: Western Regional Climate Center.

Some individuals would likely interpret the information in Figure 15 as a La Niña influence on the 2000 fire season. In our opinion, this statistical evidence is not strong enough to warrant a solid claim of relationship. Further analysis is needed to gain confidence in any relationship, especially from dynamical atmosphere-ocean coupled climate models and empirical observations of tropical and mid-latitude interaction, and to say more conclusively what the extratropical mid-latitude impacts were in relation to the equatorial Pacific. A recent journal paper by Hoerling and Whitaker (2001) notes that there was a notable persistent large-scale mid-latitude tropospheric warming in both hemispheres during the period January 1998 – January 2000. The pattern was reproduced from atmospheric general circulation models forced with global SSTs. The authors found that the pattern was related to global SSTs, especially the Indo-Pacific region that had an unprecedented warming in 1998 and 1999, rather than the La Niña of the east Pacific Ocean. While the study focused only on temperature patterns, it is feasible that global precipitation anomalies were more related to this unusual hemispheric temperature pattern than to La Niña directly. Given the available information, it is not clear to us that La Niña played a significant role in the 2000 fire season anywhere in the U.S, though the best statistical evidence points to the southwestern through southeastern regions. Despite the question for 2000 in particular, numerous empirical and model studies have shown that La Niña and El Niño can and do impact parts of the U.S., which ultimately influences the fire season in those regions. When these well-known climate events do occur, this improves the skill of long-lead forecasts that can be utilized as part of the decision-making process. Thus, we encourage the monitoring and use of this information for wildfire and fire use planning. On the other hand, given the complex nature of ocean-atmosphere-land interactions, one should interpret the impacts possibly associated with well-known climate events such as La Niña with caution.

Southwest monsoon

Next to the occurrence of seasons, the North American monsoon is one of the most regular climate patterns in the U.S. Depending upon the location of interest, it is often referred to as the Mexican or Southwest monsoon. Though the onset time, strength and duration of the monsoon can each be highly variable, it occurs every summer in the southwestern U.S. and typically lasts through August and into early September. The average onset date for Tucson, Arizona is July 3 (NWS 2001). Beginning in Mexico, monsoonal wind and moisture flow can easily extend northward into northwestern Nevada, southern Idaho and southern Wyoming and bring both wet and dry thunderstorms. Lightning from dry thunderstorms is of course a concern over the West, but for much of the Southwest low-level moisture in the form of precipitation occurrence and increased relative humidity can decrease fire danger.

Figure 16 shows the observed adjective fire danger class for June 15 (Figure 16a) and June 30 (Figure 16b) 2000 for the U.S. This class is based on the primary fuel model cataloged for the local weather station, an NFDRS index (often the burning index) to reflect staffing levels, and a climatological classification. The adjective class is a normalized rating across different fuel models and station locations. In mid-June much of the Southwest is at very high to extreme levels. On June 17 the monsoon began officially (from a climatological definition) in Tucson and quickly moved across the region. This is reflected well on the fire danger map at the end of June for which much of Arizona and New Mexico reduced to moderate levels.



a) b)

Figure 16. Observed fire danger class for a) June 15 and b) June 30 2000. Map source: Wildland Fire Assessment System.

This was the earliest onset of the monsoon in the past half-century and also started out strong in terms of precipitation. Figure 17 shows CPC analyzed observed monthly precipitation percent of normal for the U.S. Much of the Southwest easily exceeded 150% of average during June (Figure 17a), of which virtually all occurred during the last two weeks of the month. In July (Figure 17b) the monsoon reduced in strength and the month turned out to be well below average over most of the Southwest. In August (Figure 17c) some parts of the West, especially Nevada and northern Utah, experienced above average precipitation, but generally the monsoon pattern remained dry for the remainder of the summer. This pattern helped reduce fire activity in Nevada, but 37 large fires occurred in Arizona and New Mexico during July through September, a period usually associated with reduced large fire activity as a result of increased monsoonal moisture.

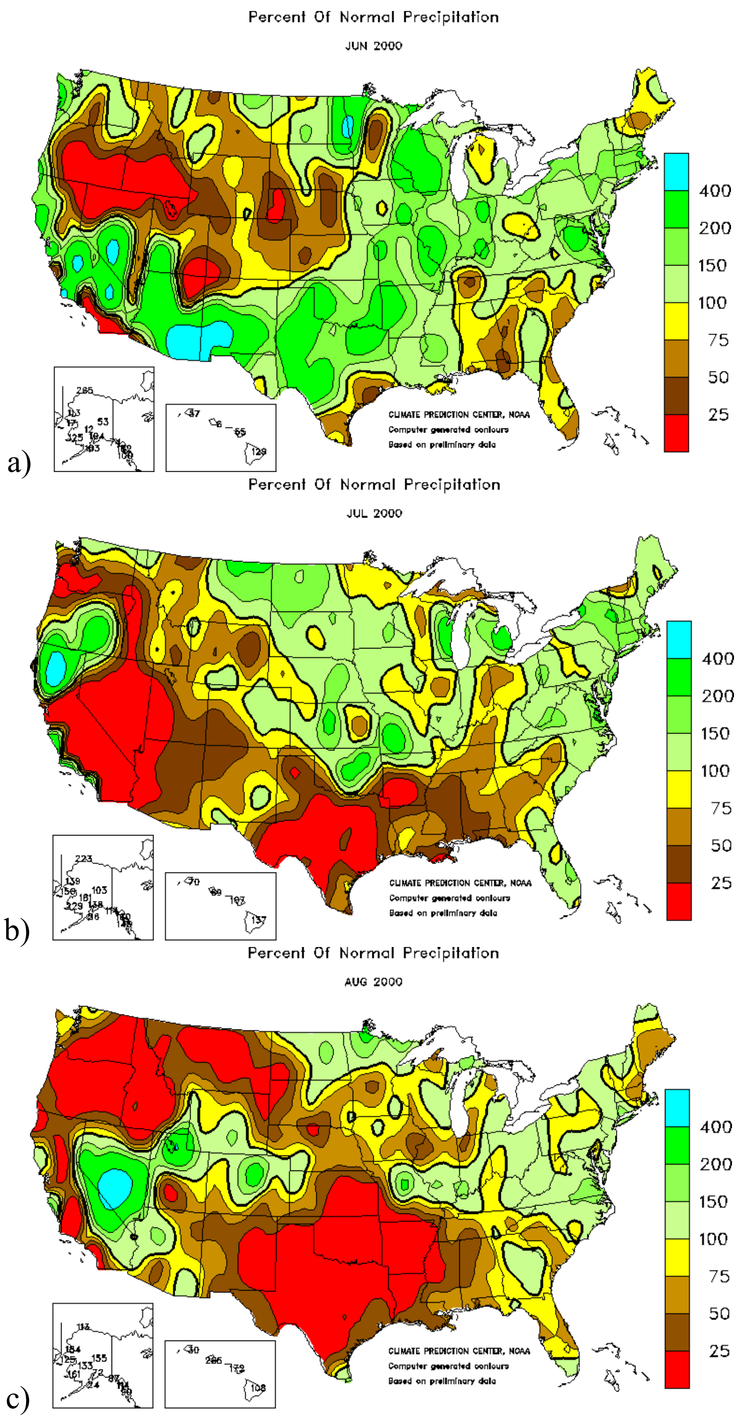


Figure 17. Observed monthly percent of normal precipitation based on NWS first-order and coop sites. Warm colors (e.g., red) indicate well below average and cool colors (e.g., green) indicate above average. Map source: NOAA Climate Prediction Center.

4. Conclusion

The 2000 fire season was unusual in terms of both its length and spatial extent. Nearly all of the fire climate factors that could impact the season did. Below average precipitation, above average temperature and below average relative humidity kept fire danger at high levels the entire season over much of the West. This was unusual in that the fire danger pattern did not geographically shift around as typically occurs during the season. Maximum relative humidity values were especially low throughout most of the season affecting nighttime moisture recovery. The 500 mb flow pattern was conducive to northward moisture flow from the eastern Pacific and monsoon region across the Great Basin to northward over Idaho and Montana and eastward over Colorado and Wyoming especially during August. This allowed for consistent wide spread lightning occurrence across the West, and a subsequent above average number of natural fire starts putting a substantial stress on geographic area suppression resources. In many areas lightning strike occurrence was low in terms of climatological rank, but was quite efficient at starting fires given large fuel loadings and dry conditions. By early July live fuel moisture across the Great Basin was generally below the long-term average, and moisture was likely below average across many parts of the West in conjunction with below average precipitation. The observed 1000-hour lag fuel moisture was consistently less than 11% across much of West from April through September. These values represent persistent dry fuel conditions. The Southwest monsoon started early and strong in mid-June, but weakened substantially during July (though returning moderately in August). As a result the Southwest fire season lasted longer than usual.

There is no strong evidence at present to link La Niña with the outcome of the fire season. The sign and strength of precipitation anomalies in the southwest is suggestive of a La Niña pattern from a purely statistical perspective especially during the previous winter. However, at least one dynamical modeling study shows eastern Pacific sea surface temperatures not to be a dominating factor in large-scale northern hemisphere tropospheric temperature anomalies during much of the recent La Niña episode. This leads us to skepticism of direct claims of La Niña impact across the western U.S., but further modeling studies to examine a possible relationship would be highly welcomed to resolve this question.

Evolution of the 2000 Season

From a climate perspective, the strength of the fire season in many parts of the West was being setup one to six years in advance. For example, the southwest Montana climate division had been experiencing below average precipitation for six years prior to the large incidents in this region. These “drought” conditions set the stage for 2000.

April: Precipitation was below average (< 40th percentile) in Arizona, New Mexico, most of the Great Basin, and parts of the northern Rockies. In many of the climate divisions less than 20th percentiles were common. Both maximum and minimum temperatures were above average (> +4°F and > +2°F, respectively) across most of the West. Both minimum and maximum relative humidity were below average (< -5% and < -10%, respectively) across most of the West. Time lag fuel moisture (1000-hour) was 11-15% over large parts of the West. These surface anomalies were related to dominating high pressure centered over the Great Basin.

May: Precipitation was below average (< 40th percentile) mainly in southern California, Arizona, New Mexico, Colorado and scattered portions of the northern states. In many of the climate divisions less than 20th percentiles were common. Both maximum and minimum temperatures were above average (> +4°F and > +2°F, respectively) across a large portion of the West especially the Great Basin and Southwest. Both minimum and maximum relative humidity were below average (< -5% and < -10%, respectively) across most of the West. Time lag fuel moisture (1000-hour) was consistently 6-10% or less over large parts of the Southwest.

June: Precipitation was below average (< 40th percentile) mainly in the northern Great Basin and Rockies. In many of the climate divisions less than 20th percentiles were common. An early and strong monsoon brought much above average (> 80th percentile) anomalies to Arizona and New Mexico. Both maximum and minimum temperatures were above average (> +4°F and > +2°F, respectively) across a large portion of the West. Both minimum and maximum relative humidity were below average across most of the West (< -5% and < -10%, respectively). Time lag fuel moisture (1000-hour) was consistently 6-10% or less over large parts of the Southwest.

July: Precipitation was well below average (< 30th percentile) across nearly the entire West with the exception of the Pacific Northwest. Both maximum and minimum temperatures were above average (> +2°F) across mainly the eastern half of the West. Both minimum and maximum relative humidity were below average (< -5% and < -10%, respectively) across most of the West. Time lag fuel moisture (1000-hour) was consistently 6-10% or less over a large portion of the West. The subtropical high centered over New Mexico aided in moisture flow from the eastern Pacific northward and subsequent daily thunderstorm development over many parts of the West. There were several days with large spatial scale lightning occurrence.

August: Precipitation was well below average (< 20th percentile) across the northern Rockies, but above average (> 60th percentile) across much of the Great Basin and Southwest. Both maximum and minimum temperatures were above average (> +2°F) across large portions of the West. Both minimum and maximum relative humidity were below average (< -5% and < -10%, respectively) across most of the West. It was especially dry across northern Idaho and western Montana. Time lag fuel moisture (1000-hour) was consistently 6-10% or less over a large portion of the West. A very well defined upper air pattern inducing moisture flow from the eastern Pacific and monsoon region northward up over Idaho and Montana allowed for subsequent daily thunderstorm development over many parts of the West on a daily basis.

September: Precipitation was well below average (< 20th percentile) across the Southwest, but above average (> 60th percentile) across parts of the northern Rockies. Both maximum and minimum temperatures were below average (< -2°F) across the northern Rockies, but the maximum was above average (> +2°F) in Arizona and New Mexico and the minimum near average for the same area. Both minimum and maximum relative humidity were below average (< -5% and < -10%, respectively) across much of the West, but was above average (> +5%) in the northern Rockies. Time lag fuel moisture (1000-hour) was consistently 6-10% or less over a large portion of the West.

Discussion

Hopefully the findings of this study can be applied in several ways. First, the climate characteristics of the season can be used as a "lesson-learned" and an improved understanding of the conditions that led to and occurred during an extremely active fire year. Second, it is of interest to develop climate forecasts of the variables used in this analysis. Understanding the role of climate in fire activity will allow for the better utilization of climate forecasts. Third, as more and more Geographic Area Coordination Centers (GACC's) prepare seasonal discussions of the upcoming fire season, the types of information presented in this report can be used as a framework for regional assessments.

This analysis raises numerous questions from a scientific perspective. For example, how well is La Niña linked to a fire season, or what is the specific relationship between live fuel moisture and precipitation deficits over time, or what is the predictability of climate variables related to fire danger, or what is the climatology of wide spread lightning occurrence? Hopefully, these types of studies can be undertaken in the near future to improve the understanding of climate and fire links and improve forecasts for wildfire suppression, prescribed fire and fire use strategic planning.

This analysis also points out the importance of consistent data monitoring networks for use in fire danger and fire severity. First, it would be highly desirable for the land management agencies to establish and coordinate a consistent national live fuel moisture monitoring network. A second goal the wildfire agencies should consider is the implementation of year-round RAWS sites. In addition to the monitoring and collection of more data, every effort should be made to maintain the national RAWS network in the context of climate information as well as fire weather uses. A third desirable national objective would be improving the coordination and management of a national database for fire occurrence. This primarily includes the accessibility of federal and state fire occurrence data in a timely manner, and the quality control of these data for accuracy and reliability. Finally, this study has demonstrated a value and need to develop and implement operational fire climate monitoring on a national scale. Basically, this is a tool to make available on an operational basis many of the products shown in this report for timely monitoring of climate variables in conjunction with other relevant fire indices for use in decision-making and strategic planning.

Acknowledgements

Paul Schlobohm served as the BLM Administrative Representative for the project, and provided valuable overall guidance and review. Ron Holle and Dr. Ken Cummins at Global Atmospherics, Inc. provided guidance on the lightning analysis. Dr. Cummins also developed and provided the lightning correction grid. Dr. Kelly Redmond from WRCC provided thoughtful discussion on analyzing various climate variables. This project was funded under the BLM-DRI Cooperative Agreement No. 1422RAA000002, Task Order 1422RAH012402.

Web sources

Several web sources for data and graphics are available for climate monitoring throughout the fire season including:

Climate, Ecosystem and Fire Applications: http://www.dri.edu/Programs/CEFA
Western Regional Climate Center: http://www.wrcc.dri.edu
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