Western Great Basin Wildfire Spread Pattern Recognition

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1. Introduction

The sparsely populated Western Great Basin (WGB) is an oddity when it comes to wildfires compared to the majority of the nation because the vast majority of fire starts and acres burned are caused by lightning, and not by humans. The National Interagency Fire Center (NIFC) database indicates an average of 339,109 lighting-caused acres and 35,750 human-caused acres have burned each year since 2001 (http://www.nifc.gov/fireInfo/fireInfo_statistics.html). Although large lightning outbreaks start numerous fires, they do not always lead to large uncontrolled wildfires that burn thousands of acres. Research previously focused on weather pattern recognition in predicting dry lightning outbreaks (Wallmann 2004; Milne 2006); however, the weather pattern that follows the dry lightning outbreak is just as important as the catalyst when it comes to allocating resources and wildfire suppression. In fact, the fire community understood this critical fire weather pattern (lightning followed by high winds and low relative humidity) as far back as the 1960s when Schroeder et al. (1964) conducted research on synoptic weather patterns across the Intermountain West. Since then, further research is virtually non-existent on these types of synoptic patterns conducive for rapidly spreading wildfires across the WGB.

The National Weather Service (NWS) in Elko (LKN) issues Red Flag Warnings (RFW) across the WGB for two types of fire weather criteria. The first criterion is for wind gusts greater than or equal to 13.4 m s^{-1} (26 kt) and relative humidity (RH) less than 15% for three or more hours (may be non-continuous) across a fire weather zone within the red flag warning's valid time. A second criterion is for dry lightning (thunderstorms that drop 0.25 cm [0.10 in] or less of rainfall) that covers 15% or more of a given fire weather zone.

This paper explores the meteorological patterns (lightning followed by high winds and low RH) further that precluded historically large fire exceeding 100,000 acres burned, grouping them to common synoptic patterns.

2. Data and methods

For this study, the Bureau of Land Management (BLM) Fire Management Specialist at the Nevada State Office in Reno, Nevada compiled the fire data. The fire database is a compilation of all fires within the Western Great Basin Coordination Center's (WGBCC)[1] geographic area from 1992 – 2014 (Fig. 1). A significant fire spread outbreak for this study is defined as having greater than 100,000 acres burned from a lightning outbreak within the WGBCC area of responsibility. Based on the aforementioned criteria, we identified 15 large fire spread events over the last 21 years (Table 1). It's also important to note that human-caused fires were not included in this study.

The WGBCC Predictive Services Meteorologist in Reno, Nevada provided the Energy Release Component (ERC) data. The ERC is a calculated output of the National Fire Danger Rating System (NFDRS) that the fire community uses to track the seasonal trends of fuels within their area of interest (Bradshaw et al. 1984). Compared to other fuel dryness indices, the ERC responds slower to change and accurately characterizes the region's long term dryness. For this study, the WGBCC Predictive Services meteorologist created the ERG graphs using the FireFamily Plus fire modeling system software (Bradshaw and McCormick, 2000). Data was provided for a two month period centered on each fire event using the 7G fuel model.

We used the National Oceanic and Atmospheric Administration/Earth System Research Laboratory (NOAA/ESRL) Physical Sciences Division, Boulder Colorado National Centers for Environmental Prediction - National Center for Atmospheric Research (NCEP-NCAR) reanalysis data webpage (Kalnay et al. 1996) to create the composite reanalysis graphics. The 500-hPa geopotential height graphics for each of the 15 events were created by averaging a five day period after the fire start date using the 6-hourly NCEP-NCAR Reanalysis site with 0000 UTC being the analysis time. For this research, we used five days to fully encompass days where winds continued to remain high and RH low. The creation of the 500-hPa composite graphics for the four different synoptic fire patterns were calculated by averaging the five-day period after the event start date, but for all the events categorized in that pattern. The higher resolution composite graphics (850/700-hPa vector wind, 2-m RH, and 2-m air temperature) were created using the daily average NCEP North American Regional Reanalysis (NARR) dataset (Mesinger et al. 2006). We calculated the NARR composite graphics in the same manner as the aforementioned NCEP-NCAR composite graphics, with the exception of the 24-hour daily analysis of the 850/700-hPa vector wind and 2-m air temperature fields.

3. Analysis and Discussion

The variety of 500-hPa geopotential height fields for the 15 separate fire events was complex with different synoptic patterns following the dry lightning outbreaks. Figure 2 shows the 500-hPa synoptic patterns and the categorized synoptic grouping for each fire outbreak case in the study. To group the fire events into specific synoptic patterns, we looked for similar 500-hPa geopotential height ridge and trough locations, in addition to anomaly strengths across the western CONUS. Overall, we categorized four separate pattern groupings and names based on similar pattern findings from Schroeder et al. (1964). The four patterns categorized were; the Pacific High Pattern, Southwest Flow Pattern, Heat Ridge Pattern, and Coastal Trough Pattern. All of these patterns, with the exception of the Heat Ridge Pattern, Shroeder et al. (1964) discussed as central Intermountain West critical fire weather patterns; however, they described the Coastal Trough Pattern as a sub-pattern of the Southwest Flow Pattern instead of a separate one. We discover these two patterns were appreciably different enough, especially in their 500-hPa composite height anomalies, to classify them as two distinct patterns. In fact, we found that the Southwest Flow pattern had the highest frequency of occurrence, followed by the Heat Ridge, Coastal Trough, and Pacific High (Table 2).

a. Pacific High Pattern

The Pacific High Pattern was considered an outlier in this study with only one occurrence; however, it was the one where the only large fire spread event occurred across the southern part of the WGBCC geographic area. All other events occurred further north across central and northern Nevada due to the lack of continuous vegetation conducive for large fire spread in the southern areas (i.e., Mojave Desert). Prior to this event, the previous winter and spring were abnormally wet for southern Nevada, resulting with a Palmer Drought Index of +7, which is much higher than normal for this region (not shown). This did lead to abnormally high grass growth that allowed for the significant fire spread in the south. Figure 3 shows the Pacific High Pattern is essentially zonal across the region at 500-hPa with a broad elongated ridge from the Pacific Ocean across the Desert Southwest. This pattern at the surface allowed for above average temperature anomalies across western and southern Nevada, in addition to very dry mean RH values at less than 10% across southern Nevada. Vector wind anomalies at 850-hPa (representable of surface) and 700-hPa (representable of mountains) are strongest across eastern Nevada out of the north. The largest fires occurred across the southeastern corner of the state where the 700-hPa and 850-hPa wind anomalies were on the order of 3 m s^{-1} and 1 m s^{-1} at respectfully.

b. Heat Ridge Pattern

The Heat Ridge Pattern was the second most prevalent fire spread pattern with four events recorded since 1992; the total acreage burnt ranked 3rd out of the patterns (Table 3). The pattern's 500-hPa composite mean height field (Fig. 4) consists of a 5910 m ridge centered over the Great Basin with a weak trough off the central California coast (36N, 135W). 500-hPa height composite anomalies for this pattern depict above average heights across the entire western CONUS, with a maximum anomaly of +90 m over Seattle, Washington. Over Nevada, 500-hPa height anomalies averaged +50 m. Not surprisingly, 2-m air temperature anomalies were above average across the entire state with the highest anomalies located over northwestern Nevada at +5^{O}C. Statewide, anomalies ranged from +2 to +4^{O}C, which were the largest of the four synoptic patterns. In addition, vast majority of the area remained below 15% RH, with the driest air across western and southern Nevada. Vector wind anomalies at 850-hPa and 700-hPa were strongest across the eastern half of the state along the Utah state line. These northeast anomalous winds essentially cut off the moist subtropical moisture flow that typically moves into the region from the southeast.

c. Coastal Trough Pattern

The Coastal Trough Pattern was the third most prevalent fire spread pattern with 3 events recorded since 1992. It burned the second most acreage out of the patterns. In fact, this pattern burned 500,000 acres more than the Heat Ridge Pattern, mostly due to the August 1999 fire outbreak where over 700,000 acres (largest in the study) burned. The 500-hPa composite mean for this pattern (Fig. 5) consisted of a 5760 m trough axis along the West Coast, with the 4-Corners's High shifted well to the east over the High Plains. 500-hPa composite height anomalies show a -60 m height over San Francisco, with an average -30 m anomaly over Nevada. This pattern is the only one that has below average temperature anomalies across the entire state, with a 2-m air temperature mean anomaly of -2^{O}C. Mean RH values of 15% or less resided across southern and central Nevada. Low level southerly winds pushed dry Mojave Desert air northward into the region, thus keeping the subtropical moisture further east. Vector wind anomalies were out of the south across the entire state, except out of the west in western Nevada. The highest wind speed anomalies were located across central Nevada with magnitudes of 3.3 m s^{-1} and 4.5 m s^{-1} at 850-hPa and 700-hPa, respectfully.

d. Southwest Flow Pattern

The Southwest Flow Pattern was the most prevalent fire spread pattern with seven events recorded since 1992 and burning the most land area at 2,233,946 acres. This pattern occurs most frequently with an event, on average, every three years after 15 July. The Southwest Flow Pattern 500-hPa composite mean height field (Fig. 6) consists of broad cyclonic flow off the Pacific Coast with an elongated 5910 m 4-Corner's High that extends into southern Nevada. Composite anomaly 500-hPa height fields show a broad area of +30 m height anomalies across the entire state. The largest anomaly signal with this pattern is a -110 m trough centered off the Pacific Coast (46N, 140W). 2-m air temperature anomalies were above average for the entire state with a mean anomaly of +2^{O}C. RH values were the driest across western Nevada (15% or less), while across eastern NV, values were slightly higher at 15-20%. Fitting to the pattern's name, vector wind composite anomalies at 850-hPa and 700-hPa show a general south to southwest wind. The western part of the state (especially the downsloping off the Sierra Nevada Mountains), depicted the largest positive anomalies, while central and eastern Nevada displayed near average vector wind speeds with no strong anomalies.

e. Fuels

Large fire spread events consist of three elements in the Great Basin: the lightning catalyst, favorable fire weather conditions, and most importantly, receptive fuels. For this study, we used ERCs for the measurement of overall fuel dryness level. Fire behavior analysts used ERCs as a historical predictor of fire activity based on specific, predefined values. For each fire outbreak day in this study, we obtained the historical ERC charts for each Predictive Service Area (PSA) with a fire. PSAs are defined as zones used by the WGBCC to group similar geographic areas and fuels together. Most fire outbreak cases in this study involved multiple PSAs. For this reason, we produced 32 ERC charts for the 15 fire outbreaks based on the period of record from 1990-2013. Figure 7 shows the WGBCC PSA-6 (central Nevada) ERC graph from the August 27, 1996 fire outbreak. ERC values ranged from a low of 80 to a high of 105 for the fire events, with an average of 97 for all fire outbreak days. It is important to note that ERC averages differ based upon the season and PSA. When looking at fire start dates, 25 out of 32 (78%) PSAs had above average ERC values, whereas 4 (13%) had average PSAs, and only 3 (9%) fell below average.

To evaluate the range of fuel dryness for different fire spread synoptic patterns, we calculated the ERC statistics for each pattern. Unfortunately, due to the limited case sample of the Pacific High pattern, findings were inconclusive. ERC values however were average for the one case. The Coastal Trough pattern displayed the lowest average ERC value at 95, with only 57% of the PSAs having above average ERC values for fire start dates. The Southwest Flow pattern noted an average ERC of 97, with 79% of the PSAs having above average ERC values for fire start dates. Not surprisingly, the Heat Ridge pattern displayed the highest average ERC at 98, with 100% of the PSAs having above average ERC values.

4. Conclusions

This paper identifies wildfire spread patterns after dry lightning outbreaks over the WGB. Some of the key findings from this research are:

- There was a greater variety of wildfire spread synoptic patterns than expected.
- The Southwest Flow pattern was the most prevalent fire spread pattern with seven major events over the past 21 years, responsible for burning 2,233,946 acres.
- The Coastal Trough pattern, although not as a prevalent of a pattern, contained two of the top three acreage burned fire outbreaks in this study.

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[1] In 2015, the WGBCC combined with the Eastern Great Basin Coordination Center (EGBCC) to form the Great Basin Coordination Center (GBCC). For use in this manuscript, the old name of WGBCC will be used.

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TABLES AND FIGURES

Table 1. Table lists the 15 lightning fire start outbreaks that ended up burning at least 100,000 acres within the WGBCC.

Fire Start Dates	Number of Fire Starts	Total Acreage Burned
8/26-27/1996	**53**	**344,493**
8/4-6/1999	**68**	**703,039**
7/17/2000	**33**	**129,045**
8/12/2001	**81**	**274,950**
6/22/2005	**30**	**492,322**
6/28/2005	**12**	**196,454**
7/15/2005	**20**	**157,348**
6/25/2006	**19**	**119,578**
7/25/2006	**30**	**291,005**
8/14-16/2006	**17**	**192,800**
9/3-4/2006	**27**	**292,980**
7/6-7/2007	**26**	**169,561**
7/16-18/2007	**83**	**549,179**
9/30/2011	**23**	**308,894**
8/4-5/2012	**83**	**336,380**

Table 2. Table lists the defined fire spread patterns of the WGB and the number of fire events per identified pattern.

Fire Spread Pattern	Number of Events	Total Acreage Burned
Pacific High	**1**	**196,454**
Heat Ridge	**4**	**739,467**
Coastal Trough	**3**	**1,388,161**
Southwest Flow	**7**	**2,233,946**

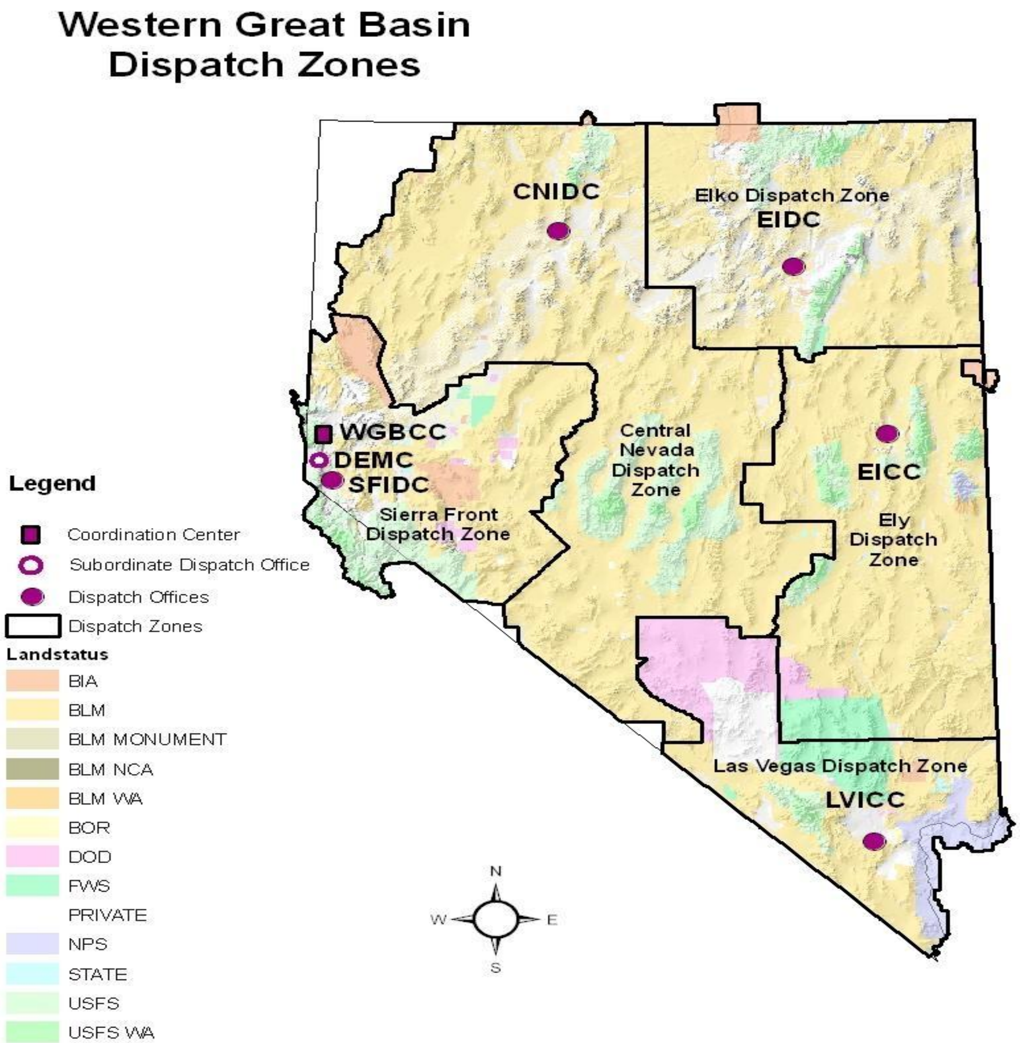

Figure 1. WGBCC geographic area of responsibility and associated dispatch zone boundaries. Fires considered for this study all occurred within this geographic area of responsibility.

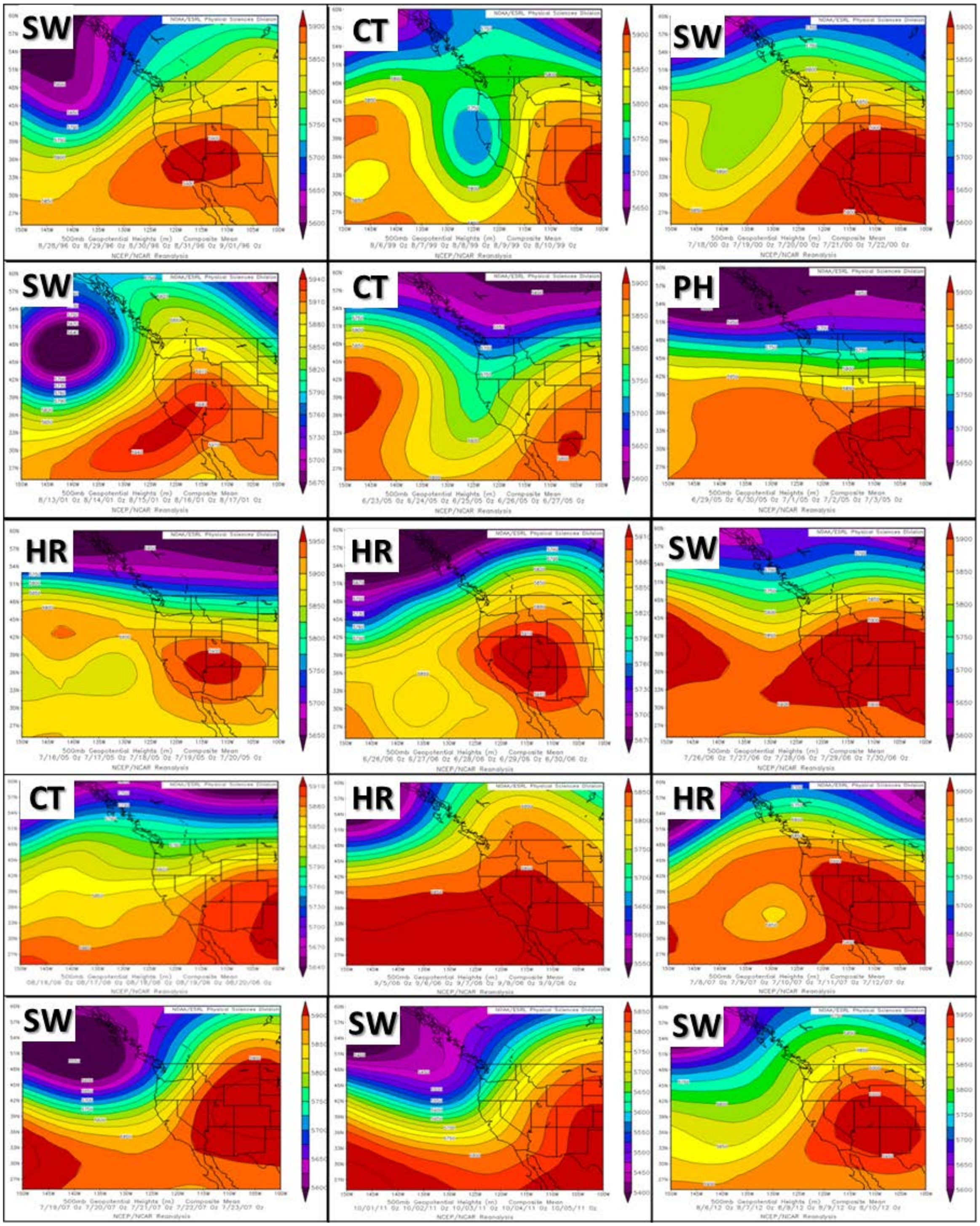

Figure 2. NARR 500-hPa geopotential height composite analysis of the 15 individual fire outbreak events across the WGB from 1996-2012, listed in chronological order from oldest in the upper left to newest in lower right. Categorized synoptic pattern for each fire event is listed in the upper left corner of each image. SW = Southwest Flow Pattern, CT = Coastal Trough Pattern, HR = Heat Ridge Pattern, and PH = Pacific High Pattern.

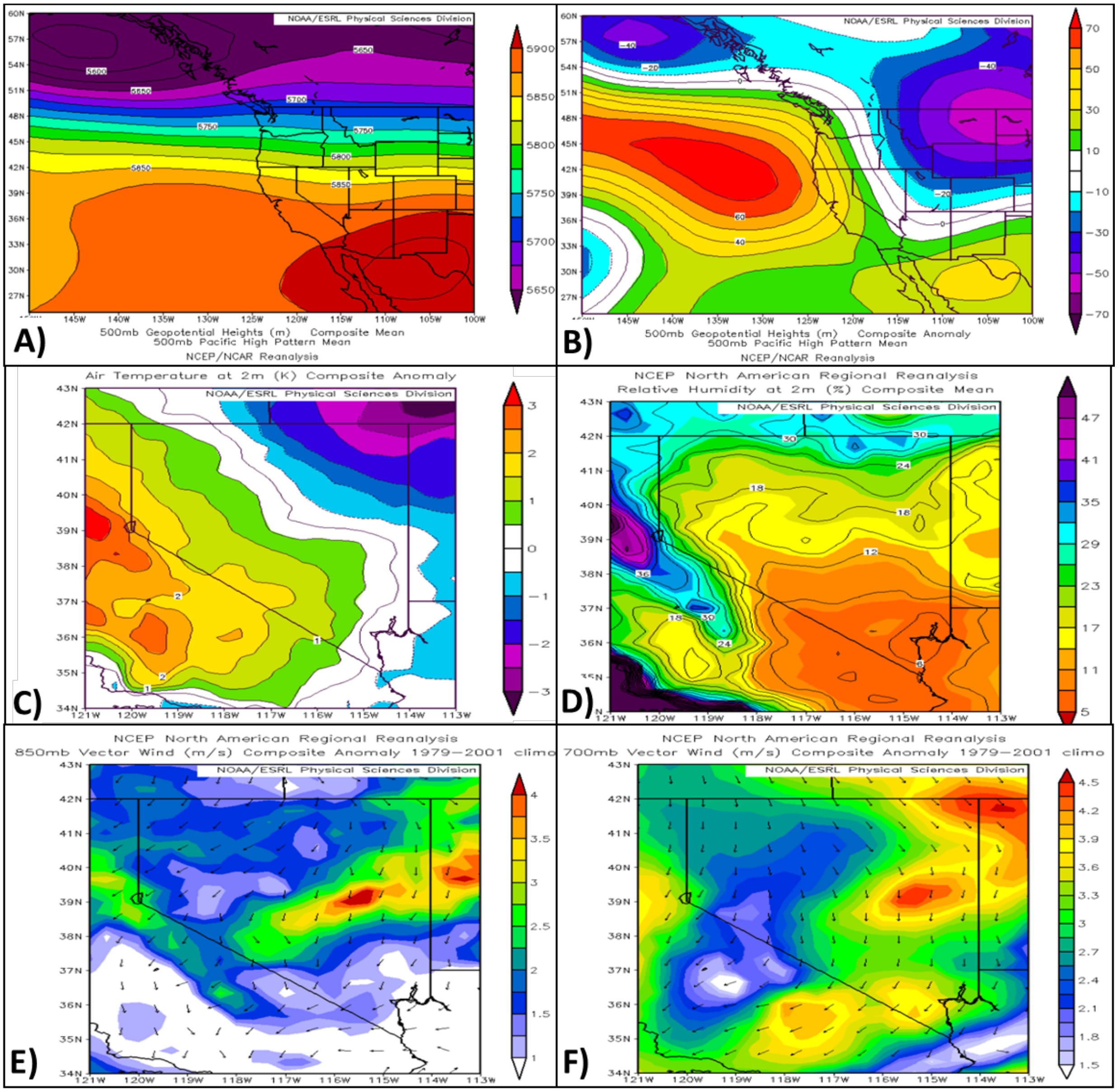

Figure 3. NCEP-NCAR and NARR reanalysis graphics for the fire spread Pacific High Pattern. A) NCEP-NCAR 500-hPa height (m; black contours) composite reanalysis. B) NCEP-NCAR 500-hPa height (m; black contours) anomaly composite reanalysis. C) NARR 2-m air temperature (K; black contours) anomaly composite reanalysis. D) NARR 2-m RH (%, black contours) composite reanalysis. E) NARR 850-hPa vector wind (m s^{-1}, color contour moving scale) anomaly composite reanalysis. F) NARR 700-hPa vector wind (m s^{-1}, color contour moving scale) anomaly composite reanalysis.

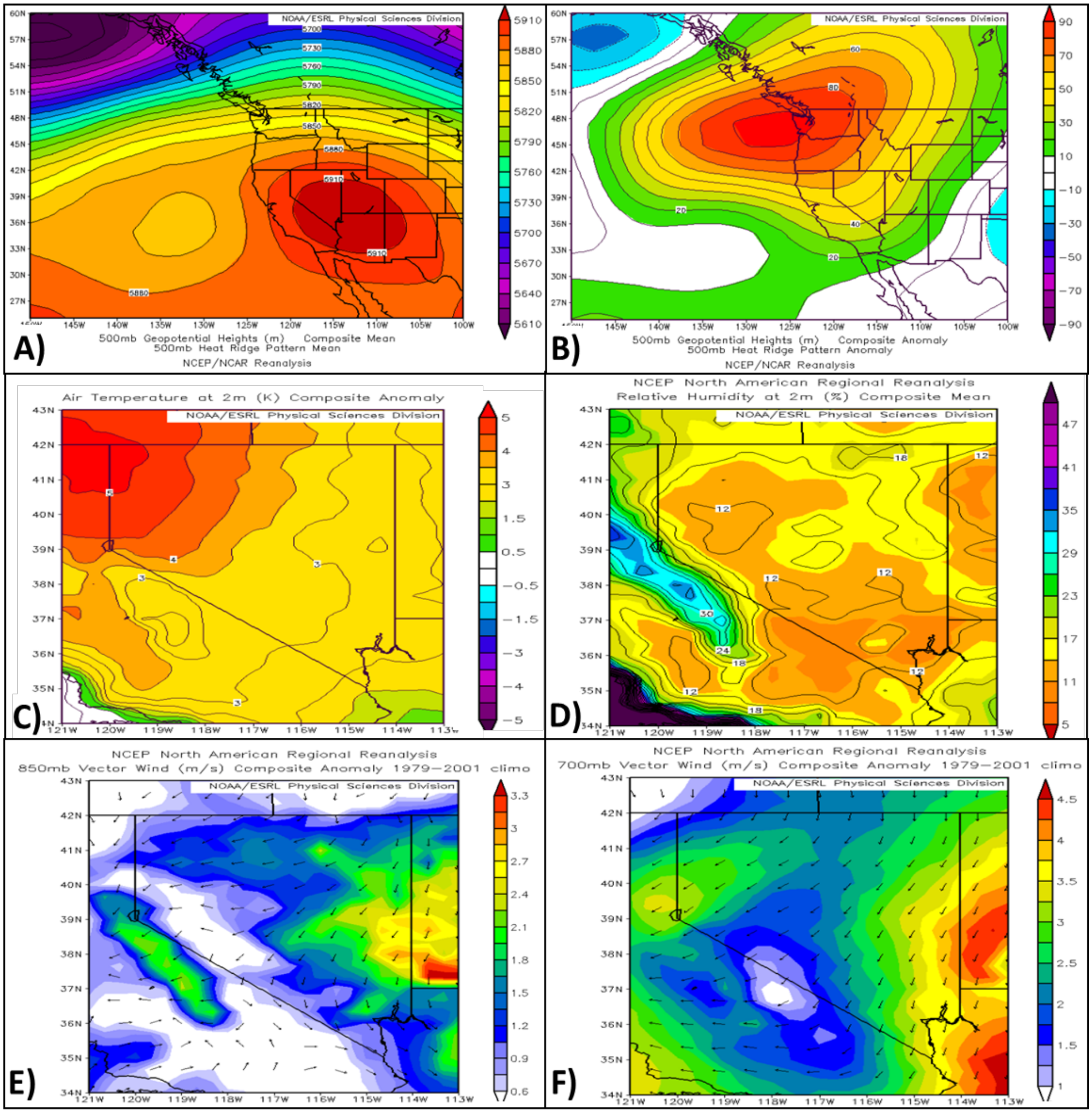

Figure 4. Same as Figure 3 except for the Heat Ridge Pattern.

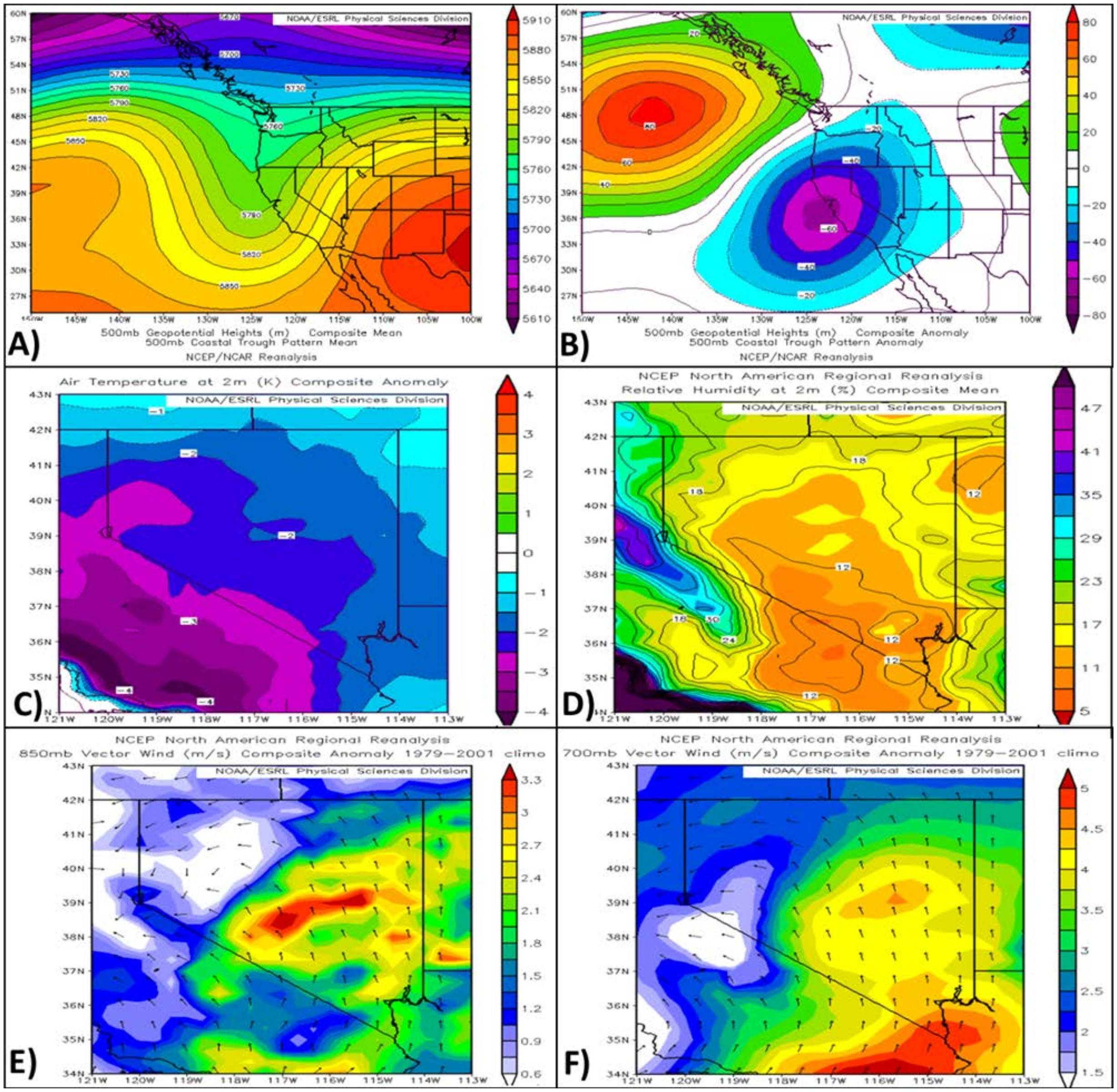

Figure 5. Same as Figure 3 except for the Coastal Trough Pattern.

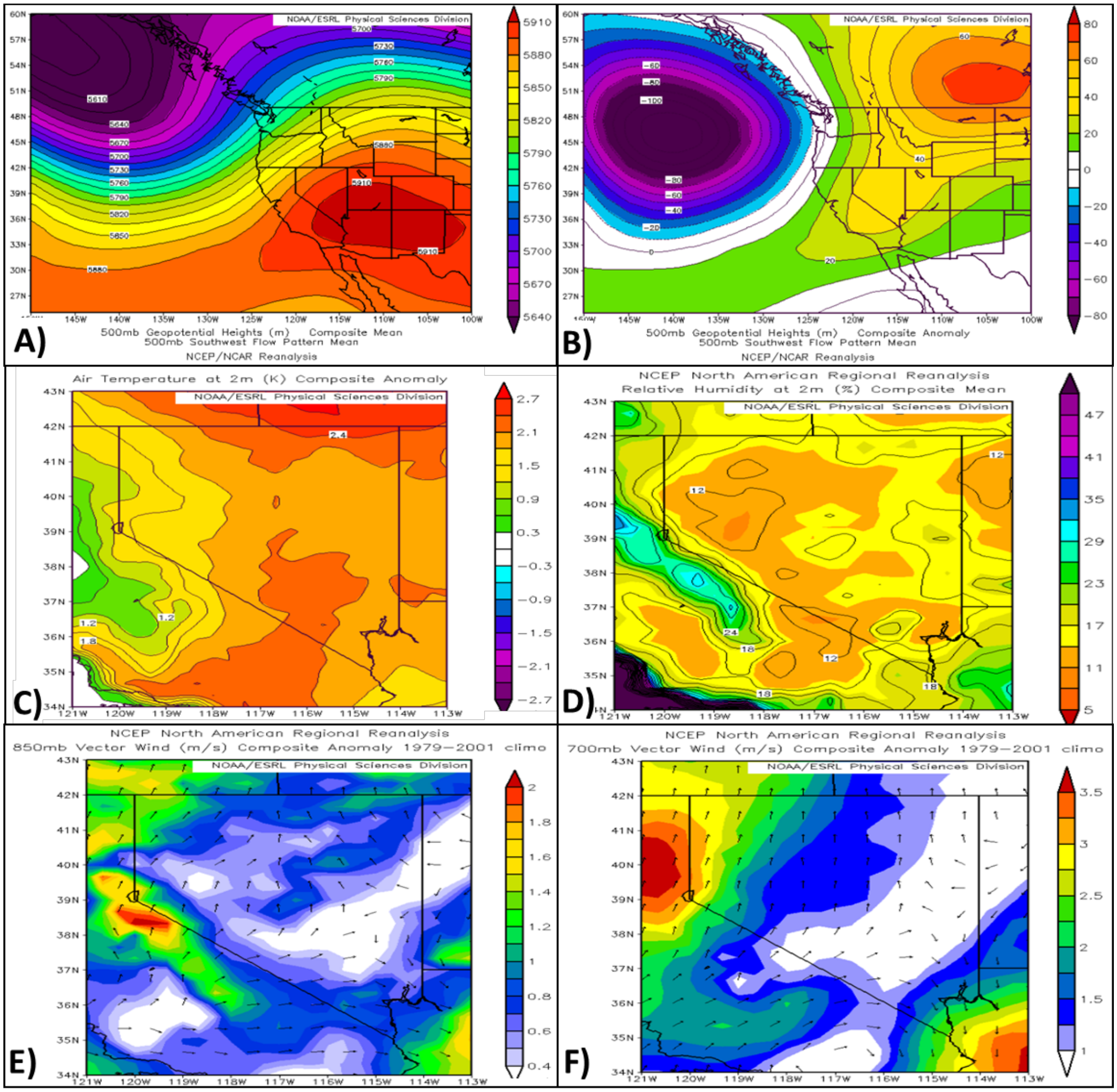

Figure 6. Same as Figure 3 except for the Southwest Flow Pattern.

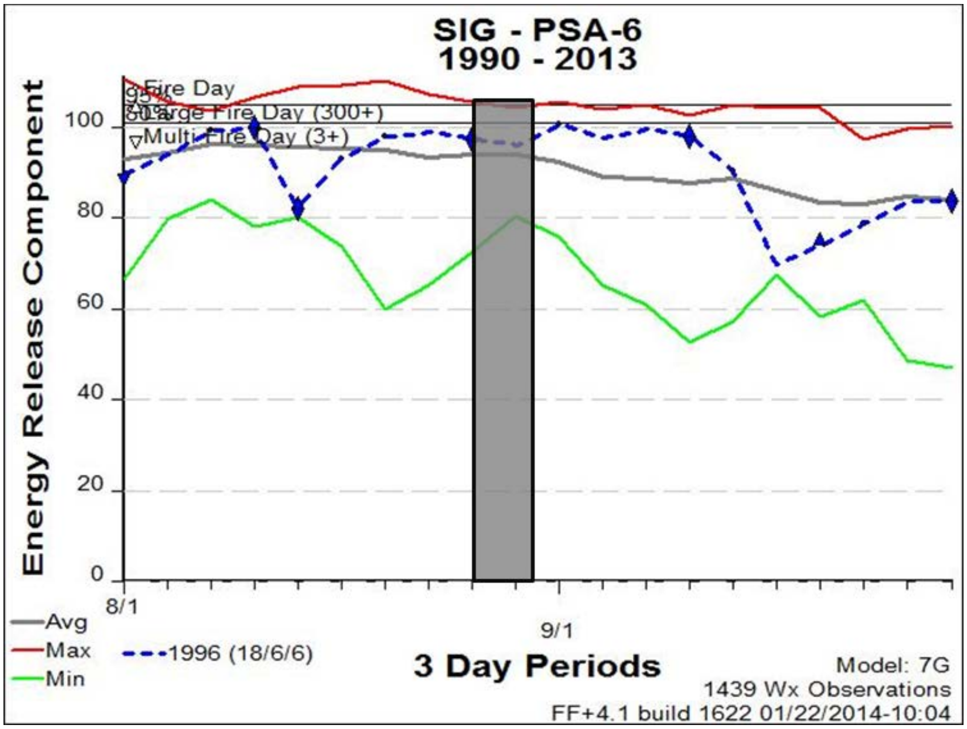

Figure 7. FireFamily Plus fire modeling system ERC graphic using the 7G Fuel Model for WGBCC PSA-6. Gray box represents the 5-day burn period for the 26-27 August 1996 fire outbreak. Average line (gray), maximum line (red), and minimum line (green) for the ERC values are based of the period of record from 1990-1996. The blue line represents the ERC fuel dryness value for 1996, with the up arrows representing large fire days and down arrows representing multi-fire start days.