Red Flag Climatology for WFO Midland's Fire Weather Forecast Area

Greg Murdoch, Ryan Barnes, and Jack Ciccone

NOAA/National Weather Service Midland, Texas

ABSTRACT

Historic fire weather data has strategic applications for land managers with respect to planning prescribe burns and to fire weather forecasters. This data provides a base of knowledge that aids in the development of working conceptual models that serve as forecast and training tools to maintain situational awareness. Land managers in the area that the Weather Forecast Office in Midland, TX is responsible for target approximately 18,210 hectares (45,000 acres) annually for prescribed burning. Understanding Red Flag conditions and weather patterns that favor these conditions is critical. In 2008 over 202,342 hectares (500,000 acres) burned, and in 2011 over 364,217 hectares (900,000 acres) burned in this same study area due to wildfires that occurred in or near Red Flag conditions. This emphasizes the need for a thorough understanding of the occurrence of Red Flag conditions. This paper details historic Red Flag fire weather observations across southeast New Mexico and parts of west Texas by analyzing the data in a temporal and spatial context. Sixty-six percent of all Red Flag conditions occur in March-May with most Red Flag conditions occurring in April (thirty two percent). The most common wind direction was from the southwest and the majority of occurrences are during the maximum heat of the afternoon around 2000 UTC (1500 LT). A by-product of analyzing this data is a synoptic pattern climatology and flow chart that provides an additional tool for recognizing weather patterns favorable for Red Flag conditions. The data is also compared to the ENSO showing a general correlation to the Red Flag conditions and general fire occurrence.

1. Introduction

Red flag warnings are issued by the National Weather Service (NWS) to reflect weather conditions that are favorable for extreme fire behavior that may result in control problems. Land management agencies have long recognized the relationship between weather and fires. They use weather as a tool to managing prescribe burns and in fighting wildland fire. From a strategic perspective, fire weather information is vital for land managers to effectively allocate resources to manage fire. Certainly fire weather forecasting plays an important role in tactical decisions; this paper will focus on historic weather data for strategic application.

Fire weather forecasting in support of fire and land management is a service that the NWS provides in the Southern Region, including Texas since 1997. Operational Meteorological research and studies with respect to fire weather has been limited across Texas through 2005. The 2005/2006 Fire Season in Texas was devastating to many of the state's urban and rural areas. Meteorologically speaking, the record fire season resulted in a significant increase in case studies including: Significant Errors in Numerical Weather Prediction Prior to the New Year's Day 2006 Southern Plains Wildfire Outbreak, Lindley et al. 2006, Climate Variability and the Texas Fire Weather Season of 2005-2006: A Historic Perspective of a Statewide Disaster, Speybroeck et al., 2007, and A Meteorological Composite of the 2005/06 Wildfire Outbreaks in The Southern Plains, Lindley et al. 2007. It is from the momentum of the 2005 and 2006 fire season that the realization of the need for a Red Flag Climatology grew.

The purpose of this climatology is threefold; first, to provide wildland fire managers a strategic perspective on the seasonality of red flag conditions, second, to allow users to better understand the frequency of red flag weather conditions thereby aiding in the development of prescribe (Rx) burn plans and third, to serve as a tool for forecasters to help identify red flag conditions temporally, spatially, and synoptically, ultimately leading to better fire weather forecast, warnings, and watches. On a temporal scale the red flag conditions are only a brief portion of the whole day. More over when you factor in the variable frequency of weather systems or weather patterns that result in red flag conditions the difficulty of identifying windows for red flag conditions becomes apparent. Nonetheless, this climatology will serve to help identify temporal red flag patterns annually, monthly, and hourly.

2. **Red Flag Definition**

The Red Flag and Fire Weather Watch program at the Weather Forecast Office (WFO) in Midland is focused around guidance set forth in NWS Instruction 10-401 and then refined on a regional scale based on an agreement between the NWS offices within Region 3 and the

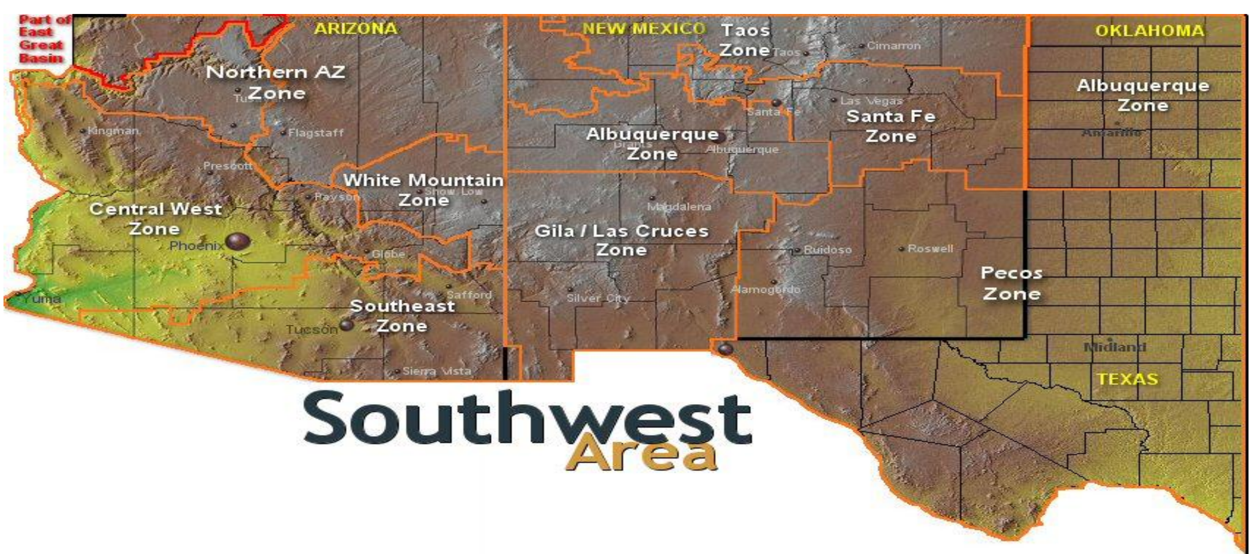


Fig 1. Shows the area known as Region 3 of the Southwest Geographic Area Coordination Center located in Albuquerque, NM.

Region 3 Geographic Area Coordination Center (Figure 1**)** and is documented in the Annual Operating Plan. As of 2011 the official Red Flag Warning criteria was; 6 meter (20 ft) sustained winds of 9 m/s (20 mph) or greater, minimum relative humidity of 15 percent or less, or wind gusts to 18 m/s (35 mph) or greater, and National Fire Danger Rating System (NFDRS) of high or higher for 3 hours within the warning period.

3. Climatological Audience

3.1 How it Began

Historically, operational climatology in the National Weather Service's Southern Region has been focused on severe, tropical, and winter weather. As the modernized NWS took root in the late 90s, the Fire Weather Forecast Programs in SR were established, and the process of developing conceptual models and familiarity with the user's needs began. In fact, most fire weather research literature was, and to some extent is still, comprised of data from the early forecast pioneers of the 1950s and 1960s, Atmospheric Conditions Related to Blowup Fires (Byram 1954) and Critical Fire Weather Patterns in the Conterminous United States (Schroeder 1969). Forecasters will be able to use this climatology as a familiarization tool for west Texas and southeast New Mexico.

Land managers have an understanding of fire weather through required training, such as S-290. Much of their knowledge about weather in their specific area during the fire season and the prescribed fire season are based on personal observation or what has been passed on from their predecessors. This climatology will provide the users with another source of information that is based on specific data that can be applied to their expertise about fire frequency.

Strategic planning decisions for developing a prescribed burn plan will include weather, and many times these decisions are based on a land manager's local weather knowledge. The ability to use the Red Flag climatology will facilitate this process, since favorable prescribed fire conditions will generally be exclusive of red flag conditions.

3.2 Summary of Rx Burn Programs

The overall prescribed burn plan of the land management agencies is reflected in the number of SPOT forecasts requested, but also by the total targeted acreage. In general, the agencies across WFO Midland's fire weather forecast area target approximately 18,210 hectares (45,000 acres) each year for prescribed burning (Figure 4). In comparison, acres burnt as a result

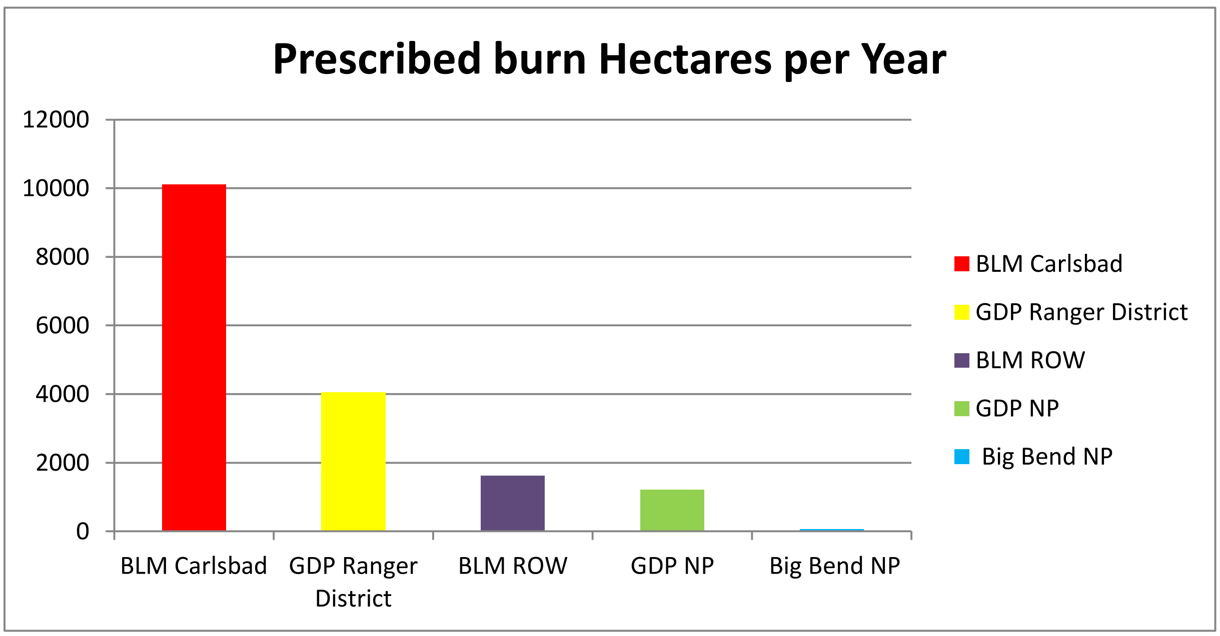


Fig 4. Target hectares per year for each land management agency within WFO Midland's Fire Weather Forecast Area.

of wildland fire is dramatically different and has been as high as 202,342 hectares (500,000 acres) in 2008 and 364,217 hectares (900,000 acres) in 2011 (Texas Forest Service 2008 and

2011). Most SPOT requests are in March and have averaged 63 request annually from 2000-2007, with the most being 140 in 2002. The monthly distribution of total SPOT request verses Red Flag conditions (Figure 5) indicates that they are off-set from March-May inferring the desire to mitigate the potential for escaped fires due to extreme weather conditions. The similar trend line from May-Dec generally indicates the Rx burn season.

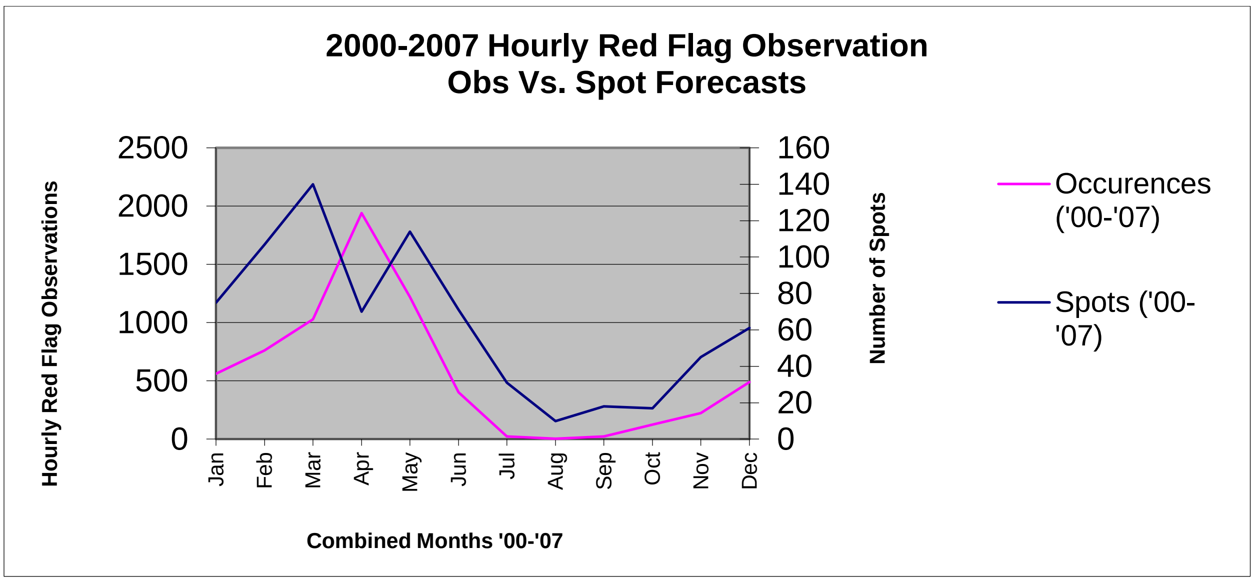


Fig 5. Depicts total SPOT request verses number of red flag conditions for Midland's fire weather forecast area for the period of 2000-2007.

4. Methodology

4.1 RAWS US Climate Archive

WFO Midland's fire weather forecast area is well represented with respect to coverage of observational data. This data is a mixture of NWS owned Automated Surface Observing System (ASOS) equipment, municipally owned Automated Weather Observing System (AWOS) equipment, state owned mesonet stations, and state or federally owned Remote Automated Weather System (RAWS) and Forest Technology System (FTS) stations. However, for this climatological study, use has been limited to the RAWS and FTS stations (Figure 2) from December 1985 to April 2008 and included over 1 million hourly observations. Data found on the RAWS USA Climate Archive (http://www.raws.dri.edu/index.html) was used for each RAWS/FTS site within Midland's fire weather forecast area. Over the years there has been concern about the reduction factor between the ASOS/AWOS measured 10 m (33 ft) wind and the RAWS/FTS measured 6 m (20 ft) wind. Since the Red Flag criteria are defined by 6 m (20 ft) winds we are able to avoid this inconsistency by using the sensors that measure 6m (20 ft) winds. Further, the land managers are more familiar with the RAWS/FTS sites, with respect to physical location and trends, since these are the same sites that are used in the National Fire Danger Rating System (NFDRS) program.

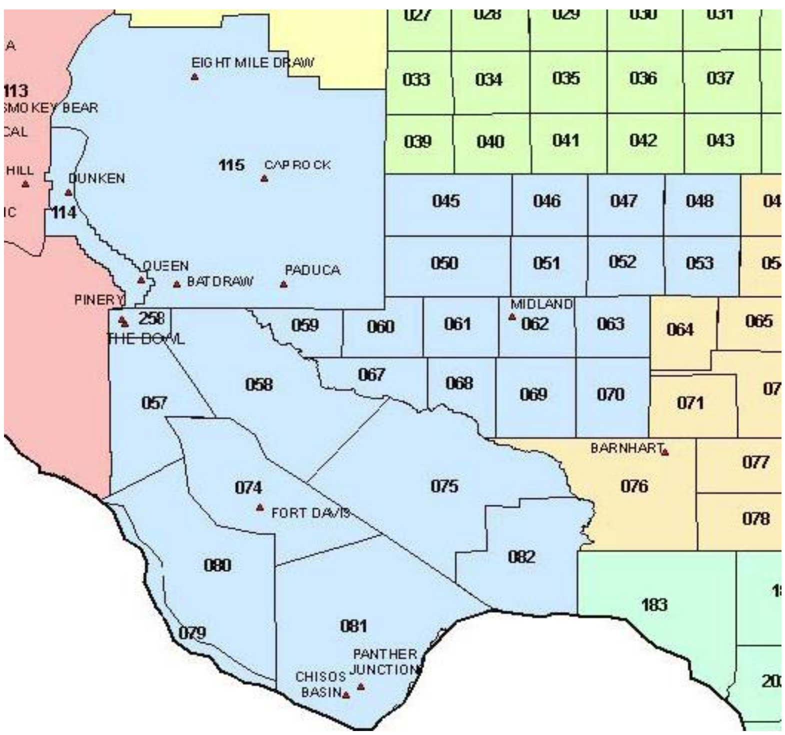


Fig 2. Midland's Fire Weather Forecast Area in blue. RAWS/FTS sites are also plotted with the red triangles.

4.2 Data Manipulation

Data was imported into Excel from the RAWS USA Climate Archive. An Excel macro was created to sort through the data, which resulted in finding the number of hourly red flag observations for each day/month/year, the wind direction of each occurrence and the local time of the occurrence. Local climatology charts describing the previous were then created.

5. Data Presentation, results, and discussion

5.1 Hourly Occurrences Per Year

On an annual basis the length and intensity of the Red Flag season varies, but is generally tied to the presence of mid latitude westerly winds; while the fire season will typically be of longer duration than the Red Flag season due primarily to possibility of fuel driven fires in the absence of critical fire weather conditions. It's not surprising that the years of peak red flag occurrence are correlated to years of peak fire occurrence. Figure 6 shows the years 1999, 2000, 2002, 2003, and 2006 were years associated with above normal red flag occurrence. This generally follows the national trend for fire occurrence as seen in Figure 7a (NIFC Historical Wildland Fire Info 2007) and Figure 7b, which shows fire occurrence for Texas**.** Conversely, with respect to the down years of 1992, 1997, 2001, 2004, 2005 a similar relationship is noted in a downturn of fire occurrence.

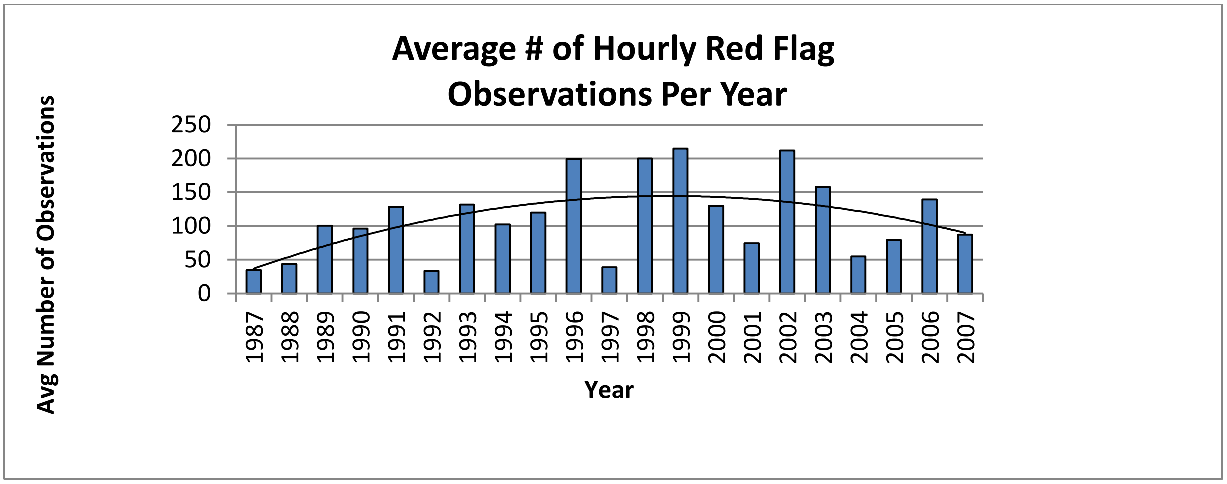


Fig 6. Average annual occurrence of Red Flag conditions across WFO Midland's Fire Weather Forecast Area.

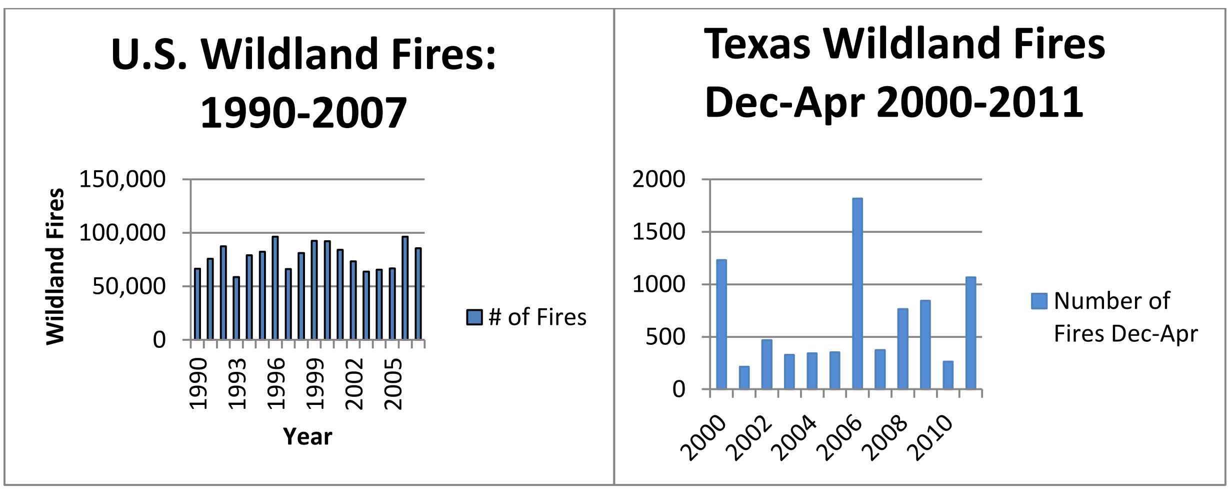


Fig 7a. U.S. wildand fire data for 1990-2007 and 7b. Texas wildland fire data 2000-2011.

5.2 Relationship to ENSO

Just as the annual precipitation varies, so does the intensity and duration of a red flag season. There are large scale atmospheric circulation patterns that can influence the fire season, such as the El Nino Southern Oscillation (ENSO), as seen through the use of the Oceanic Nino Index (ONI). This is especially the case when the index is in phase with long term drought and seasonal trends (Speybroek et al. 2007). Figure 8 indicates an agreement with respect to the trends. El Nino years tend to be associated with red flag occurrences that are decreasing, while La Nina years tend to be associated with red flag occurrences that are increasing, respectively. However, Figure 8 also shows through comparison of the cold season ONI (December through April) verses Red Flag occurrences that the influence from ENSO is not necessarily proportional to the frequency of red flag conditions for that same period. This is especially noted in 1998

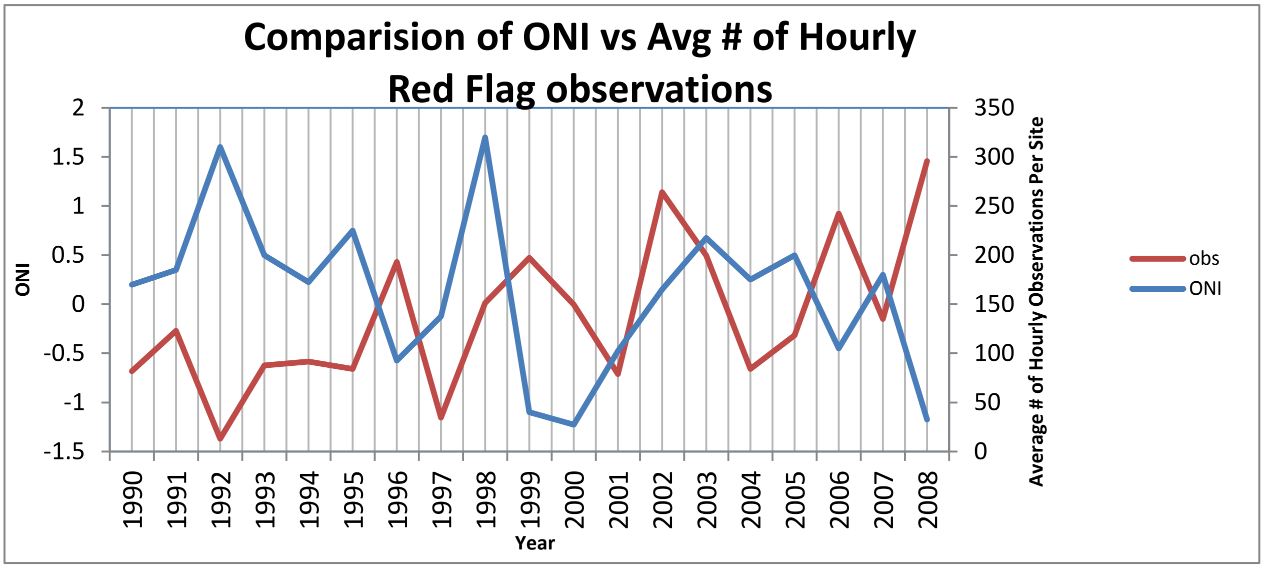


Fig 8. Represents a comparision of the ONI December through May verses the number of red flag observations.

when a very strong El Nino was in phase with a notable increase in red flag occurrences. Also, 2002 and 2003 were two years for large occurrences of red flag conditions, yet the ONI indicated neutral to warm conditions. A local study for the Permian Basin (Figure 9) has shown a link between precipitation and ENSO that indicates below normal precipitation during cool episodes of ENSO (Naden and Platt 1999).

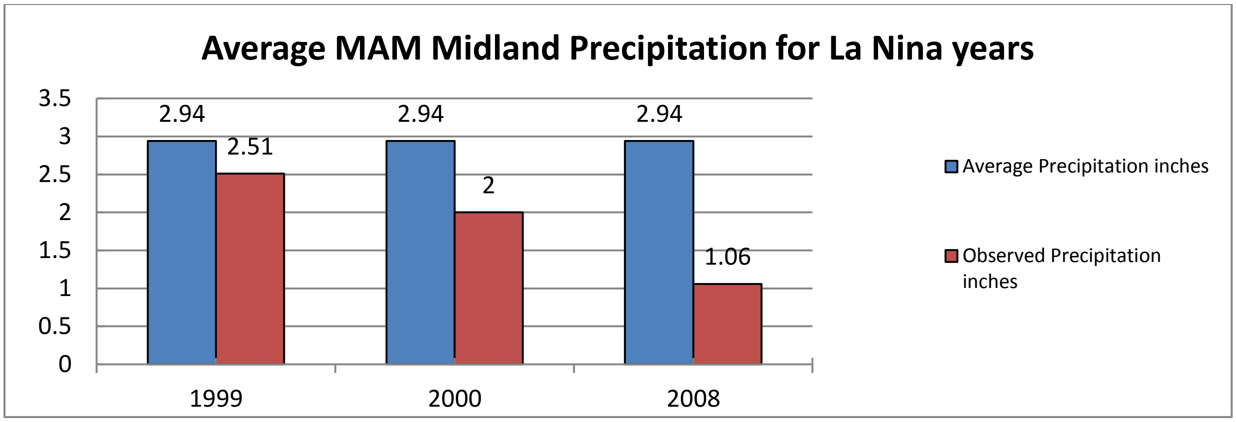


Fig 9. Average precipitation for Midland, TX compared to observed precipitation during La Nina years.

An important link has been established as identified in the 2006, 2008, and 2011 fire seasons and the prior antecedent warm ENSO of 2004/05, 2007, and 2010. Speybroek et al. 2007, identified a correlation between ENSO and the fire season when phased with on-going long term drought and seasonal trends**.** Schroeder 1969 mentions that antecedent weather and its affect on fuels must be considered with respect to fire danger. The link is evident by the warm episode of ENSO 2004/05 when available fuel increased in a period of above normal precipitation, followed by an abrupt cool episode, ENSO 2006 (Figure 8). As the phase changed from warm to cold there was a marked increased in the number of annual red flag occurrences. This trend was again observed in the transition from the neutral phase in 2007 to the cold ENSO of 2008 (Figure 8).

Even though there is variability as demonstrated in 1998, 2002 and 2003, possibly due to trying to correlate hemispheric scale phenomena (ENSO) with sub-synoptic scale data, there will be times when cold episodes of ENSO, long term drought, and seasonal trends work synergistically to increase the probability of red flag conditions. Consider the affect that topography may have in the cold episodes. Since weather systems tend to pass north of this area during La Nina, west winds are favored. West winds in the lee of the Rockies are a documented critical fire weather pattern, Schroeder 1969, known as the Chinook Critical Fire Weather Pattern. Thus, with an increased likelihood of occurrence of the Chinook Pattern there would by default be an increased likelihood of red flag conditions. Depending on when the ENSO phase changes occur (warm or cold season), it may take some time for fuel to cure and become available to burn. This results in an apparent lag of the increased occurrence of red flag conditions, with respect to fire danger.

5.3 Synoptic Weather Patterns

Critical fire weather conditions are certainly related to synoptic weather patterns that occur over a large area (Schroeder 1969). In fact, recent weather research on the Texas and New Mexico plains has identified synoptic weather patterns that favor Southern Plains Fire Outbreaks (Lindley et al. 2007).

Observed synoptic fire weather patterns for WFO MAF's region usually involve strong 10k ft MSL orthogonal height gradients across the southern Rockies. This results in the occurrence of surface pressure falls near the lee of the Rockies and an associated meridianally oriented surface low developing. In this paper we do not exam statistical correlations relating to the number of occurrences within a certain year to particular synoptic oscillations. We do, however, attempt to correlate extreme fire weather occurrences (according to the number of red flag hourly observations for each day within the set) and 700 hPa synoptic height patterns and gradients. This is discussed in the following section.

5.3.1 Identifying Critical Fire Weather 700 hPa Patterns

The 700 hPa level was used because of its proximity to the higher elevation areas of the southwest, but yet it is still low enough to be associated with surface weather regimes (Crimmins 2005). Mixing heights, throughout most of the southwest CONUS, are also usually found up to or above 700 hPa. This allows for momentum transfer through deeper portions of the mid and lower troposphere, especially during the spring and early summer.

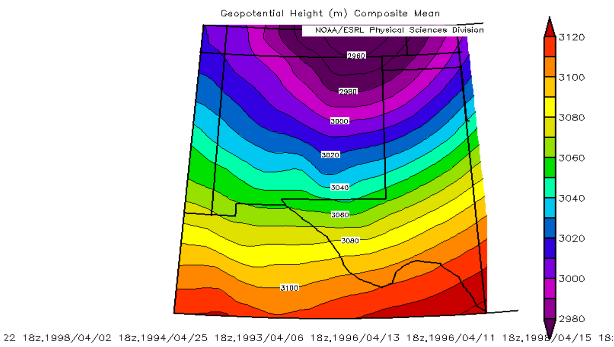
Identifying critical fire weather 700 hPa patterns consisted of three steps within this analysis. First, critical fire weather days within the entire set were found. This was accomplished by totaling the number of hourly red flag observations for each day. A 90th percentile rank within the set was then defined as being a critical day. This number was chosen arbitrarily. However, most of the fire community considers the 90th percentile as a common breaking point when describing extreme fire-weather conditions.

For instance on April 2, 1998, 45 hourly observations that met red flag criteria were observed across southeast New Mexico and west Texas. Comparing this with the entire set of April resulted in April 2, 1998 being in the 97th percentile. This day was then defined as being a critical fire weather day. Each month was analyzed in this way.

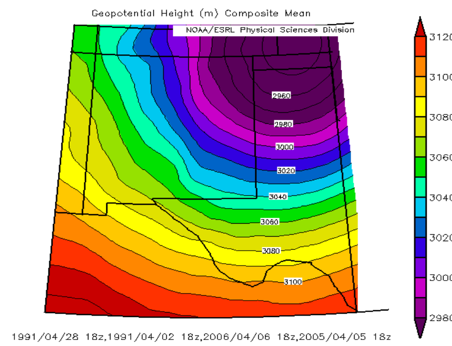
Secondly, after all of the critical days were found, 3 hour NCEP North American Regional Reanalysis (NARR) Composite/Mean charts were created. This was done by using the Climate Analysis Branch website (http://www.cdc.noaa.gov/cgi-bin/NARR/plothour.pl). The months of December – June were considered for this study. These months contained (on average) the most red flag observations in the set. Each month was held constant, while the critical days were first individually inputted into the "plotter" to obtain multiple 700 hPa height fields for each critical day. In recent work by Crimmins, daily synoptic-scale circulation patterns were classified into different key weather types using an unsupervised classification technique known as the self-organizing map (SOP). This technique basically involved entering vectors and then running an algorithm that was able to discern nonlinear relationships. The algorithm then separated the data into different patterns within the set (in this case synoptic patterns), allowing the user to determine which days correspond to what patterns. This technique was considered, but limited computing resources and inexperience with the SOP lead to the aforementioned simplistic technique.

From Figure 19 (Section 5.6), one may observe that there is a sharp increase in the number of red flag observations from 1800 UTC-2300 UTC (1300-1800 LT). For this reason, 1800 UTC (1300 CDT/1200 MDT) was chosen as the time for the plots. After all of the 700 hPa heights were plotted for each critically defined day, the plots were organized into groups according to their patterns. The pattern recognition involved the low's position, flow into and out of the region, and trough-ridge positions.

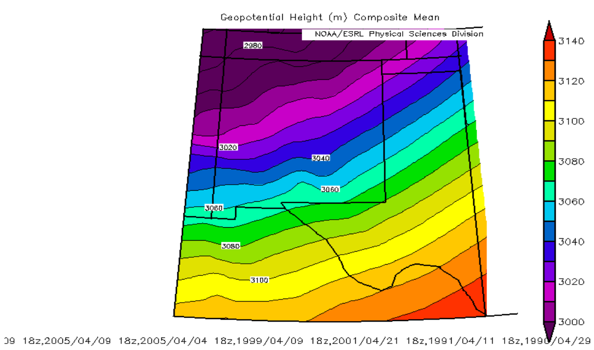
Lastly, the groups of days for each established pattern were plotted together using the composite 3 hour reanalysis. This resulted in multiple mean 700 hPa height contour plots for different months. For example, in the month of April (to limit the length of this paper, April is the only month discussed within), five different composites were developed from the critical days for the entire month. None of the individual critical daily patterns in April were considered outliers, or those days in which the pattern did not match any of the others, although this was not the case for other months. For the month of April, the patterns all resulted in strong height gradients across southeast New Mexico and southwest Texas. Figure 10 indicates that composite 1 for April resulted in the 700 hPa low being positioned over southeast CO, strong northwest flow over western NM, and strong southwest flow over much of west TX. Composites 1 and 2 are very similar, with the position of the low the only significant difference between the two. Strong drying southwest flow is dominant in Composite 3, while Composite 4 has a shortwave trough over eastern NM and shortwave ridge over northwestern NM.



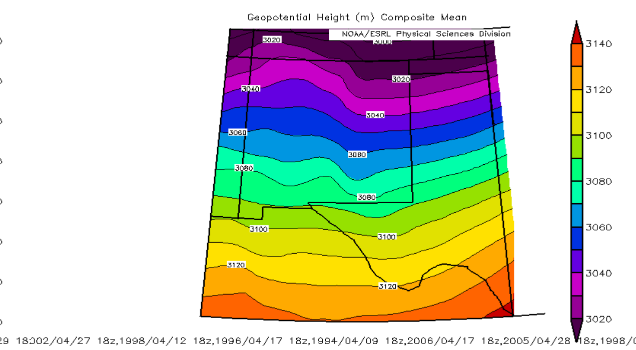
Composite 1



Composite 2



Composite 3



Composite 4

Fig 10. The dates under each composite are those critical days included in the plot. Composite 2 contained the least number of critical red flag days. Not all days for each composite are listed.

After the composites were created for each month, some characteristics were identified that could be used during the forecast process. These lead to creating a flowchart for fire weather forecast applications. This is discussed in the next section. However, one must remember that these plots were created from what we considered critical red flag days and some extreme events were outlier patterns whose influence on the flowchart/study as a whole were disregarded. Research by Lindley et al. 2007, A Meteorological Composite of the 2005/06 Wildfire Outbreaks in The Southern Plains, is focused on extreme critical fire weather patterns and provides detailed information about the extreme cases.

5.4 Composite Flow Charts

In order to generate a flowchart from the data, the first step simply involved selecting what month was being considered. Next, a 700 hPa pattern was selected from that month. Then, since Midland's CWA ranges mostly from southeast NM to the tip of the Big Bend, an average height gradient from the midpoint of the western/eastern TX/NM borders to the tip of the Big Bend was calculated. Of course this gradient changes with each different pattern and month, but the variation is minimal between patterns found within the same month. An example of a flowchart for April is shown in Figure 11. Independent agreement is confirmed by comparing the results of an operational high wind decision tree developed in the 1970s at the WFO in Lubbock, TX (Johnson).

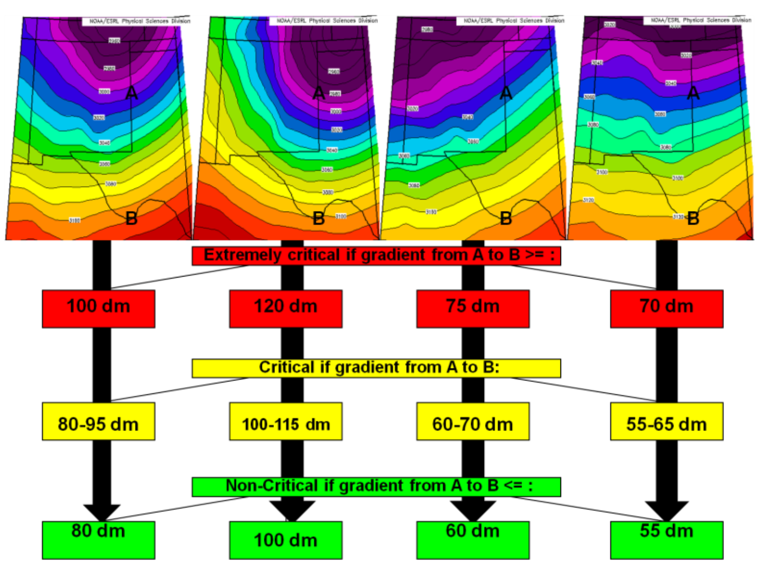


Fig 11. Flow chart for the month of April showing 4 different critical fire weather day

patterns at 700 hPa. After a pattern is selected from the top row, the user assesses the height gradient from point A to point B.

5.5 Monthly Trends

Monthly trends are especially evident with sixty-six percent of all red flag conditions occurring in March through May. April is the peak month, or thirty-two percent of the red flag conditions (Figure 12). Conversely, July through September are the minima months. Somewhat surprisingly, the plains and mountains with respect to April being the peak month is consistent, although the Davis Mountains are the exception as March replaces April for the most occurrences. May is generally the month with second most occurrences.

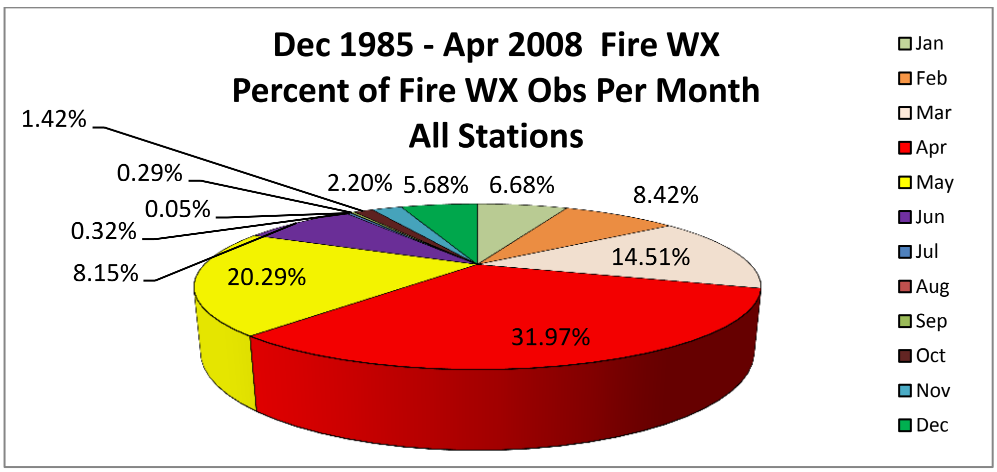


Fig 12. Monthly distribution of red flag conditions for all sites combined within Midland's Fire Weather Forecast Area.

Red flag season start dates (Figure 13) indicate that the season first starts in the southeast New Mexico plains, as shown by the Eight Mile Draw, and progresses south and eastward to the Big Bend and Barnhart sites. Start and end dates were defined in such a way that in order for a date to be established; three or more hourly observations had to occur within 24 hours of each other. Some of the data for the start and end dates are skewed by a short data set within wet years, for example Queen, New Mexico.

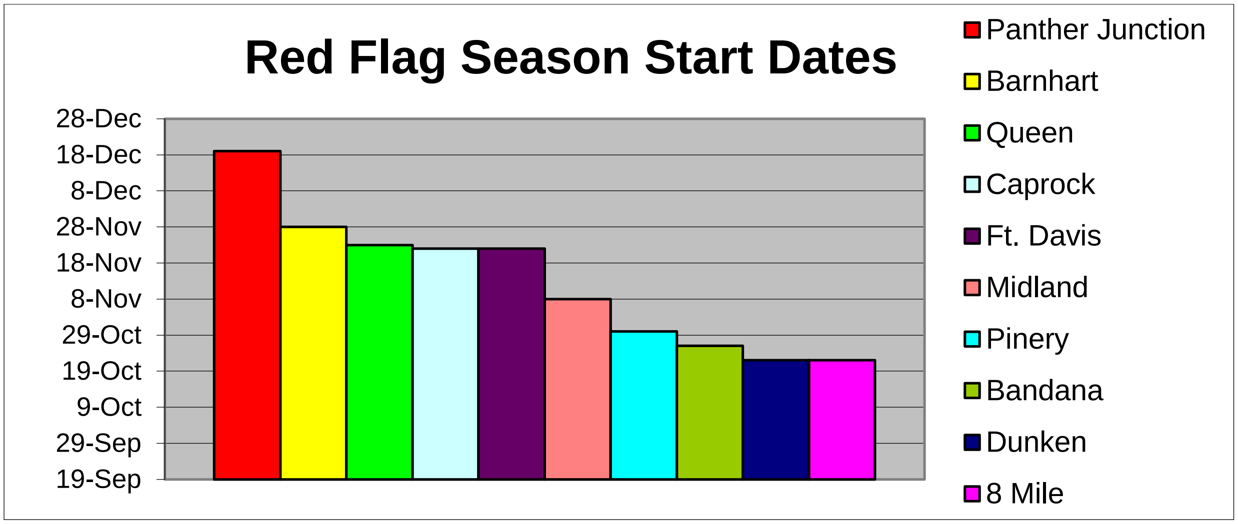


Fig13. Average red flag season start dates for all the fire weather specific observing stations in Midland's Fire Weather Forecast Area.

The red flag season end dates are again systematic with the east and southern sites being the first to end the season as indicated by Barnhart and Midland, while the west and northwest sites are the last to end the season, as shown by Dunken and Bandana (Figure 14). Some inconsistencies are noted on the end dates for several sites. The end date of the red flag season falls in April, which curiously is the peak month for red flag conditions.

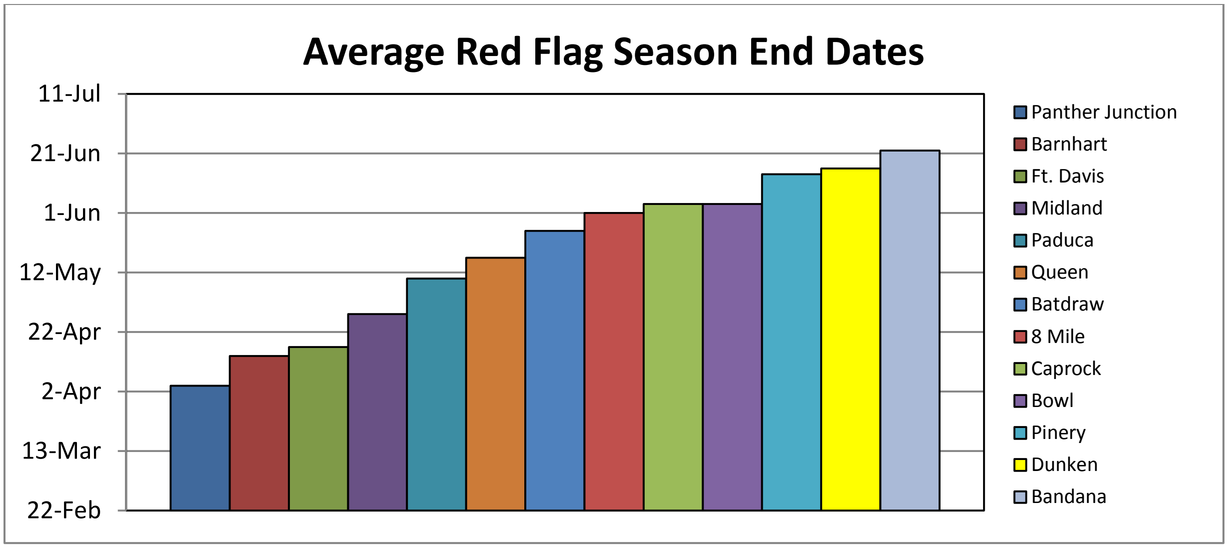


Fig 14. Average red flag season end dates for all the fire weather specific observing stations in Midland's Fire Weather Forecast Area.

Another way to look at the start and end dates is the length of red flag season in days (Figure 15). Since the red flag season straddles both the warm and cold season it makes the forecasting of red flag conditions somewhat unique.

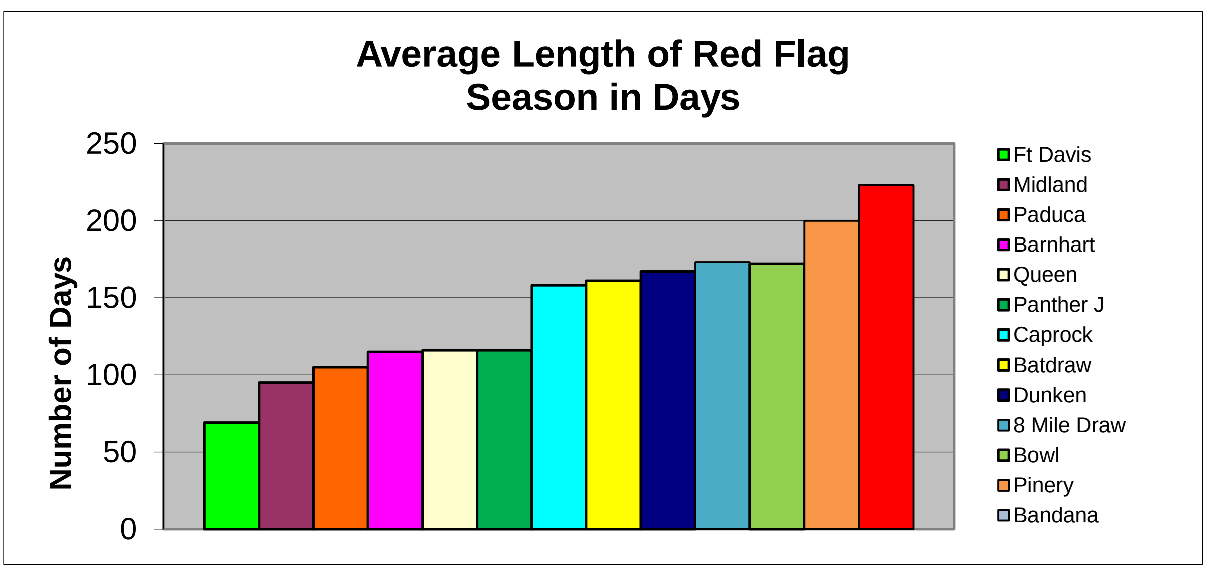


Fig 15. Average length (in days) of the red flag season for all the fire weather specific observing stations in Midland's Fire Weather Forecast Area.

5.5.1 Chisos Basin - A Special Case

The Chisos Basin RAWS has a unique situation with respect to wind. Being located in a basin or a nearly closed "bowl", this site is protected from the wind. As a result it is uncommon for the Chisos Basin RAWS to reach sustained 9 m/s (20 mph), even from the west. Earlier research by Naden in 2001 showed that the 90th percentile wind at Chisos Basin was a mere 5 m/s (11 mph) and the 97th percentile wind was 6 m/s (13 mph). Still, this is only one location within the Chisos Mountains and will not represent the mountain as a whole. Much of the Chisos Mountains extend above 1829 m MSL (6000 ft) and are exposed to stronger winds. Naden's research also revealed that the favored wind direction at Chisos Basin was west through northwest, which isn't too surprising considering the elevation increases in the basin from west to east and the only exposed area of the basin is on the west side. This lighter wind regime at the Chisos Basin RAWS results in a large degree of variability in the red flag conditions and the start and end dates of the red flag season.

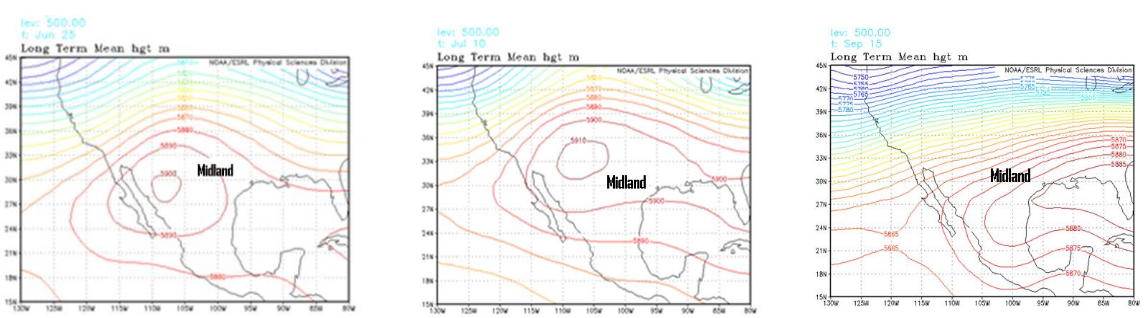


Fig16. The progression of development to dissipation of the subtropical ridge or the "monsoon high" from its late June position in northern Mexico, to the New Mexico and

Arizona position in the first half of July, and then the return of mid latitude westerly winds with the ridge axis south into Mexico.

The average end dates of the red flag season and the fire season are, in general, closely tied to the presence of the mid latitude westerly wind, and the development of the subtropical ridge sometimes referred to as the “monsoon high”. Typically, the presence of the subtropical ridge is evident in the last week in June and is fully developed across all the southwestern states by mid July (Figure 16).

The development, with respect to time, of the subtropical ridge does vary and some research has shown a relationship to the snow pack across the southwest mountains (Gutzler 2000). An above normal snow pack would tend to result in a delayed onset of the subtropical ridge, while a below normal snow pack would tend promote an early development of the subtropical ridge. The circulation associated with this ridge is the key to the return of moisture and a distinct decrease in the opportunity for strong dry west winds and thus an end to the red flag weather driven fire season. As summer comes to an end in mid to late September the subtropical ridge will start to move south into Mexico favoring the return of dry west winds and eventually the beginning of the red flag season. This pattern is certainly evident in the data. Note the abrupt decrease in red flag occurrences at the Pinery from June to July and the gradual return of red flag conditions in the fall (Figure 17).

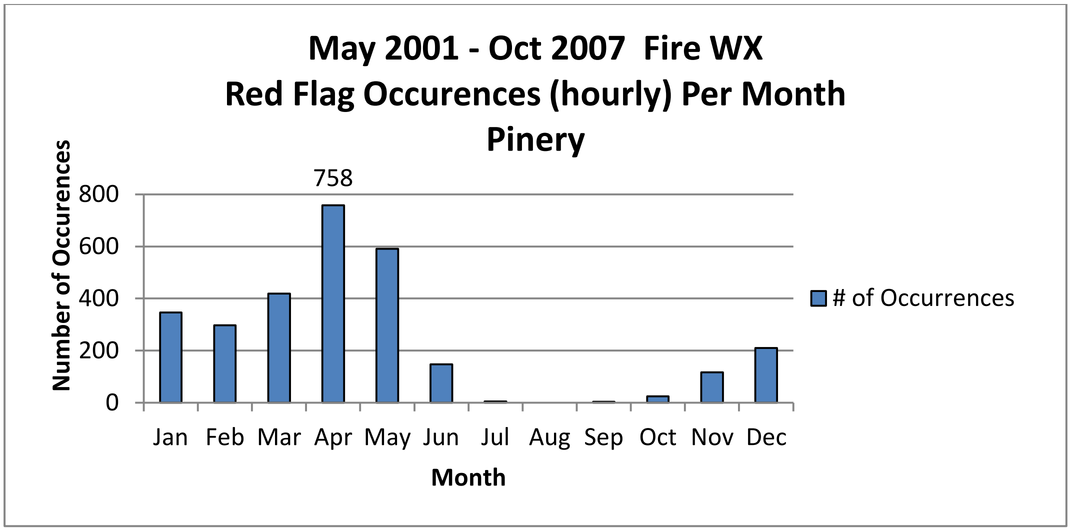


Fig 17. Monthly red flag conditions for Pinery, which is related to the development of the subtropical high or the "monsoon high".

The strategic application of the typical beginning and end dates of the red flag season, especially the end, are valuable information to those who manage wildland fires and the allocation of resources. In Texas and southeast New Mexico, the fire season and the red flag season begin earlier than in the western states. From the monthly data at Pinery, (Figure 17) it is apparent that the typical red flag season gradually builds (data for all other sites available at WFO MAF). This is advantageous for land managers in Texas and southeast New Mexico since the competition for resources is typically low in the winter and early spring. Conversely, the end dates of the red flag season occur at a time that is coincident with the start of the fire season for the remainder of New Mexico and Arizona resulting in increasing resource demands. By using the end date climatology combined with medium range forecasting the user will have another tool to make allocation of resource decisions in critical periods.

5.6 Hourly Trends

It is no surprise red flag conditions are closely tied to the diurnal heating cycle, and from Figure 18 it is clear that most red flag conditions occur near 2000 UTC (1500 LT). Since much of the area is south of 33 N latitude, intense insolation begins early prolonging the time period which will be susceptible to red flag conditions. Most of the area is considered plains, and the interface of the mountains and plains can contribute to the intensity of red flag conditions. When phased with a strong system passing across the region, the affected areal extent can be large.

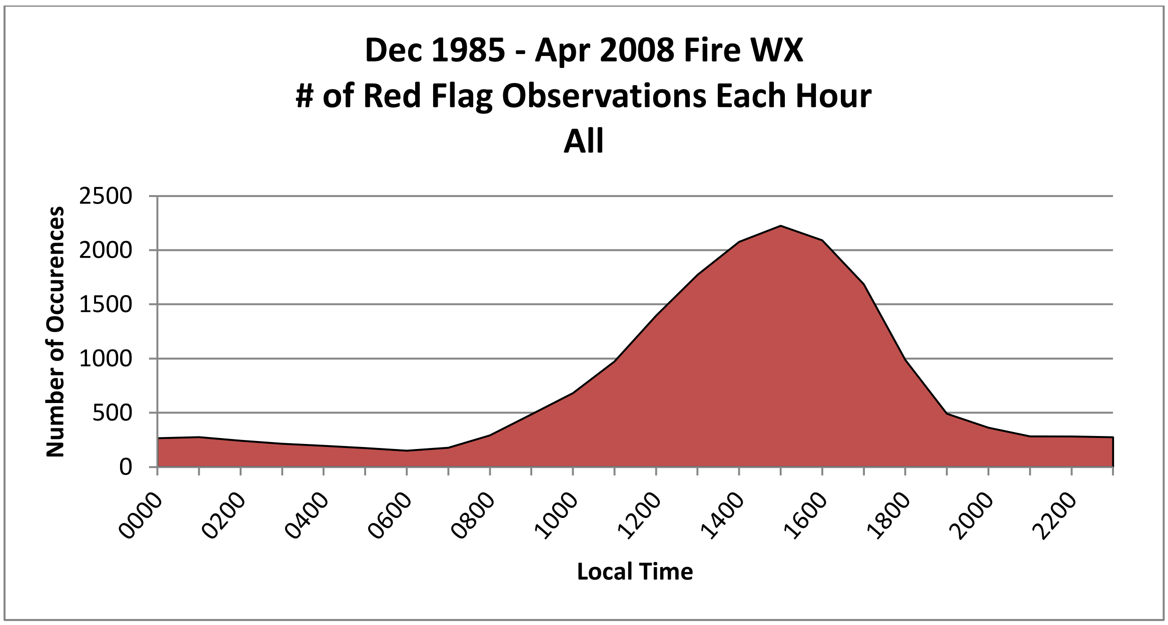


Fig 18. Hourly distribution of red flag conditions for all sites combined with the area.

Generally, the three hour period between 1900-2200 UTC (1400-1700 CDT) has the highest frequency of red flag conditions. A westerly component is favored on red flag days and the majority of red flag conditions occur with a wind direction between 180° (south) and 320° (northwest). The most likely sustained wind direction was from 240° (southwest), Figure 19. The greatest number of fire weather observations occurred in the year 2002. There are

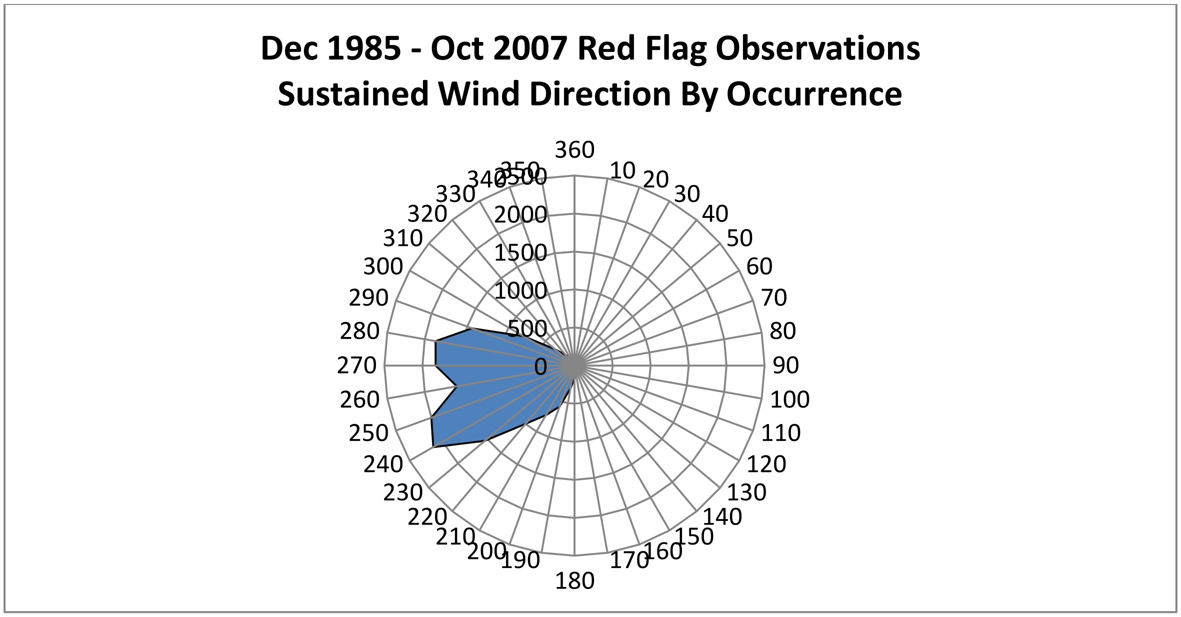


Fig 19. Wind direction associated with sustained winds of 9 m/s (20 mph) or greater.

exceptions however, especially in the mountains where winds can stay strong into the overnight hours with very dry air in place above the thermal belt on exposed ridges. Frontal passages across the plains can also result in earlier and extended duration red flag conditions across the plains.

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