University of Nevada, Reno

Climate Impacts on Escaped Prescribed Fire Occurrence in California and Nevada

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Geography

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May 2005

ABSTRACT

In reviews of escaped prescribed fires, investigators frequently report that fire management personnel erroneously failed to recognize existing drought conditions. I hypothesized that fire managers in California and Nevada who have had escaped prescribed fires use more climate information and tools than those who have not had escapes. I found no significant difference between these two groups of fire managers.

Whether escaped fires are even correlated to climate was also assessed. Escaped fires in California and western Nevada were associated with wetter-than-normal conditions, while escaped fires in eastern and southern Nevada were associated with drought conditions. Large escaped fires (>200 ha) were found to occur under wetter conditions than smaller fires, and on low fire danger days. These results indicate that drought conditions are not a factor in escaped prescribed fire in the study region, and that meteorological events and fuels build-up may play a role in escaped fire occurrence.

ACKNOWLEDGEMENTS

When Scott Mensing agreed to be my advisor, he had no idea what he was getting into. I thank him for his patience, his enthusiasm, and his continual support as this thesis made its slow, painful, and inevitable evolution. I hope I will continue to make him proud as I move forward on my academic journey.

This project would not have happened without Dr. Tim Brown's commitment to finding funding for me and having faith in my abilities, even before he knew me very well. He let me into his lab even though I was a hardcore PC user (don't worry, Tim, I'm converted), let me go play with fire all summer, and continues to believe in me and my work. Thank you for taking a chance on me.

Kate Berry was the first person I met in the department of Geography, convinced me to apply to the program, and has gone above and beyond the call of duty as my third committee member. The rest of the Geography department has made my three years here fly by; I am proud to be a graduate of one the most friendly, tight-knit, respected, and fun-loving departments on campus.

My time in the CEFA lab at DRI has been a box of Bertie Bott's Every Flavor Beans (you never know what you're going to get). Beth Hall helps solve my FORTRAN problems. Hauss Reinbold and Ryan Kangas have been my co-conspirators in creating left-leaning chaos, and have made coming to work a lot more interesting.

Several people have been a source of inspiration and never-ending amusement the last three years in Reno. Ali Reiner is my fellow pyro, Teresa Wriston showed me the ropes of being a grad student, and Tristan Ashcroft is always willing to mock me. The Mickey's crowd, Scott and Nicole and rest of the Forest Circus crew, and all of my friends and roommates deserve my thanks for their friendship, their support, and their willingness to listen to me talk on and on (and on and on) about fire.

Finally, my family, especially my parents Mike and Kathy, have always been my rock. I am who I am today because of the love and support my immediate and extended family continues to provide, and I only hope that I can always be a source of bragging rights for them, even though I'm not Ivy any more. I love you Mom, Dad, Sam, Jim, and Angie; thanks for always reminding me of the importance of family.

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CHAPTER 1

INTRODUCTION

Each year, millions of hectares in the United States and throughout the world are burned by wildfires. While weather, topography, and fuels make up the three legs of the Fire Behavior Triangle (Agee 1993) and determine when and where wildfires occur, research in the last two decades has begun to look at a less apparent contributor to wildfire severity: climate regimes.

Recent studies looking at climatic events over hundreds or even thousands of years have drawn conclusions that large-scale climate patterns drive wildfire events in ways that, if not predictable, are less random than initially thought (Westerling and Swetnam 2003, McKenzie et al. 2004). This knowledge is being used by fire managers in the United States each year to make forecasts of potential high-fire severity regions (Brown 2003, Brown and Wordell 2003) and make more informed fire management decisions. For example, fire managers might increase staffing levels in response to severe drought conditions, or alter the timing of spring fire training recognizing the potential for an earlier-than-normal fire season (NWCG 2002, SWCC 2004). Thus, climate patterns have been accepted as drivers of wildfire and are being treated by fire managers accordingly.

There is another type of fire in the United States that is used as a land management tool across several million hectares each year. Controlled burning, known in government agencies as prescribed fire, has been used by humans for thousands of year to clear fields, hunt, protect homes, etc. (Pyne 1995). State and federal agencies responsible for managing the one hundred million hectares of public lands in the United States use prescribed fire to treat over a million hectares annually (USDI 2003). With more frequent severe wildfires burning homes each year, both government and private interests are pushing to expand the use of prescribed fire on public lands, as it is considered the most efficient means to reduce and remove vegetation that may eventually fuel an uncontrolled wildfire (USDI 1995). One problem with using prescribed fire, however, is the potential for a prescribed fire to escape control and become a wildfire. In 1999, the Bureau of Land Management (BLM) lost control of a prescribed fire that eventually burned 23 homes in northeastern California (USDI 2000). This event was minor in comparison to the Cerro Grande Fire near Los Alamos, New Mexico in 2000, which destroyed 235 homes and threatened hundreds more after a prescribed fire escaped control at Bandelier National Monument. In each of the incident reports that followed the escaped fires, the reviewers noted that conditions had been much drier than expected, and each fire’s management team had failed to calculate the impacts of drought on the fuels and prescribed fire behavior (USDI 2000, USDI 2001). The fire managers, the reports said, had failed to sufficiently account for drought and the effects of climate.

A review of numerous escaped prescribed fire investigation reports reveals that this is a reoccurring theme in the investigations, and brings to light an interesting question. With all of the information put forth by the scientific community on the relationship between climate and wildfire, and with all of the climate-related information and indices available to fire managers, are fire managers actually using this climate information to help them plan and execute their prescribed fires? Are the escaped fires due to an anomalous few individuals who do not utilize climate information, or is this prevalent throughout the prescribed fire management community? If fire managers in general are not using climate information in their prescribed fire programs, will the push to increase prescribed fire use in the coming decades spell disaster in the form of escaped prescribed fires? If so, the entire prescribed fire program could eventually be lost as a management tool.

This study seeks to assess whether the use of climate information in prescribed fire management is instrumental in preventing escaped prescribed fires, as is suggested by the escaped fire reports. It also seeks to determine what obstacles fire managers may face in attempting to use climatic information in prescribed fire planning and implementation. Finally, it will evaluate quantitatively what role climate plays in impacting escaped prescribed fires, and make recommendations for future research in the study of climate and prescribed fire as a whole. It focuses on the states of California and Nevada as a study region, as these two states have enormously complex issues surrounding the use of prescribed fire.

The results of this study have widely ranging benefits to the fire management community. Understanding the conditions under which escaped prescribed fires occur will allow fire managers to better plan prescribed fires and reduce risk of escapes through recognition of potential conditions. This, in turn, greatly reduces the risk to the public of a prescribed fire escaping. Furthermore, fire managers can utilize this information for training purposes, and assessing the policies and conflicting interests that prevent prescribed fire from being used as a management tool. The results of this study will also be beneficial to future researchers who wish to assess prescribed fire and its relationship to climate.

CHAPTER 2

BACKGROUND

Visible fire behavior on the ground during both wildfires and prescribed fires is the result of a complex set of interactions between the weather, topography, and fuels in the immediate area; a relationship that has been described as the “fire behavior triangle” (Agee 1993). On a temporal scale, topography is the least variable of these three factors, and thus, the most predictable for resultant fire behavior. Weather and fuels, however, are highly variable both temporally and spatially. The averaging of day-to-day weather events results in seasonal, annual, and decadal cycles that are described as climate patterns. These climate patterns influence fire behavior by slowly changing landscape-scale fuel loads and controlling the availability of grasses, shrubs, and woody material. Because they are patterns, however, they are somewhat predictable, making the occurrence of wildfires and wildfire behavior somewhat predictable.

Climatic Variation

As the saying goes, “Climate is what you expect, weather is what you get.” Although numerous definitions exist for climate depending on the context in which the word is being used, climate is generally understood to be an averaging of weather observations over time. This may be an average of observations such as temperature, precipitation, or windspeed across a spatial spectrum from a single weather station to an entire state, or temporally over periods from months to millennia (Brown 2003). The fluctuation of these average conditions over space and time has shown us that climate also varies. For example, the variability in precipitation by season is a seasonal climate cycle; in much of the western US the winter precipitation average is much higher than the summer average. At multi-year scales, the annual precipitation averages for a region such as the southwestern US rise and fall in patterns associated with the El Niño Southern Oscillation (ENSO), a phenomenon defined by anomalies in average sea surface temperature.

Climate variation at scales of months to years is of great concern to fire managers, because of the effects it produces on ignitions rates, fuels, and fire behavior. Climate variability on longer time scales, such as decadal oscillations, and centennial to millennial-scale global climate change are discussed regularly in the wildfire literature (Brown et al. 2004, Whitlock et al. 2003, Hessl et al. 2004, McKenzie et al. 2004) but are not discussed here. The most prominent types of climate variability discussed in recent wildfire literature have been ENSO and variations in precipitation and temperature, as these have been linked to widespread drought conditions in the western US. This study focuses on climate variability at the scale of one to three years because drought conditions occurring on this temporal scale are the primary concern of fire managers.

Drought conditions and their effects on fuels and fire behavior are one of the major concerns for fire managers in the west. Despite their concern for drought, however, fire managers do not have a definition for drought that specifically highlights its relationship to fire management. McKee et al. (1995)

define drought hydrologically as the reduction of precipitation leading to a shortage of water relative to demand for water. From a fire perspective, the shortage occurs in water available to the grasses, shrubs and trees that will burn; the fuels. Drought conditions are still poorly understood in terms of what determines their length and severity, particularly in the study region. Since California and northwestern Nevada receives almost all of their annual precipitation in the winter months (Mitchell and Blier 1997), drought conditions there stem from fewer winter storms or less precipitation associated with these storms. The results are visible in reduced snowpack and reservoir levels. The eastern Great Basin, meanwhile, receives approximately half of its annual precipitation during the summer months, when the Bermuda High and the North American Monsoon force moisture from the Gulf of Mexico into the region, creating convective thunderstorms (Houghton 1969). Drought effects in most of the Great Basin are seen in reduced winter snowpack and reduced summer thunderstorm activity from lack of moisture.

One cause of drought conditions for this region is ENSO. There is much evidence indicating that ENSO is a factor in the variability of wintertime precipitation in the United States, particularly in the southwest and northwest regions of the country (Cayan et al. 1998, Gershunov 1998), and these portions of the western US see the lasting effects after a strong ENSO event due to the prolonged summer dry season that dominates western climates. The primary atmospheric measurement for ENSO is the Tahiti-Darwin atmospheric pressure comparison, which indicates a positive phase, or El Niño event, when lower than normal sea level pressure is measured over Tahiti and a negative phase, or La Niña event, when higher than normal sea level pressure is measured over Tahiti and the western equatorial Pacific. These events usually correspond to Sea Surface Temperatures (SST), thus an El Niño is considered a “warm” event due to warmer-than-average water that pools in the eastern Pacific, and a La Niña is typically a ‘cold’ event (Fig. 2.1) (Diaz and Markgraf 1992). The anomalies of pressure and sea surface temperature associated with ENSO events range temporally from less than one to several years, although the strength of the anomaly over decades has been more recently attributed to the Pacific Decadal Oscillation (PDO) (Gershunov and Barnett 1998). The PDO is a sea surface temperature ‘shift’ much like ENSO, but taking place over 20 to 30 years and being most prominent in the northern Pacific Ocean, as opposed to the tropics region (Mantua 1999).

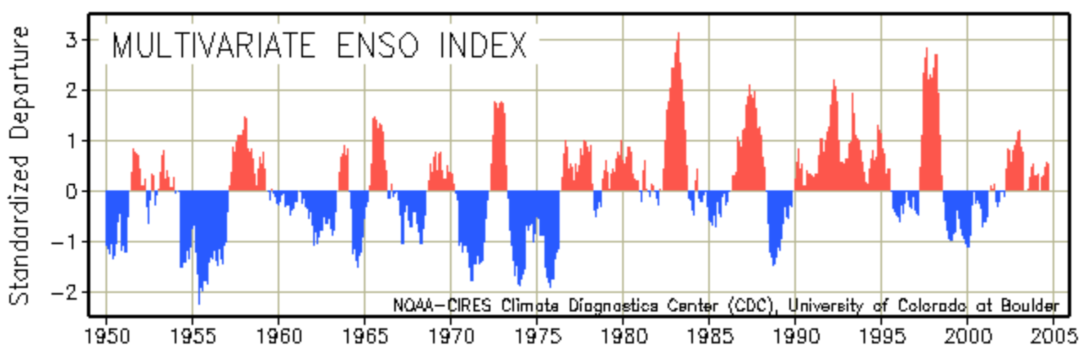

Figure 2.1. Time series depicting one indicator of ENSO anomalies, the Multivariate ENSO Index, on a standardized departure for 1950-present (www.cdc.noaa.gov). More frequent and severe El Niño events have dominated since the late 1970s, a shift many scientists attribute to a shift in the PDO (Gershunov and Barnett 1998).

While ENSO effects on the southwest and northwest regions of the US are well-understood, the study region sees highly variable impacts from ENSO. Eastern Nevada tends to see the same effect as the southwest, which is a wetter-than-normal winter and spring with an El Niño event, and drought conditions resulting from a La Niña event. Northwestern California, however, sees opposite impacts and has weather similar to the Pacific Northwest. Everything in between these two corners is highly variable and seems to depend on the location of a shifting pivot point that demarcates the boundary between the regions of a wet/dry “dipole” (Dettinger et al. 1998, Westerling and Swetnam 2003). Taylor and Beatty (2004) indicated that there is good evidence for the location of the pivot to lie close to the Lake Tahoe area, around the 39th parallel.

Since ENSO anomalies affect the study region with a high degree of spatial variability, it is difficult to assess long-term drought that may or may not be associated with ENSO. Drought conditions result from strong ENSO events in the northwest and southwest corners of the study region, but in between, the impacts of ENSO are less clear. Drought conditions in the central part of the study region tend to be localized and not in sync with ENSO events, which means that the beginnings and endings of the droughts are harder to predict. Thus, this study is primarily concerned with annual and monthly-scale drought conditions. ENSO can be predicted moderately well a few months in advance, so its effects on weather and fuel conditions can also be predicted, but local precipitation and temperature fluctuations are much more difficult to predict. For fire managers, the inability to predict the local precipitation and temperature fluctuations that cause drought conditions leads to a reliance on short-term (days to weeks) weather forecasts and an uncertainty about fuel conditions and resulting fire behavior when those fuels are burned.

Climate Influences on Fuels

Fire managers define fuels by their moisture content, which is controlled by temperature, precipitation, and relative humidity. Fuels are generally separated into live and dead categories, and then broken further into size classes. For dead fuels, there are four classes: 1-hour, 10-hr, 100-hour, and 1000-hour. For a 1-hr fuel it takes one hour for its fuel moisture content to reach two-thirds equilibrium moisture content with the environmental conditions, and the material is generally less than one-quarter inch in diameter. Ten-hour fuels range up to an inch, 100-hr fuels up to three inches, and anything greater than three inches is classified as a 1000-hr fuel (Lancaster 1970, Deeming et al. 1978). For live fuels, variability in flora makes the understanding of moisture content less precise. Live fuels are distinguished by whether they are grasses and forbs or shrubs, and then by whether they are annual or perennial (Deeming et al. 1978).

Climate variability controls fuels in three primary ways: fuel composition, fuel loading, and fuel availability. Fuel composition refers to the percent composition of each species of vegetation type/fuel on a landscape. Although the composition of tree species takes centuries to millennia to change in response to climate change, grasses and herbaceous forbs that serve as the primary carriers of fire are quite sensitive to minor climate fluctuations, particularly when a disturbance event such as a fire or flood occurs and accelerates successional processes. In the Great Basin, for example, drought conditions may favor annual invasive grasses while suppressing perennials (Brooks and Pyke 2001).

Fuel loading refers to the amount of fuel available on the landscape, often quantified in tons per acre (Deeming et al. 1972). Depending on the timing of the growing season, the vegetation will eventually die and add a significant boost to the fine fuel supply (Crimmins and Comrie 2004), so a wetter-than-average period would tend to contribute to an increased fine fuel load. Drought also increases fuel loads, but only through lowering the fuel moistures of large dead fuels and making them more available to burn (100- and 1000-hr) (Deeming et al 1978). A beetle infestation resulting from drought stress in trees can dramatically increase the standing dead fuels, altering the fuel loading (Swetnam and Betancourt 1998).

Finally, the influence of climate upon fuel availability is the most important for fire managers. No matter how much wood is on the ground, it needs to be dry to burn; and the drier it is, the more thermal energy will be produced in combustion (Rothermel 1983). Fuel moisture levels determine how readily combustion will occur, and fuel moisture is controlled by environmental conditions (Rothermel 1983). While 1-, 10-, and 100-hr fuels fluctuate tremendously over the course of a day or week and are controlled primarily by the weather (Bessie and Johnson 1995), 1000-hr and live fuel moistures are controlled by long-term averages over weeks and months (Deeming et al. 1978). This is observed in the western US by comparing fuel conditions in the spring and fall (Fig. 2.2). Fuel moistures are much higher at the beginning of the growing season, and by fall, much of that year's annual vegetation has cured completely, adding to the dead fuel loading (Sapsis and Kauffman 1991). Historic droughts have been cited several times as the culprit for record-low fuel moistures recorded during times of severe wildlfires, and unusually late-in-the-season wildfires (Goens and Andrews 1998).

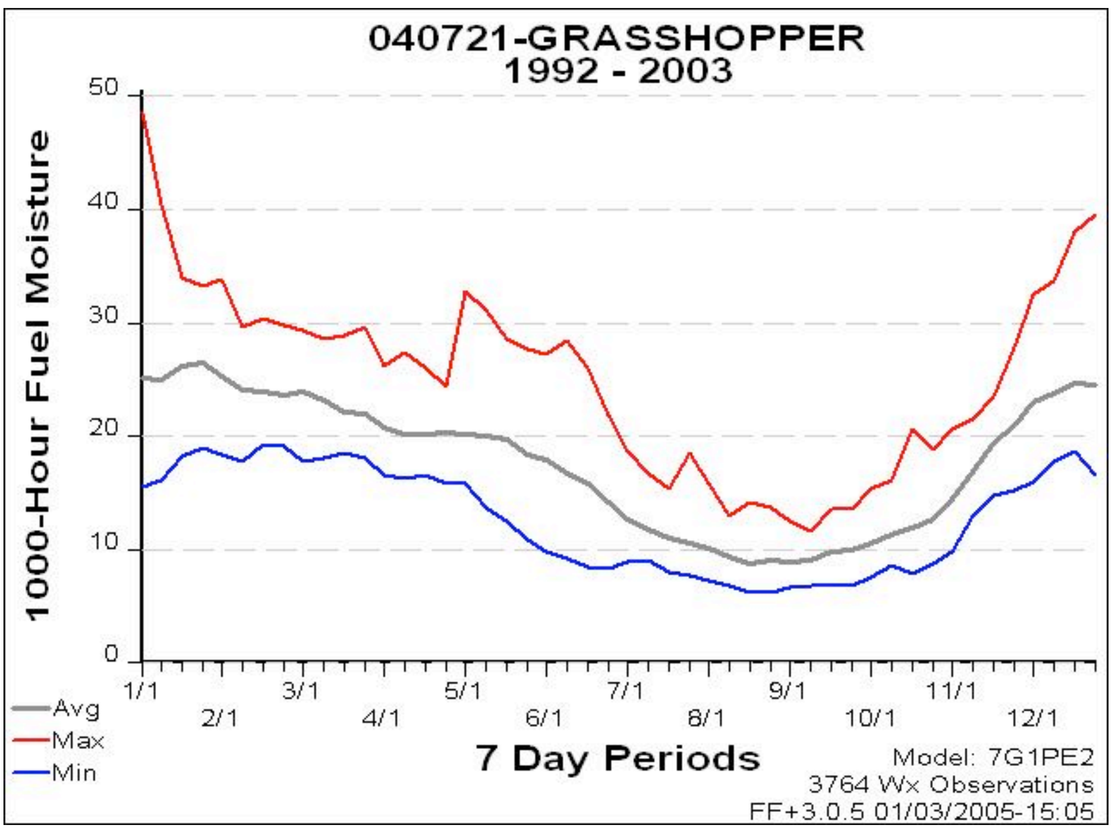

Figure 2.2. Historical maximum, minimum, and average of 1000-hr fuel moistures recorded at the Grasshoppper Weather Station near Susanville, California from 1992 to 2003 (smoothed by seven-day running average) shows the seasonal variability between spring and fall, as well as the inter-annual variability for a given date (USDA 2000).

The link between fuel moisture levels and resultant fire behavior is one of the few well-documented areas of fire research, with numerous fire behavior models built upon the calculations (Andrews 1986, Finney 1995, Finney 2002). Rothermel (1972, 1983) first quantified these relationships, and Anderson (1982) linked weather components such as wind and relative humidity to better describe observed fire behavior. It is surprising, then, that it took so long for the relationships between long-term weather averages and fire behavior (the climate-fuels-fire relationship) to be observed.

Climatic Influences on Wildfire

Wildfire managers have long observed the nuances of weather patterns affecting fire behavior, but the work of Anderson (1982) and Rothermel (1983) initiated the quantification and modeling of weather and fire behavior relationships. A decade later, Swetnam's (1993) work sparked a revolution in the way fire managers thought of the relationship between fire and climate.

It has become evident that much of what drives wildfire severity and size are regional climatic influences. In the United States, the Southwest provides perhaps the most solid example of climate variability influencing wildfire. Here there are links between the seasonal severity and extent of wildfire and the ENSO, PDO, and the North American monsoon. These links are based primarily on the precipitation fluctuations associated with each climatic pattern. For example, fire history and precipitation reconstructions from dendrochronologies have shown that the Southwest experiences region-wide severe fire years corresponding to the occurrence of a La Niña episode in the Southern Oscillation (LNSO), when springs are drier than average resulting in drought conditions (Fig. 2.3). Fire severity is subsequently below-average during the spring-wet El Niño phase of the oscillation (Swetnam and Betancourt 1990). Westerling and Swetnam (2003) indicated that the effects of ENSO on wildfire severity may be dampened or amplified by the PDO, depending on whether it is in the warm or cool phase. Additionally, the southwest sees varying degrees of fire severity associated with the strength and timing of the North American (or southwest) Monsoon, which can induce weekly to monthly drought conditions in years when it brings less moisture to the region (Mohrle 2003).

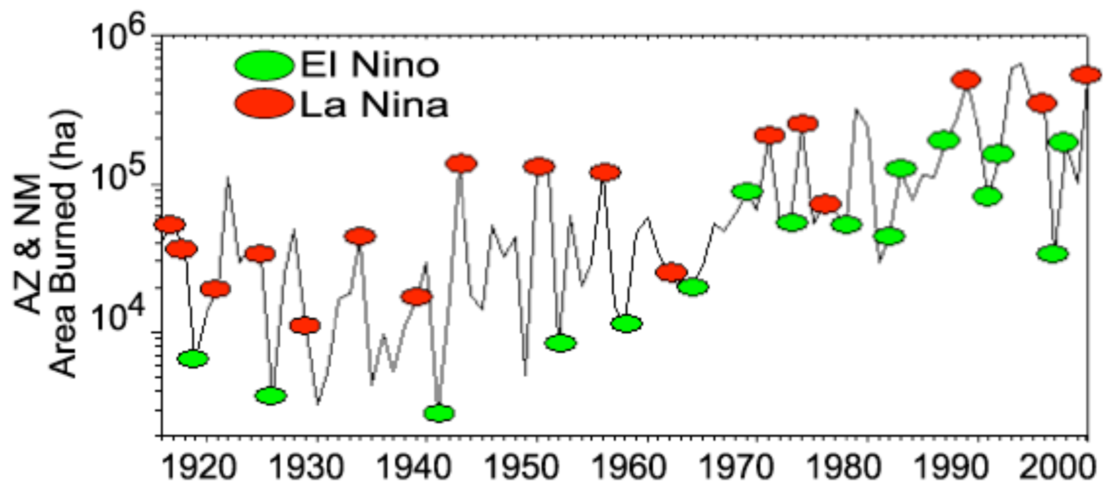

Figure 2.3. Relationship between hectares burned in the southwestern United States and phase of ENSO indicates severe wildfire years associated with La Niña events (Swetnam and Betancourt 1990).

In the northwestern US, the impacts of PDO and ENSO are similar to what occurs in the southwest. Dry summers and drought episodes, here caused by stronger El Niño episodes, and PDO phase shifts usually result in severe wildfire years for the Pacific Northwest, although the correlation between PDO and wildfire is much clearer than between ENSO and wildfire (Hessl et al. 2004). The Florida Everglades and Alaska fire regimes have also been linked to ENSO signals (Beckage et al. 2003, Hess et al. 2001). Drought conditions in the remainder of the western US have not been shown to be the result of ENSO and PDO fluctuations, and instead tend to be localized phenomena, but not necessarily independent of ENSO or PDO. Thus the fire regimes for the Rocky Mountains and Interior West are not strongly correlated to ENSO and PDO, even though they are linked to fluctuations in precipitation causing drought conditions, with severe wildfire years coming in the late stages of severe droughts (Schoennagel et al. 2004).

Climate and Wildfire in the Study Region

In northern California and Nevada, few studies on correlations between climate and wildfire have been published. This likely has some roots in the lack of extensive fire histories for these regions, since fire histories are critical for any kind of climate analysis. In California, Norman and Taylor (2003) found strong links between widespread fire and an El Niño episode, particularly when in connection with the warm phase of the PDO, while Westerling and Swetnam (2003) concluded that California follows the Pacific Northwest climate-fire patterns some years and the Southwest patterns other years. They also noted that at a very coarse scale, drought in California is well-correlated to wildfire via the Palmer Drought Severity Index (PDSI), a standardized drought index. The severe fires in California in 1987 came in the first year of a drought after several consecutive wet winters in the early 1980s led to fuel build-up. Swetnam and Baisan (2003) confirmed this pattern in their Sierra Nevada study, where they separated fire occurrence into extensive fire years and less extensive fire years. Their study indicated that years of extensive fire occurred during a severe drought year after several years of prevailing wetter-than-normal or only slightly droughty conditions, while less extensive fire years occurred the first year after a severe drought year. The widespread fires of 1999 in both California and Nevada were observationally but not quantitatively attributed to drought conditions caused by La Niña: a dry spring followed by a hot, dry summer, ending with a long dry-spell in the fall (NIFC 1999).

In Nevada, the influence of climate on fire season extent and severity is tied to fine fuel production and lightning ignition patterns (Westerling et al. 2003, Hall 1998). Brown and Hall (2000) also noted the occurrence of La Niña during the severe 1999 fire season in Nevada, but concluded that a strong Southwest Monsoon contributed significantly through increased lightning ignitions. This emphasis on current-year conditions (as opposed to multi-year fuel build-up or drought situations in California) may be due in part to the lack of widespread fire history studies in the region (Mensing et al., *in press*), as most of the studies looking at climatic factors in Nevada fire season severity use data sets spanning less than a decade (Hubbard 1985, Knapp 1995, Knapp 1997). This would support suggestions that poor correlations between long-term climatic variability (such as ENSO) and wildfire seasons in California and Nevada stem from drastic land-use changes that have altered fire regimes too rapidly to be influenced by climate in a clear manner (Baker and Shinneman 2004, Keeley and Fotheringham 2003, Keeley 2004).

History of prescribed fire

Long before the United States Forest Service (USFS) and other government agencies began purposely setting fires, native Americans throughout the pre-European continent heavily utilized fire as a tool for a multitude of purposes (Stewart 2002, Vale 2002). While many of the burning practices were small-scale and localized within a village or community, other practices had far-reaching implications on the surrounding landscapes. The Chumash Indians of the Santa Barbara region, for example, annually burned several thousand hectares in the foothills about their piece of coastline; thereby promoting fire-sprouting grass species and keeping the woodier shrub species at bay (Timbrook et al. 1982). On the western slopes of the Sierra Nevada and in parts of Nevada, burning by American Indians promoted favored plant species and, in conjunction with naturally occurring lightning-ignited fires, kept the pine and fir overstory widely spaced and the travel corridors through the understory open and free of brush. Although the extent of these indigenous fires is heavily debated and their full impact on the pre-European landscape will likely never be known, there is sufficient evidence to indicate that human-ignited fire was a factor in the evolution of the ecosystems in the West (Reynolds 1959, Lewis 1993, Anderson 2002, Griffin 2002, Parker 2002, Stewart 2002).

With the arrival of European settlers, the practice of intentional burning continued in many forms. Clearing land for homesteading and agriculture became a priority, as well as slash burning associated with logging practices (Pyne 1997). Not until the close of the 19th century did forest fire suppression, the demise of intentional burning, become a fully organized effort, particularly in the still sparsely-settled west. While some attempts at curtailing burning by settlers were made sporadically by the fledgling USFS, it was the great Northern Rockies fires of 1910 that transformed the USFS from a tree-growing agency into a tree-protection agency (Pyne 1997). As fire suppression became the mission of federal agents throughout the country, small-scale intentional burning was slowly put to death. For the first half of the 20th century, only a few individuals had the foresight to question the policies of total fire suppression. One of these was Harold Biswell, fondly known as “Harry the Torch” for his widespread use of prescribed fire in the oak and pine woodlands of northern California in the 1940s, ‘50s, and ‘60s. Biswell, working for the USFS in the 1940s, participated in the reintroduction of fire via controlled burning into the longleaf pine forests of the southeastern US and saw the benefits of the practice (Biswell 1989). When he moved to the west coast, Biswell took his practical knowledge of fire with him and became a pioneer in the field of widescale controlled burning, although for decades his work was underappreciated by most western land managers (van

Wagtendok 1995). Except for isolated incidents, complete fire exclusion was the mantra of land managers until the early 1960s.

The first attempts at reversing the total exclusion of fire came on the heels of the Leopold Report of 1963 and the Wilderness Act of 1964, which described the need for fire as part of a natural wilderness ecosystem. By the mid-1970s, the National Park Service (NPS) was allowing lightning-ignited fires to burn throughout its parks, the so called “let-burn” natural fire, and the USFS had followed suit and reintroduced prescribed burning in the national forests. Catastrophic wildfires periodically reminded land managers that prescribed fire use allowed them to reduce the undergrowth and maintain healthier stands of trees, thereby decreasing the threat from wildfire. In 1988, however, prescribed fire policies were dealt a severe blow when almost half of Yellowstone National Park burned as a consequence of the “let-burn” policy. The fiery images splashed across American television by the media effectively shut down “let-burn” practices and severely hampered prescribed fire use, despite the eventual understanding that the fires had been necessary to Yellowstone’s ecosystem (Pyne 1997). It might have been the end to the prescribed fire experiments, but for a new type of catastrophic wildfire that emerged in the 1990s: the Wildland-Urban Interface (WUI) fire.

With communities reaching further into the forests, proponents of prescribed fire saw its potential for a new category of forest management: hazardous fuels reduction. This became a particular focus for the USFS and the Bureau of Land Management (BLM), whose holdings often checkerboard private lands and communities at-risk of wildfire. NPS, however, continued to embrace the policies of returning fire to its natural role in the ecosystem. When an NPS prescribed fire near Los Alamos, New Mexico escaped control and eventually took 235 homes and forced 18,000 people to evacuate, prescribed fire policies suffered another blow. Unlike the response to the 1988 Yellowstone fires, however, there was little talk of abandoning prescribed fire programs completely. This time the push was to understand prescribed fire behavior better so as to avoid future catastrophic escaped prescribed fires (Babbitt 2000). The 2001 review of the Federal Wildland Fire Management Policy supported prescribed burning for fuels treatments and described the need to further implement controlled fire programs on federal lands. It also described the need for further scientific research supporting prescribed fire implementation (USDI 2001b). While much research has been geared towards fire effects and smoke management, little has addressed the issue of escaped prescribed fires, and the potential role that climate variability plays.

Escaped Prescribed Fires

While the Yellowstone fires of 1988 may have captured the national spotlight as a fire management decision gone wrong, one of the first major escaped prescribed fires had occurred eight years earlier, on the Huron National Forest in Michigan. The Mack Lake Fire of May 1980 consumed 9,600 hectares and 44 structures, and also caused one fatality. The review team noted that the Palmer Drought Severity Index (PDSI) value for the month was only -1.17, a fairly insignificant moisture deficit. They also noted, however, that they were unable to take fuel moisture samples immediately following the fire due to a light rainfall, (showing their lack of concern for 1000-hr fuel conditions, which would not have been much affected by a light rain). They concluded that the event was driven by a low-pressure cold front moving into the region at a time when the prevalent fuel, jack pine, was phenologically experiencing its annual low fuel moisture level (Simard et al. 1980).

The Yellowstone fires were wildland fire use fires (WFU), and not truly prescribed fires, but they brought public attention (and outrage) to the use of fire as a management tool, and temporarily derailed the prescribed fire program as a whole for several years. Yellowstone had both a severe fuels build-up and a severe drought situation on its hands in 1988, and the fire management's lack of recognition of the situation was cited as being a factor for the severity of the damage (Pyne 1997).

The early 1990s is marked by a period of fewer prescribed fires, and also a period of fewer escapes. In 1998, however, the National Interagency Fire Center (NIFC) standardized its national prescribed fire tracking system (prescribed fire had previously been administered regionally), and also developed several checklists and guides for prescribed fire managers. One of these, a list of "Watch Out," or danger, situations for prescribed fire use, acknowledged that managers should be aware of drier than normal fuels or heavier than normal fuel loads, but did not note that drought or other aspects of climate variability may play a role.

The Pahcoon escaped fire in 1998 was neither large nor destructive, but it is noteworthy because it is one of the few escapes that was attributed to excess moisture instead of drought conditions. The Bureau of Indian Affairs (BIA) conducted the burn in late June in southeastern Utah, an area that received above-average spring precipitation in 1998. For this particularly arid region, the moisture surplus contributed to higher-than-normal fuel loading of the annual invasive cheatgrass (*Bromus tectorum*), and the inexperience of the burn boss in this fuel type contributed to his failure to recognize the potential for extreme fire behavior (USDI 1998).

The Lowden Ranch escaped prescribed fire occurred near Redding, California, in July of 1999. What was scheduled as a 40-hectare prescribed fire eventually burned over 400 hectares and 23 homes. While the BLM reviewers found many factors for the escape, most of them procedural, they did analyze the environmental conditions under which the fire was ignited and found them to be at or near historical maximums. Although the region was suffering only a mild drought, the long-term climatic averages indicated that fuels would be much drier, and more available to burn, than normal. The Lowden Ranch Fire was a severe blow to California BLM prescribed fire use, and an example of manager non-use of historical climate data contributing to an escaped fire (USDI 2000).

The severe year 2000 fire season was also a notable year for escaped prescribed fires, particularly in the southwestern US. While the Cerro Grande fire in New Mexico captured the national spotlight at the beginning of May, two escaped fires in neighboring Arizona occurred under similar conditions to Cerro

Grande. The EB-3 escape preceded Cerro Grande by three weeks and should have been a warning for prescribed fire managers in the southwest. Occurring on BLM lands in the Arizona Strip north of the Grand Canyon, the top causal factor noted by reviewers in the EB-3 escape was the extended drought that plagued the region, and the failure of fire managers to adjust for this in their prescribed fire operations, despite high fire danger indices (USDI 2000b). Overshadowed by the Cerro Grande Fire, and due partly to the lack of resources which were sent to New Mexico to fight it, the Outlet prescribed fire was declared an escaped wildland fire on May 10. Again, reviewers noted the drought conditions, and particularly the moderate to severe rating of the PDSI for the period (USDI 2000c).

The Cerro Grande Fire, of course, overshadowed every other escaped prescribed fire since the 1988 Yellowstone Fires. The cost of the escape also prompted two very different commentaries on prescribed fire use. An editorial in the *Wall Street Journal* not only blasted NPS policies on prescribed burning, it suggested that the entire federal approach to fire management should be one of complete fire suppression, dropping fire use altogether. Such an approach would revert to policies that federal agencies have recognized since the 1950s is not sufficient for managing fire-adapted landscapes (Morrison 2000). A more scientific understanding of the problem was presented by Swetnam (2000) in his testimony to the House subcommittee of Forests and Forest Health at the height of the 2000 fire season. He specifically noted that incorporating “broad-scale perspectives of regional conditions and climate patterns” into prescribed fire planning and implementation might have prevented the Cerro Grande Fire, and is vital to preventing future escaped prescribed fires, because prescribed fire is a critical tool in management of fire-adapted ecosystems.

Despite the lessons learned in spring of 2000, and the observations by Swetnam and others (Brown and Betancourt 1999) that climate variability information needs to be incorporated in prescribed burning, escaped fires continued to occur. In October of 2000, BLM in Nevada experienced an escaped fire east of the state capitol in Carson City. One of the contributing factors noted by the review team was below-normal fuel moisture levels, although the team did not specifically cite a drought (USDI 2000d). Since the prescribed fire plan had been written in 1996 and the prescribed fire did not occur until 2000, the change in fuels over three years should have been expected and incorporated into the prescribed fire plan.

The spring of 2002 produced another notable escaped prescribed fire, primarily for size, but also for public reaction. The Sanford Fire burned 31,500 hectares on the Dixie National Forest in Utah after two prescribed fires escaped and burned into each other. Again, one of the contributing factors for the escape was the drought situation, which reviewers noted had the effect of turning what was normally a natural fuel break (with high fuel moistures making fuels unavailable to burn) into a continuous bed of available fuel. Despite the fairly recent memories of the Cerro Grande Fire, the residents of nearby communities noted that the escape succeeded in burning fuels that they had been afraid would feed a large, destructive wildfire during hot and dry summer conditions, and they encouraged USFS to continue with the prescribed fire program (USDA 2003).

Finally, the Blanco escaped fire in Albuquerque, New Mexico, in 2003 served to remind southwest region fire managers that the drought continued to persist. The reviewers once again noted specifically that fire managers had failed to take the drought into consideration and adjust their expectations for fire behavior accordingly. The result was that large, 1000-hr fuels burned more severely than expected and caused fuels to burn outside the maximum boundary set in the prescribed fire plan (USDI 2003b). This escaped fire was minor, but served to show that fire managers were still not listening to recommendations concerning climate variability influences on fuels and prescribed fire.

While only the more notable escaped fires are discussed here, they display a common problem in lack of recognition from fire managers about climate patterns and their impacts on fuels. Not discussed in this review are the pages of policy-related mistakes, basic safety violations, and weather phenomena that also contribute to escaped fires. These additional factors serve to show the complexity of prescribed fire use, an important point to remember when analyzing just one component of the equation, as I am doing with climatic variability.

CHAPTER 3

SOCIAL ASSESSMENT OF PROBLEM

If the claims of the escaped fire reports are valid, and failing to use climate information in prescribed fire planning and implementation is a factor in escaped fire occurrence, then we would expect to find a significant difference in the amount and types of climate information used by fire managers who have not experienced escaped fires. The fire managers who have not experienced escaped fires we will identify as “non-escape” for this analysis, while those fire managers who have experienced escaped fires will be identified as “escape.”

Study Region

Escaped prescribed fires are particularly troublesome for fire management programs that have a tenuous existence to begin with, and one region of the country that embodies this problem particularly well is the Sierra Nevada and surrounding areas. California has one of the worst Wildland Urban Interface (WUI) problems in the country, demonstrated in a terrific manner during several wildfire events over the last decade (i.e. 1991 Oakland/Berkeley Hills Fire, 1993 southern California fire siege, 1996 Malibu fires, 2003 southern California fire siege). It has also experienced the most escaped prescribed fires of any state in the country for the period between 1970 and 2002, with 20% of the national total. While the National Park Service (NPS) accounts for 77% of these escaped fires, the US Forest Service (USFS) in California also leads the nation in the number of escaped fires for that agency (Fig. 3.1), doubling the number of escapes of second-place South Carolina, and takes second behind Utah for total acreage burned by escaped fires (and only because the 2002 Sanford escaped prescribed fire makes up most of Utah's total).

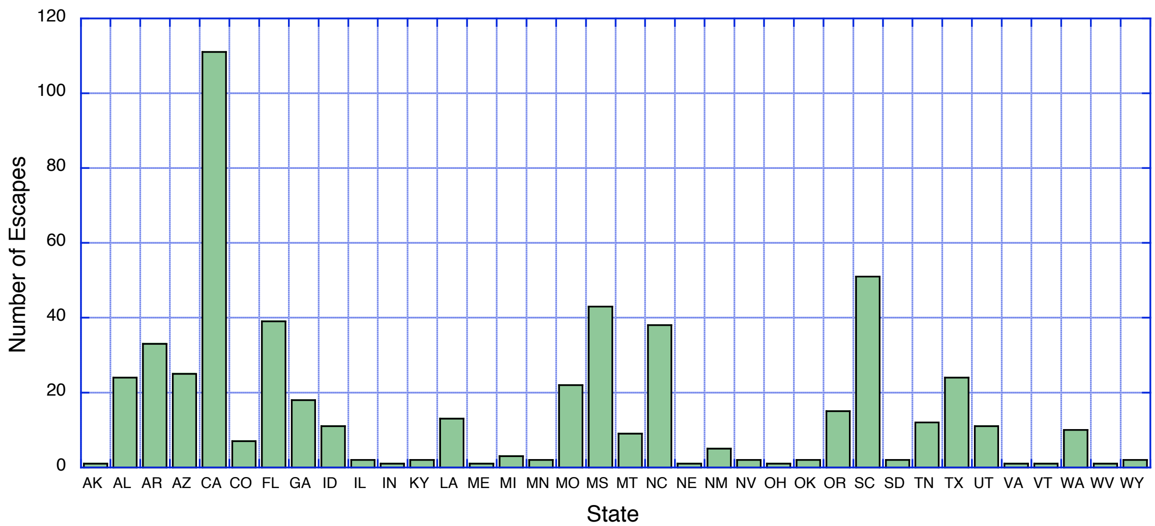

Figure 3.1. The number of USFS escaped prescribed fires by state from 1970-2002 shows that California surpasses all other states by more than twofold.

Nevada, while far less populous than California and having very few escaped fires in its history, has an ever-expanding WUI region along the eastern Sierra Nevada front and the largest percentage (87%) of land managed by the federal government in any state. Due to population booms and recent catastrophic wildfire years, fire managers in both states are being pushed to treat more area with prescribed fire, yet a five-year average of area burned from 1999-2003 indicates that the states still account for only three percent of prescribed fire use nationwide (Kolden, unpublished data), despite signs that more fire use is needed. A 2000 analysis of fire regime instability (Hardy et al. 2000) indicated that much of this region has fire adapted-vegetation and has missed one or more fire return intervals due to fire suppression, leading to ecosystem conditions that are far removed from historic conditions (Fig. 3.2). While increased prescribed fire use is not the only way to manage fuels build-up and restore healthy ecosystems conditions, it is one of the best management tools from an ecological standpoint because it is a natural part of landscape.

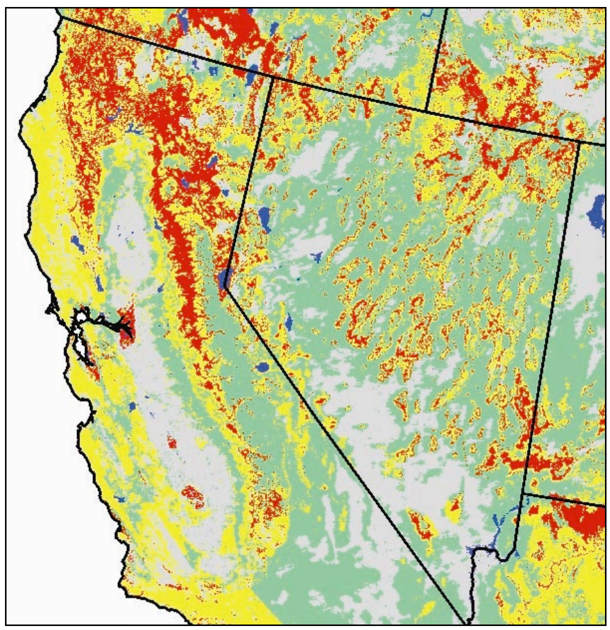

Figure 3.2. The Fire Regime Condition Class (FRCC) conditions for the study region as of 2000 (from Hardy et al.) Green regions are still within historic limits, yellow are slightly removed from historic conditions (missing one fire return interval), and red are completely removed from historic conditions (missed more than one fire return interval and often have species conversion).

Escaped fires in the study region are particularly troublesome because of extensive WUI boundaries, and the checkerboard land ownership that makes an escape onto privately-owned lands that much more probable. The Lowden Ranch escaped fire of 1999 made it difficult for BLM to utilize prescribed fire in northeastern California due to public backlash, even as the USFS implemented prescribed fire only a few miles away. Sierra Pacific Industries, the largest private landholder in California, has set prescribed fires in recent years that escaped onto USFS land and cost the federal land managers time, money, and public trust (http://yubanet.com/graniteville.shtml). Looking at this study region, minus the complex and problematic Transverse Range of southern California, will allow us to begin understanding how climate information can be used to aide prescribed fire use in this region and prevent future escaped fires.

The Hypothesis

Since the escaped prescribed fire reports indicate that fire managers in charge of prescribed fires that escape (the ‘escape’ managers) failed to account for drought conditions, we should assume that they failed to use the climate information that would have notified them of “dangerous” drought conditions and fire danger in general. It should be noted that not all drought events are dangerous, as some prescribed fires must be conducted under drought conditions to meet ecological objectives (this is frequently the case in US Fish and Wildlife Service prescribed fires). If we are trying to determine whether this is the critical broken link in the prescribed fire planning and implementation process, we need to determine that ‘non-escape’ fire managers do use this climate information at significantly different rates than ‘escape’ managers. This constitutes my hypothesis.

H_0: There is a significant difference between ‘non-escape’ and ‘escape’ fire managers in terms of the type and amount of climate information they use for prescribed fire planning and implementation ($p \leq 0.05$).

H_a: There is no significant difference between ‘non-escape’ and ‘escape’ fire managers in terms of the type and amount of climate information they use for prescribed fire planning and implementation ($p > 0.05$).

Methods

To determine the type and quantity of climate information fire managers use, and also to determine how many fire managers have been in charge of escaped fires, a survey was created and administered in the spring of 2004. Federal fire managers were selected in a non-random manner and interviewed over the telephone. Detailed information on survey methods and survey data are found in Appendix B.

Of the 92 fire managers surveyed from California and Nevada (Fig. 3.3), 40 answered that they have not experienced an escaped prescribed fire event in the last 15 years, and were classified ‘non-escape.’ The remaining 52 managers surveyed were deemed the ‘escape’ group. Out of the 33 questions asked in the survey, four questions asked respondents directly if they used different types and amounts of climate information in their planning and implementation of prescribed fires (Table 3.1). The number of ‘yes’ responses for each question alluded to the number of respondents who use that type of climate information, and these were transformed into proportions of all answers for each group ('non-escape' versus 'escape' managers) (Table 3.2). For non-binary questions (for example, Question 6), answers were stratified into climate-related and unrelated answer counts. To determine if there was a significant difference between the two groups of proportions, a paired t-test was utilized. In addition to the paired t-test, the paired proportions were plotted on a scatter plot and a linear regression equation was created to assess the correlation between the two groups. Residuals from this regression line were analyzed to see which questions produced the most different answers between the two groups. Chi-squared analysis was utilized to examine other survey questions not relating to use of climate information that might better explain the results of the hypothesis test. The results of the chi-squared analysis are found in the discussion section.

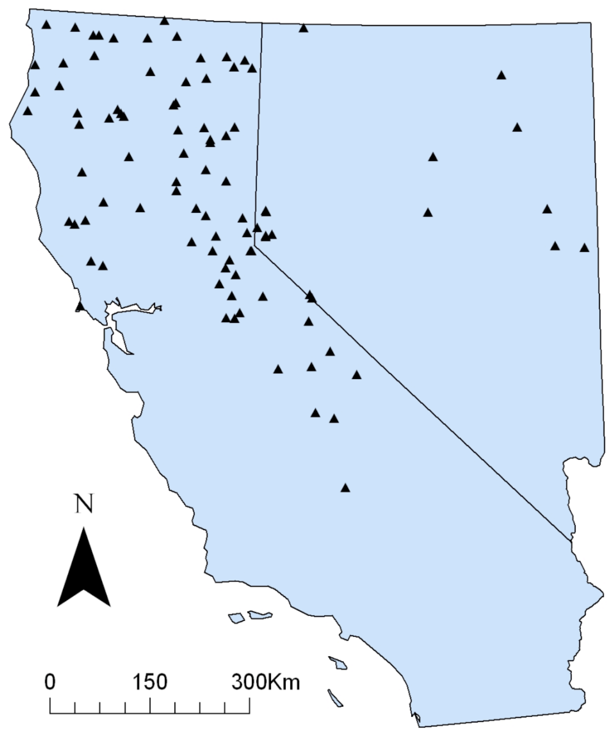

Figure 3.3. Locations of survey respondents indicate that responses are heavily weighted towards California fire managers. The response rate, however, was approximately the same for both states (estimated 90%) as Nevada respondents manage higher area per person.

Question Number	Description of Question (please see Appendix B for full survey and terminology)
6	Asks respondents to rank the factors that affect the annual treatment targets they set. Potential responses include funding, permitting, public input, previous treatments completed, weather information, climate information, seasonal climate forecasts, and an ‘other’ option. Top three rankings were assessed, and selections of ‘climate information’, or ‘seasonal climate forecasts’ were considered uses of climate information for the proportion analysis.
10	Asks respondents to select all of the indices, databases, and other sources of climate information that they use in monitoring conditions, planning, and implementing prescribed fire. Choices include RAWS data, seasonal climate forecasts, seasonal severity maps, NWS data, KBDI, PDSI, NDVI, SPI, US Drought, SWSI, NFDRS, VCI, ECPC, Predictive Services, Historical Data, FF+, WIMS, NIFMID, Haines, and ‘other’. Each choice was considered separately; proportions reflect “yes” answers.
11	Asks respondents how much RAWS or historical weather data they use prior to a prescribed fire, giving them an example for reference. Choices include less than a week, a week to a month, 1-3 months, 3-12 months, 1-2 years, more than 2 years, and don’t use this type of data. Answers of less than 3 months were considered “no” answers for proportion testing, answers of 3 months or more were considered ‘yes’ answers.
19	Asks respondents if they measure on-site 1000-hr fuel moisture prior to a prescribed fire. Proportions reflect ‘yes’ answers.

Table 3.1. Questions that survey respondents answered pertaining to the use of climate information in prescribed fire planning and implementation, and the manner in which answers were transformed to binary “yes/no” responses.

Question	'Non-escape' (% of 40)		'Escape' (% of 52)	
	"Yes"	"No"	"Yes"	"No"
Q6- #1	0.0	100.0	0.0	100.0
Q6- #2	5.0	95.0	3.8	96.2
Q6- #3	10.0	90.0	11.5	88.5
Q11	5.6	94.4	15.7	84.3
Q19	37.5	62.5	44.2	55.8
Q10-Raws	92.5	7.5	98.1	1.9
Q10-Seasonal Climate	37.5	62.5	40.4	59.6
Q10-Seasonal Severity	22.5	77.5	19.2	80.8
Q10-NWS	80.0	20.0	94.2	5.8
Q10-KBDI	17.5	82.5	5.8	94.2
Q10-PDSI	35.0	65.0	21.2	78.8
Q10-NDVI	2.5	97.5	5.8	94.2
Q10-SPI	2.5	97.5	5.8	94.2
Q10-USDrought	15.0	85.0	11.5	88.5
Q10-SWSI	0.0	100.0	0.0	100.0
Q10-NFDRS	57.5	42.5	59.6	40.4
Q10-VCI	10.0	90.0	3.8	96.2
Q10-ECPC	0.0	100.0	0.0	100.0
Q10-PS	58.1	41.9	67.3	32.7
Q10-Historical	55.0	45.0	46.2	53.8
Q10-FF+	47.5	52.5	48.1	51.9
Q10-WIMS	30.0	70.0	32.7	67.3
Q10-NIFMID	0.0	100.0	1.9	98.1
Q10-Haines	20.0	80.0	15.4	84.6

Table 3.2. Percent of respondents who answered 'yes' and 'no' to each question about using climate information for both the 'non-escape' and 'escape' manager groups.

Results

A paired t-test evaluating the two proportion datasets produced a p-value of 0.736 (degrees of freedom [d.f.] = 23). Since the hypothesis calls for a maximum p-value of 0.05, we can reject the hypothesis that the two groups of proportions are significantly different.

The similarity between how the two groups of fire managers use climate information is most evident in a scatter plot of the paired proportion values including a regression line (Fig. 3.4). The slope of the regression line ($y=1.068x - 0.014$) indicates an almost 1:1 relationship between the two groups, and a high correlation value was produced ($R^2= 0.953$). There are no evident outliers, and, more importantly, there are no points at all on the plot that support the hypothesis that non-escape fire managers use climate data differently than escape fire managers. Points that support this hypothesis would have been located nearer to (0,1) or (1,0). Another noteworthy feature of the scatter plot is that only two points are located near (1,1), with most of the points clustered nearer to (0,0), indicating that most respondents answered ‘no’ to questions about climate information use. That the pairs of proportions are so linear, and the slope so near 1.00, indicates that we can not only reject the hypothesis, we can reject it soundly.

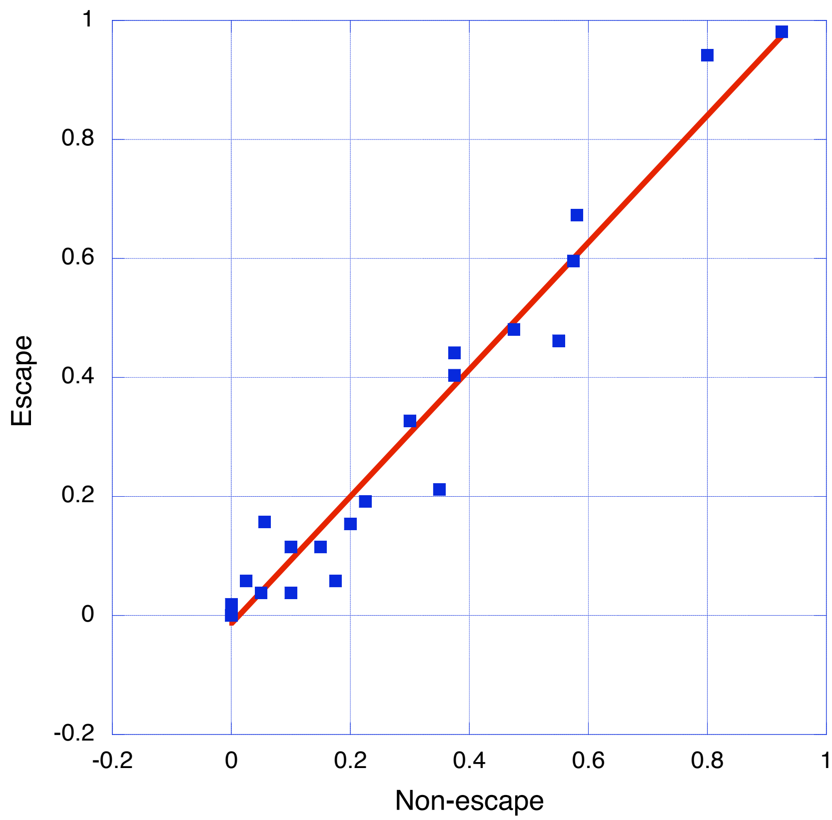

Figure 3.4. Linear regression correlation of 'non-escape' versus 'escape' proportions of managers who answered affirmatively in questions regarding the use of climate information.

Discussion of Hypothesis

What is perhaps most remarkable about the survey results is not merely the lack of significant difference between how much climate information each group uses, but that prescribed fire managers do not use much climate information in general. In Question 6, not a single respondent ranked climate information as the number one or two influence on the acreage targets they set, and only a handful ranked it third. Only 10 fire managers use more than three months worth of Remote Automated Weather Station (RAWS) or historical weather data to assess conditions before a prescribed fire (Question 11), meaning that the vast majority have no quantitative basis for determining how severe conditions are compared to normal. The only two indices/tools from Question 10 that had over a 75% use-rate by managers (the two points closest to [1,1] on the scatter plot) were RAWS data and National Weather Service forecasts, and the latter is *required* for all state and federal prescribed fires.

The development of user-friendly climate indices and information networks to disperse information to fire managers has led to widespread use of climate variability information in the wildland fire suppression effort, but despite the dual roles that many prescribed fire managers play in wildland fire suppression each fire season, use of climate variability information does not seem to transfer to prescribed fire use. While 77% of fire managers surveyed thought that climate variability has some impact on their prescribed fire program (Question 27), only a small percentage use indices that track this variability (Fig. 3.5). Only 41% of respondents track 1000-hr fuel moistures, the primary fuels that are affected by long-term climate variability. While 92% of respondents use either RAWS or other historical weather data prior to a prescribed fire to track conditions, only 12% of these use more than three months of data, meaning that they are tracking weather, 1-hr, and 10-hr fuel conditions. Only 8% of those respondents that use RAWS or historical data use more than two years of data. In the Cerro Grande Fire Investigation report, the investigators noted that if the prescribed fire managers had merely analyzed six months worth of historical data, they would have identified the extremity of the drought situation under which they were attempting to conduct the prescribed fire (USDI 2001).

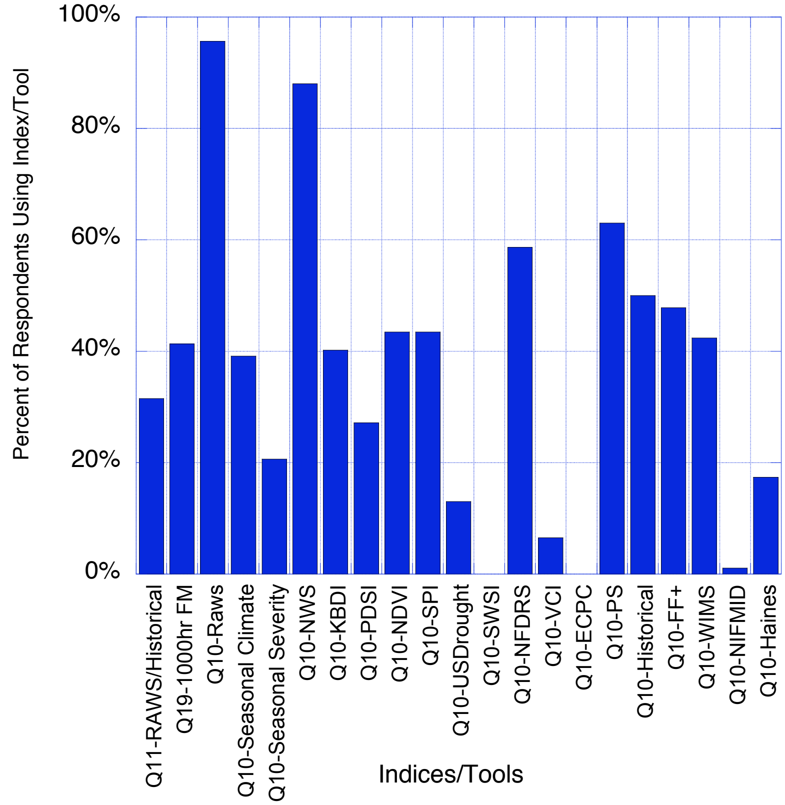

Figure 3.5. Percent of survey respondents who indicate that they use each source of information on climate variability. Extremely low use rates prevailed, with only three sources of climate information having over a 50% use-rate: RAWS data, NWS forecasts (required), and Predictive Services.

Other climate indices have low use rates as well. While 59% of respondents utilize the National Fire Danger Rating System (NFDRS), the primary climate analysis software programs taught to fire personnel in their agency courses, only 27% use PDSI to assess their current drought situation, and a mere 9% use KBDI. Both of these indices are heavily discussed in fire danger outlooks, seasonal fire danger forecasts, basic firefighter training and refresher sessions, and other materials that fire managers receive both in spring training and throughout the year from NIFC and the individual agencies. Only 4% of respondents use SPI, while 13% use the US Drought Monitor, although both of these indices are less favored by the fire community. It is easily argued that these indices are coarse-scale and do not apply to certain climate regions, or that fire managers use one index but not the others and the figures represent this split, but 13% of respondents do not utilize any of the tools available for tracking climate variability and associated fire conditions (drought indices, NFDRS, and historical weather data). An additional 4% use only NFDRS, and none of the other indices.

All of this indicates that perhaps the problem is not that the group of escape prescribed fire managers failed to use climate variability information, but that prescribed fire managers in general fail to use climate information. Since NIFC has pushed for more climate information to be available to fire managers in recent years, why are they not using it? One potential problem is in obtaining the information. Fire managers primarily get climate information from four sources: the internet, nationally accessible databases (such as WIMS data), NWS, and the interagency group Predictive Services. When respondents were asked how difficult it is for them to acquire climate variability information, 37% indicated that it was medium or difficult, while 55% indicated that it was easy to find what they were looking for. Respondents were also asked to rate the information they received from NWS and Predictive Services, since these two agencies are responsible for fire danger forecasting and providing interpretation of changing weather and climate conditions in terms of fire and fuel conditions. For Predictive Services, 55% of respondents felt that their data needs were met by the agency, but 14% of respondents said that they do not use Predictive Services at all. NWS faired far worse, with only 39% of respondents satisfied with the services provided and 22% indicating they do not use NWS at all, despite the federal mandate that prescribed fire managers obtain a NWS spot weather forecast prior to every prescribed fire (NWCG 2002).

Another potential reason why fire managers do not utilize climate information in prescribed fire planning is a conflict in the support infrastructure for prescribed fire. Question 6 queried respondents on how they set their annual acreage targets, asking them to rank the factors which most influence their prescribed fire goals for the upcoming year. The top influence on acreage targets was funding availability, with 37% of respondents denoting funding as the primary control on their targets and 33% ranking it as a secondary influence. Another major influence on acreage targets was the permitting process, with 17% of respondents ranking permit acquisition the top influence, and an additional 32% marking it their second-most influential factor. While other factors such as staff sizes, fire suppression resource availability (both human and equipment), public input, and the weather all weighed in as having minor impacts on the prescribed fire targets set by managers, climate variability information was not listed as a primary influence by a single respondent. Only 5% of respondents ranked it as the second influence, and 16% ranked it as a third influence.

Since funding for fire management, like most federal programs, is annually reviewed and designated, there is little flexibility for the variability in prescribed fire use conditions that climate patterns bring. Brown and Betancourt (1999) noted that there is much variability from year to year, and prescribed fire managers need to monitor climate variability to take advantage of prime conditions when they arise, and to reduce their prescribed fire use in years when conditions are marginal and the possibility of escaped fires is high (such as in 2000). The federal land management agencies, however, evidently continue to push prescribed fire managers to burn as much as they can with existing dollars each year, or risk losing funding for the next year. Many survey respondents called this a “use or lose” policy that rewards managers who have optimal environmental conditions or take a lot of risks.

The infrastructure’s inability to support prescribed fire under climatically variable conditions is further evidenced by two other questions answered by respondents. Question 9 acknowledged that several years often pass between when a prescribed fire is planned and when it is finally completed, and asked respondents to identify the primary reason why it takes so long to complete the prescribed fire. Sixty pecent of respondents selected answers not relating to climate variability; with air quality regulations, environmental permitting, staffing shortages, logistics problems, and lack of support from superiors being the most frequent responses. Only 7% of respondents specified a long-term drought or overly wet period as the reason they could not burn, and the remaining 34% said they could not get the “burn window” they sought, which is more weather-related than climate-related but can be a side effect of a long-term climate pattern such as drought.

Question 20 assessed reasons for last-minute postponements or cancellations of prescribed fires. When asked why they most frequently have to terminate a planned prescribed fire for the day, 42% of respondents cited non-weather related causes such as lack of personnel or a superior's decision not to proceed, a further indication of poor infrastructure support for prescribed fire use. Of these, 77% cited air quality regulations as the reason they could not proceed with their prescribed fire, and 21% did not have the personnel and equipment necessary. An additional 27% said that they were "out-of-prescription," meaning that at least one component of their prescribed weather and fuel moisture parameters was not met. While prescription parameters once again can have some links to climate variability, a last-minute cancellation more likely indicates poor forecasting which had originally put conditions within prescription parameters.

What the answers to Questions 6, 9, and 20 indicate is that we should not be surprised that so few fire managers utilize climate variability information in their prescribed fire planning and implementation. The current infrastructure for prescribed fire use pushes fire managers to plan prescribed fire use for the coming year based not on climatic conditions, but on an annual funding scheme that rewards completing as much prescribed fire as possible. Furthermore, even when fire managers have optimal climatic conditions to use prescribed fire, they are evidently hindered by a lack of personnel and equipment resources, by air quality and other environmental restrictions (i.e. bird nesting periods), and by poor weather forecasting.

The rejection of the hypothesis initially seems to indicate that the escaped fire reports are not exactly correct in blaming fire managers for not using climate information. There is, however, quite a bit of potential error associated with this assumption. The manner in which prescribed fires are declared escaped, the method of defining non-escape and escape fire managers, the low percentage of fire managers in general who utilize climate information, and the difficulty they have in obtaining usable climate information should all be examined further before conclusions about climate information use and escaped prescribed fires can be made.

A review of the literature reveals vague criteria for declaring that a prescribed fire has “escaped” and become a wildland fire. The primary resource used for prescribed fire planning states it thus:

> *“A Prescribed Fire becomes a wildland fire when the Prescribed Fire Burn Boss determines that an escape has, or is likely to occur, or environmental conditions and/or fire behavior exceeds the parameters in the prescribed fire plan and as such, the fire is no longer meeting the identified management objectives.”* (USDI 1999)

Of the 52 fire managers who were identified as having had an escaped prescribed fire in the last 15 years, less than 10 have been associated with the type of large, destructive escaped fires that make the news. Many escapes are declared as such because the fire moved onto adjacent private lands; an automatic qualifier for an escape according to federal agencies. Some “escapes” in California are not actually related to excess combustion of fuels on the land, but violation of air quality regulations. This loose definition of an escaped fire means that all escapes are not created equal, and the 52 fire managers who have experienced an escape could better be described as falling under a wide range of the label “escape.” This study may not actually be looking at non-escape and escape prescribed fire managers, but instead looking at those who have never had an escape, those who have had to declare a prescribed fire escaped due to a technicality, and those who have experienced a large-scale escaped fire that was truly due to error in judgment or lack of using climate information. Since fire managers were not asked details about the escaped fire they experienced, those determinations cannot be made here.

Another source of error associated with the labeling of non-escape and escape managers is the time span they were asked to recall. Many of the fire managers who experienced escaped fires mentioned off the record that these events were more common in the late 1980s and early 1990s, when more prescribed fire was used in conjunction with logging sales. It is entirely possible that a fire manager may have experienced an escape 10 years ago, and since then has become much more aware of climatic variability and its influence on fuel conditions, perhaps even as a result of the escape. This would alter the results of the study, but the survey questions do not provide information that allows assessment of whether or not fire managers were using climate data at the time of their escaped fire.

The Use of Climate Information

The results of the hypothesis test indicate that there is no significant difference between prescribed fire managers who have had escaped fires and those who have not in terms of the type and amount of climate variability information they are using, but a review of the classification methods and the data indicate a slightly different story. It is difficult to classify fire managers as non-escape or escape based on whether they have had an escaped fire unless more details about the escape are known, and fire managers would need to be surveyed immediately following the fire to determine if they were using climate information in their planning process, which is essentially what escaped fire investigators do. What is evident, however, is that prescribed fire managers overall are not using climate information at high rates, which may be a validation to some extent of the escaped fire reports. Respondents indicated that if they do utilize historical trend data or other types of indices, the information is used in limited quantities, and rarely incorporates multi-year trends. Part of the reason for this may be the difficulty respondents have in obtaining useful climate data from the two agencies primarily responsible for providing it to the fire managers. Additionally, data indicates that many regulations not related to climate hinder fire managers from using prescribed fire during climatically optimal periods, which may discourage them from even trying to utilize climate information. This raises an interesting question, however: does it even matter? Are escaped prescribed fires correlated to climate, as the escaped fire investigation reports suggest, or is there no evident correlation between climate and escaped fire? If there is no evident correlation between climate and escaped prescribed fires, it might help to explain why prescribed fire managers do not use very much climate information, since the results show that they see short-term weather conditions affecting prescribed fire use more than long-term climate conditions. These questions are addressed in the next two chapters.

CHAPTER 4

ESCAPED FIRES AND CLIMATE

If we reject the hypothesis that 'non-escape' fire managers use climate data more effectively than 'escape' fire managers, and the use of climate information by fire managers in general is shown to be minimal, it is important to establish whether escaped fires are, in fact, linked to climate. Although fire managers do not use climate information in prescribed fire use, is there a link between probability for escaped fires and climate conditions? If escaped fire occurrence is not linked to climate, we would expect escaped fire occurrences to be completely random regardless of climate variability trends, and that escaped prescribed fires do not occur under significantly different conditions than all other non-escaped prescribed fires. While the simplest way to test this theory would involve comparing escaped fie occurrences to a larger prescribed fire data set, no such data set exists. While escaped fires have been tracked for over 30 years at the federal level, prescribed fire use has been tracked in a consistent manner at the federal level for only the last seven years, since 1998. Prior to this time, the use of prescribed fire was a matter of concern only at the local office level, and many offices tracked only how much money was spent, not how many prescribed fires or acres were completed. Thus, escaped prescribed fires can only be assessed for correlation to climate outside of the context of all prescribed fire use.

Data

Once a prescribed fire escapes, it becomes a wildland fire and is tracked as such by the National Interagency Fire Center (NIFC). A quality control (QC) analysis performed by Brown et al. (2002) on the NIFC federal wildfire data base for 1970-2001 consolidated federal wildfires for five land management agencies: the US Forest Service (USFS) in the Department of Agriculture, and the Department of Interior's Bureau of Indian Affairs (BIA), Bureau of Land Management (BLM), National Park Service (NPS), and Fish and Wildlife Service (FWS). It also removed duplicate fire records, and records that had critical information missing (such as the date of the fire) or had location coordinates that were not possible fire locations (such as in the Pacific Ocean). Approximately 10% of USFS records and 29% of DOI records were removed. The wildfire database was culled to create an escaped prescribed fire database for this study. Each wildfire in the database has a cause associated with it, and wildfires marked as escaped prescribed fires (ignition source #17 in the NIFC reporting system) were selected for the escaped fire database. The limitations of this database are, therefore, associated primarily with the original QC analysis performed on the entire wildfire database, which may have removed some records of escaped fires if they did not meet QC criteria. One example of this is the Lowden Ranch Fire discussed earlier, which does not occur in the escaped fire database because of a problem associated with the original wildfire record. Finally, a GIS overlay was used to map and separate the escaped prescribed fires into the eight climate divisions that encompass most of the study area (Fig. 4.1).

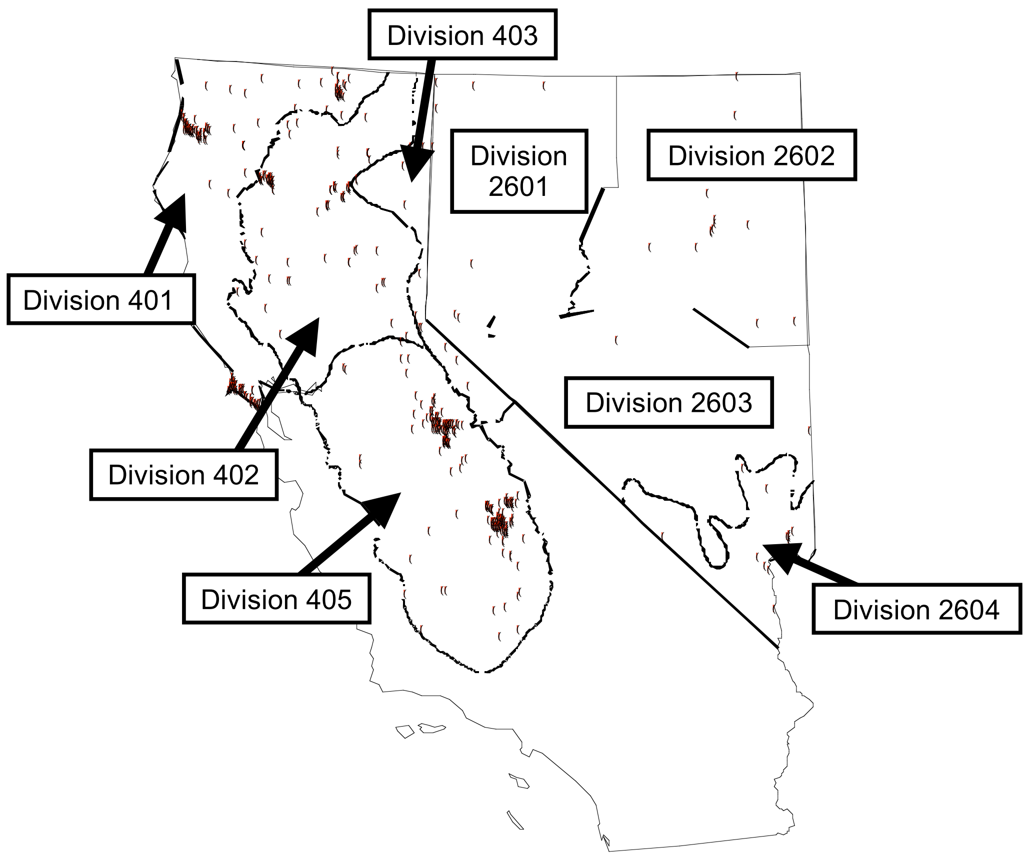

Figure 4.1. Escaped prescribed fires from 1970-2002 in the eight climate divisions considered in the study. Division designations are from the NOAA National Climatic Data Center. Clusters of escaped prescribed fires are locations of the seven National Parks where prescribed fire has been in use for the longest time period: Redwood NP, Lava Beds NM, and Pt. Reyes NS in division 401, Whiskeytown-Shasta Trinity NRA in division 402, Yosemite NP and Sequoia-Kings Canyon NP in division 405, and Lake Mead NRA in division 2604.

The number of escaped fires and the total hectares burned were summed by month and year. An initial assessment of the summed area burned revealed a high amount of variance in the summed totals, so I calculated the sum of the log of area burned to reduce variance in the data. Review of the data revealed a steady linear increase in the number of escaped fires with time (Fig. 4.2), which mirrors the linear increase of prescribed fire use in general for the region over the last 30 years. To account for this trend, the number of hectares per fire (area/fire) was also calculated, revealing the size of earlier escaped fires in the record (Fig. 4.3). Monthly area/fire values were not calculated due to the low number of escaped fires at monthly scales, particularly at the climate division spatial scale. Additionally, annual area/fire was not calculated for divisions 2602 (northeastern NV) and 2603/2604 (southern NV) as there was no year with multiple fires, so the total area results are equal to area/fire for those divisions.

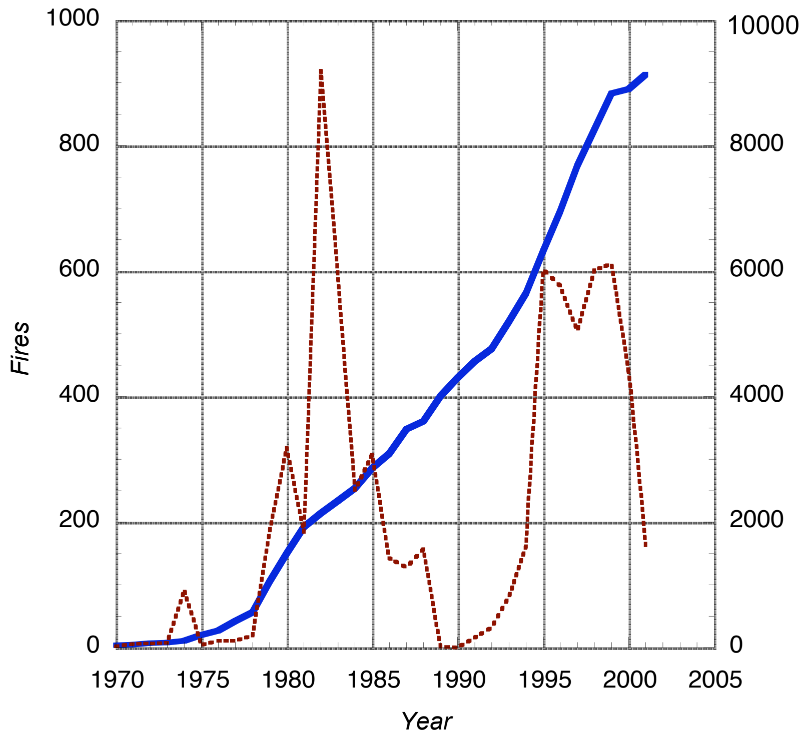

Figure 4.2 The number of escaped fires per year from 1970-2002 (solid line) versus area burned (dotted line).

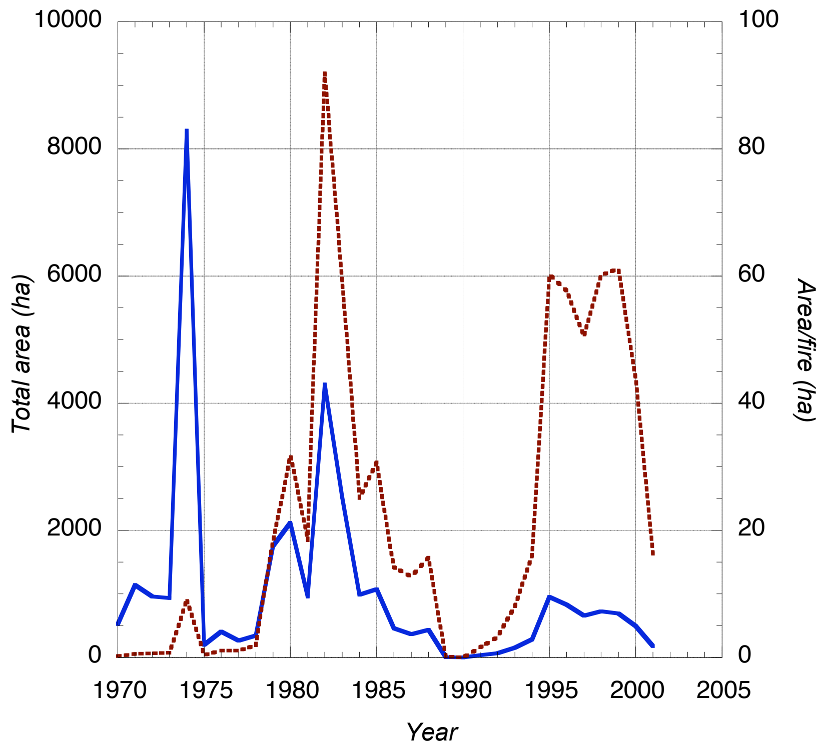

Figure 4.3. A comparison of area/fire each year (solid line) to total area burned per year (dashed line). This reveals the severity of fires in early years from the period, and that elevated area burned totals in the last decade are partially a factor of more smaller escaped fires.

The escaped fire data set was initially evaluated over two temporal periods. The entire data set covers approximately a 33-year period from 1970 to 2002 (only through 2001 for some stations due to reporting problems), however, very few locations were even using prescribed fire as a management tool in the 1970s. Almost all of the early escaped prescribed fires are attributed to three California national parks because those were the only locations completing large-scale prescribed fires. Therefore, a second data set spanning the last 20 years, from 1982-2001, was also analyzed to assess if correlations improved without the inconsistencies of the 1970s. Since preliminary results indicated that the 20-

year data set increased correlation strength, only those results are presented here.

The escaped fire records were correlated to three climate variability indices to assess impacts of climate variability on escaped prescribed fires: the MEI, PDSI, and PZI. The first index was the Multivariate ENSO Index (MEI), developed by Wolter and Timlin (1993), which utilizes Principal Components Analysis to derive standardized monthly values based on a 60-day running average of SST, cloud cover, surface winds, surface air temperature, and sea-level pressure. Even though we have a poor understanding of how ENSO impacts fuels and weather in the study region, it has been repeatedly shown to be an important influence on large wildfire occurrence in parts of the western US (Swetnam and Betancourt 1990, Westerling and Swetnam 2003, Hessl et al. 2004) as discussed in chapter 2. Additionally, ENSO fluctuations are somewhat predictable at 3-6 months (Federov et al. 2003), so it is important to assess whether escaped fires are linked to ENSO.

MEI data were obtained from NOAA’s Climate Diagnostics Center (http://www.cdc.noaa.gov/ENSO/) and two additional data sets were created from the monthly MEI values. An annual MEI value was derived for each year (1970-2002) by averaging the twelve values from DEC/JAN through NOV/DEC. Additionally, since ENSO events typically most affect winter precipitation, an additional annual value called “WinterENSO” was derived using the average of MEI values from JUN/JUL of one year through MAY/JUN of the following year to better capture the strength of a winter ENSO event, instead of having it split between two years. Figure 4.4 illustrates the difference between the annual MEI averages based on calendar year and the “Winter ENSO” averages, and demonstrates that strong ENSO events, such as the 1982-83 and 1997-98 El Niños are better represented in the modified water year.

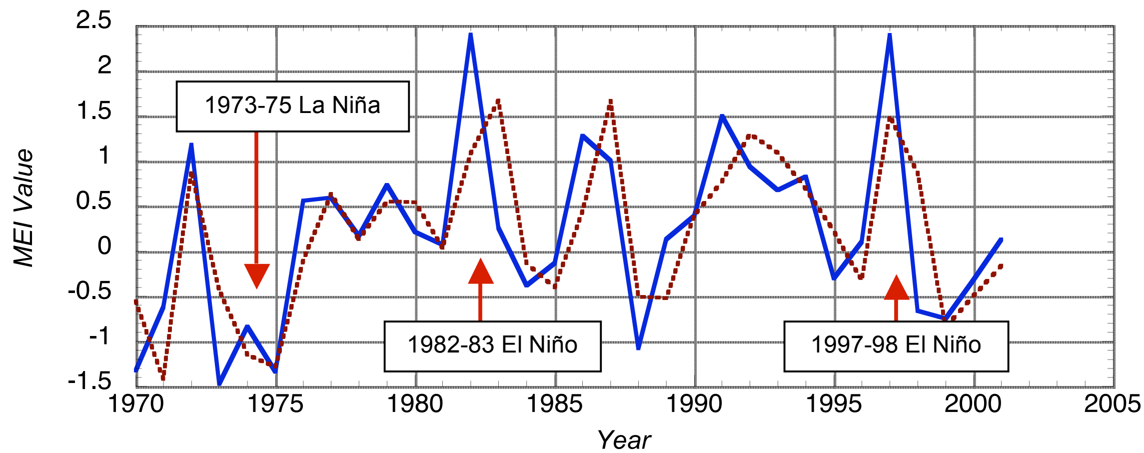

Figure 4.4. Comparison of average MEI values for January through December calendar year (dashed line) to average MEI values for modified water year from previous July through June of year indicated (solid line).

Numerous drought indices are available to track different aspects of drought across the country. The Standardized Precipitation Index (SPI), Surface Water Supply Index (SWSI), US Drought Monitor (USDM), the Palmer Indices, and the Keetch-Byram Drought Index (KBDI) were all considered for correlation to escaped fire occurrences, but the Palmer Drought Severity (PDSI) and Palmer Z (PZI) Indices (Palmer 1965) were determined to be the most suitable for the analysis. Only the PDSI and PZI track water content departure from normal using precipitation and temperature, and incorporate cumulative drought and the water stress from evapotranspiration processes into the calculation algorithm to produce a standardized monthly value representing drought. Additionally, the PDSI and PZI are suitable across larger temporal and spatial scales due to this standardization. SPI does not track any weather observation besides precipitation, so it does not take into account the stress on vegetation that higher temperatures cause due to increased evapotranspiration and reduced soil moisture. SWSI does not take into account soil moisture availability, and better serves the hydrologic community. USDM, which combines multiple indices and expert opinions to create a map that best represents conditions, is not available as a standardized monthly index value, only as a coarse-scale contour map. By comparison, KBDI is widely used as an indicator of fire severity because it assesses how dry the soil and duff layers are in a water budget model. However, is unsuitable for this project because it is not standardized and monthly values are inconsistent across a larger spatial region due to inconsistencies in the Remote Automated Weather Stations (RAWS) and other weather station data that KBDI is calculated from.

PDSI is a better indicator of long-term drought, over periods of 6-9 months or greater, while PZI fluctuates with precipitation events, and is a better indicator of short-term drought on the scale of a few weeks to months (Fig. 4.5) (Heim Jr. 2002). The advantage of using these two Palmer Indices is that PDSI is likely a better indicator the condition and dryness of large fuels like trees or downed logs, while PZI would be more indicative of small-fuel conditions like twigs, shrubs, and grasses, since these fluctuate more dramatically with individual precipitation events.

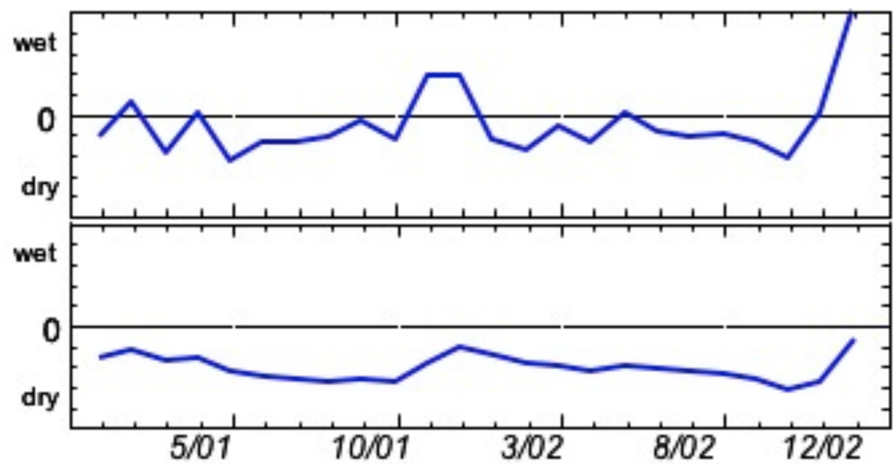

Figure 4.5. Example of difference between PZI (top) and PDSI (bottom) representation of drought conditions. For climate division 402 from January 2001 to December 2002, PZI shows the intermittent drought conditions broken up by rain events, while PDSI shows that, despite the rain events, the division was in an overall long-term drought.

PDSI and PZI data were obtained from the National Climatic Data Center (NCDC) for the period 1970-2002 in eight climate divisions; four in California (401, 402, 403, and 405), and four in Nevada (2601, 2602, 2603, and 2604). Data are standardized monthly values with negative values indicating drought conditions, and positive values indicating wetter-than-normal conditions. To assess drought correlations to escaped fire across annual temporal scales and regional spatial scales, monthly data was averaged across the calendar year and by state and region.

Hypotheses

If climate anomalies and extremes cause conditions under which the risk of escaped prescribed fires is increased, a strong correlation between the indices that quantitatively represent climate fluctuation and the area burned is expected. Since this correlation exists for wildfire area burned as discussed in Chapter 2, and an escaped prescribed fire is considered a wildfire, then a correlation is expected.

H_1: Escaped prescribed fires are not correlated to the MEI ($-0.5<R<0.5$) in any climate division region

H_{a1}: Escaped prescribed fires are correlated to the MEI ($R\leq-0.5$, $R\geq0.5$) in at least one climate division region

H_2: Escaped prescribed fires are not correlated to PDSI ($-0.5<R<0.5$) in any climate division region

H_{a2}: Escaped prescribed fires are correlated to PDSI ($R\leq-0.5$, $R\geq0.5$) in at least one climate division region

H_3: Escaped prescribed fires are not correlated to PZI ($-0.5<R<0.5$) in any climate division region

H_{a3}: Escaped prescribed fires are correlated to PZI ($R\leq-0.5$, $R\geq0.5$) in at least one climate division region

Methods

One of the limitations of the escaped prescribed fire dataset is that it has too much variation associated with the seasonal fluctuation in fire occurrence (i.e. prescribed fires are rarely performed in winter months). Additionally, the small size of the data set is a problem, as the annual data set spans only 20 years (1982-2001). The monthly data set, despite having 12 times the data as the annual data set, is limited by the number of months where the number of fires and hectares is greater than zero. For example, the data set for climate division 2603 (Nevada central) consists of one escaped fire over the 20-year period, so it was combined with climate division 2604 (Nevada south) for a more robust analysis. Throughout most of the higher elevation regions, prescribed fire (and therefore escaped prescribed fire) is limited to the summer months, so the winter values of the monthly escaped fire data set are almost always zero.

Another limitation of the data in this analysis is the skewed distribution of the escaped fire dataset. Since the most frequent occurrence is a small escaped fire of less than an acre, and large escaped fires are far more rare, all of the escaped fire data sets are right-skewed, and most have large escaped fires as an anomalous event. While the climate indices exhibit a normal Gaussian distribution, the skewed escaped fire data were taken as an indicator that exploratory data analysis (EDA) would provide more meaningful results than discriminant data analysis (DDA) for this project. EDA provides a number of tools for exploring the relationships between data sets without the user asking for conclusive evidence that a relationship is significant. This is particularly useful for evaluating this problem since the human factors (such as ignition decisions and fire suppression actions) and numerous other unknown variables (such as weather, land use change, topography, etc.) make it very complex. It would be difficult to say anything conclusive about the escaped fire data set given its many limitations.

With these limitations, it was apparent that a Spearman Rank correlation was a better choice for analysis than a simple linear regression. I am not asking if the relationship between climate variability and escaped prescribed fires is significant; I merely want to assess if there is a relationship at all and make some observations about it. Spearman's Rank correlation assigns integer rankings to each variable in the data set and evaluates how well correlated the *rankings* are, as opposed to the actual values. This will assess whether the year with the most escaped fires is ranked with or opposite the worst drought year, without making any reference to the severity of drought or escaped fire. Because rankings rather than values are correlated, the Spearman correlation is both more robust and more resistant to outliers than ordinary correlation; it recognizes strong, but not necessarily linear, relationships. A Spearman Rank correlation coefficient was calculated for each pair of variables, and the regional escaped fire data was compared to the climate data through additional calculation of a Pearson correlation. Pearson correlation, more accurately referred to as the Pearson product-moment coefficient of correlation, is a more classic correlation found by dividing the covariance of the variables by the product of their standard deviations. While it is neither robust nor resistant, it is a more explanatory correlation for large data sets where a linear relationship is expected between variables; and the weighting of the variables (i.e. the severity of the drought) is important (Wilks 1995; Hall and Brown, *in preparation*). A correlation coefficient of 0.5 (or -0.5 for negative correlations) was chosen as a break point based on discussion by Fomenky (1992). Since the annual data set consists of 20 pairs of data, then the degrees of freedom (d.f.) for the analysis is 18, and a 95% confidence level for 18 d.f. is approximately 0.5 (or -0.5) (Fig. 4.6). Spearman Rank correlation coefficient analysis does not have a p-value associated with it, and although contingency tables could be used to visualize the strength of the correlations, a chi-squared test of significance could not be performed on such a small data set, since over 20% of the counts in the tables are less than five.

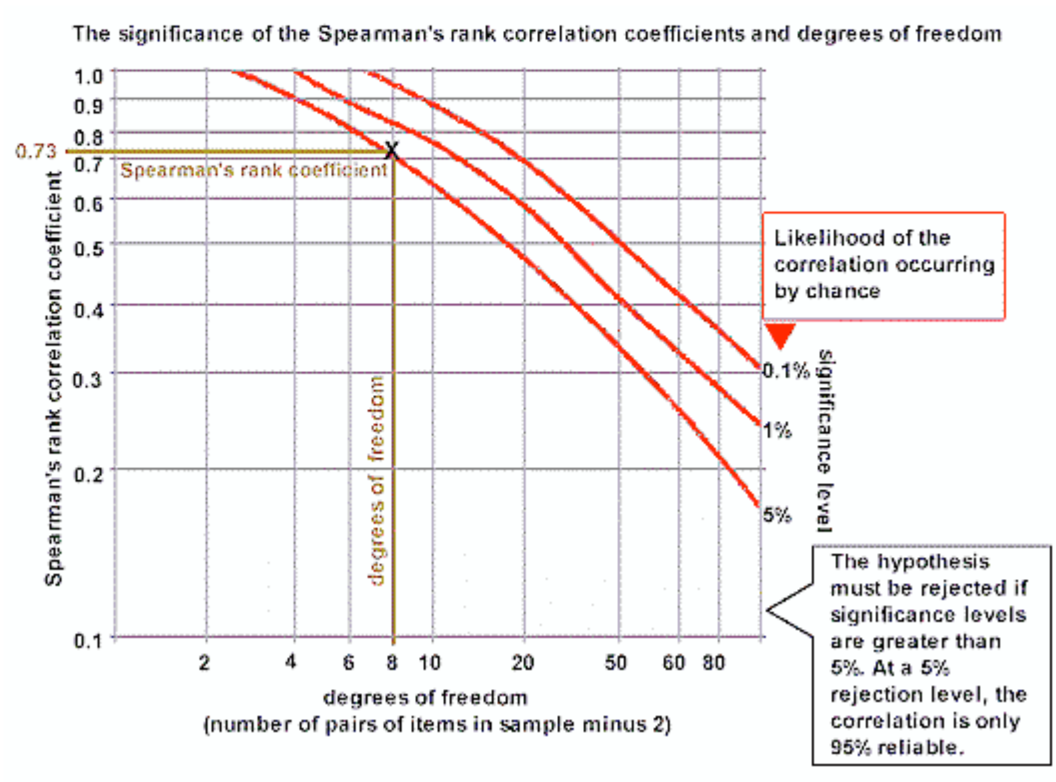

Figure 4.6. Graph used to determine at what level the Spearman Rank correlation coefficient would be considered a strong positive or negative correlation. Since the annual data set comparisons contained 20 ranked pairs, the d.f. for the set was 20-2 = 18 d.f., which intersects the 95% confidence level curve at 0.5. Image from www.geographyfieldwork.com, adapted from Fomenky (1992).

Using 0.5 as a break value also allowed me to classify the correlations into four classes to observe regional trends in correlation: strong negative (-1.0 to -0.5), weak negative (-0.5 to 0), weak positive (0 to 0.5), and strong positive (0.5 to 1.0). For ENSO (MEI values), a strong negative correlation indicates that escaped fires are well-correlated to a La Niña event, a strong positive correlation indicates that escaped fires are well-correlated to an El Niño event, and weak correlations indicate that fires occur irrespective of the current state of ENSO. Since the value of PDSI is describing a water deficit level, a strong negative correlation indicates that escaped fires are occurring during drought conditions, a strong positive correlation indicates that escaped fires are occurring during fairly wet conditions, and weak correlations indicate that fires occur irrespective of drought levels.

Results

All three null hypotheses were rejected, as at least one region was strongly correlated to the climate variability index for that division at either the monthly or the annual temporal scale. Total area (Table 4.1) exhibited similar correlation strengths to ENSO (MEI) and PDSI annual averages as escaped fire area/fire (Table 4.2), with the exception of climate division 402 correlated to PDSI, which was a strong positive correlation for total area and only a weak positive correlation for area/fire. Strong correlations (R≤-0.5, R≥0.5) also occurred statewide and across the entire study region in some cases. Strong correlations did not result from the Pearson correlations of the regional data, only in the Spearman Rank correlations. Complete results for all correlations are found in Appendix C.

Total Area burned Correlations		Annual Index Values			Monthly Index Values		
		MEI	PDSI		MEI	PDSI	PZI
Division	CA-401	-0.314	0.182		-0.330	0.185	-0.089
	CA-402	0.121	0.632		-0.060	0.119	-0.005
	CA-403	0.657	-0.257		0.444	-0.310	-0.225
	CA-405	-0.417	0.442		-0.190	0.062	-0.047
	NV-2601	-0.600	0.800		-0.800	0.600	0.200
	NV-2602	-0.095	-0.595		0.018	-0.709	-0.248
	NV-2603,2604	0.429	0.200		-0.120	-0.207	-0.628
State	California	-0.386	0.529		-0.170	0.044	-0.016
	Nevada	0.203	0.060		0.096	-0.067	0.231
Study Region		-0.293	0.678		-0.100	0.236	0.094

Table 4.1. Spearman Rank correlation coefficients for the total area of each climate division, each state, and the entire region correlated to the climate index value for that division or region for annual ENSO (MEI), annual PDSI, monthly ENSO (MEI), monthly PDSI, and monthly PZI. Shaded cells indicate strong (R≤-0.5, R≥0.5) correlations, except for division NV-2601, with only five data pairs (Spearman Rank correlation is intended for seven data pairs or more).

Ha/fire Correlations		Annual Index Values	
		MEI	PDSI
Division	CA-401	-0.141	0.235
	CA-402	-0.031	0.280
	CA-403	0.543	-0.314
	CA-405	-0.370	0.423
	NV-2601	-0.600	0.800
State	California	-0.242	0.648
	Nevada	0.214	-0.088
Study Region		-0.242	0.758

Table 4.2. Correlation of escaped fire data by ha/fire annually to annual MEI and PDSI index values shows similarities to the annual total area data set except for division CA-402, where a weaker correlation occurred. Shaded cells indicate strong (R≤-0.5, R≥0.5) correlations, except for division NV-2601, with only five data pairs (Spearman Rank correlation is intended for seven data pairs or more).

Correlation maps

The correlation maps on the following pages divide the strength of correlations between area burned values and climate indices into four classes: strong negative (-1.0 to -0.5), weak negative (-0.5 to 0), weak positive (0 to 0.5), and strong positive (0.5 to 1). Strong negative correlations are indicated by the lightest shading, with strong positive correlations indicated by the darkest shading. Climate divisions are marked by the following letters for easier identification: (a) division 401/northwest California, (b) division 402/Sacramento River drainage, (c) division 403/northeastern California, (d) division 405/San Joaquin River drainage, (e) division 2601/northwest Nevada, (f) division 2602/northeastern Nevada, and (g) division 2603/2604/southern Nevada.

ENSO Correlations

ENSO events, not surprisingly, were best correlated to escaped prescribed fire at annual temporal scales, but were only correlated strongly to one region in Nevada and one region in California (Fig. 4.7). Climate division 2601 (e) area burned had a strong negative correlation with the “winter ENSO” annual indices (Fig. 4.7i and 4.7ii), as well as with the monthly ENSO (MEI) values (Fig. 4.7iii), indicating that escaped fires may be occurring under conditions caused by La Niña events. Since this division has only five data pairs, however, the strength of these results is questionable. Climate division 403 (c) total area and area/fire exhibited a strong positive correlation to winter ENSO (Fig. 4.7i and 4.7ii), indicating that escaped fires may be occurring under conditions caused by El Niño events. Monthly ENSO values showed a strong negative correlation to division 2601 (e). Only correlations to winter ENSO are reported, as correlations to annual ENSO were much weaker.

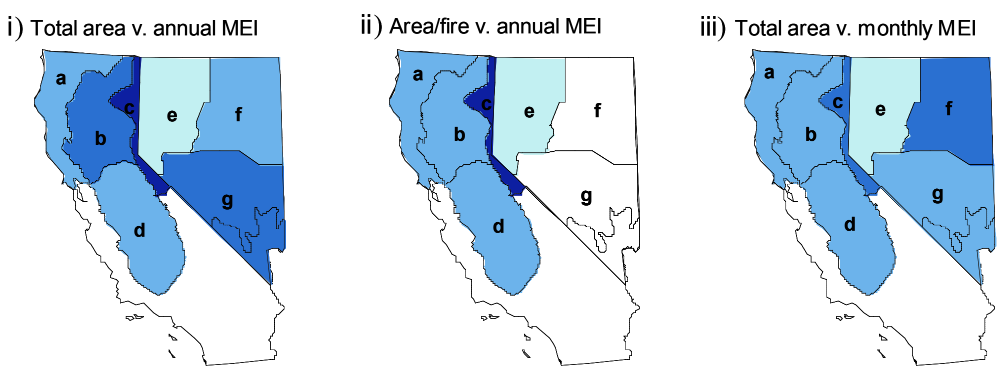

Figure 4.7. Total area burned (i) and area/fire (ii) correlated to “winter ENSO” (MEI annual index values from July to June), and total area correlated to monthly ENSO (iii). Correlation coefficients are divided into four classes: -1.0 to -0.5 (lightest blue), -0.5 to 0 (medium light blue), 0 to 0.5 (medium dark blue), and 0.5 to 1.0 (darkest blue).

Drought Index Correlations

PDSI and PZI correlations varied, but at least one climate division's area burned correlated strongly to the drought index values for that division for both indices. Annual PZI values were only weakly correlated in all cases, as would be expected with an index that is intended to track month-to-month fluctuation and is a poor representative of annual conditions; those results are not presented here.

Annual PDSI averages were strongly correlated to area burned in three climate divisions, for both total area and area/fire (Fig. 4.8). As with ENSO correlations, the small data set (five data pairs) associated with division 2601 (e) resulted in strong positive correlations to PDSI that are questionable because the data set size is below the minimum recommended for Spearman Rank Correlation. Division 402 (b) total area exhibited a strong positive correlation to annual PDSI averages (Fig. 4.8i), indicating fires occurred in wet years, while Division 2602 (f) total area exhibited a strong negative correlation to annual PDSI, indicating escaped fires occurred in drought years. The remaining divisions exhibited only weak correlations to annual PDSI.

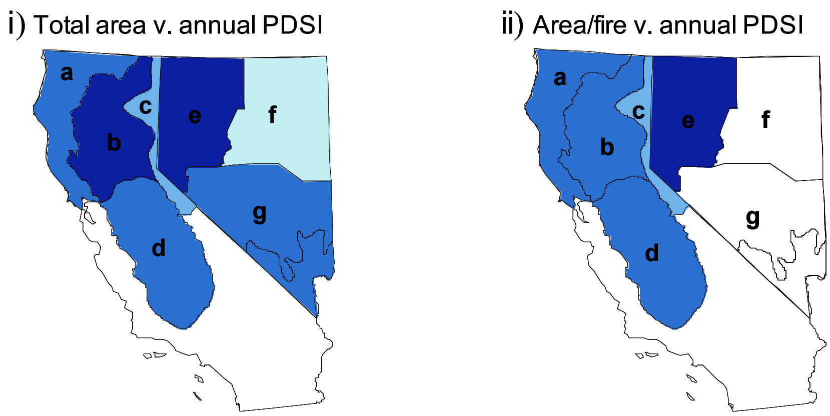

Figure 4.8. Correlations coefficients for annual PDSI averages correlated to total area (left) and area/fire (right) for each climate division. For this comparison, more divisions exhibited strong correlations to total area than to area/fire. Correlation coefficients are divided into four classes: -1.0 to -0.5 (lightest blue), -0.5 to 0 (medium light blue), 0 to 0.5 (medium dark blue), and 0.5 to 1.0 (darkest blue).

At the monthly scale, a comparison between PDSI and PZI correlations to escaped fire occurrence revealed weak correlations to California divisions, and the only regions that exhibited strong correlations between total area and climate indices were in Nevada (Fig. 4.9). Division 2601(e) exhibited a strong positive correlation to monthly PDSI, although the small data set again makes this correlation questionable. Division 2602(f) exhibited a strong negative correlation to monthly PDSI, but only a weak negative correlation to monthly PZI. In contrast to this, Division 2603/2604(g) exhibited a weak negative correlation to monthly PDSI, but a strong negative correlation to monthly PZI. This indicates that larger southern Nevada escaped fires tend to occur under conditions associated with drought in the short-term (1-3 months), while larger northeastern Nevada escaped fires occur under conditions associated with drought in the long-term (9-12 months).

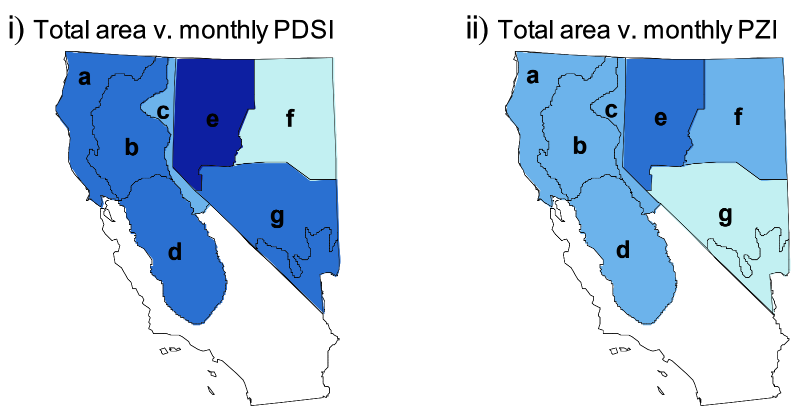

Figure 4.9. Monthly PDSI (left) and monthly PZI (right) correlated to monthly total area burned for each climate division. Correlation coefficients are divided into four classes: -1.0 to -0.5 (lightest blue), -0.5 to 0 (medium light blue), 0 to 0.5 (medium dark blue), and 0.5 to 1.0 (darkest blue).

Regional Correlations

While individual climate division correlations between climate and escaped fire occurrence allow us to assess the impacts of local drought, it is also interesting to assess the impacts of a region-wide drought. This has particular application to fire management, as well, since resources for prescribed fire and fire suppression tend to be shared across a region. Two regional analyses were performed. In the first regional analysis, total area and area/fire per year over each state (California and Nevada) and across the entire study region (Regional) was correlated to both annual and monthly climate indices to assess whether region-wide climate impacts the occurrence of region-wide escaped fire occurrence. The second analysis correlated region-wide climate to fire occurrence in individual divisions to assess where region-wide drought patterns had the most impact.

Correlations of annual values resulted in strong positive correlations between California total area and California PDSI (Fig. 4.10i), as well as between Regional total area and Regional PDSI (Fig. 4.10iii). The strength of the Regional correlation is likely a function of the California correlation, as Nevada escaped fires comprise only 5% of the total Regional data set. Nevada total area was only weakly correlated to PDSI (Fig. 4.10ii), indicating that Nevada escaped prescribed fires occur under different climatic conditions than California escapes. Correlations to annual ENSO index values were weak at the state and regional level (Fig. 4.10iv,v, & vi).

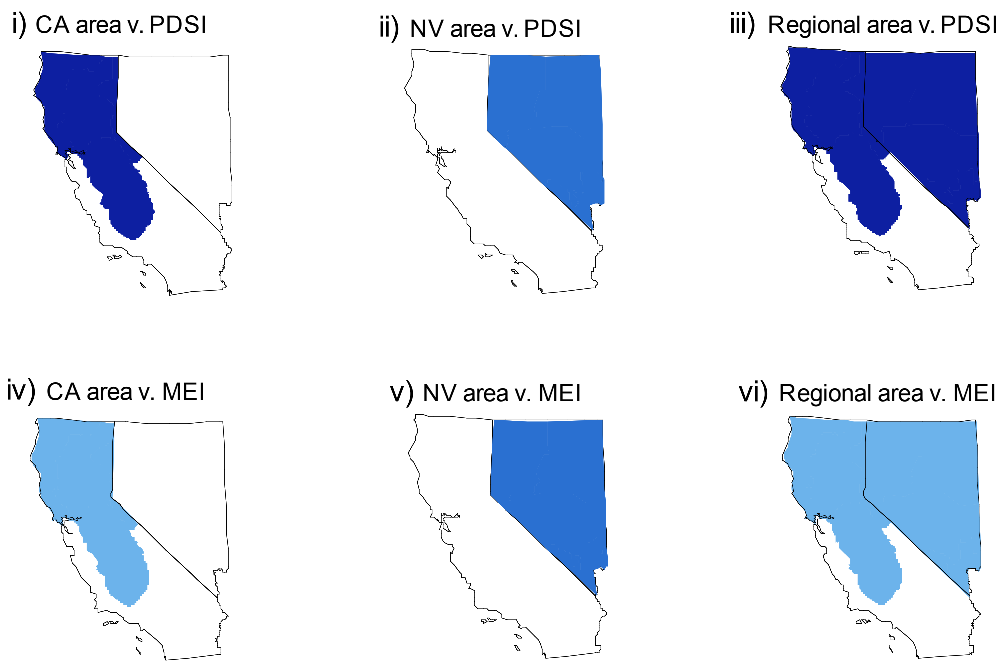

Figure 4.10. Correlations of state-wide and region-wide averages of PDSI (top row) and MEI (bottom row) to state-wide and region-wide annual escaped fire area burned, including: (i) Calif. total area v. Calif. PDSI, (ii) Nev. total area v. Nev. PDSI, (iii) Regional total area v. Regional PDSI, (iv) Calif. total area v. MEI, (v) Nev. total area v. MEI, and (vi) Regional total area v. MEI. Correlation coefficients are divided into four classes: -1.0 to -0.5 (lightest blue), -0.5 to 0 (medium light blue), 0 to 0.5 (medium dark blue), and 0.5 to 1.0 (darkest blue).

Correlations of state-wide and regional monthly total area to climate variability indices resulted in weak correlations in all instances (Fig. 4.11). Given the highly variable fuel loads, vegetation type, and microclimatology across the landscape in question, however, it seems unlikely that a short-term drought could affect the entire region in a uniform manner conducive to increased escaped fire.

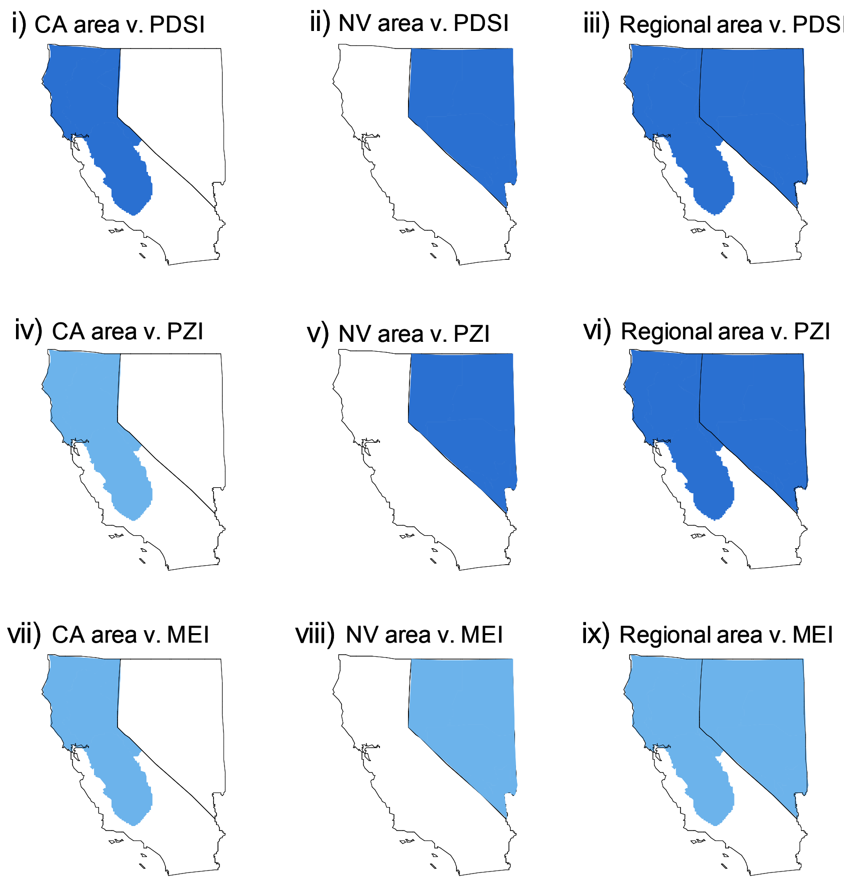

Figure 4.11. Correlations of state-wide and region-wide monthly averages of climate variability indices to total area burned. Correlations pairs are: (i) Calif. total area v. Calif. PDSI, (ii) Nev. total area v. Nev. PDSI, (iii) Regional total area v. Regional PDSI, (iv) Calif. total area v. PZI, (v) Nev. total area v. PZI, (vi) Regional total area v. PZI, (vii) Calif. total area v. MEI, (viii) Nev. total area v. MEI, and (ix) Regional total area v. MEI. Correlation coefficients are divided into four classes: -1.0 to -0.5 (lightest blue), -0.5 to 0 (medium light blue), 0 to 0.5 (medium dark blue), and 0.5 to 1.0 (darkest blue).

The second regional analysis assessed regional drought correlations further by correlating average drought values across each state and the entire study region to total area burned for each individual climate division (Fig. 4.12). Average annual California PDSI values (Fig. 4.12i) exhibited a strong positive correlation to division 402(b), and average annual Nevada PDSI values (Fig. 4.12ii) exhibited a strong positive correlation with division 2601(e). Regional average PDSI (Fig. 4.12iii) exhibited a strong positive correlation to divisions 402(b), 405(d), and 2601(e), and a strong negative correlation to division 2602(f). This indicates that regional drought only impacts escaped fire occurrence in northeastern Nevada, while regional wet years are linked to central California and the western slope of the Sierra Nevada.

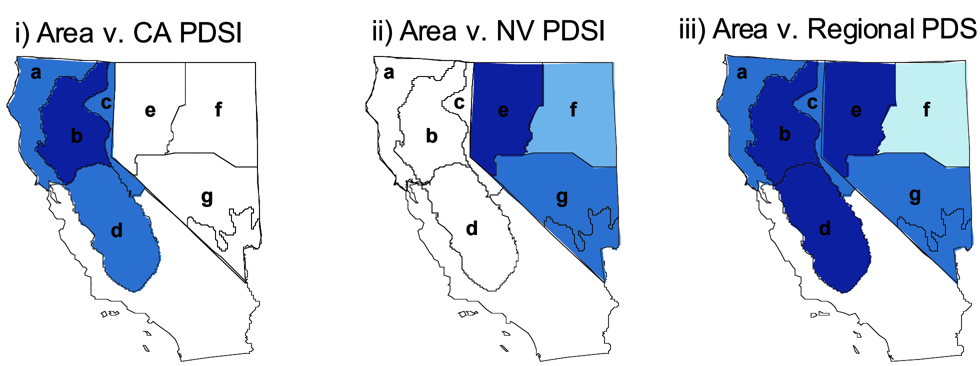

Figure 4.12. Average annual PDSI values for (i)California, (ii)Nevada, and (iii) the entire study region correlated to total area burned in individual climate divisions. Correlation coefficients are divided into four classes: -1.0 to -0.5 (lightest blue), -0.5 to 0 (medium light blue), 0 to 0.5 (medium dark blue), and 0.5 to 1.0 (darkest blue).

Discussion of Escaped Fire and Climate Analysis

While the objective of this analysis was to assess whether or not climate, particularly drought, is associated with a higher incidence of escaped prescribed fires, the results of the analysis were fairly unexpected. Fire investigation reports seeking to identify causes of escaped prescribed fires have suggested that drought conditions were in effect at the time, but the results of this analysis indicated strong correlations between wetter-then-normal conditions and escaped fire activity in most regions.

Nevada Division 2601

One problem with the results that needs to be addressed concerns Nevada climate division 2601. Since the data base had only five escaped prescribed fires for this division, there is some question of the validity of the many strong correlations exhibited by the division. The sample size needs to be considerably larger to reduce error, but the results provided here can still be useful in terms of management, as they may be taken into consideration when trying to prevent the next escaped fire.

Links to Climate Variability Indices

Only two divisions exhibited noteworthy correlations to ENSO. The southern Nevada region was positively correlated to ENSO (although the correlation was only strong in the 33-year data set analysis [see appendices], with a 0.643 correlation between total area and annual ENSO [MEI]). This indicates that increased area burned resulted from stronger El Niño events. This result is opposite of the findings of Swetnam and Betancourt (1990) regarding wildfire occurrence in the southwest, where they found severe and extensive wildfire years linked to strong La Niña events. This finding is not entirely surprising, however, in the context of the overall findings. In the southwest, a strong El Niño tends to bring more moisture-than-average in the spring, which would then increase fine fuel loads in the region. Prescribed fire in the southwest depends on these increased fine fuel loads to carry the fire, and further analysis might reveal increased prescribed fire use in general linked to stronger El Niño events in the southwest. The results may also indicate that managers are seeing a double-edged sword where increased, El Niño-related, fine fuel loads that dry out in the late spring allow escaped fires to spread far more than during dry years. Additionally, the stronger correlations to total area than area/fire may indicate that very large escapes are best correlated to ENSO, and minor escapes are not as well correlated.

The situation in division 401 in northwest California may be similar, and somewhat opposite, the southern Nevada region. Although division 401 is not correlated strongly to ENSO at either annual or monthly scales (Fig. 4.7), the moderate negative correlation to winter ENSO (-0.432) at the annual scale greatly exceeds the minor correlations of ENSO to the other five climate divisions (excluding the southern Nevada division). This indicates that escaped fire in this region at annual scales is correlated to stronger La Niña events, which tend to be associated with wetter conditions in the Pacific Northwest, again lending moisture to increase fine fuels. As Hessl et al. (2004) note, however, ENSO events are only weakly linked to wildfire extent and severity in the Pacific Northwest, and more attention should be paid to long-term PDO fluctuations and short-term summer drought. The results presented here do not agree with Hessl et al. (2004), as division 401 escaped fire area burned is moderately correlated to ENSO at annual levels, and strongly correlated to positive PDSI and PZI at monthly scales, particularly over the abbreviated 20-year period. The positive correlation points to escaped fires occurring during wetter-than average months, with the largest escapes coming during the wettest periods.

In contrast to this were the strong negative correlations exhibited in the northeastern and southern divisions of Nevada, particularly at the monthly scale. These two Nevada divisions are particularly interesting at the monthly scale because they are the only two divisions that exhibit strong correlations, but each is tied to a specific index. Northeastern Nevada is not correlated to ENSO, but is negatively correlated to annual (Fig. 4.8i) and monthly (Fig. 4.9i) PDSI, indicating a long-term drought (at least 6-9 months) is most conducive to escaped prescribed fire occurrence. This would tend to agree with the escaped prescribed fire reports, and it also indicates that the escape is related to very dry large fuels, particularly the 100-hr and 1000-hr fuels. Since much of northeastern Nevada is covered by sagebrush steppe and pinyon-juniper woodlands, it would appear that these two fuel types are prone for escaped fires when the large fuels are very dry, regardless of how much fine fuel is available in the understory. This is supported by the lack of correlation of division 2602 to PZI (Fig. 4.9ii), which is a better indicator of the type short-term drought that would increase drying in the 1-hr and 10-hr fine fuels.

The strong negative correlation between southern Nevada and PZI at monthly scales (Fig. 4.9ii) helps explain the correlation between the division and ENSO. A wet El Niño year would produce excess fine fuels, but a short dry spell associated with a negative PZI value (but not necessarily a negative PDSI value), would allow the fine fuels to dry out, making them readily available to burn. An unsuspecting fire manager who fails to recognize the situation would then be susceptible to an escaped fire.

Central California and the western Sierra Nevada, where most of the escaped fires have occurred, show little correlation to the monthly ENSO (Fig. 4.7) or drought (Fig. 4.9) values. The strong positive correlations between annual drought indices and escaped fire area burned for central California and northwest Nevada (Fig. 4.8i) are opposite of what is expected in light of the escaped prescribed fire reports; it appears that wetter-than-average years are associated with escaped fires. Above-average moisture for the year in California is a sign of above-average winter moisture, since almost all of its precipitation is received in the winter months. This would be conducive to excess fine fuel production, and perhaps even an average, arid California summer is enough to lower fuel moistures considerably and produce above-average fuel loadings. Fire managers may attempt higher rates of prescribed fire use during these periods, thinking that they are taking advantage of wetter (and therefore “safer”) conditions, thus, resulting in higher incidence of escaped prescribed fire. It would be difficult to say anything conclusive about this relationship, however, without a more in depth assessment of the problem.

The regional assessments further support the enigma of California escaped fire area burned totals. The state and regional strong positive correlations to annual PDSI (Fig. 4.10i & iii) indicate that California escaped fires occur under wet conditions. Additionally, the region-wide PDSI indices correlated to individual climate divisions indicate through strong positive correlations in central California and northwest Nevada that increased escaped fire area burned is associated with wet years (Fig. 4.12i & ii). The strong negative correlation between region-wide PDSI and northeastern Nevada (Fig. 4.12iii), on the other hand, supports the theory that long-term drought increases potential for escaped fires for this part of that state.

Conclusions on Escaped Fire and Climate

While it is easy to speculate on the reasons and the mechanics for some of the correlations between escaped fire area burned and the climate indices, without further investigation we cannot conclusively say that climate is linked to escaped fires through any specific means. Too many variables exist; fire manager decision-making, fire suppression practices, land-use change throughout much of the region, changes in objectives for prescribed fire use, changes in fuel loading and type, and changes in the fire managers themselves and their perceptions about their land-management practices. The variables are many, and our abilities to accurately quantify them are inadequate.

What we can conclude, however, is that there are some strong correlations between past escaped prescribed fires and climate related to ENSO and precipitation and temperature fluctuations. This information should be sufficient evidence that prescribed fire managers should be aware of climate and be tracking how it impacts their fuels and fire behavior in their prescribed fires so as to avoid escaped prescribed fires. The logic of the escaped fire investigations that prescribed fire managers failed to assess and assimilate “dangerous” drought conditions into their prescribed fire planning, which then led to escaped fires, does not appear to apply for this study region, excepting northeast and southern Nevada. What does appear to be strongly linked is the incidence of escaped fire and long-term wet periods in California and northwest Nevada. This leads to further questions about the remainder of those escaped fire investigation documents, which tend to detail meteorological events and personnel decisions and mistakes that contributed to the escapes. Since most escaped fire reports investigate the largest escaped prescribed fires, it is worth analyzing these large fires further in the next chapter.

CHAPTER 5

OBSERVATIONS ON LARGE ESCAPED FIRES

While escaped prescribed fire reports point to drought conditions as a cause for escaped fires, the analysis in chapter 4 revealed that escaped prescribed fires in much of the study region occurred under wet, not dry, conditions. But the rank correlations did not necessarily differentiate between minor escapes and large, catastrophic escaped fires, such as the 2000 Cerro Grande Fire in Los Alamos. The right skew of the escaped fire area burned histograms (Fig. 5.1) reveal that the vast majority of escaped fires are relatively minor. Many fire managers repeat the phrase, “if you burn long enough, eventually you’ll lose one.” The consequences of “losing” a prescribed fire that burns less than a hundred hectares, however, are far different than the consequences of a multi-thousand hectare fire that requires a vast fire suppression effort and may damage private property. It is important to determine if these large fires occur under significantly drier or more extreme conditions than smaller fires, as the escaped fire reports would indicate.

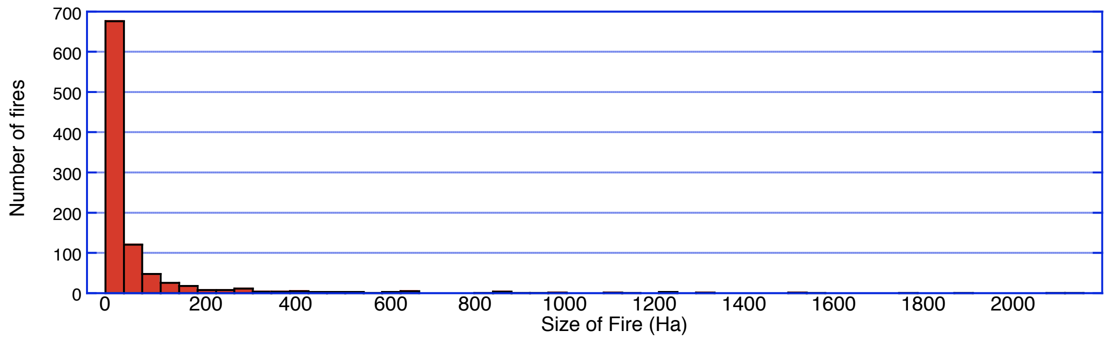

Figure 5.1. Histogram of the number of escaped prescribed fires for each 40 ha size interval. 97% of escaped fires are less than 200 ha in size. The two fires over 2,000 ha (2,068 and 3,347 ha) are excluded to improve resolution.

Of the 974 escaped prescribed fires that have occurred on federally managed lands in the study region from 1970 to 2002, only 57 (6%) were over 200 ha, and only 30 (3%) were over 400 ha. These are the 3% of prescribed fires that garner the vast majority of the media attention and public ire, and cause the increasingly tight restrictions on prescribed fire use in general.

This chapter asks what these large escaped fires have in common, and what role climate may play in large escaped fires. In particular, two specific questions were asked:

1) Do large escaped fires occur during significantly different dry or wet periods than escaped fires in general?

2) Since fire managers often use 90th percentile weather observations as a fire danger "trigger point," what percentage of large escaped fires occur at or above 90th percentile fire danger days?

By answering these two questions, the goal is to make recommendations on reducing the number of large escaped prescribed fires, and giving fire managers the tools to do so.

The National Fire Danger Rating System (NFDRS)

The creation of NFDRS in 1972 (Deeming et al.) and subsequent updates in 1978 (Deeming et al.) and 1988 (Burgan) allowed fire managers to begin integrating the numerous complex variables associated with fire danger and prediction. The guiding principles of NFDRS are that it is scientifically based, easy to use, meets the needs of fire managers, uses local data for inputs, and is applicable nationally. It utilizes daily inputs of weather, local fuel condition data, the principles of combustion physics, and a complex set of algorithms to produce various outputs that predict the worst-case fire danger scenario for the next 18-36 hours (Fig. 5.2).

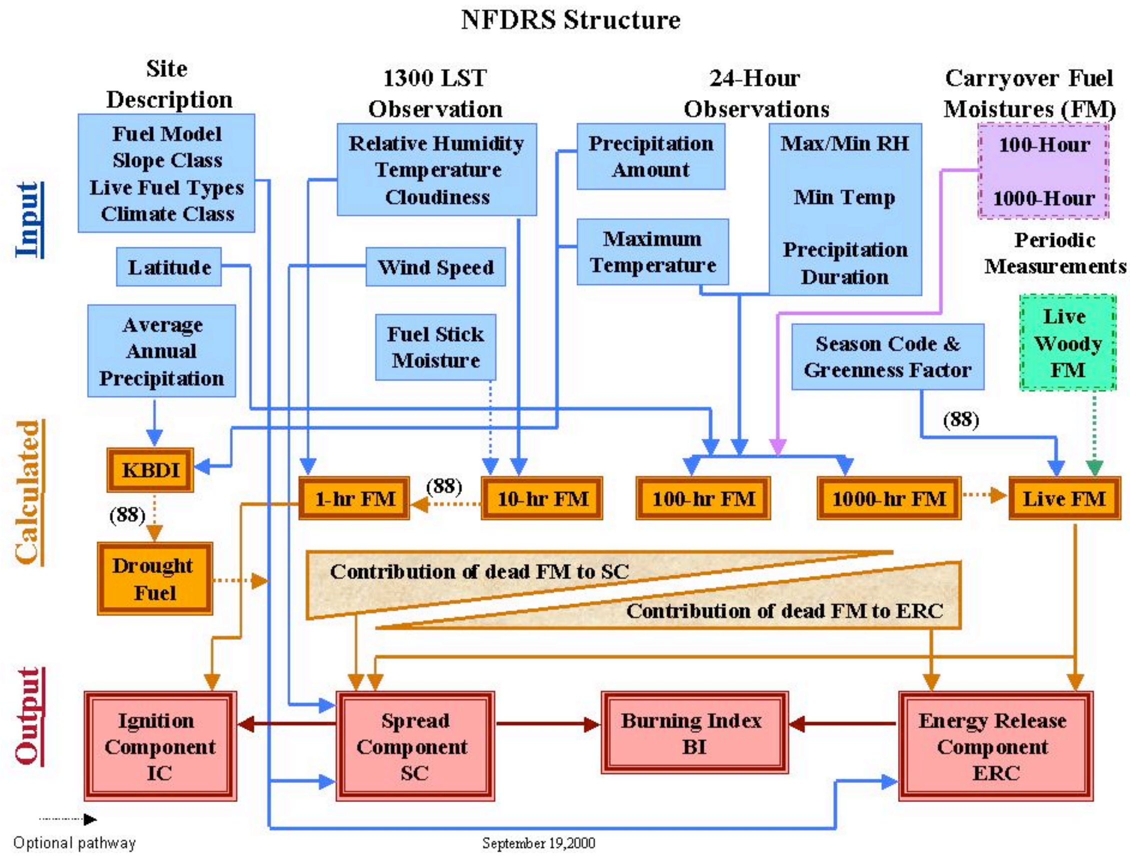

Figure 5.2. Structure of NFDRS including inputs, calculated values, and output indices (NWCG 2002).

For wildfire suppression, these outputs are indicators of how likely a fire is to ignite and spread, and how much work will be required to contain the wildfire. For prescribed fire, there are four primary outputs (and two secondary outputs) that best relate to the danger of a prescribed fire escaping and spreading beyond control. The Energy Release Component (ERC) is a measure of how much energy (in BTUs) is released from one square foot of burning material, and is a good indicator of drought conditions, as it increases when fuels are more available to burn as a result of drought. The Burning Index (BI) predicts the length of flames, and as flame length dictates the nature of suppression efforts (human or machine) required, it incidentally predicts the effort required to suppress a fire. Spread Component (SC) is a predictor of the rate of spread (feet/second) of a fire front. Ignition component (IC) is the fourth primary output of NFDRS used by fire managers, as it predicts the likelihood that a spark or ember will not only ignite a fire, but that it will spread. In addition to ERC, BI, SC, and IC, NFDRS also calculates the value of the Keetch-Byram Drought Index (KBDI) (discussed in chapter 4), and the 1000-hr fuel moisture as intermediates.

Methods

Monthly values for ENSO, PDSI, and PZI were assigned to every California fire in the 33-year escaped fire data set by climate region. There were not enough large Nevada fires (only five were larger than 200 ha) to validly assess this region. A two-tailed student t-test was used to determine if there is a significant difference between values for each climate index associated with different groups of large escaped fires. Index values for all fires equal to or over 200 ha in size were tested against values for all fires under 200 ha; over or equal to 400 ha tested against under 400 ha; and over or equal to 800 ha tested against under 800 ha. A significance value of p=0.1 was chosen (more liberal than the traditional p-value of 0.05) to better capture the relationship between large and non-large fires, particularly in light of the small data sets associated with large fires (i.e. the over-800 ha data set includes just 14 fires).

To assess whether large, catastrophic escaped prescribed fires occur under extreme fire danger conditions, the four NFDRS output values (ERC, BI, SC, and IC), were found for each large escaped fire over 400 ha and compared against the range of conditions reported for that date. For each of the five climate divisions in the study region where large escaped fires have occurred, all of the weather station data that fall into that climate division were loaded into FireFamilyPlus (FF+), the same software package used by fire managers to assess historic weather levels, common denominators of large wildfires, optimal conditions for prescribed fire, etc. FF+ accesses weather and fire data from the National Interagency Fire Management Integrated Database (NIFMID) and the thousands of WIMS, RAWS, and other weather stations compiled in the web-based Kansas City Fire Access Software (KCFAST). It utilizes this data to compute fuel moistures based on the predominant fuel type near a specific weather station, as well as fire danger index values such as KBDI. The NFDRS outputs for ERC, BI, SC, and IC were calculated for the entire climate division for each date of an escaped fire in that division. KBDI and 1000-hr fuel moisture values were also calculated for each fire date. Each large escaped fire was then placed in the context of historic maximums, minimums, and averages for the week surrounding each escaped fire date using the overlay option on climatology graphs in FF+. This allowed me to determine if escapes occurred on days when conditions were in the top 10 most severe days for that week for the 32-year period from 1970-2001 (at or above the 90th percentile), in the top five most severe days (above the 95th percentile), or if the date of the fire was the most severe fire danger day on record (100th percentile). For the 1000-hr fuel moisture value, the percentiles are reversed (10, 5, and 0%) as lower 1000-hr fuel moistures are representative of more severe fire danger conditions, while higher index values for the five other NFDRS outputs are a measure of more severe conditions.

Results

The student t-test revealed that the mean index values for large escaped fires are significantly different from the mean index values for the small escaped fires in five of the nine cases (Table 5.1). In the ENSO comparisons, the large escaped fires had a mean MEI value significantly lower than the small fires for the 200-ha and 400-ha breaks. In the PDSI comparisons, the large escaped fires had a significantly higher mean value than the smaller fires for all three area burned breaks. In the PZI comparisons, there was no significant difference between the means of the large and small escaped fires (Fig. 5.3).

Two-tailed t-test results		Climate Variability Index		
		MEI	**PDSI**	**PZI**
Area burned Break (ha)	**200**	t = -1.8749	t = 2.801	t = 0.5972
		p = 0.0612	**p = 0.0052**	**p = 0.5506**
	400	t = -1.6584	t = 1.9845	t = -0.2905
		p = 0.0977	**p = 0.0476**	**p = 0.7715**
	800	t = -0.3408	t = 1.8368	t = 0.2745
		p = 0.7333	**p = 0.0666**	**p = 0.7838**

Table 5.1. Results of two-tailed t-test comparing the values for each climate variability index associated with escaped fires of area greater than/equal to and less than the area burned break value. P-values of less than 0.1 are considered significant (d.f. = 765).

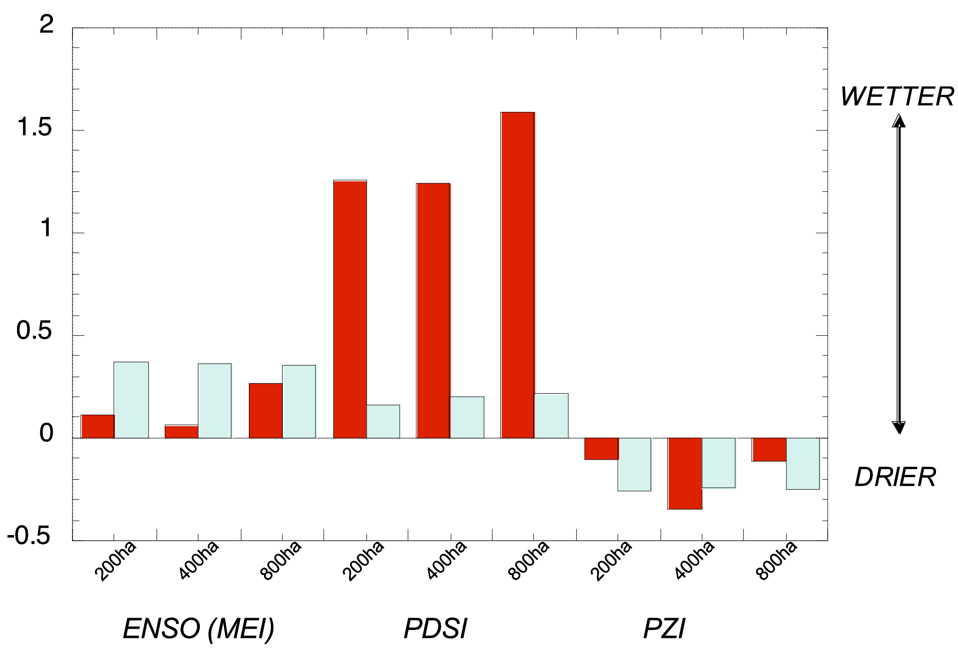

Figure 5.3. Means of each set of monthly climate index values associated with escaped fires whose size falls above (dark red) or below (light blue) the area burned break value. Significant differences at the 90% level were found for the 200-ha and 400-ha ENSO comparisons, and all three (200-, 400-, and 800-ha) PDSI comparisons. The wetter-to-drier indicator to the right of the graph applies to the PZI and PDSI indices only.

In assessing the individual large escaped fires for coinciding with extreme fire danger days, only six of the 29 large (>400 ha) escaped fires occurred on days when one or more NFDRS output value was at or above the 90th percentile (Table 5.2). The six fires were from three different climate divisions, of variable sizes (i.e. they were not the six largest fires), and occurred across the entire temporal span of the data set. Only two of the fires had more than one NFDRS value at or above the 90th percentile for the fire date, which indicates consistently severe fire danger conditions for the dates in question (Fig. 5.4). The remaining 23 large escaped fires did not occur on days when NFDRS output values indicated severe fire danger conditions, and in many cases fell on dates when fire danger indices were below average (Fig. 5.5). All fire danger index graphs for large fires are found in Appendix D.

Year	Month	Day	Hectares	1000hr FM	KBDI	BI	ERC	SC	IC
2000	9	29	3347	No	No	No	No	No	No
1996	10	2	2068	No	No	No	No	No	No
1982	8	24	1535	No	No	No	No	No	No
1995	10	6	1212	No	No	No	No	No	No
1997	9	18	1212	No	No	No	No	No	No
1983	9	3	1131	No	No	No	No	No	No
1999	10	3	1097	No	No	No	No	No	No
1979	9	10	1083	No	No	No	No	No	No
1983	9	12	973	No	No	No	90%	No	No
1988	6	20	953	No	No	No	No	No	No
1998	10	13	929	No	No	No	No	No	No
1996	5	20	897	No	No	No	No	No	No
1986	8	16	848	95%	90%	No	90%	No	No
1995	10	11	848	No	No	No	No	No	No
1998	10	3	808	No	No	No	No	No	No
1980	9	11	663	No	No	No	No	No	No
1995	11	9	646	No	No	No	No	95%	No
1997	10	27	646	No	No	No	No	No	No
1998	10	7	625	No	No	No	No	No	No
1998	10	13	620	No	No	No	No	No	No
1984	8	29	606	90%	No	No	No	No	No
2000	10	20	558	No	No	No	No	No	No
1974	10	25	525	90%	No	No	No	No	No
1984	10	24	525	No	No	No	No	No	No
1994	9	12	487	No	No	No	No	No	No
2000	3	31	461	No	No	100%	100%	95%	95%
1998	9	30	408	No	No	No	No	No	No
1998	8	27	406	No	No	No	No	No	No
1996	1	14	404	No	No	No	No	No	No

Table 5.2. Large escaped prescribed fires (>400 ha) by area burned. The six NFDRS values are described by where the fire date fell in the context of the historic record (1970-2001): “No” represents a less than 90th percentile day, “90%” is a day falling in the top 10 most severe days for that index, “95%” is a day falling in the top 5 most severe days, and “100%” indicates that the fire day was the most severe day during the record.

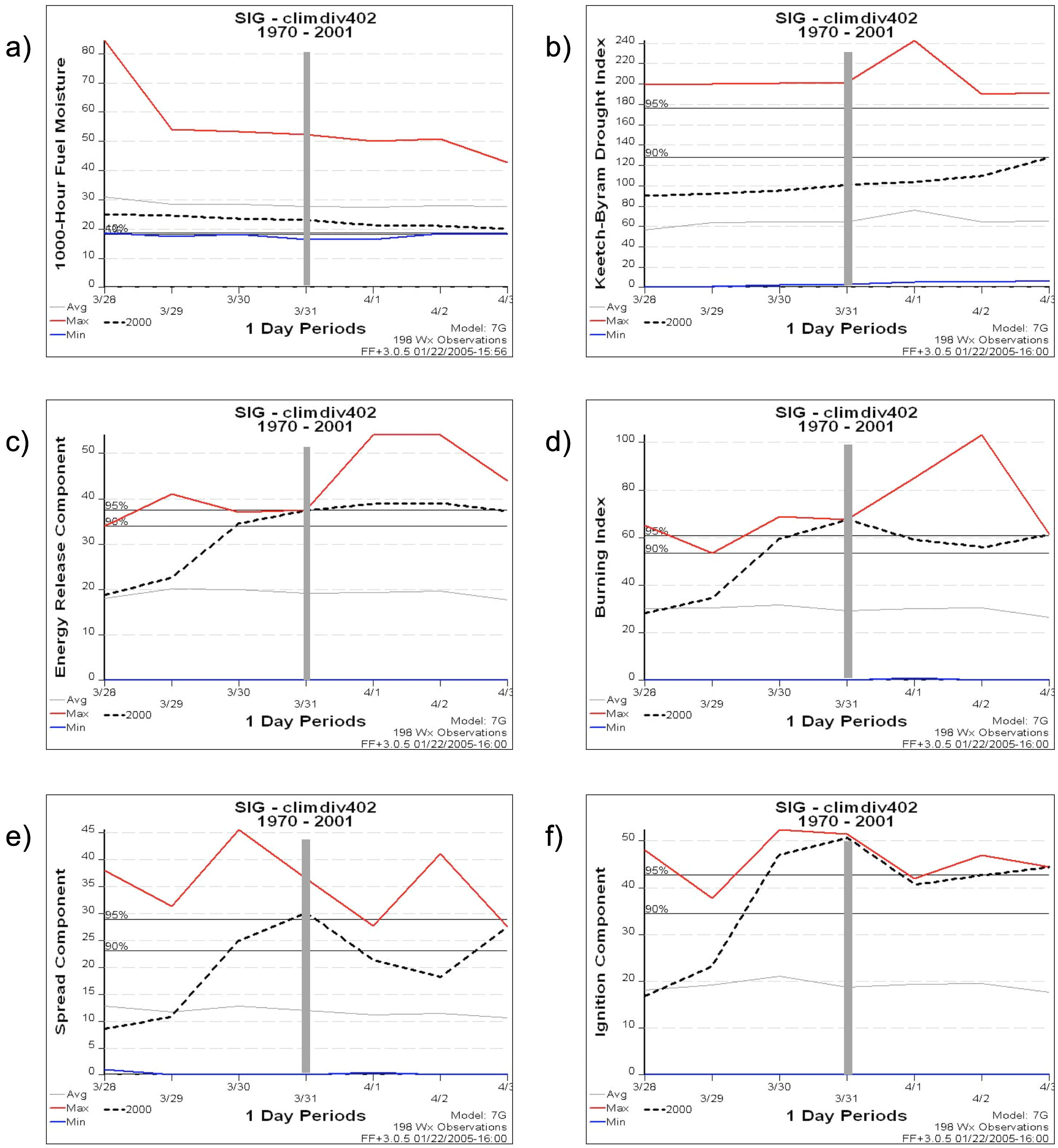

Figure 5.4. NFDRS output values for an escaped fire occuring on March 31, 2000 under extreme fire danger conditions. The fire occurred in climate division 402 (Sacramento river drainage basin), so the 2000 values for division 402 during the week of the fire (black dashed line) are placed in the context of historic (1970-2001) minimum (blue line), maximum (red line), and average (thin gray line) values to show index values that were at or above the 90th percentile on the fire date. 1000-hr fuel moisture (a) and KBDI (b) were above average on the fire date, ERC (c) and BI (d) values on the fire date were the worst on record, and SC (e) and IC (f) were both above the 95th percentile (top 5 most severe fire danger days) for the fire date.

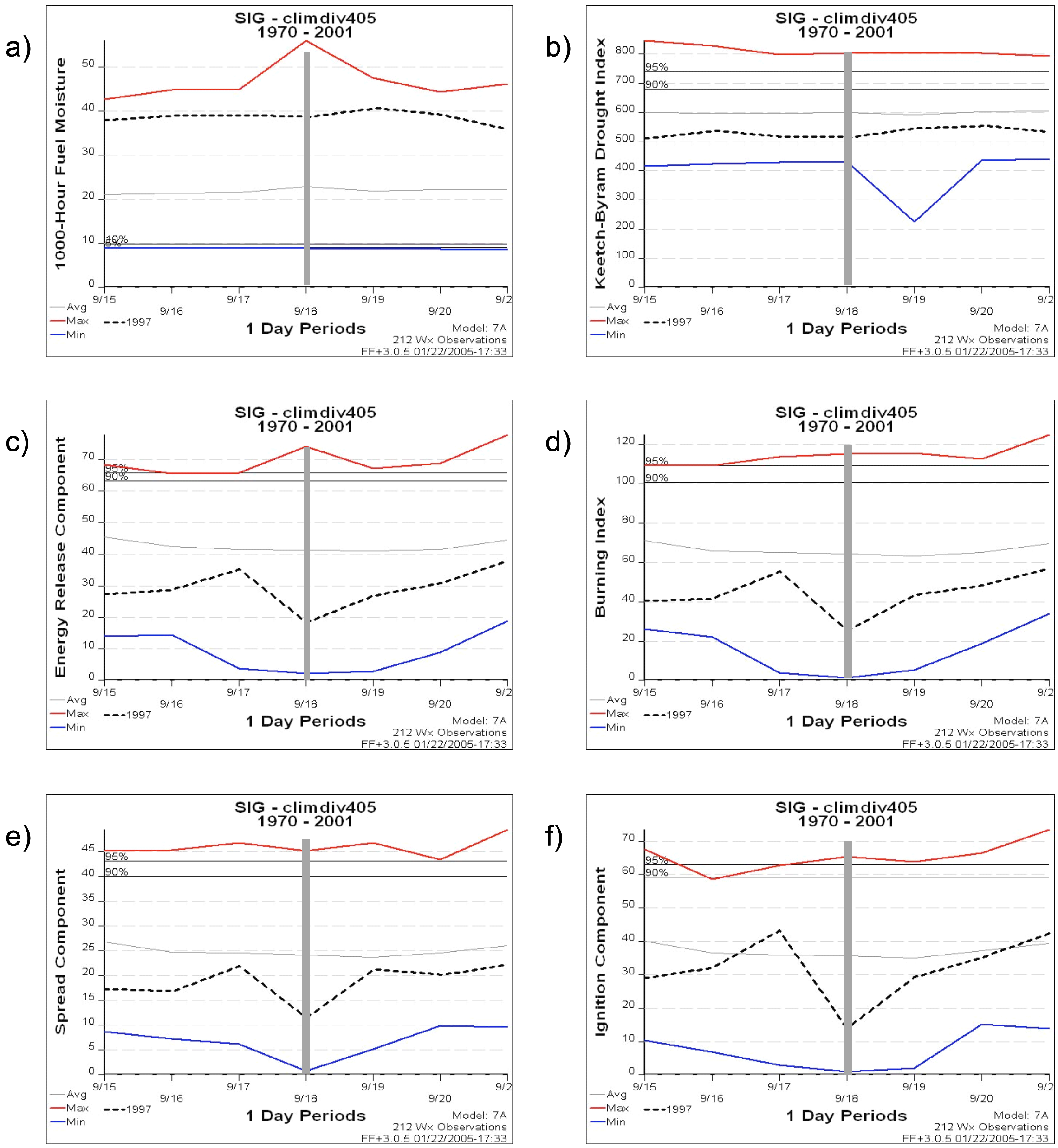

Figure 5.5. NFDRS output values for an escaped fire occurring on September 18, 1997 under below average fire danger conditions. The fire occurred in climate division 405 (San Joaquin river drainage basin), so the 1997 values for division 405 during the week of the fire (black dashed line) are placed in the context of historic (1970-2001) minimum (blue line), maximum (red line), and average (thin gray line) values to show index values that were at or above the 90th percentile on the fire date. 1000-hr fuel moisture (a), KBDI (b), ERC (c), BI (d), SC (e), and IC (f) values were all well below average for the fire date.

Discussion

The results of both large escaped fire analyses indicate that, for the study region and primarily California, climate does have an influence on large escaped fires, but not in the manner indicated in many of the escaped fire reports.

T-test analysis

The mean of the MEI values for 200- and 400-hectare fires or larger was higher than the mean MEI value for smaller escaped fires, indicating that stronger El Niño events are associated with large escaped fires. For California, however, the relationship between ENSO, precipitation, and fire severity is poorly understood, as discussed in the background chapter, so this relationship has less meaning. Additionally, the lack of a significant difference at the 800-hectare break level shows that the largest escapes occur independent of climate variability influences from ENSO, although the small size of the 800-hectare fire data set (only 14 fires), means that a fair amount of error may be associated with those results.

The two drought indices show more uniform results across the three area burned break levels. The significantly higher PDSI means associated with large fires in all the groups indicate that large escaped fires are occurring not during long-term droughts, as described by the escaped fire reports, but instead during long-term wetter-than-normal periods. The lack of a significant difference between means of PZI values associated with fires further enforces the long-term nature of these wet spells, as PZI is a better indicator of 1-3 month drought conditions, while PDSI indicates conditions on the 9-12 month scale.

These indications that large escaped prescribed fires occur during wetter years than smaller escaped fires further reinforce two of the theories discussed in Chapter 4 on the nature of escaped fire occurrence. Long periods of above-average precipitation and soil moisture support increased production of fine fuels; the 1- and 10-hour fuels that sustain fire spread. When these fine fuels dry out rapidly due to a synoptic event such as a week-long heat wave, it increases the fuel loading available for an escaped fire event, even if long-term conditions are unaffected by the heat wave and remain wetter-than-normal for the long-term. Additionally, fire managers may be trying to burn the fine fuels before a rain event makes them unavailable as fuel, and would likely commence with prescribed fire use while conditions are still fairly dry and hot. The fact that drought conditions are NOT present may serve to exacerbate the situation by presenting fire managers with a situation that they believe has less potential for extreme fire behavior.

NFDRS Indices

The outputs for the fire danger indices indicate that escaped fires occur primarily on days when NFDRS outputs are average, not extreme. Four of the six escapes which did occur on days when NFDRS values were at or above the 90th percentile occurred before NFDRS was refined in 1988, and the 1974 escape occurred before NFDRS existed. This leaves just two escapes for the region that may have been prevented by closer attention to NFDRS indices, and the fires were in different climate divisions and in entirely different seasons (fall and spring).

The fact that most escapes did NOT occur on “extreme” fire danger days further supports that fire managers are actually utilizing NFDRS, which agrees with the findings of the survey in Chapter 3. Of all of the various climate information sources which survey respondents were asked if they used, NFDRS had one of the higher use rates, with 59% of respondents indicating that they use NFDRS indices in their prescribed fire planning and implementation. It also helps to narrow the search for causes of escaped fires, and asks what other observation can be made about large escaped fires in an attempt to understand why they happen.

Observations on large escaped prescribed fires

If large escaped fires in California and Nevada are not occurring during droughts or on days when environmental conditions are producing extreme fire danger, then another causal factor that must be considered is the occurrence of a synoptic event. In the survey described in Chapter 3, respondents who were “escape” and had experienced an escaped prescribed fire were asked to indicate the primary cause of the escape. Out of the 52 “escape” respondents, 23 (44%) indicated that an unexpected wind event caused their escaped fire.

Unexpected wind events can take many forms, but an assessment of the timing of large escaped fires indicates that one particular type of wind event may play a large role in large California escapes. A histogram of just the large escaped fires (>200 ha) by month of occurrence reveals that the vast majority of escapes occurred in three fall months: August, September, and October, with exactly 50% of the escapes occurring in October alone (Fig. 5.6).

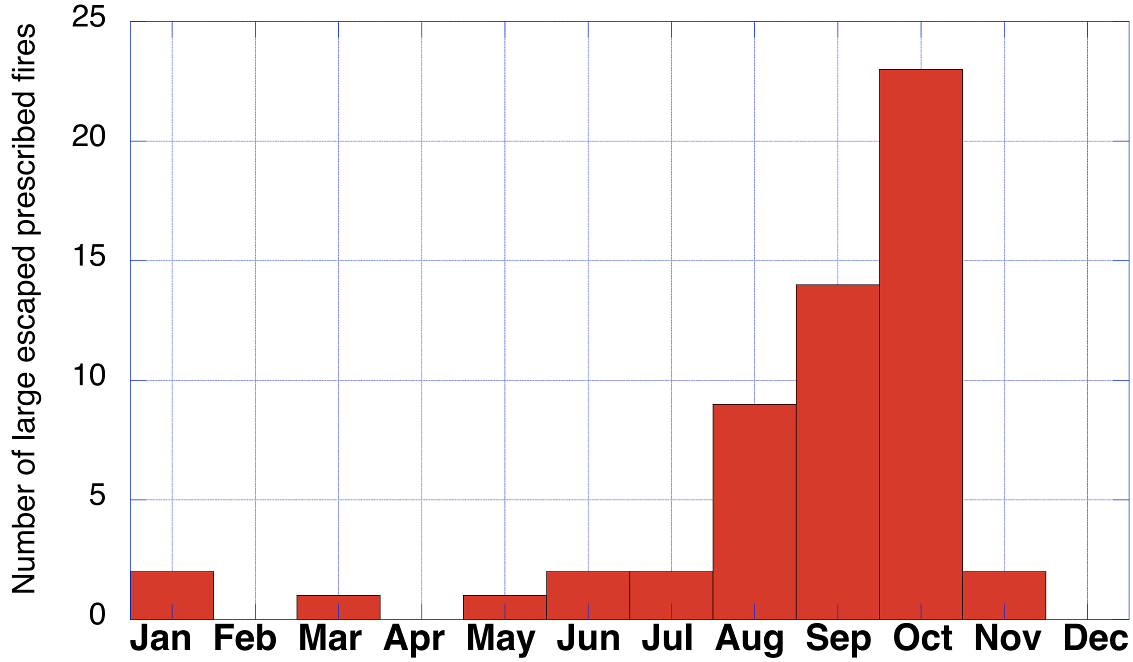

Figure 5.6. Histogram of large (>200 hectares) escaped fire occurrence by month for the 33-year data period reveals high rate of escapes in fall.

While the timing of prescribed fire use is split fairly evenly between the spring and fall months for this region (Kolden, unpublished data), few large escapes have occurred in the spring. Due to the prolonged summer dry season, large fuels are much drier in the fall, and fine fuels are cured and ready to burn, creating optimal conditions for extreme fire behavior. But fire managers know this, and as the NFDRS analysis above indicated, the fall large escaped fires are not occurring on extreme fire danger days when fuel conditions are at critical levels.

What does occur during the fall months, but not the spring, is a wind phenomenon known all too well by fire managers and residents alike in southern California. In the Transverse mountain ranges of southern California, the events are characterized by the Santa Ana winds; dry, hot, and extremely strong east/northeast winds that have fueled numerous catastrophic wildfire events in the past, including the record-breaking October 2003 firestorm event. The east winds are created as summer transitions into fall, and a persistent ridge of high pressure sits over the deserts of southeastern California and Nevada. When a low pressure system moves into position off the coast of California, the strong pressure gradient between the high and the low causes the mass of dry air over the deserts to rush westward, and the mountain barrier allows the winds to gain speed as they crest the summits and rush down the other side, warming and drying adiabatically as they sink towards the coast.

While the Santa Ana winds are the strongest because of the elevational gradient of the Transverse ranges and the heat of the Mojave desert, similar east wind events occur up the entire length of the Sierra Nevada under various local names such as Mono winds, Chinook winds, and Foehn winds. In October 1991, an east wind event (called a Diablo wind) fueled the disastrous Oakland/Berkeley Hills wildfire in the San Francisco Bay Area, claiming 25 lives and over 3,000 homes (www.firewise.org).

This type of east wind is a likely contributor to large escaped prescribed fires in California due to the timing of most of the large escapes and the problems with trying to predict east wind events. NIFC has archived its daily National Fire Situation Report (SIT Report) on its website back to 1997, and as the SIT Report contains an account of all large fires and any weather warnings (such as a Red Flag warning issued by the National Weather Service for an east wind event), I browsed the archives for fall months when escaped fires occurred. While many Red Flag and other weather warnings are listed around the time of many of the escapes, it is difficult to pinpoint each escape to a specific east wind event. This is because dates for escaped fires are inconsistent, as there is no standard method for reporting. It may be the date the prescribed fire began (before it escaped), the date it escaped, the date it was reported as an escape (up to 1 or 2 days after the initial loss of control), or even the date the fire was contained. In many cases during the survey portion of the study, a fire manager described an escaped prescribed fire that escaped several weeks after the initial prescribed fire was completed, when a strong, dry wind would find a remnant ember and fan it into a wildfire.

After analyzing the large escaped fires, it is easy to imagine how an escape could occur on the western slope of the Sierra Nevada. A wetter-than-normal year has produced an abundance of fine fuels, which fire managers try to reduce using prescribed fire. There is no drought, and they try to burn the fine fuels while they are cured, before the rains come, perhaps under drier and hotter conditions than they would consider during a drought situation. Either during or after the prescribed fire takes place, an east wind event that could not be predicted prior to igniting the fire raises the level of fire behavior beyond the control of the fire managers; perhaps an ember takes flight and creates a spot fire, and the prescribed fire escapes and becomes a wildland fire. If the east wind event persists and no fire suppression personnel are immediately available, the escaped fire becomes a large escape. This is precisely what happened during the largest escaped fire in the data set, the Weinstein fire, which started from the remnants of a California Department of Forestry and Fire Protection (CDF) prescribed fire in 2000 and grew to 3,347 hectares under east wind conditions in primarily 1- and 10-hr fuels (shrub types).

Conclusions about Large Escaped Fires

The analysis of large escaped fires and speculation on what causes them further supports the theory that escaped fires in the California portion of the study region are not usually associated with drought conditions. The evidence for wetter conditions during times of large escaped fires and the timing of the fires in the late summer and early fall points to meteorological events such as Foehn or other east winds driving large escapes, as well as a possible misinterpretation of conditions on the part of fire managers conducting prescribed fires under what they would consider to be “safer” conditions. While it would again seem that fire managers would have little use for utilizing the types of climate information and tracking indices discussed in Chapter 3 if they are trying to prevent large escaped fires, in fact, these findings should encourage them to be more aware of the dangers associated with increased fuel loads during wetter years, and have a strong understanding of the climatology associated with east wind events.

CHAPTER 6

CONCLUSIONS

Escaped prescribed fire events in California and part of Nevada do not appear to occur under drought conditions, despite the suggestions made in escaped fire incident reports. In California, escaped fires tend to occur under wetter-than-normal conditions, and larger escaped fires occur under wetter conditions than smaller escaped fires. In Nevada, it appears that escaped prescribed fires occur in conjunction with long-term drought conditions primarily in eastern Nevada and with short-term drought conditions primarily in southern Nevada.

Even the largest escaped fires for the region did not occur on days when fire danger indices indicated extreme conditions, and many of the largest escaped fires occurred on days when fire danger was below average. Most large escaped fires, however, did occur in the early fall, and fire managers suggest that unpredicted wind events have a role in causing escaped fires in California. This suggests that meteorological events such as fall east winds may play a role in causing escaped fires, but in conjunction with wetter-than-normal periods that promote build-up of fine fuels.

These mixed correlations to drought conditions and the inconsistencies with the findings of escaped fire investigations may help to explain why few fire managers in the region use tools and indices to track climate variability and its impacts on fuels and fire conditions. The initial objective of the study was merely to assess whether fire managers who have not had escaped prescribed fires (the so-called ‘non-escape’ managers) utilize more climate information than fire managers who have had escaped fires (the ‘escape’ managers), but the results of the survey indicated that not only is there no significant difference between the two groups of fire managers, neither group of fire managers uses much climate information at all. Further exploration of this result through other survey questions revealed that using prescribed fire is a complex task with numerous political obstacles such as funding issues, environmental regulations, resource shortages, inability to acquire reliable information, and a general lack of infrastructure support for prescribed fire use.

The incidence of escaped prescribed fires has great potential to increase as the pressure to use prescribed fire increases. To limit the number of destructive escaped prescribed fires, future work should not only focus on assessing the meteorology associated with escaped fires, but also on methods for making the fire management community more aware of the climatological conditions under which escaped fires occur. Research needs to focus on the fuel conditions associated with escaped fires, how climate impacts these fuel conditions, and what climate indices and information best track this process. We also need a better understanding of exactly how escaped fires occur; as the inconsistent tracking of dates, causes, size, location, weather events, and property boundaries leads to inaccurate data sets.

This study set out to assess whether or not climate conditions, as opposed to weather, was important in understanding and preventing escaped prescribed fires. The results indicated that climate conditions have a strong, quantifiable relationship to the conditions under which escaped prescribed fires occur, and that a better understanding of how climate and synoptic weather events work in an integrated manner to impact prescribed fire use and fuel conditions could prevent future escaped fires. Furthermore, it demonstrated that fire managers do not utilize climate information in their prescribed burning programs, which may be one of the reasons that escaped fires are still occurring regularly. The need to utilize climate information in prescribed burning to prevent escaped fires is evident.

Currently, the only assessment of an escaped fire is a subjective review process by fire management personnel that tends to focus on fire management and personnel mistakes at the time of the escape. A quantitative assessment of the environmental conditions under which escaped fires occur, and the search for climatological patterns under which escaped fires occur, may allow fire managers to better predict conditions under which prescribed fire use is unfavorable, and risk of escaped fire is high. Prescribed fire use as a fire management tool in this region is inevitable. But reducing destructive escaped fires is possible with a clearer understanding of the conditions under which they occur.

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TERMINOLOGY and ACRONYMS

1,10,100,1000hr fuels: Dead plant material is described as a time-lag fuel. The descriptor (1hr) is the amount of time it takes for the fuels interior moisture level to reach two-thirds equilibrium moisture content with its surrounding environment.

BIA: Bureau of Indian Affairs

BLM: Bureau of Land Management

ECPC: Experimental Climate Prediction Center (at Scripps Institute)

ENSO: El Niño Southern Oscillation

ERC: Energy Release Component

FF+: FireFamilyPlus software

FRCC: Fire Regime Condition Class

FWS: US Fish and Wildlife Service

IC: Ignition Component

KBDI: Keetch-Byram Drought Index

KCFAST: Kansas City Fire Access SofTware

MEI: Multivariate ENSO Index

NDVI: Normalized Difference Vegetation Index

NFDRS: National Fire Danger Rating System

NIFC: National Interagency Fire Center

NIFMID: National Interagency Fire Management Integrated Database

NOAA: National Oceanic and Atmospheric Administration

NPS: National Park Service

NWCG: National Wildfire Coordinating Group

NWS: National Weather Service

PDO: Pacific Decadal Oscillation

PDSI: Palmer Drought Severity Index

PZI: Palmer Z Index

RAWS: Remote Automated Weather Station

SC: Spread Component

SPI: Standardized Precipitation Index

SWSI: Surface Water Supply Index

US Drought: US Drought Monitor

USDI: US Department of the Interior

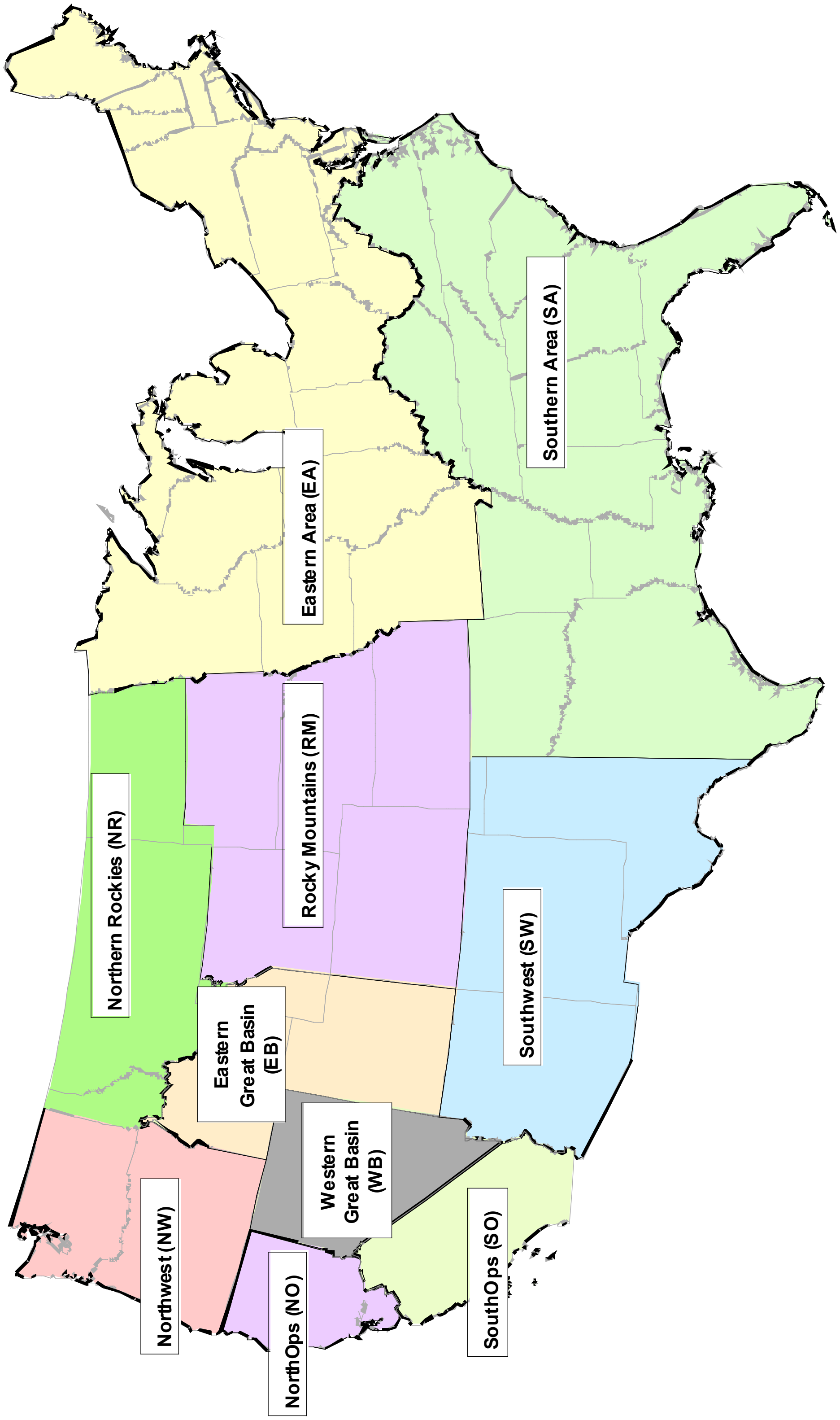
USFS: US Forest Service

VCI: Vegetation Condition Index

WIMS: Weather Information Management System

WUI: Wildland Urban Interface

APPENDIX A



Jurisdiction and abbreviations for each of the Geographic Area Coordination Center (GACC) regions coordinated by the National Interagency Fire Center.

APPENDIX B

The survey data utilized for this thesis came from a larger project on climate variability and prescribed fire being conducted by the Program for Climate, Ecosystem, and Fire Applications (CEFA) at the Desert Research Institute. The survey project was approved by the University of Nevada, Reno, Office of Human Research Protection (Approval E03/04-61). The survey was sent to participants, and their responses were collected over the telephone. Every effort was made not to guide or misinterpret responses, and participants were encouraged to add comments for clarity or ask for clarification of questions. Nonetheless, the timing and manner in which surveys were conducted could probably not be replicated, and therefore, the results of the survey could likely not be replicated.

On the following pages is a copy of the survey questions, exactly as participants received them. Additionally, pivot tables containing counts of the answers analyzed as part of this study follow.

PRESCRIBED FIRE SURVEY
PROGRAM FOR CLIMATE, ECOSYSTEM, AND FIRE APPLICATIONS
DESERT RESEARCH INSTITUTE, RENO, NEVADA

Please answer all questions as completely as possible. Your answers will remain anonymous, therefore, I ask you to be honest. If a question does not apply to you or you don't know, please answer "Don't know" or "Not Applicable".

Agency: ___________________________

*National Forest/National Park/BLM district/etc.:*___________________

Part I. *Information about your position*.

1. How many years have you been involved in the prescribed fire program at this location?______________________

2. Have you been involved in the prescribed fire program at another location? _____

   If so, what GACC region?_______________________________

Part II. *Information about your prescribed fire program*.
By "prescribed burning," I mean fires that are planned and intentionally set, including broadcast burns, pile burns, etc.

By "WFU," I mean Wildland Fire Use, previously known as Prescribed Natural Fire (PNF).

3. Over the last few years, approx. what percentage of **acres** was burned by each type of prescribed fire at your current location? (Please make sure percentages total 100%.)

   - Broadcast/underburning _________
   - Pile burning ________________
   - Wildland Fire Use ____________

The remaining questions in this survey apply only to prescribed burns. If 100% of prescribed fire acreage comes from Wildland Fire Use, please stop here.

I am asking for acreage data for burns that your district or field office planned and/or conducted for last 10 years (or as many years as you can complete). If acreage data is not available, please try to estimate instead of leaving the space blank.

In the last column, I would like you to give your opinion of how well you think the year went in terms of completing prescribed burns (rate on a scale of 1 to 4):

1 = Great! We completed most of our burning and the conditions for burning were good.

2 = Good. We had to postpone a few burns because of problems with conditions or permits or resource availability.

3 = Fair. We completed about half the burning that we wanted to, and had to postpone many burns.

4 = Poor. We completed very little or no burning.

N/A = No burning this year or not involved with program during this year.

Year	Est. # of acres Rxburned	# of acres (or burns) targeted	# of Rx burns completed	# of escaped Rx fires	Rating of year for Rxburning	Reason for rating (why year was good or bad)
2003						
2002						
2001						
2000						
1999						
1998						
1997						
1996						
1995						
1994						

4. What percentage of your prescribed burning is performed in each season? (Please make sure percentages total 100%.)

    - Fall (September - November) _______
    - Winter (December - February) _______
    - Spring (March - May) _______
    - Summer (June - August) _______

5. What are the **TWO** most common objectives of the burns your program performs? (Check one or two answers)

    - Hazardous fuels/vegetation reduction
    - Habitat improvement
    - Increase forage production for livestock
    - Creation of fuel breaks (such as greenstrips, shaded fuel breaks, DFPZs, etc.)
    - Ecosystem restoration (including mimicking natural processes)
    - Other ____
    - Don't know/ Not applicable

Part III. *Planning Prescribed burns*

6. What factors have the most influence on the amount of acres or burns you *target* for burning each year? Please **RANK** (1 through x) all of the factors that affect your planned acreage.

    ___Funding
    ___Permits (NEPA, air quality, EIS approval, city/state approval)
    ___Public input
    ___Number of acres/burns completed the previous year
    ___Weather information
    ___Climate information
    ___Seasonal climate forecasts
    ___Other____
    - Don't know/ not applicable

7. For your location, what is the *minimum* amount of time that must elapse between initial completion of a Prescribed Fire Plan and the completion of a burn (due to approval or NEPA process)?

____

8. For your location, what is the *maximum* amount of time that you have seen elapse between planning and completion of a burn (**if your answer is more than 10 years, please answer 10 years)?**

____

9. What is the primary factor that lengthens this lapse period? (Check only one)

- ☐ NEPA
- ☐ Air quality concerns
- ☐ Environmental concerns (species issues, lawsuits, etc.)
- ☐ Political pressure (politicians actively preventing burn plan approval or completion)
- ☐ Very strict prescription parameters- it's hard to get a burn window
- ☐ Long-term drought or wet period
- ☐ Inability to acquire resources for burn
- ☐ Other ________________________________
- ☐ Don't know/ Not applicable

10. What resources do you use when planning prescribed burns, from the initial planning process right up until the burn day (check all that apply):

- ☐ RAWS data
- ☐ Seasonal Climate Forecasts
- ☐ Seasonal severity maps
- ☐ National Weather Service Forecast
- ☐ Keetch-Byram Drought Index (KBDI)
- ☐ Palmer Drought Severity Index or Palmer-Z (PDSI)
- ☐ NDVI
- ☐ Standardized Precipitation Index (SPI)
- ☐ US Drought Monitor
- ☐ Surface Water Supply Index
- ☐ NFDRS outputs (i.e. ERC, BI, SC)
- ☐ Vegetation Condition Index
- ☐ ECPC Forecast
- ☐ Predictive Services (if so, what GACC location(s)? ____________
- ☐ Historical Weather data
- ☐ FireFamilyPlus
- ☐ WIMS
- ☐ NIFMID
- ☐ Haines Index
- ☐ Other________________________________
- ☐ Don't know/ Not applicable

11. If you utilize RAWS data or historical weather data, how much data did you use on your most recent prescribed burn? (Check only one. Example: if your burn was on October 31, 2003 and you used RAWS data from October 15th to burn day, you would answer "1 week to 1 month prior to burn")
    - less than 1 week's worth of weather data prior to burn
    - 1 week to 1 month prior to burn
    - 1 to 3 months prior to burn
    - 3 to 12 months prior to burn
    - 1-2 years prior to the burn
    - more than 2 years prior to burn
    - I don't generally use RAWS data or historic weather data
    - Don't know/ Not applicable

12. How would you describe the information and products available at your GACC's Predictive Services? (Check only one)
    - It provides great forecasts, data, etc.; my data needs are met
    - It provides some information for us
    - I don't use the products much because the products don't work for my area
    - I don't use the products much because I get better products from somewhere else
    - I don't use Predictive Services because I'm not aware of what products are available
    - Don't know/ Not applicable

13. How would you describe the information and products available at your NWS office (check only one) which is (please fill in the blank) ________________?
    - It provides great forecasts, data, etc.; my data needs are met
    - It provides some information for us
    - I don't use the products much because the products don't work for my area
    - I don't use the products much because I get better products from somewhere else
    - I don't use NWS because I'm not aware of what products are available
    - Don't know/ Not applicable

14. Which phrase **BEST** describes how you determine when your **primary** prescribed burning season begins? (Check only one)
    - Our prescribed burning season is usually year-round
    - Our prescribed burning season is usually any time outside of fire season
    - Our prescribed burning season usually begins as soon as the snow melts
    - Our prescribed burning season usually begins right after green-up
    - Our prescribed burning season usually begins at the end of fire season
    - Our prescribed burning season usually begins after the first big rainfall/snowfall
    - Our prescribed burning season is determined by permits from local, county, or state agencies (including air quality compliance restrictions)
    - Our prescribed burning season is determined by wildlife or endangered species issues (such as breeding or nesting periods)
    - Our prescribed burning season usually begins when a burn window opens
    - Our prescribed burning season usually occurs about the same time every year (for example, the first two weeks of April or around the beginning of November), and that time is (please fill in the blank)____________________
    - Other ____
    - Don’t know/ Not applicable

15. What tools/resources do you use to monitor when your burn season begins? (check all that apply)
    - RAWS station or manual weather data
    - Fuel moisture sticks or samples
    - Visual observation of snowmelt, green-up, precipitation, etc.
    - NDVI or other remotely sensed data
    - Other ____
    - Don’t know/ Not applicable

Part IV. *Burn implementation. Questions 16-19 apply to your most recent completed prescribed burn.*

16. Did you measure onsite 1-hour fuel moistures before your last burn?
 Yes No Don’t know/Not applicable

17. Did you measure onsite 10-hr fuel moistures before your last burn?
 Yes No Don’t know/Not applicable

18. Did you measure onsite 100-hr fuel moistures before your last burn?
 Yes No Don’t know/Not applicable

19. Did you measure 1000-hr fuel moistures before your last burn?
 Yes No Don’t know/Not applicable

20. What is the **primary** cause for last-minute postponement or cancellation of a prescribed burn for you?
 Not enough resources on-hand
 Air quality issues
 Winds
 Precipitation
 Drought conditions
 State or county no-go decision
 Out-of-prescription
 Unsatisfactory fire behavior conditions (test fire behavior, lightning in area, etc.)
 Other ____
 Don’t know/ Not applicable

Part V. *Burn Windows*.

I would like examples of prescribed burn windows for various ecotypes and regions. This information will be used to study the predictability of optimal burning conditions. I would appreciate copies of any recent burn plans you are able to send (even if it is only one or two); the information contained in them will remain confidential. The information I plan to use is:

- Parameters of the burn window (min, max, and ideal values for temperature, RH, 1-hr fuel moistures, wind speed, wind direction, how long window must hold for, etc.)
- Severity of planned burn
- Location of the burn
- Vegetation burned or targeted for burning
- Time of year the burn was planned for (if applicable)

Please use the envelope provided to send burn plans. Any unnecessary information (such as who prepared the plan, appendices, BEHAVE runs, etc.) may be removed at your discretion.

21. What is the minimum number of *hours* of “good” weather you need to commence burning for a given day? ______

22. What is the minimum number of *days* of “good” weather you need to commence burning? _______

23. On average, about how many days is your burn season?
____

Part VI. *Climate*.

24. Based on your experience, how far ahead can you usually tell how favorable the conditions are for your prescribed burning season?
    - ☐ Conditions are unpredictable at a seasonal level
    - ☐ Less than 2 weeks before the season begins
    - ☐ Usually within one or two months before the season begins
    - ☐ Usually within three to six months before the season begins
    - ☐ Longer than 6 months before the season begins
    - ☐ Don’t know/ Not applicable

25. Based on your experience, which of the following weather components is the hardest to predict/most variable for trying to come into/stay in prescription at your location? (check all that apply)
    - ☐ Relative humidity
    - ☐ When precipitation will occur
    - ☐ How much precipitation will fall
    - ☐ Wind speed
    - ☐ Wind direction
    - ☐ Temperature
    - ☐ 1-hr or 10-hr fuel moisture
    - ☐ Mixing height/transport wind/ventilation
    - ☐ Other ____
    - ☐ Don’t know/ Not applicable

26. Based on your experience, which of the following climate patterns have the greatest impact on prescribed burning in your location? (check all that apply)
    - ☐ High pressure ridges
    - ☐ Drought
    - ☐ Temperature departures from average
    - ☐ Precipitation departures from average
    - ☐ Variability of burn windows
    - ☐ El Niño Southern Oscillation (ENSO) or La Niña
    - ☐ Pacific Decadal Oscillation cycles
    - ☐ Snowpack
    - ☐ Santa Ana winds
    - ☐ Foehn or Chinook winds
    - ☐ Southwest Monsoon
    - ☐ Other ____
    - ☐ Don’t know/ Not applicable

27. In your experience, do long-term climate trends significantly affect your prescribed burning program?
    - ☐ Yes, they have a major impact on our prescribed burning program
    - ☐ Sort of, they have some impact on our prescribed burning program
    - ☐ No, they really don’t have any impact on our prescribed burning program
    - ☐ I’m not sure
    - ☐ Not applicable

28. How difficult is it to get forecasts or data on the long-term climate trends affecting your fuels and/or your prescribed burns?
    - Easy. I can get them with minimal effort, or someone else gets them for me.
    - Medium. Sometimes it takes me a while to find what I am looking for.
    - Difficult. It takes a lot of effort and time.
    - Climate data is not used in fuels assessment and burn decisions.
    - Don’t know/ Not applicable

29. Have you taken any college-level or agency-provided training courses in climatology?

     Yes No

30. Do you feel like you receive adequate climate education in agency training courses (such as the skills training series)?

     Yes No Don’t know/ Not applicable

31. Does your agency provide you with seasonal climate forecasts or seasonal fire potential outlooks?

     Yes No Don’t know/ Not applicable

Part VII. *Escaped prescribed burns*.

32. Have you observed or know of an escaped prescribed burn on your district in the last 15 years?

     Yes No Don’t know/ Not applicable

33. If yes, what was the primary cause of the escape (check only one)?
    - Unexpected wind gusts or cold front
    - Inadequate personnel for fire
    - Drier 1-hr or flashy fuels than expected
    - Drier large or 1000-hr fuels than expected
    - Outside of prescription from start
    - Unexpected extreme fire behavior
    - Can’t remember
    - Other ____________________
    - Don’t know/ Not applicable

34. If you have any additional comments pertaining to this survey, please indicate them here. I am trying to determine how climate impacts prescribed fire use, and how available climate information is to the people who need it most in their planning and execution of burns. Your input is very important to me.

END OF SURVEY

Thank you for taking the time to complete this survey. Results will be published in approximately 18-24 months and will be available on our webpage: www.cefa.dri.edu

Please don't forget to send acreage data and burn plans if you have not already done so. Thank you!

Counts of answers for Questions used in Social Analysis

Since questions were closed-ended (potential answers were provided), the answers for each question in the survey were assigned numbers in order. For example, for Question 6, the numbers correspond to the answers as follows:

6. What factors have the most influence on the amount of acres or burns you *target* for burning each year? Please **RANK** (1 through x) all of the factors that affect your planned acreage.
   (1) ___Funding
   (2) ___Permits (NEPA, air quality, EIS approval, city/state approval)
   (3) ___Public input
   (4) ___Number of acres/burns completed the previous year
   (5) ___Weather information
   (6) ___Climate information
   (7) ___Seasonal climate forecasts
   (8) ___Other________________________________
   (9) Don't know/ not applicable

The following pivot tables give the counts of answers for each questions. These counts were stratified by whether or not respondents fell in the "non-escape" (0) or "escape" (1) fire manager group.

Count of 6.#1 Influence	6.#1 Influence								
32.Escapes?	1	2	3	4	5	8	9	(blank)	Grand Total
0	13	9			4	13	1		40
1	21	7	3	4	4	13			52
(blank)									
Grand Total	34	16	3	4	8	26	1		92

Question 6, #1 influence by answer number.

Count of 6.#2 Influence	6.#2 Influence								
32.Escapes?	1	2	3	4	5	6	8	(blank)	Grand Total
0	14	9	2		6	2	3		36
1	14	18	1	2	4	2	7		48
(blank)									
Grand Total	28	27	3	2	10	4	10		84

Question 6, #2 influence by answer number.

Count of 6.#3Influence	6.#3Influence									
32.Escapes?	1	2	3	4	5	6	7	8	(blank)	Grand Total
0	3	5	3	4	6	3	1	3		28
1	5	5	2	6	6	2	4	3		33
(blank)										
Grand Total	8	10	5	10	12	5	5	6		61

Question 6, #3 influence by answer number.

Count of 11.Historical	11.Historical									
32.Escapes?	1	2	3	4	5	6	7	8	(blank)	Grand Total
0	4	24	5		1	1	1	4		40
1	7	33	2	1	1	6	1	1		52
(blank)										
Grand Total	11	57	7	1	2	7	2	5		92

Question 11 counts by answer number.

Count of 12.Pred Serv	12.Pred Serv							
32.Escapes?	1	2	3	4	5	6	(blank)	Grand Total
0	20	11		3	3	3		40
1	31	17	1	2	1			52
(blank)								
Grand Total	51	28	1	5	4	3		92

Question 12 counts by answer number.

Count of 13.NWS	13.NWS						
32.Escapes?	1	2	3	4	6	(blank)	Grand Total
0	17	14	1	7	1		40
1	19	22		11			52
(blank)							
Grand Total	36	36	1	18	1		92

Question 13 counts by answer number.

Count of 19.thous-hr	19.thous-hr				
32.Escapes?	0	1	2	(blank)	Grand Total
0	24	15	1		40
1	29	23			52
(blank)					
Grand Total	53	38	1		92

Question 19 counts by answer (yes=1, no = 0).

Count of 27.trends	27.trends						
32.Escapes?	1	2	3	4	5	(blank)	Grand Total
0	12	16	6	6			40
1	13	30	5	3	1		52
(blank)							
Grand Total	25	46	11	9	1		92

Count of 28.Difficulty?	28.Difficulty?						
32.Escapes?	1	2	3	4	5	(blank)	Grand Total
0	18	11	3	2	6		40
1	28	14	3	5	2		52
(blank)							
Grand Total	46	25	6	7	8		92

Question 28 counts by answer number.

Count of 29.Courses?	29.Courses?			
32.Escapes?	0	1	(blank)	Grand Total
0	22	18		40
1	35	17		52
(blank)				
Grand Total	57	35		92

Questions 29 counts by answer number.

APPENDIX C

As discussed in chapter 4, escaped fire area burned was correlated to climate indices at two temporal scales and using two different methods of correlation. The original escaped fire data set included data from 1970 to 2002, but a high amount of variance in the first decade of the data set was due to the developing nature of the prescribed fire programs, and was therefore excluded in a second escaped fire data set covering 1982-2001. Spearman Rank correlation was performed for annual correlations, but monthly correlations were performed utilizing both Spearman Rank correlation and Pearson Product-Moment correlation. Pearson correlations and all correlations involving the 33-year escaped fire data set were not discussed in chapter 3. All correlation results are presented in the following tables. Correlations were divided into four classes: strong positive (1.0 to 0.5), weak positive (0.5 to 0), weak negative (0 to -0.5), and strong negative (-0.5 to -1.0).

Spearman Rank (Rs) 33-year Annual Correlations					
		WinterENSO	**AnnENSO**	**PDSI**	**PZI**
Log(ha)					
Division	401	-0.432	-0.398	0.177	0.149
	402	-0.019	0.281	0.625	0.556
	403	0.036	-0.143	-0.143	-0.036
	405	0.199	0.090	0.422	0.333
	2601	-0.600	-0.800	0.800	1.000
	2602	0.055	-0.285	-0.212	-0.067
	2603/2604	0.643	0.536	-0.250	-0.464
State	California	-0.040	0.197	0.413	0.311
	Nevada	0.282	0.071	0.018	0.024
Study Region		0.060	0.257	0.438	0.362
Ha/fire					
Division	401	-0.122	-0.105	0.101	0.187
	402	-0.131	0.160	0.272	0.213
	403	0.000	-0.167	0.000	-0.310
	405	-0.251	-0.007	0.374	0.264
	2601	-0.100	-0.600	0.800	0.900
State	California	-0.280	-0.108	0.495	0.407
	Nevada	0.350	0.110	0.093	0.145
Study Region		-0.195	-0.069	0.628	0.349

33-year Monthly data set		*Spearman Rank (R_s)*				*Pearson Product Moment*		
		ENSO	**PDSI**	**PZI**		**ENSO**	**PDSI**	**PZI**
Division	**401**	-0.290	0.269	-0.023		-0.174	0.214	0.030
	402	-0.009	0.167	0.049		0.060	0.216	0.034
	403	0.082	-0.337	-0.255		0.118	-0.343	-0.286
	405	-0.073	0.147	0.123		-0.015	0.153	0.166
	2601	-0.800	0.600	0.200		-0.481	0.829	0.667
	2602	-0.070	-0.270	0.004		-0.151	-0.299	0.160
	2603/2604	-0.116	-0.207	-0.628		-0.229	-0.325	-0.520
State	**California**	-0.076	0.127	0.105		-0.015	0.164	0.132
	Nevada	0.128	-0.009	0.156		0.112	0.041	-0.063
Study Region		0.011	0.229	0.167		0.056	0.267	0.178

Spearman Rank (Rs) 20 -year Annual Correlations					
		WinterENSO	**AnnENSO**	**PDSI**	**PZI**
Log(ha)					
Division	401	-0.314	-0.271	0.182	0.143
	402	0.121	0.371	0.632	0.589
	403	0.657	0.371	-0.257	-0.086
	405	-0.417	-0.017	0.442	0.272
	2601	-0.600	-0.800	0.800	0.100
	2602	-0.095	-0.381	-0.595	-0.500
	2603/2604	0.429	0.257	0.200	-0.371
State	California	-0.386	-0.056	0.529	0.388
	Nevada	0.203	-0.060	0.060	0.044
Study Region		-0.293	-0.045	0.678	0.502
Ha/fire					
Division	401	-0.141	-0.008	0.235	0.280
	402	-0.031	0.325	0.280	0.226
	403	0.543	0.200	-0.314	-0.257
	405	-0.370	0.074	0.423	0.272
	2601	-0.600	-0.800	0.800	1.000
State	California	-0.242	0.120	0.648	0.499
	Nevada	0.214	-0.038	0.088	0.066
Study Region		-0.242	0.030	0.758	0.632

20 -year Monthly data set		*Spearman Rank (R_s)*				*Pearson Product Moment*		
		ENSO	**PDSI**	**PZI**		**ENSO**	**PDSI**	**PZI**
Division	**401**	-0.331	0.185	-0.089		-0.205	0.142	-0.019
	402	-0.059	0.119	-0.005		0.030	0.193	-0.001
	403	0.444	-0.310	-0.225		0.451	0.294	-0.331
	405	-0.190	0.062	-0.047		-0.125	0.052	-0.003
	2601	-0.800	0.600	-0.600		-0.481	0.829	0.667
	2602	0.018	-0.709	0.018		-0.111	-0.726	-0.119
	2603/2604	-0.116	-0.207	-0.366		-0.229	-0.325	-0.520
State	**California**	-0.190	0.044	-0.016		-0.093	0.081	0.030
	Nevada	0.096	-0.067	0.231		0.041	-0.021	-0.015
Study Region		-0.096	0.236	0.094		-0.044	0.256	0.110

APPENDIX D

As discussed in chapter 5, large escaped prescribed fires (>400 ha) were assessed for whether they occurred on extreme fire danger days, where fire danger indices were at or above the 90th percentile for that day. This assessment was accomplished using the same FireFamilyPlus software that fire managers use for assessing fire danger conditions. Graphs of fire danger conditions for the week of the escaped fire were created for each of the four primary output values of the National Fire Danger Rating System and two secondary outputs, with the year of the fire graphed to show conditions for the fire date. Two examples were presented in the text on pages 89-90, and the graphs for all 30 large fire dates are presented on the following pages. For each fire I present value graphs for (a) 1000-hr fuel moisture, (b) Keetch-Byram Drought Index, (c) Energy Release Component, (d) Burning Index, (e) Spread Component, and (f) Ignition Component. Please see the text for definitions of these values. For each graph, the maximum (red line), average (thin gray line), and minimum (blue line) values for the corresponding date are graphed , as well as the value for the date of the fire (black dashed line) which is highlighted by the gray vertical bar.

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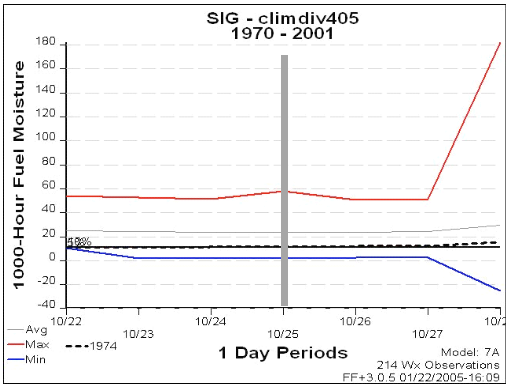

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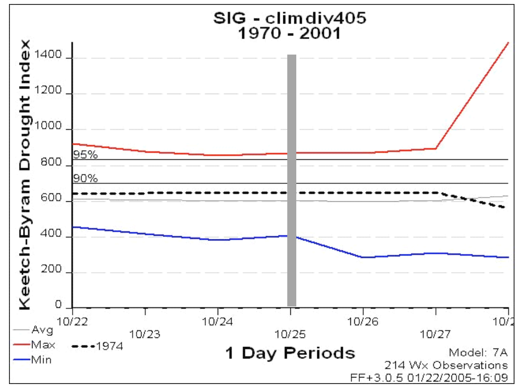

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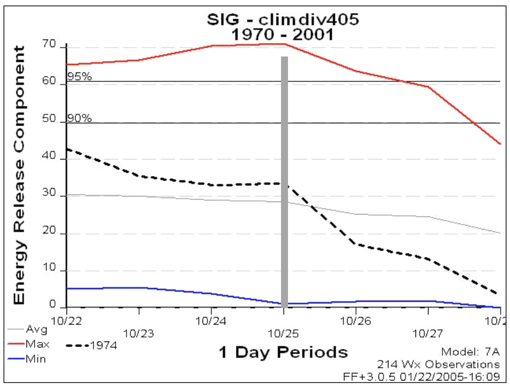

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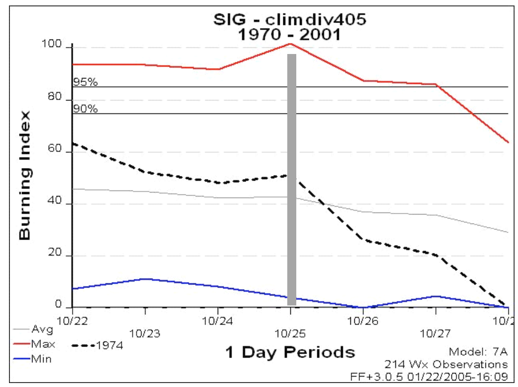

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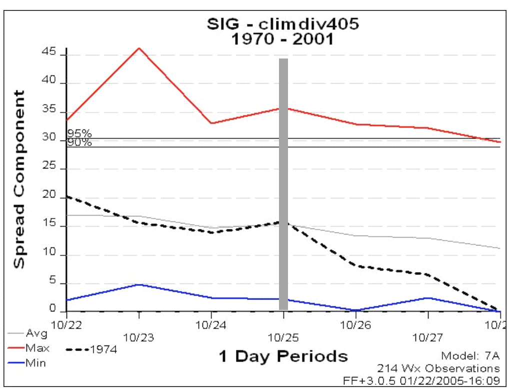

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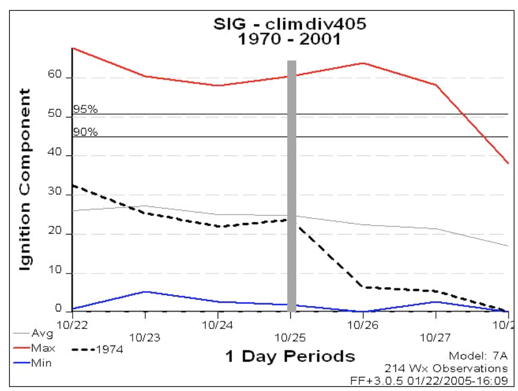

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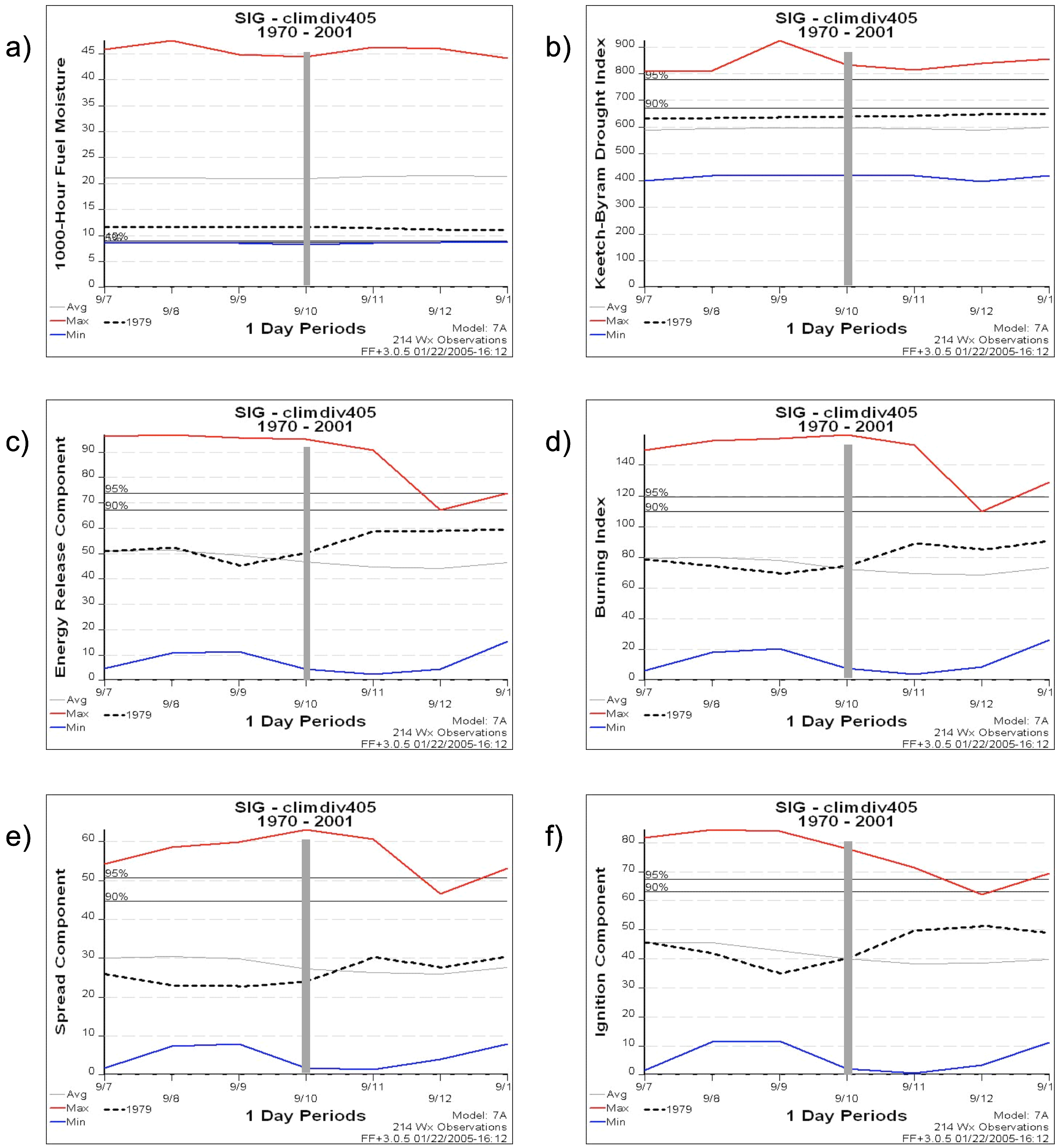

Fire Date: 9/10/79

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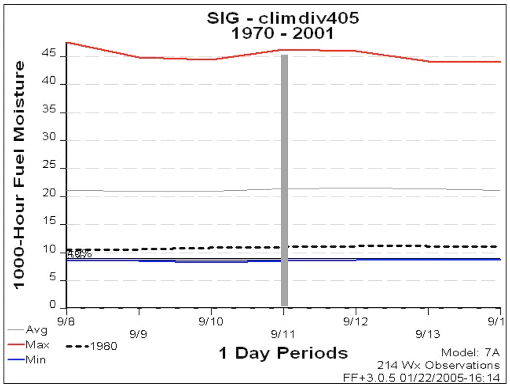

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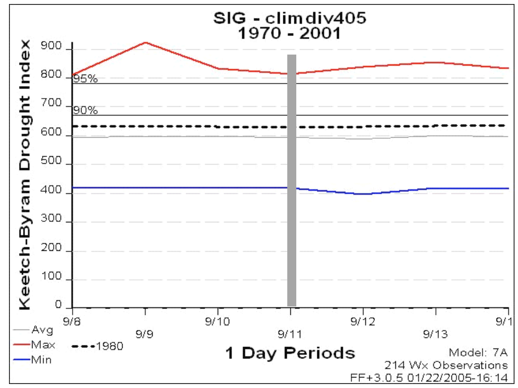

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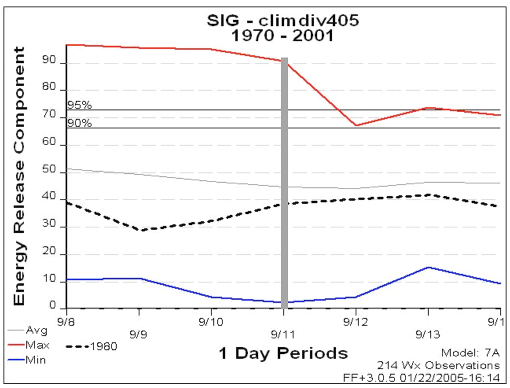

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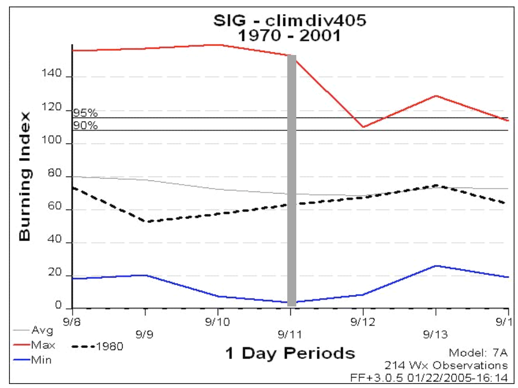

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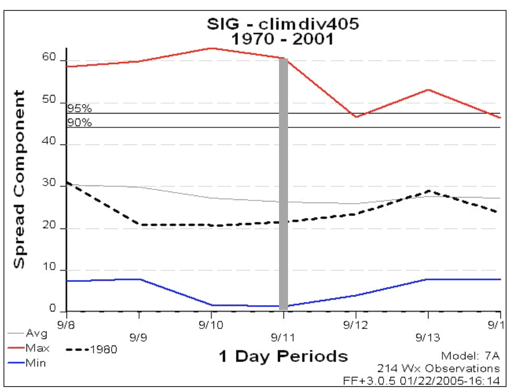

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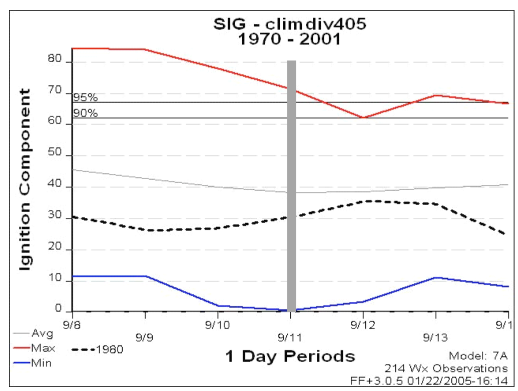

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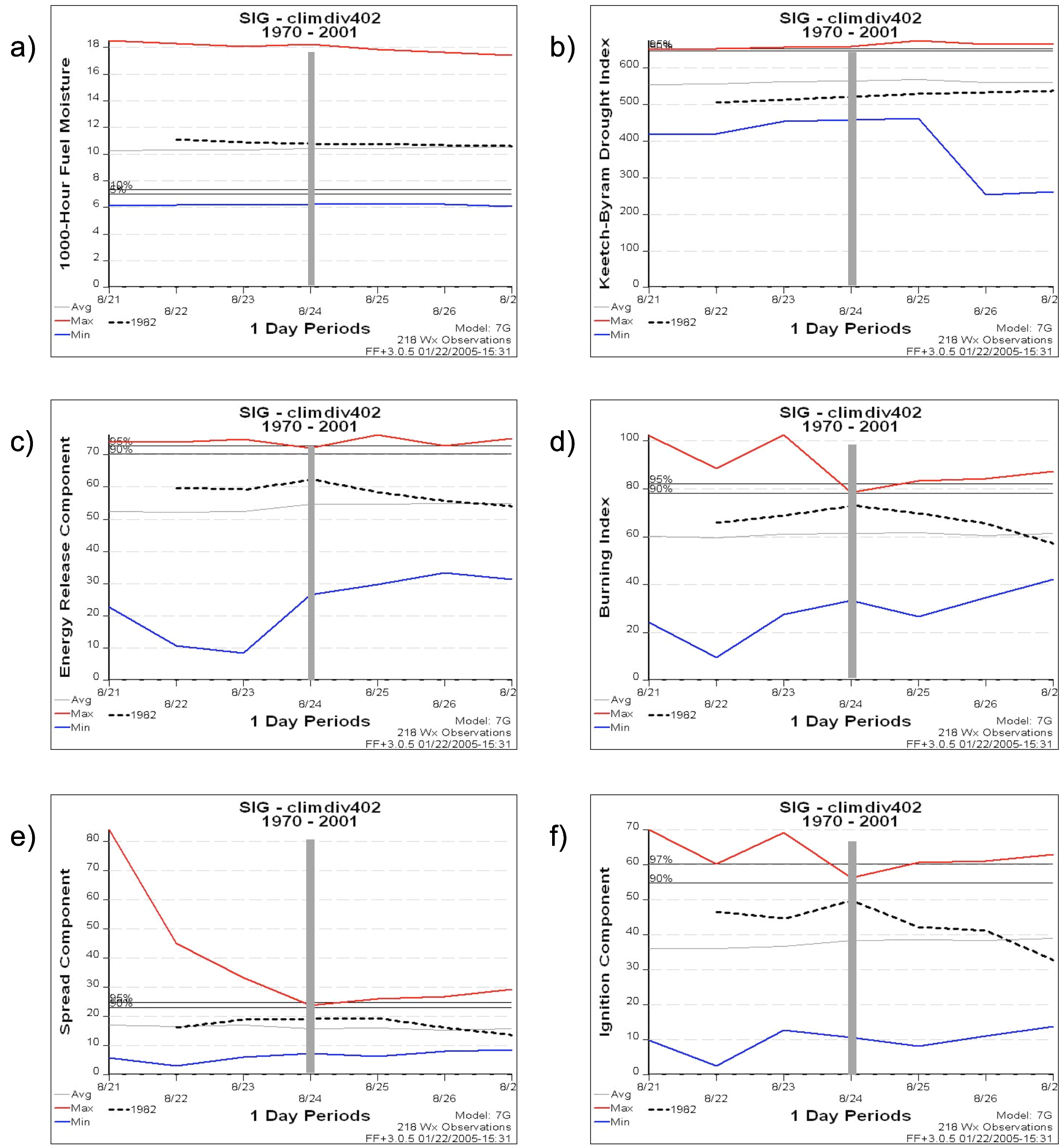

Fire Date: 8/24/82

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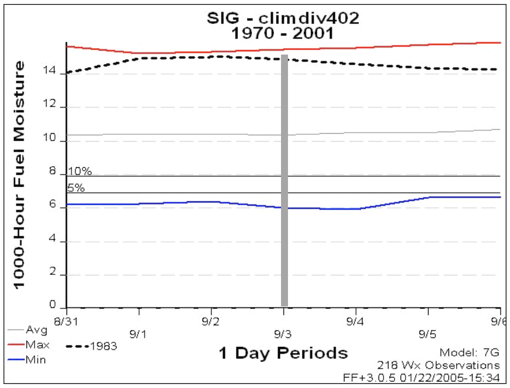

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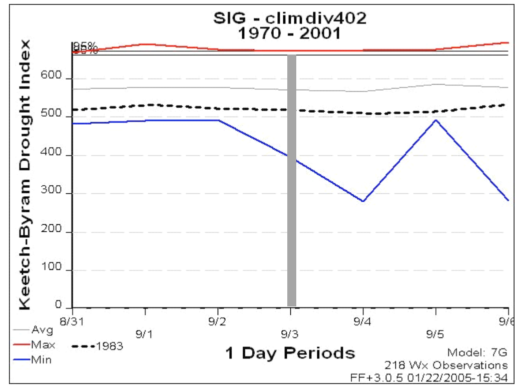

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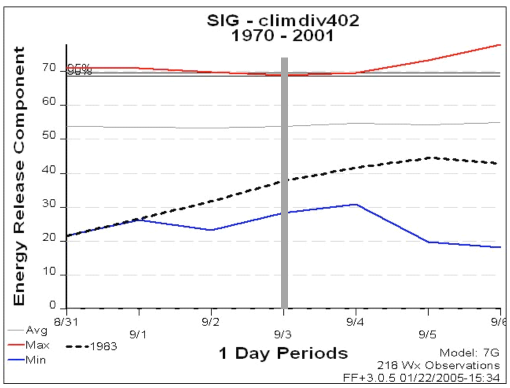

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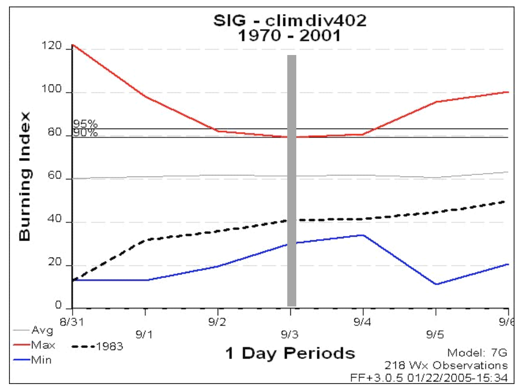

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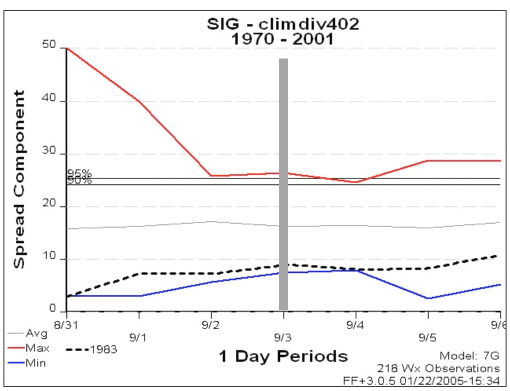

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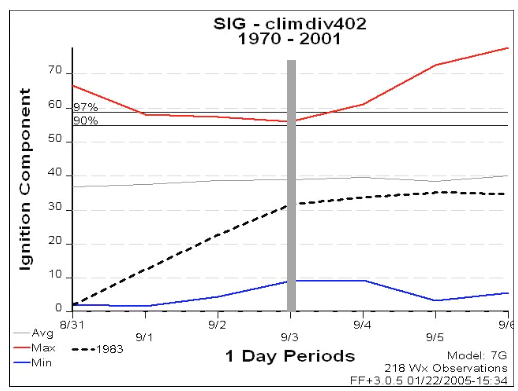
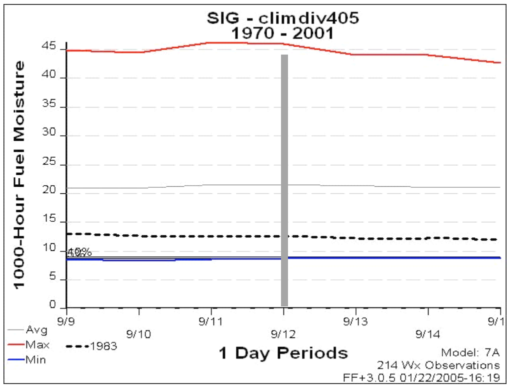


Fire Date: 9/03/83

a)



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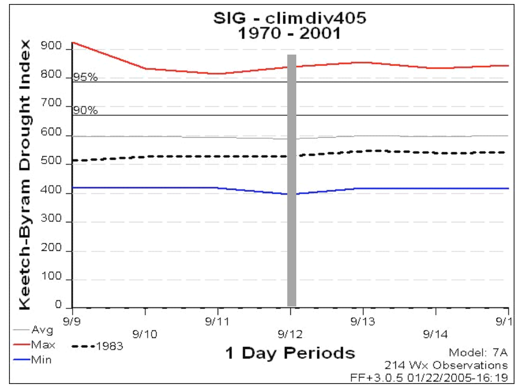

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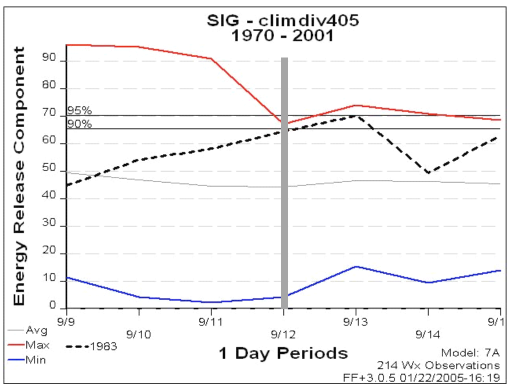

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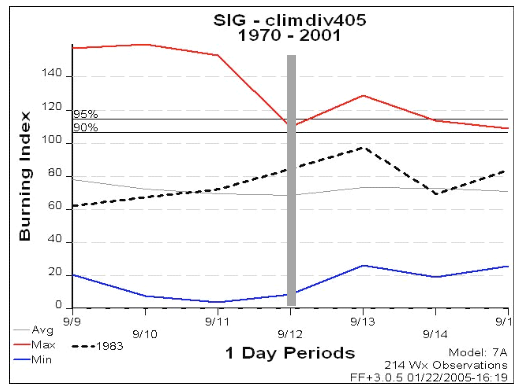

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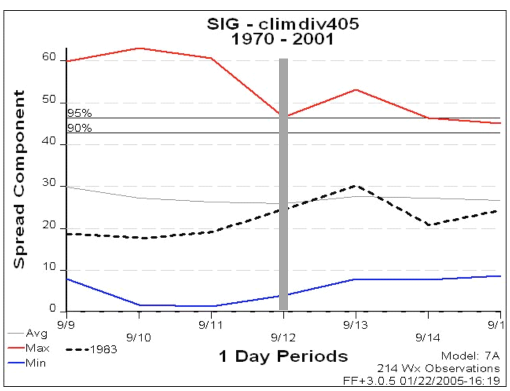

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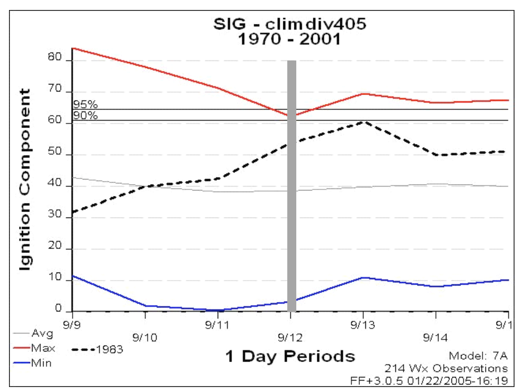
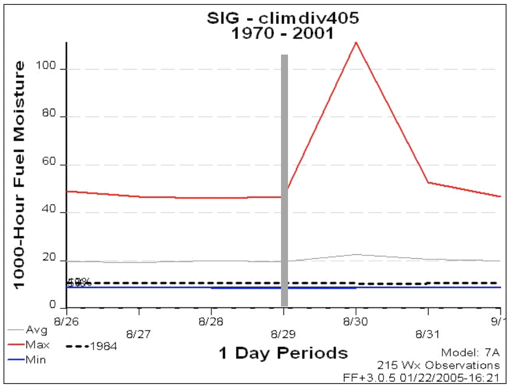
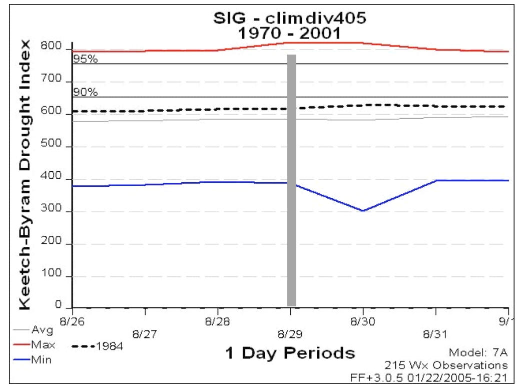


Fire Date: 9/12/83

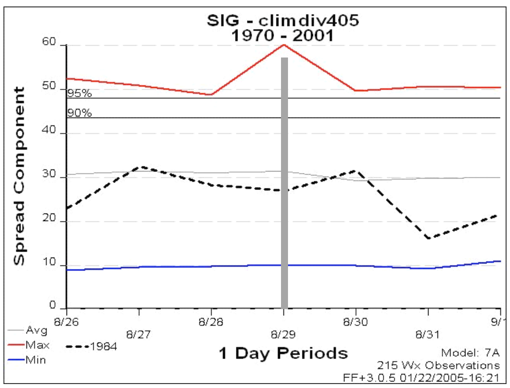
a)



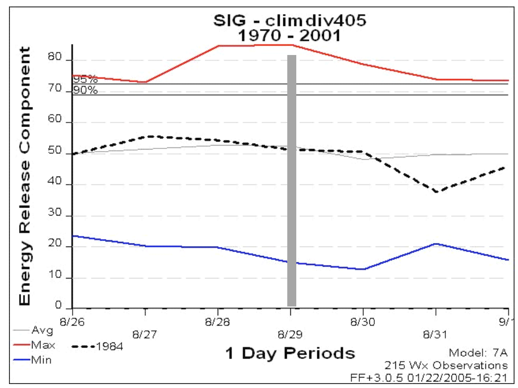
b)



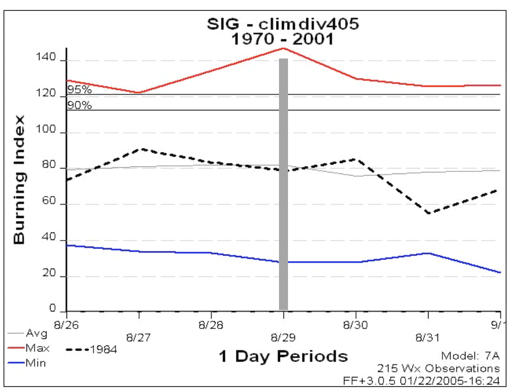
c)



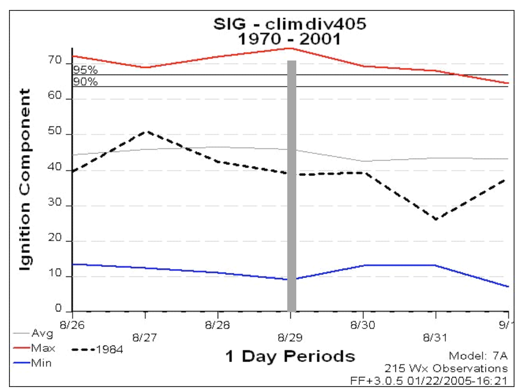
d)



e)

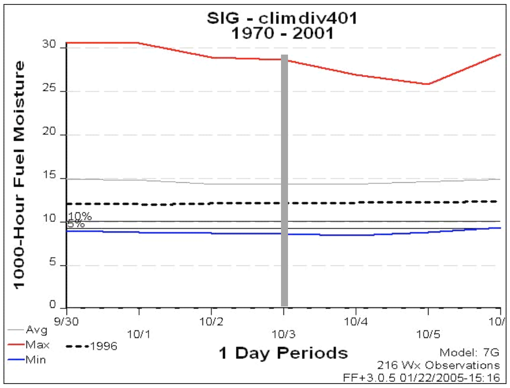


f)

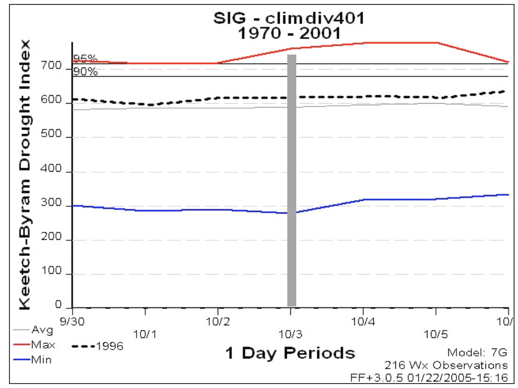


Fire Date: 8/24/84

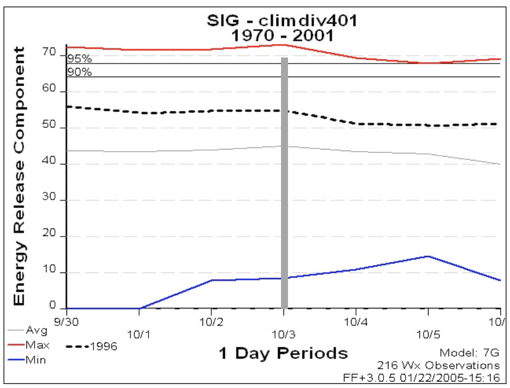
a)



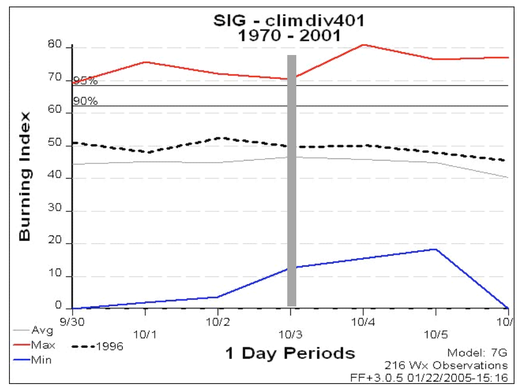
b)



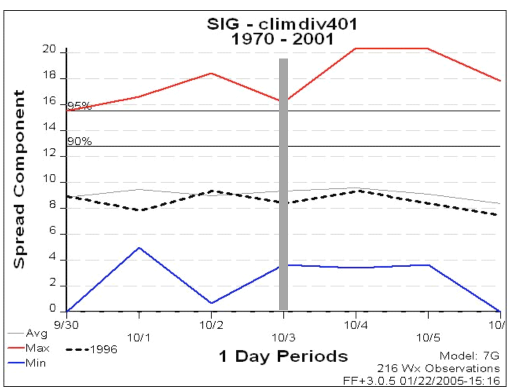
c)



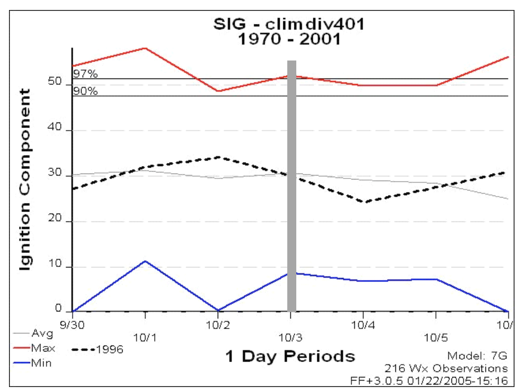
d)



e)

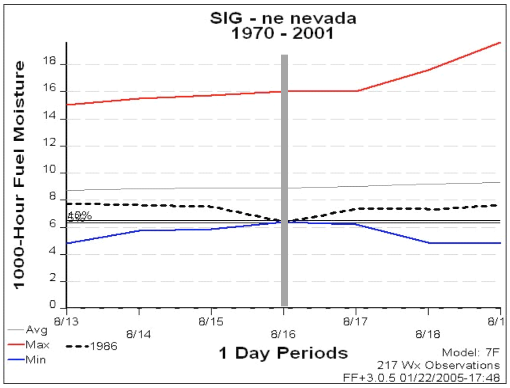


f)

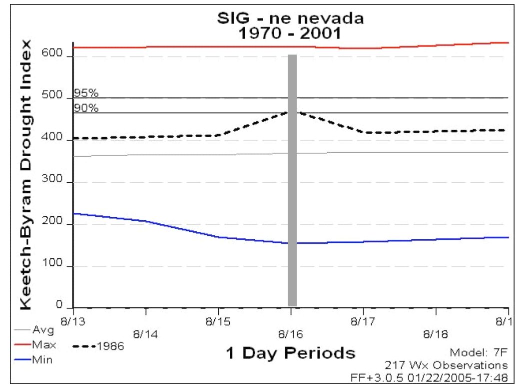


Fire Date: 10/24/84

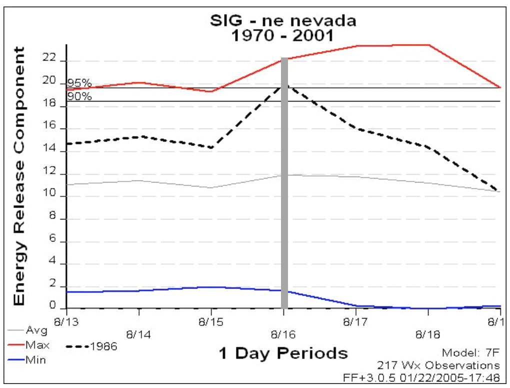
a)



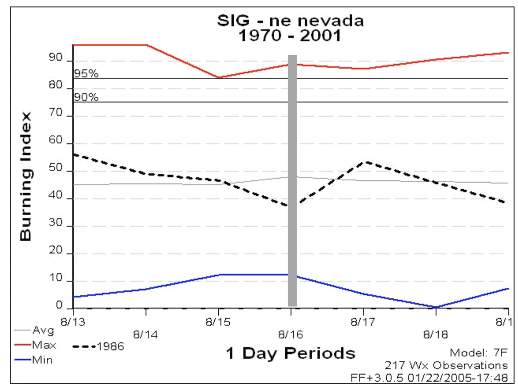
b)



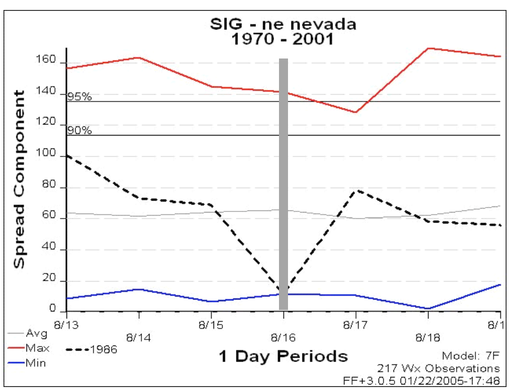
c)



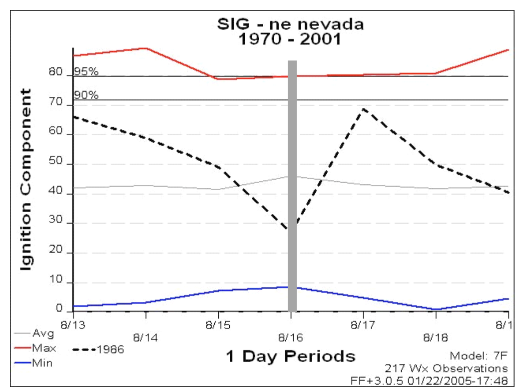
d)



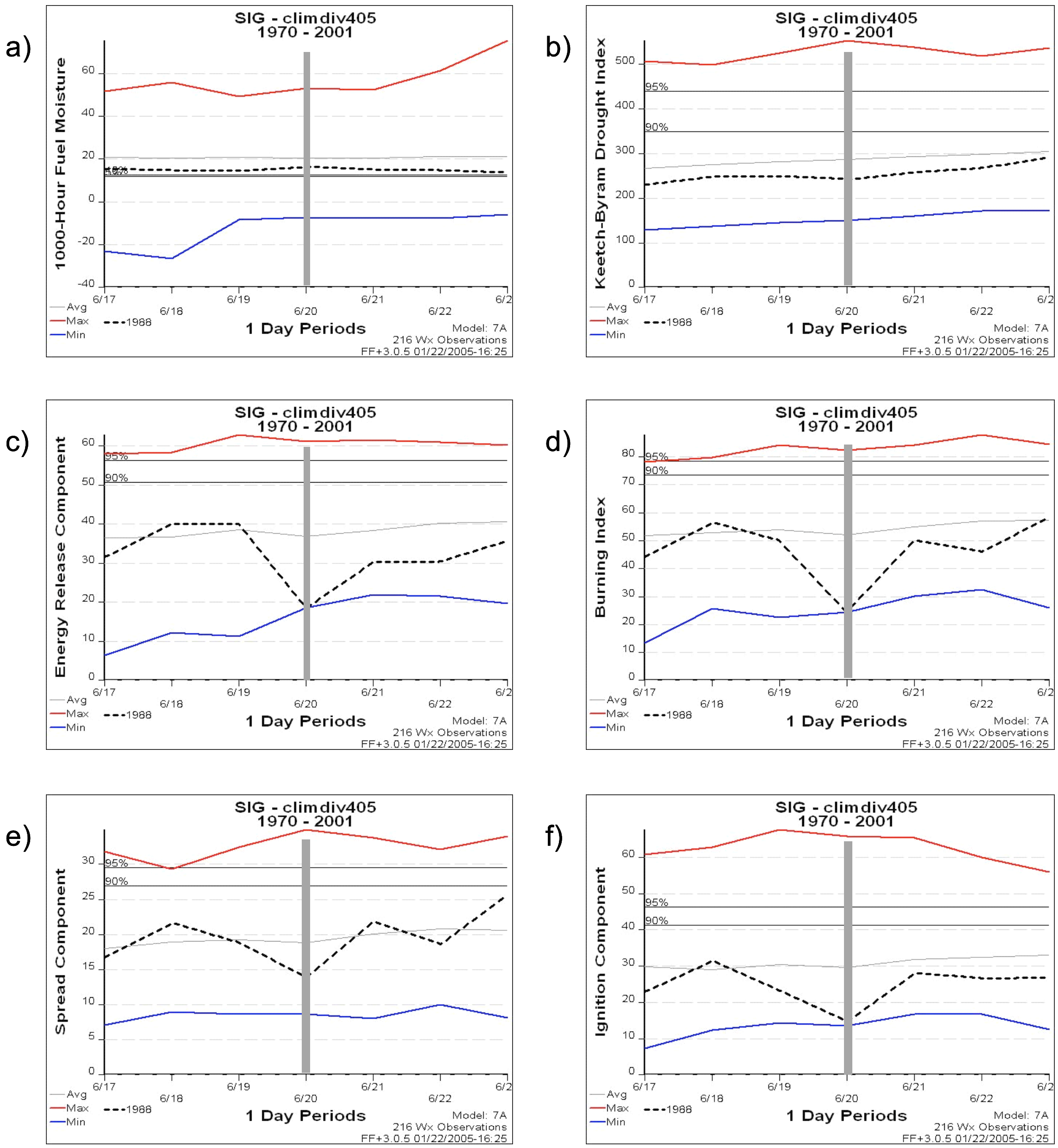
e)



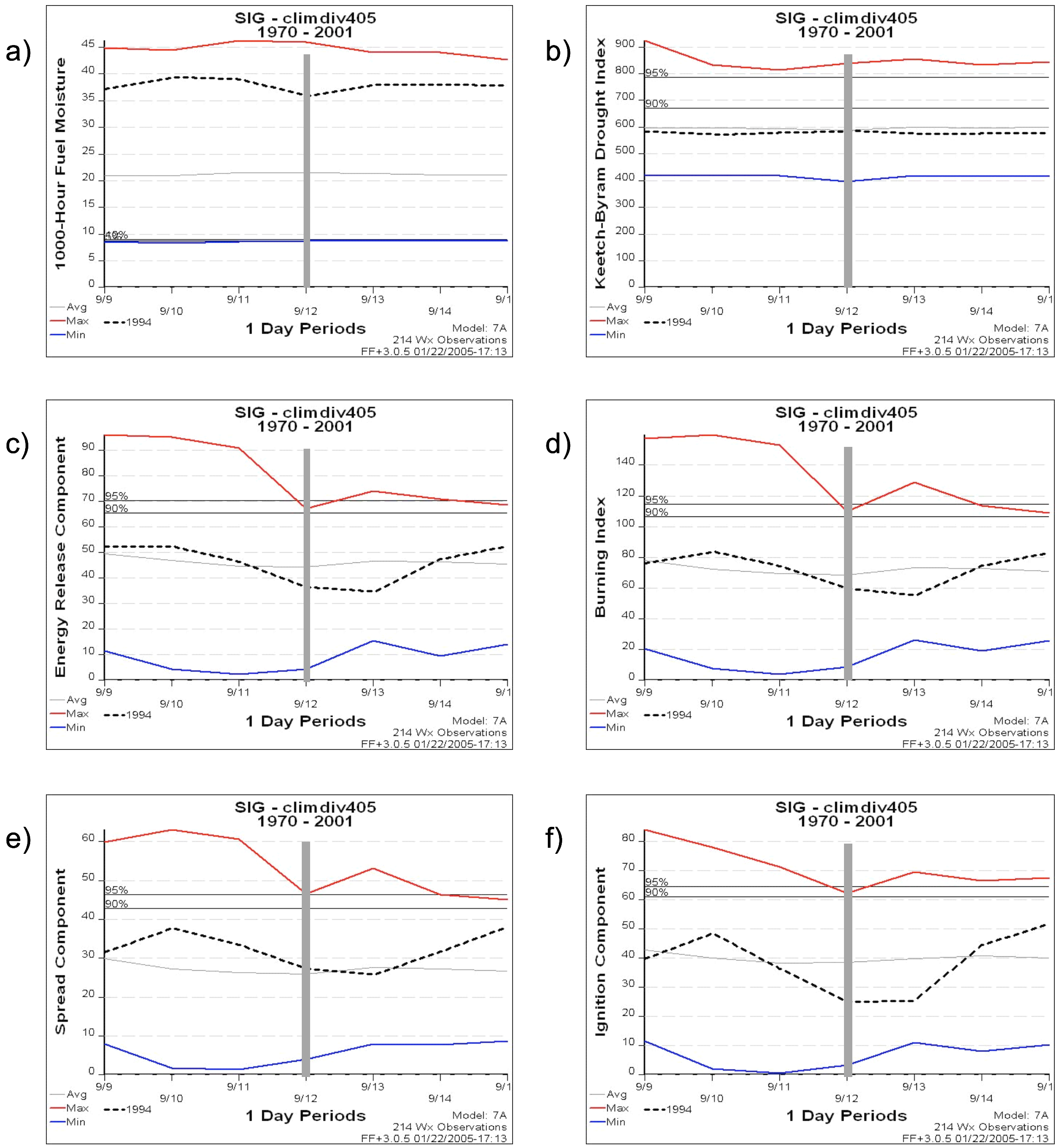
f)



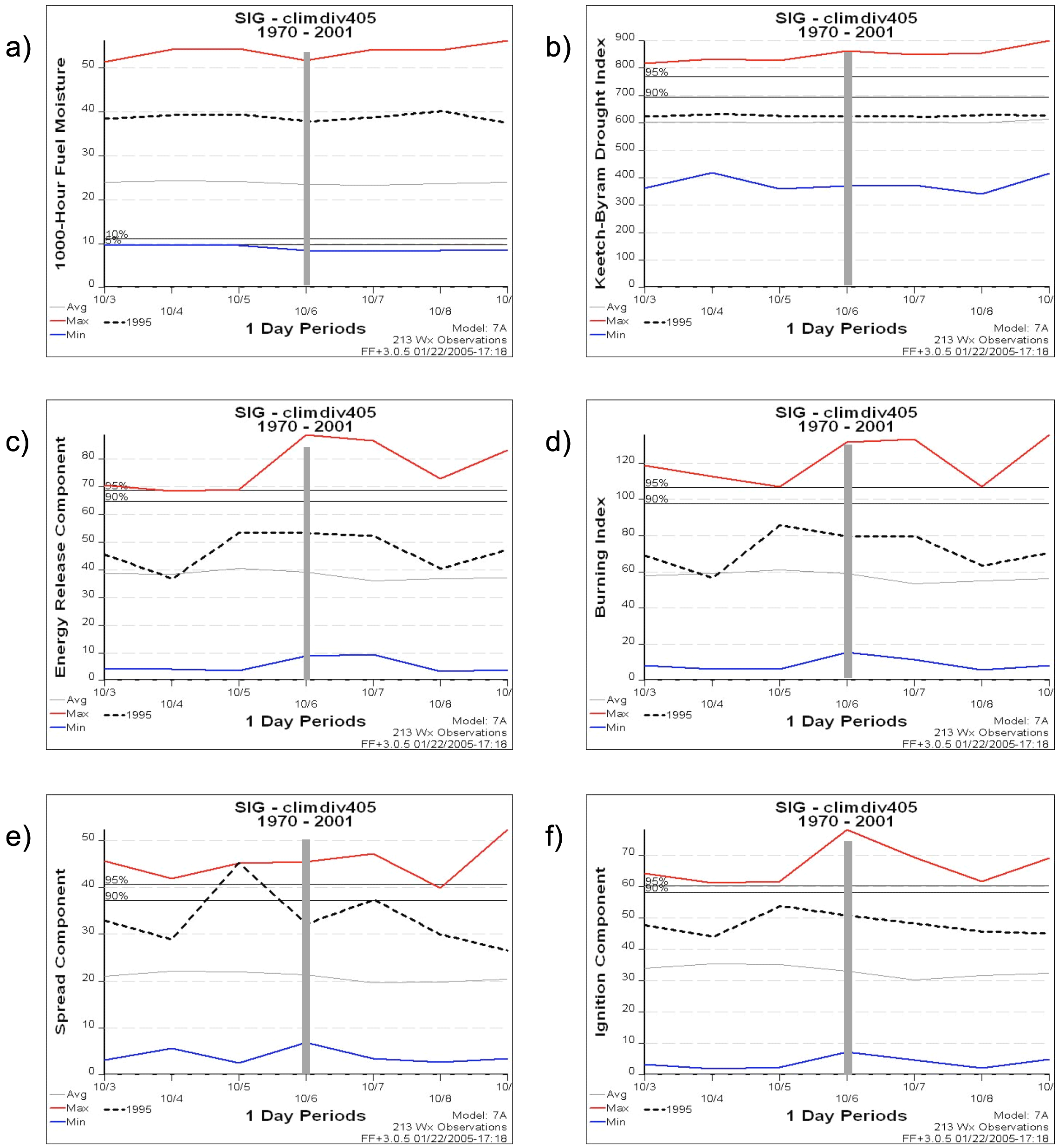
Fire Date: 8/16/86



Fire Date: 6/20/88

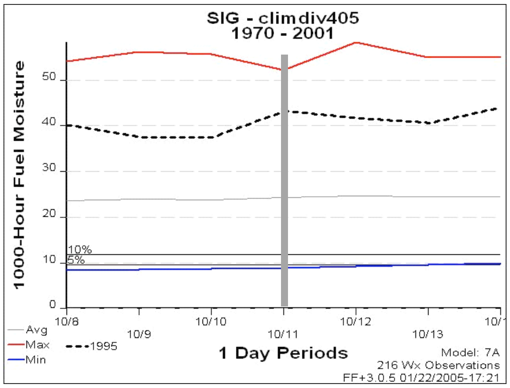


Fire Date: 9/12/94

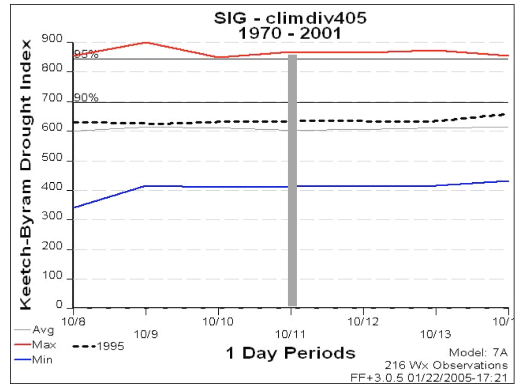


Fire Date: 10/06/95

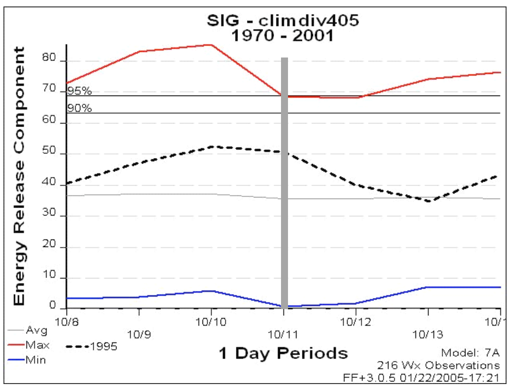
a)



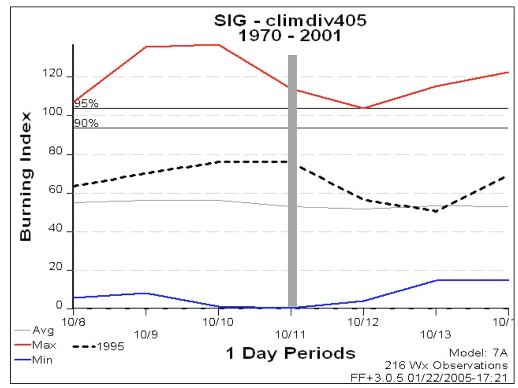
b)



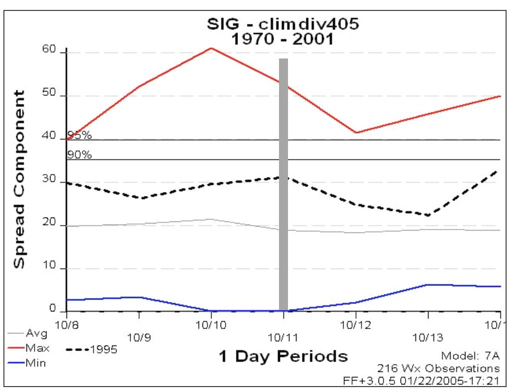
c)



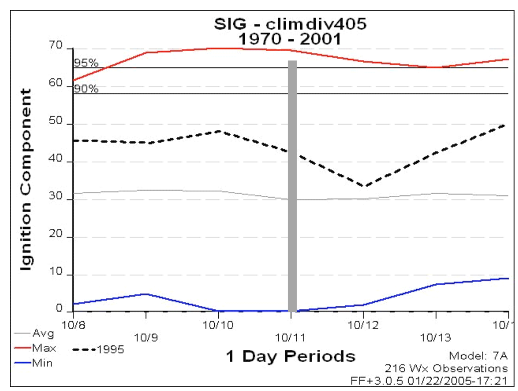
d)



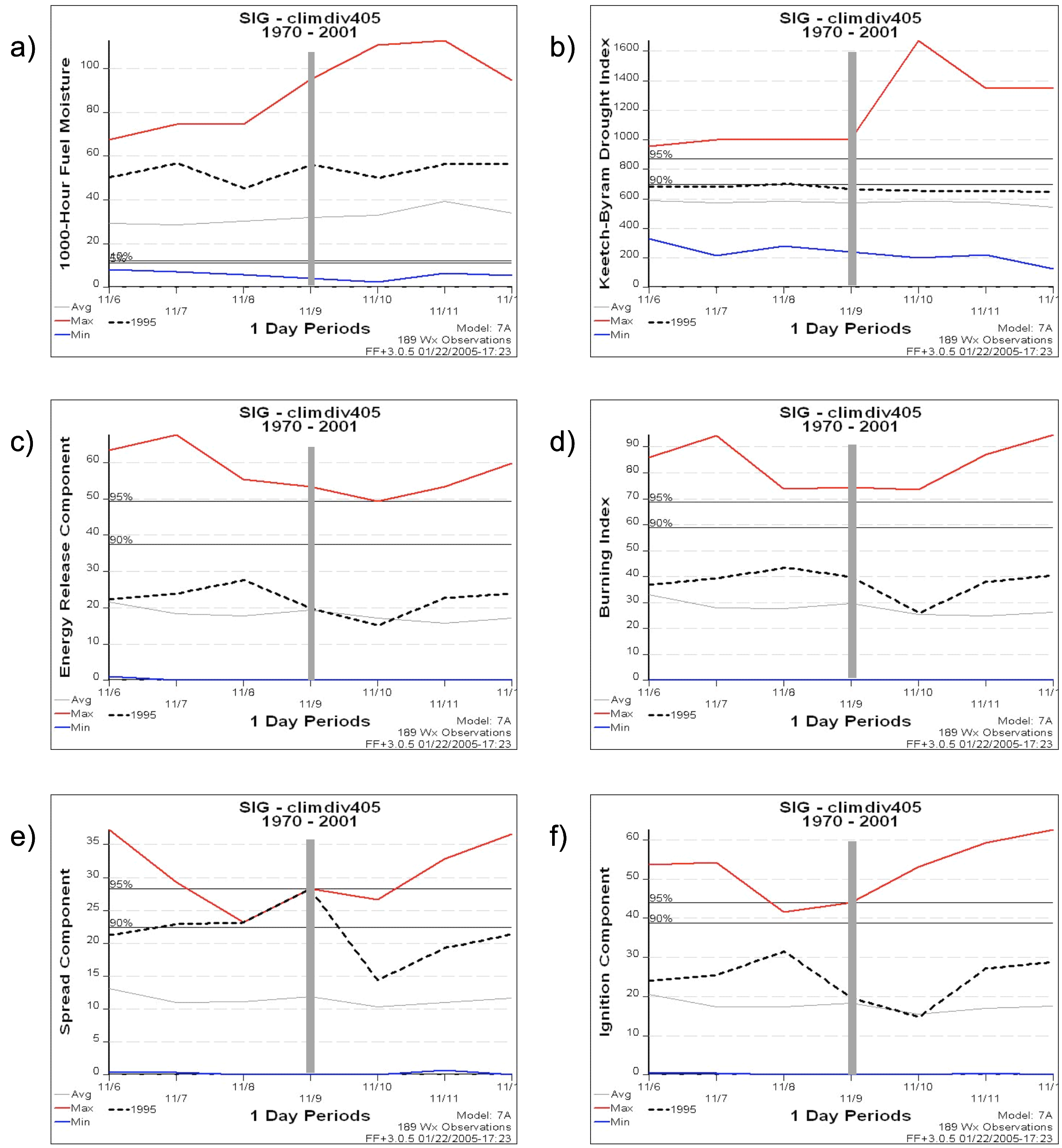
e)



f)

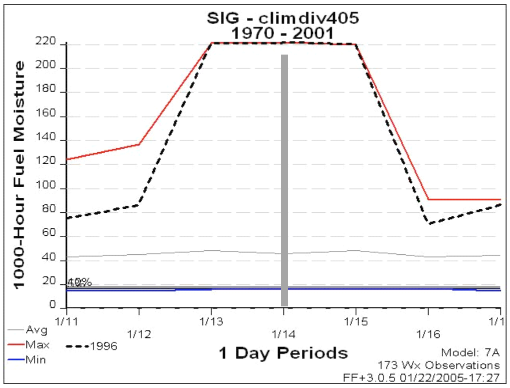


Fire Date: 10/11/95

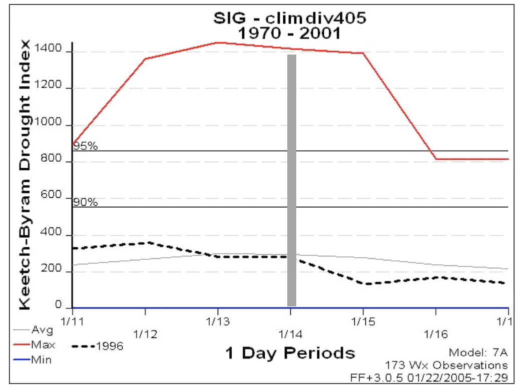


Fire Date: 11/09/95

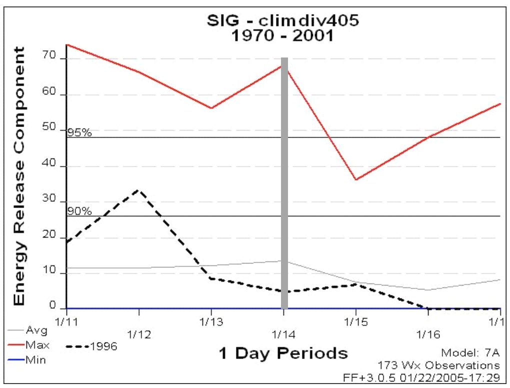
a)



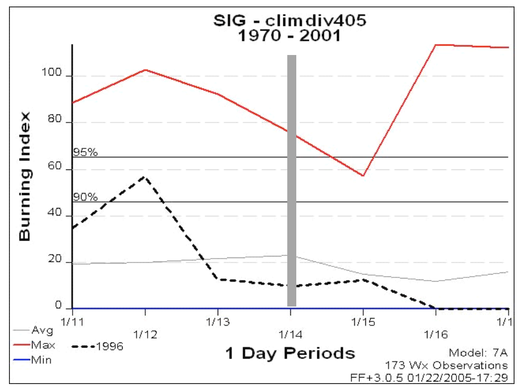
b)



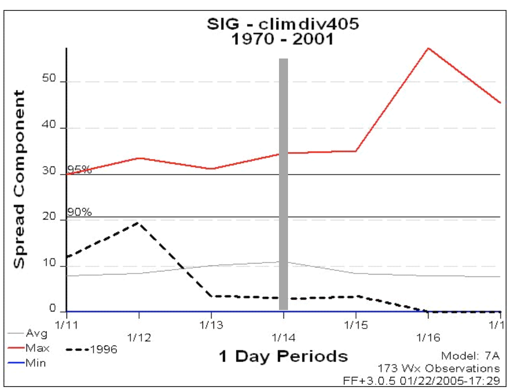
c)



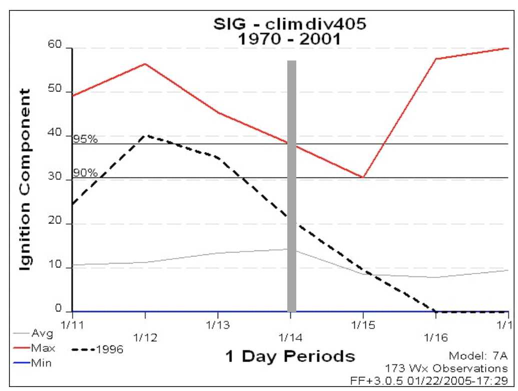
d)



e)

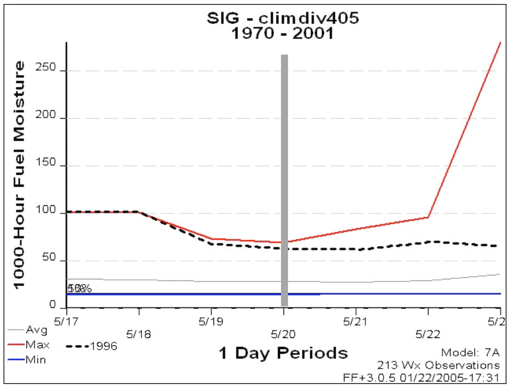


f)

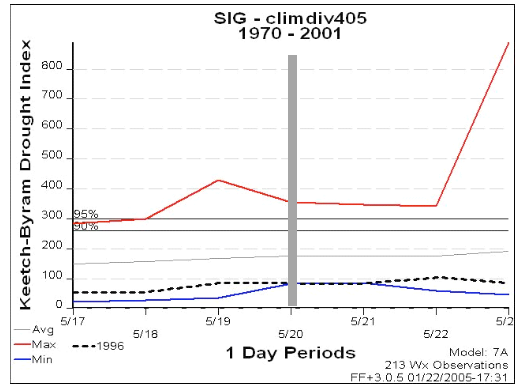


Fire Date: 1/14/96

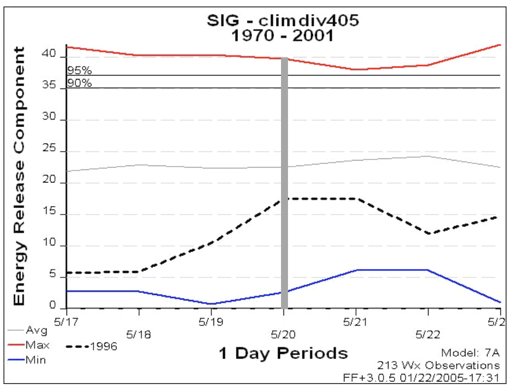
a)



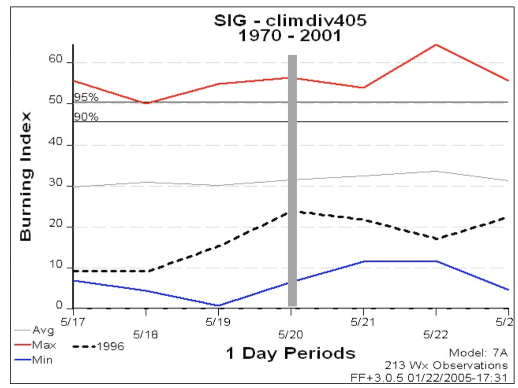
b)



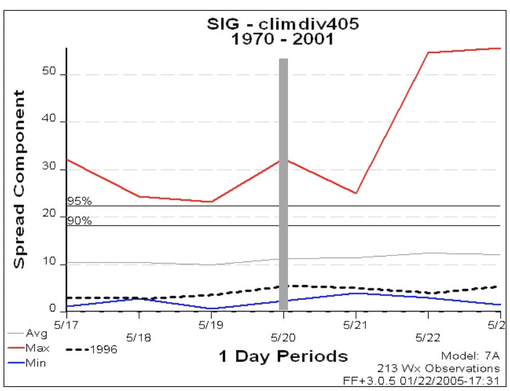
c)



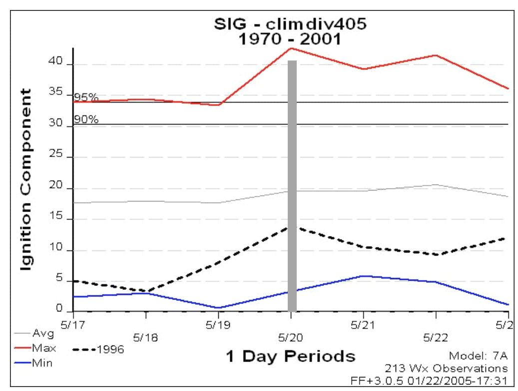
d)



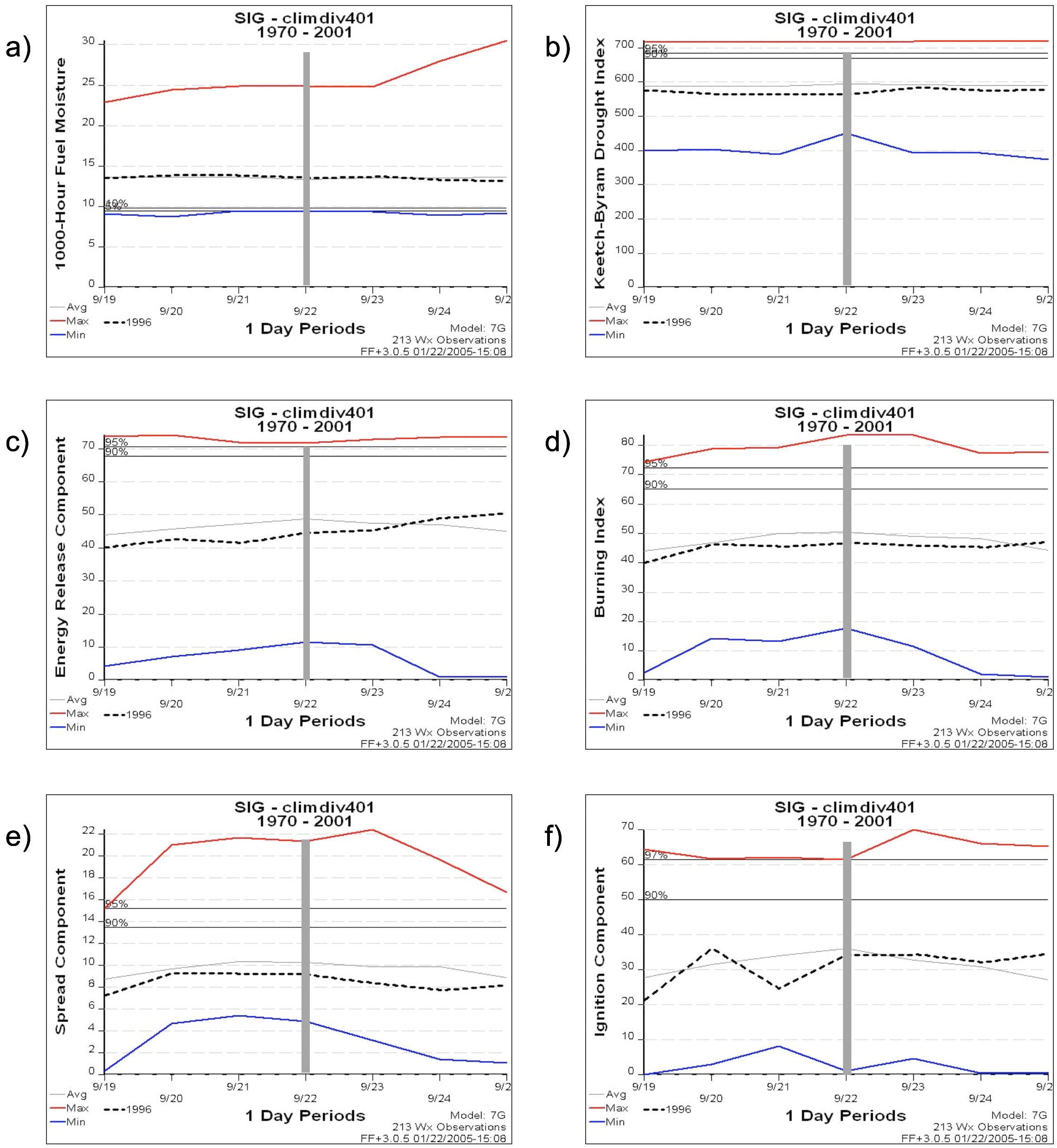
e)



f)

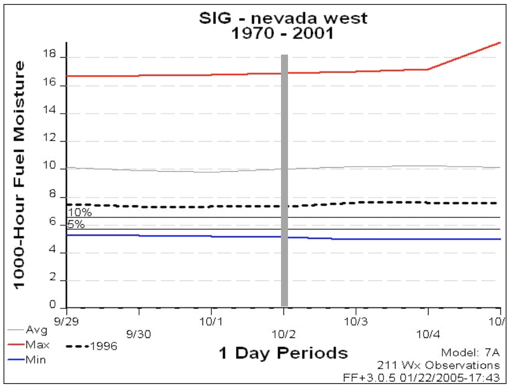


Fire Date: 5/20/96

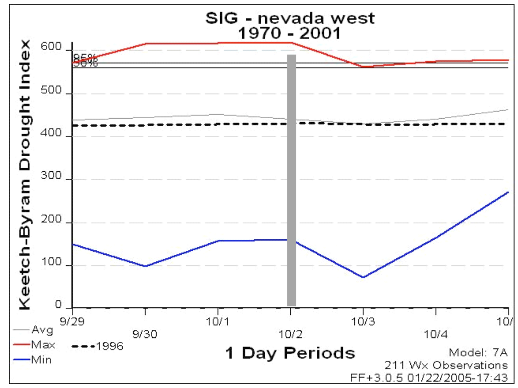


Fire Date: 9/22/96

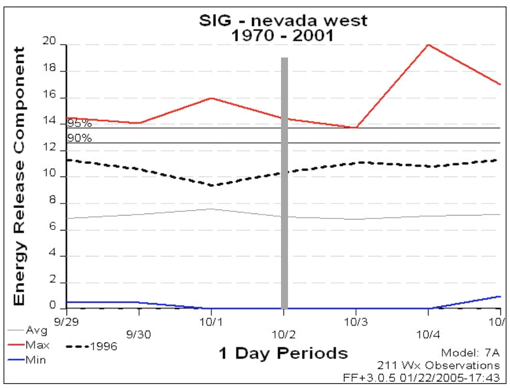
a)



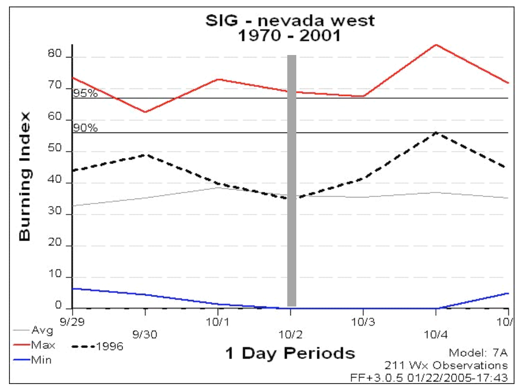
b)



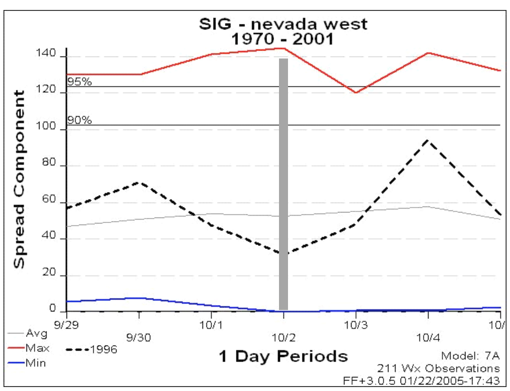
c)



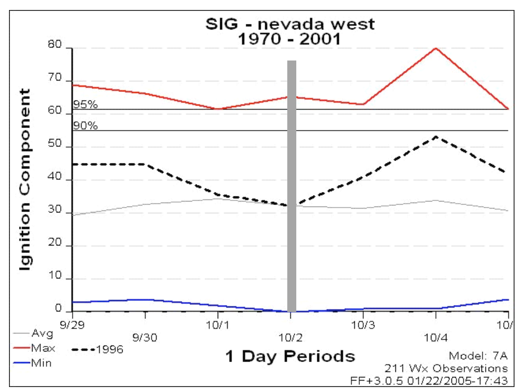
d)



e)

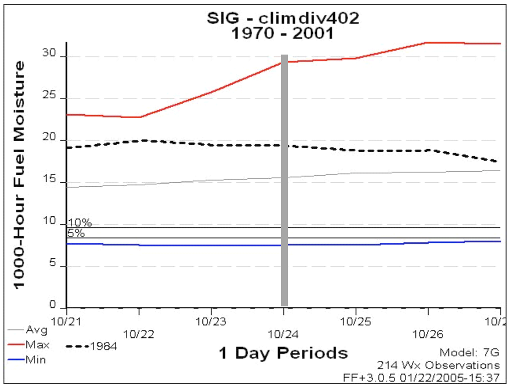


f)

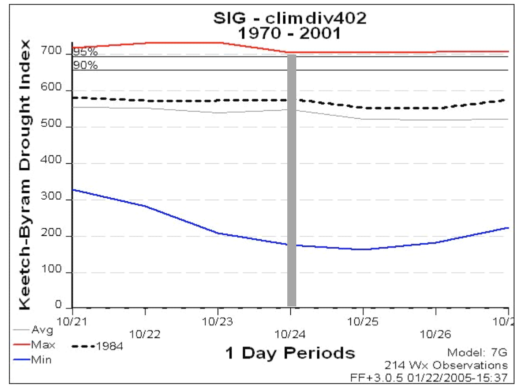


Fire Date: 10/02/96

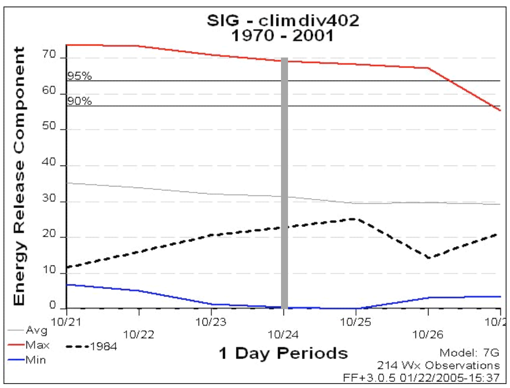
a)



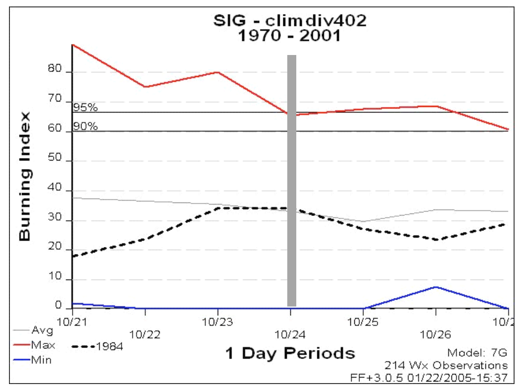
b)



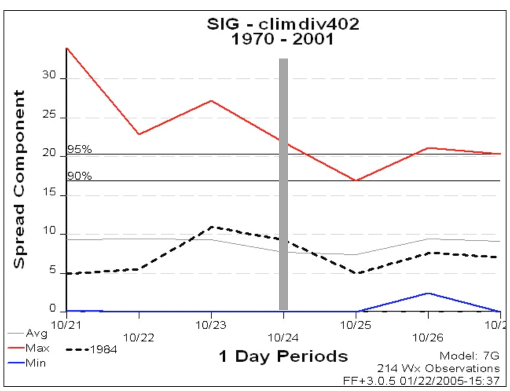
c)



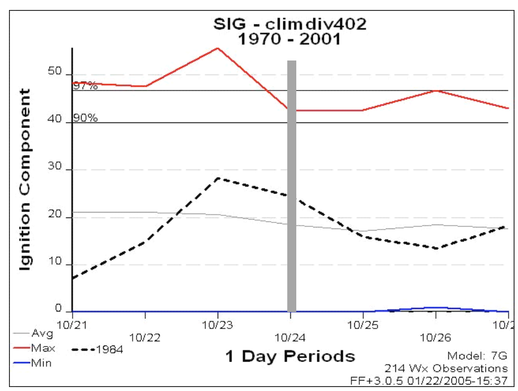
d)



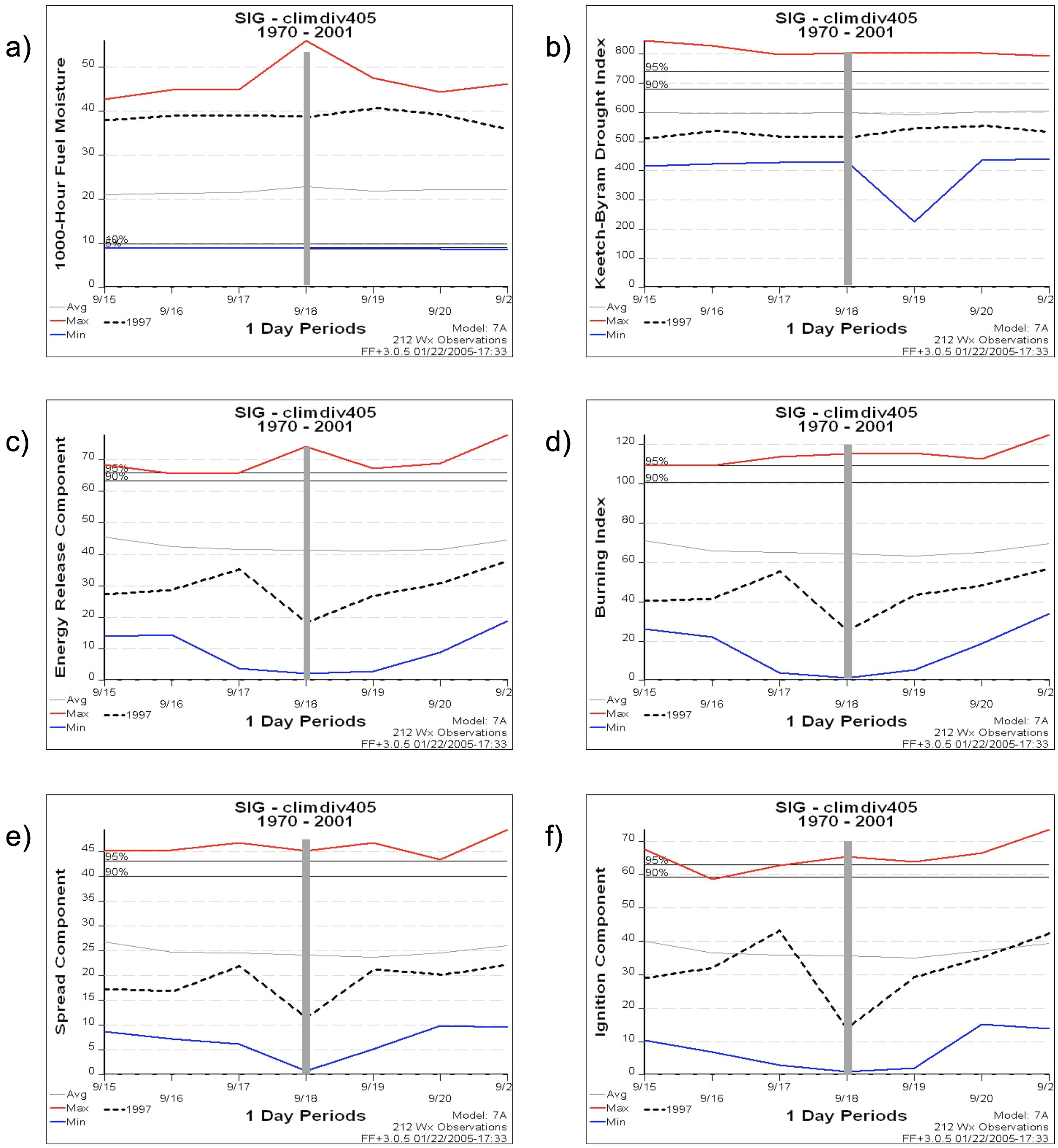
e)



f)

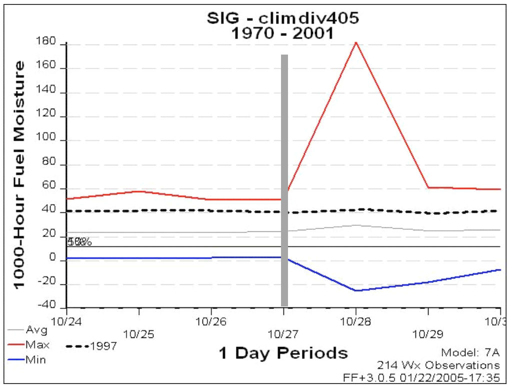


Fire Date: 10/03/96

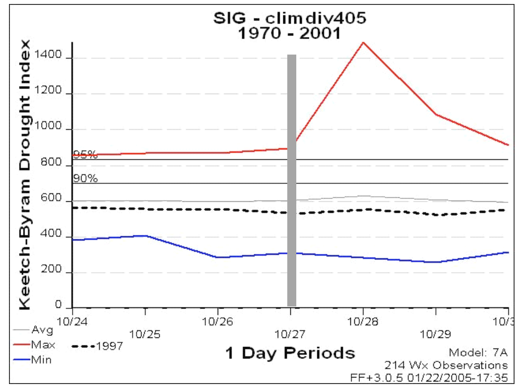


Fire Date: 9/18/97

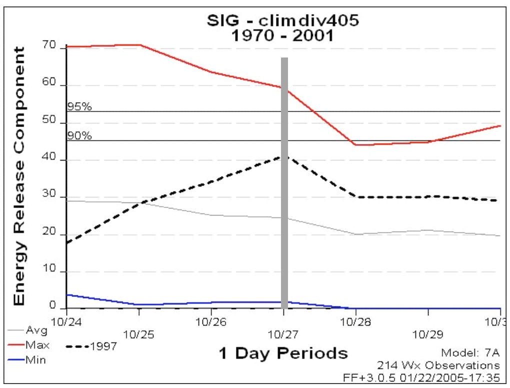
a)



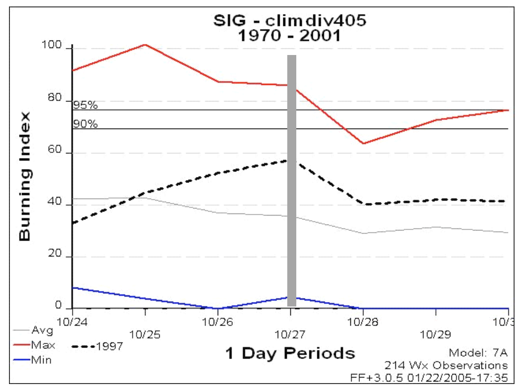
b)



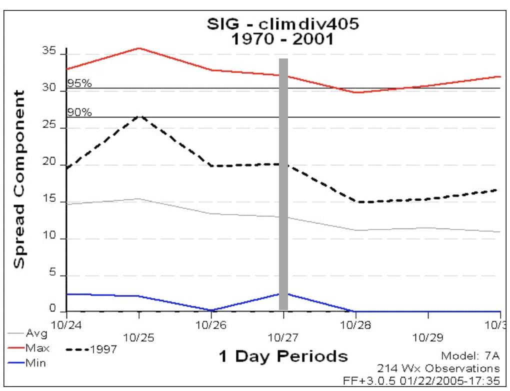
c)



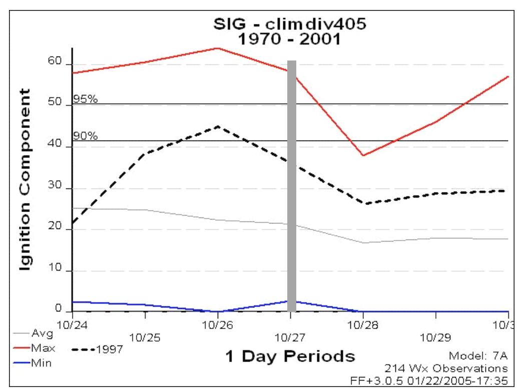
d)



e)

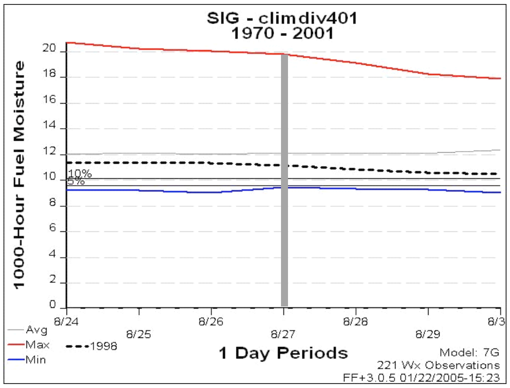


f)

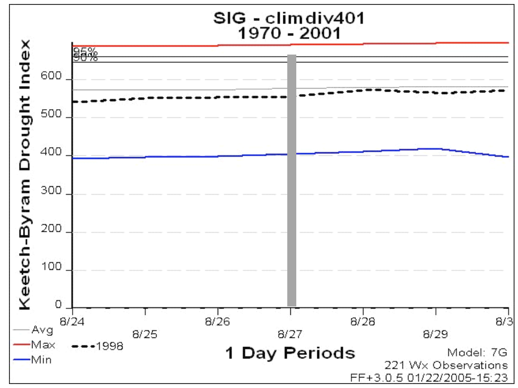


Fire Date: 10/27/97

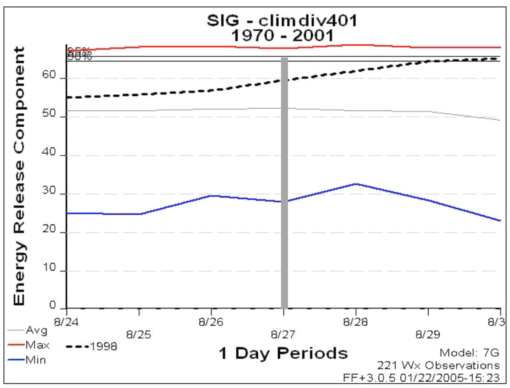
a)



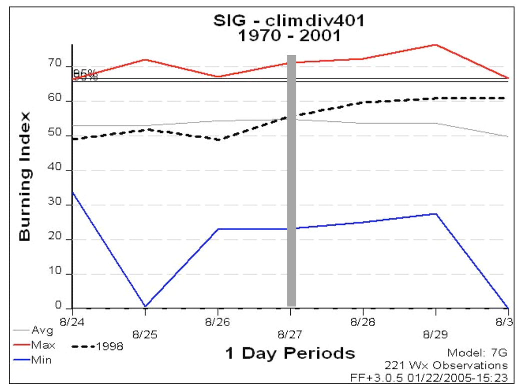
b)



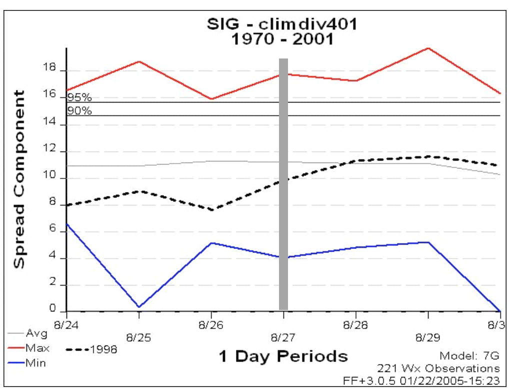
c)



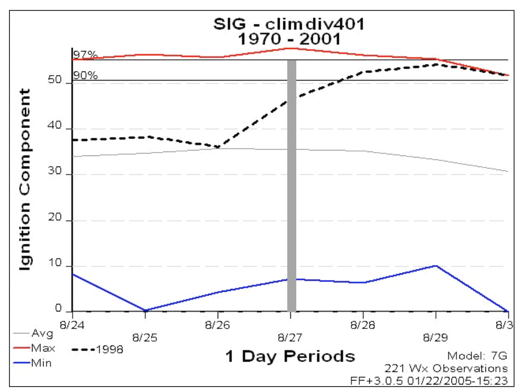
d)



e)

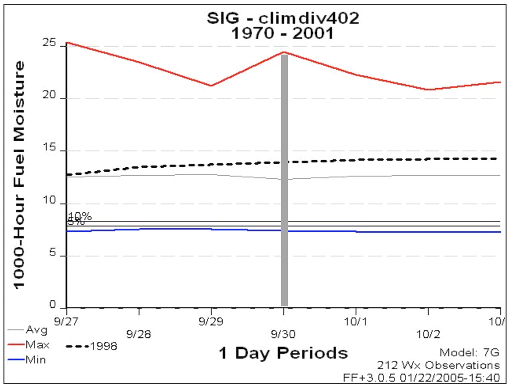


f)

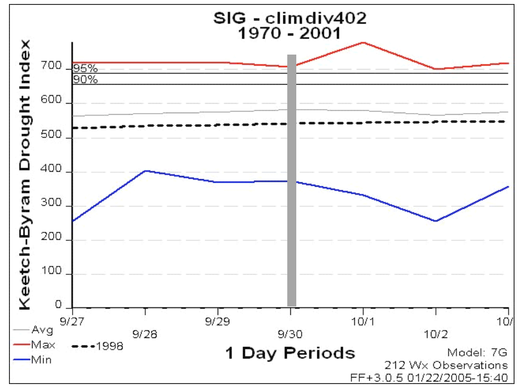


Fire Date: 8/27/98

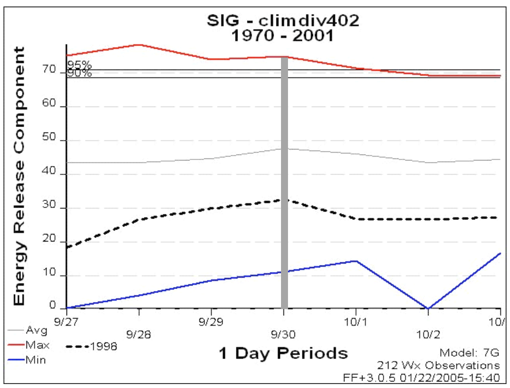
a)



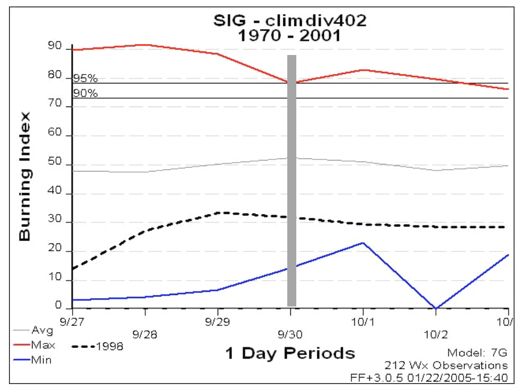
b)



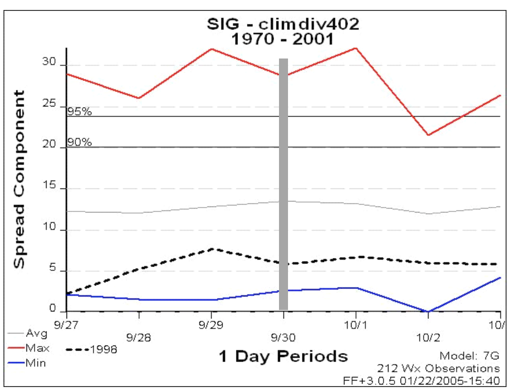
c)



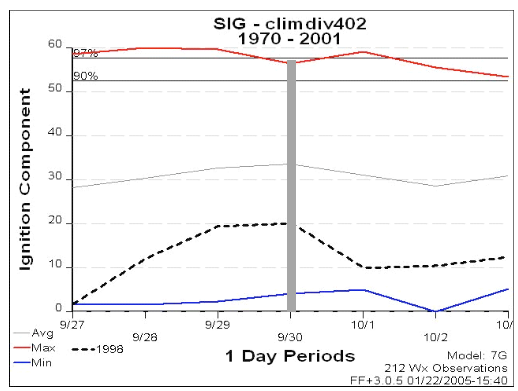
d)



e)

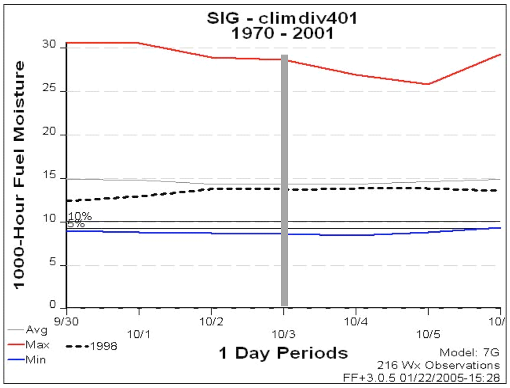


f)

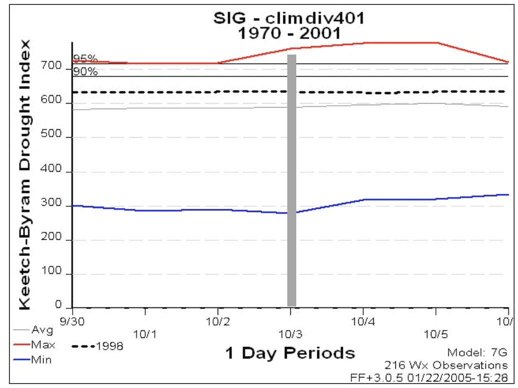


Fire Date: 9/30/98

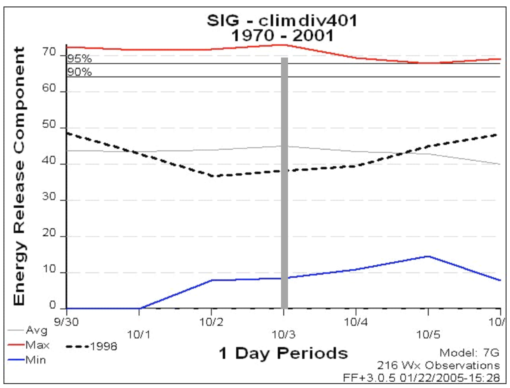
a)



b)



c)



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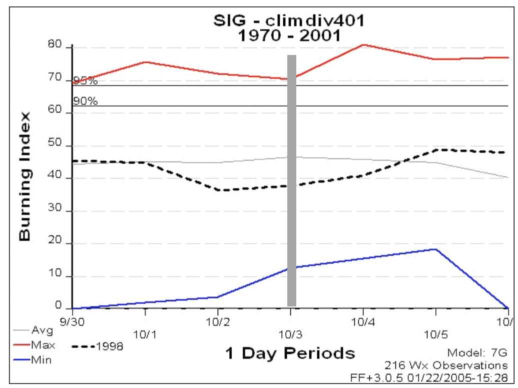
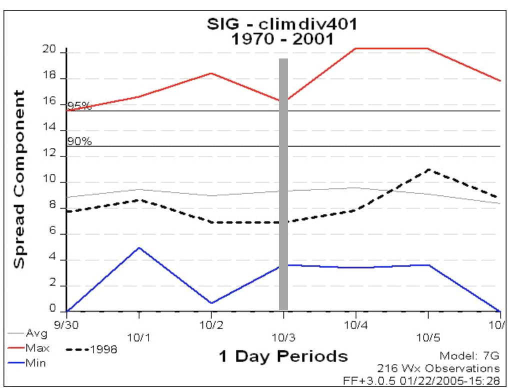


e)



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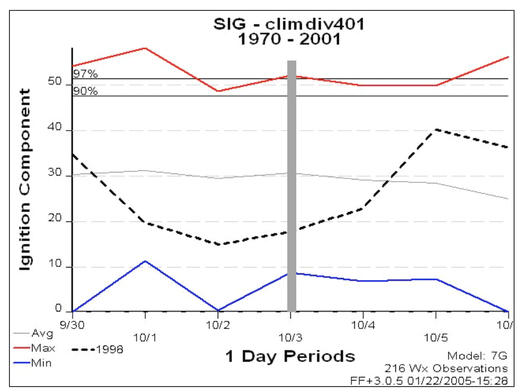
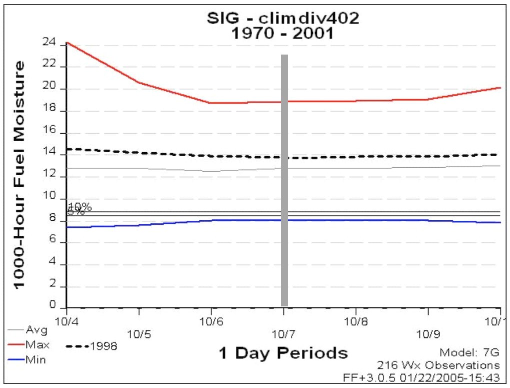


Fire Date: 10/03/98

a)



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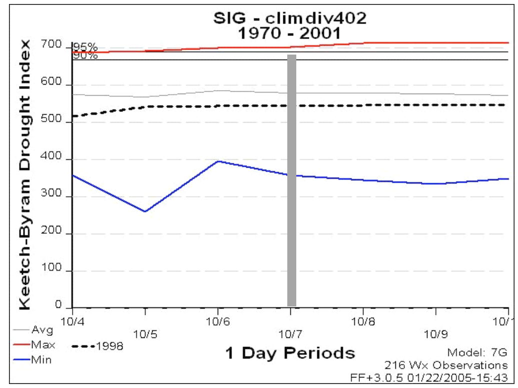

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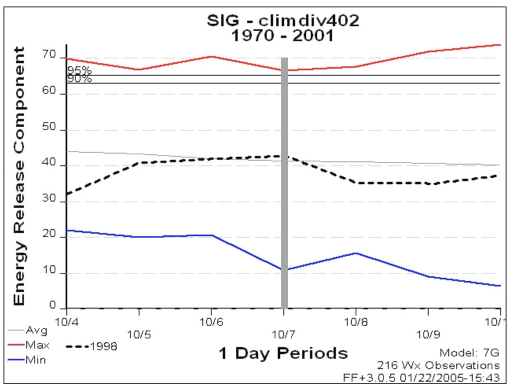

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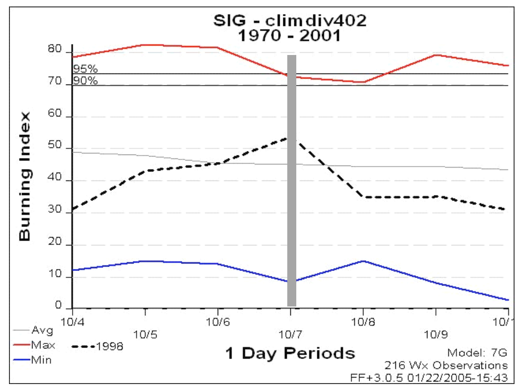

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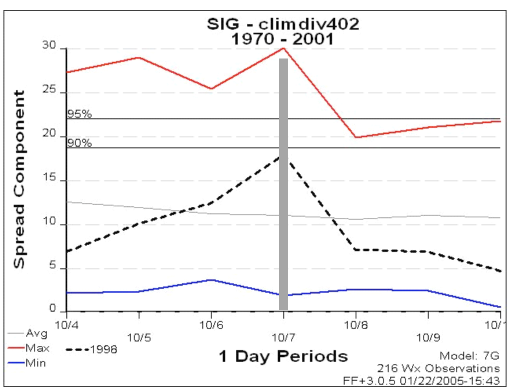

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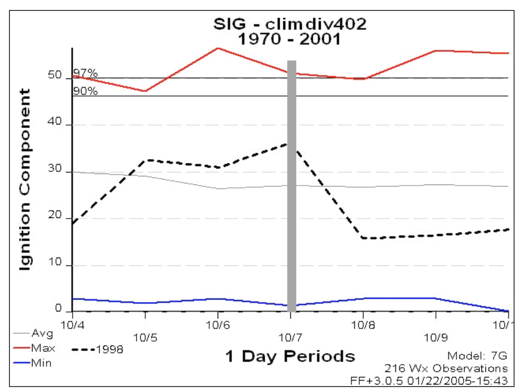
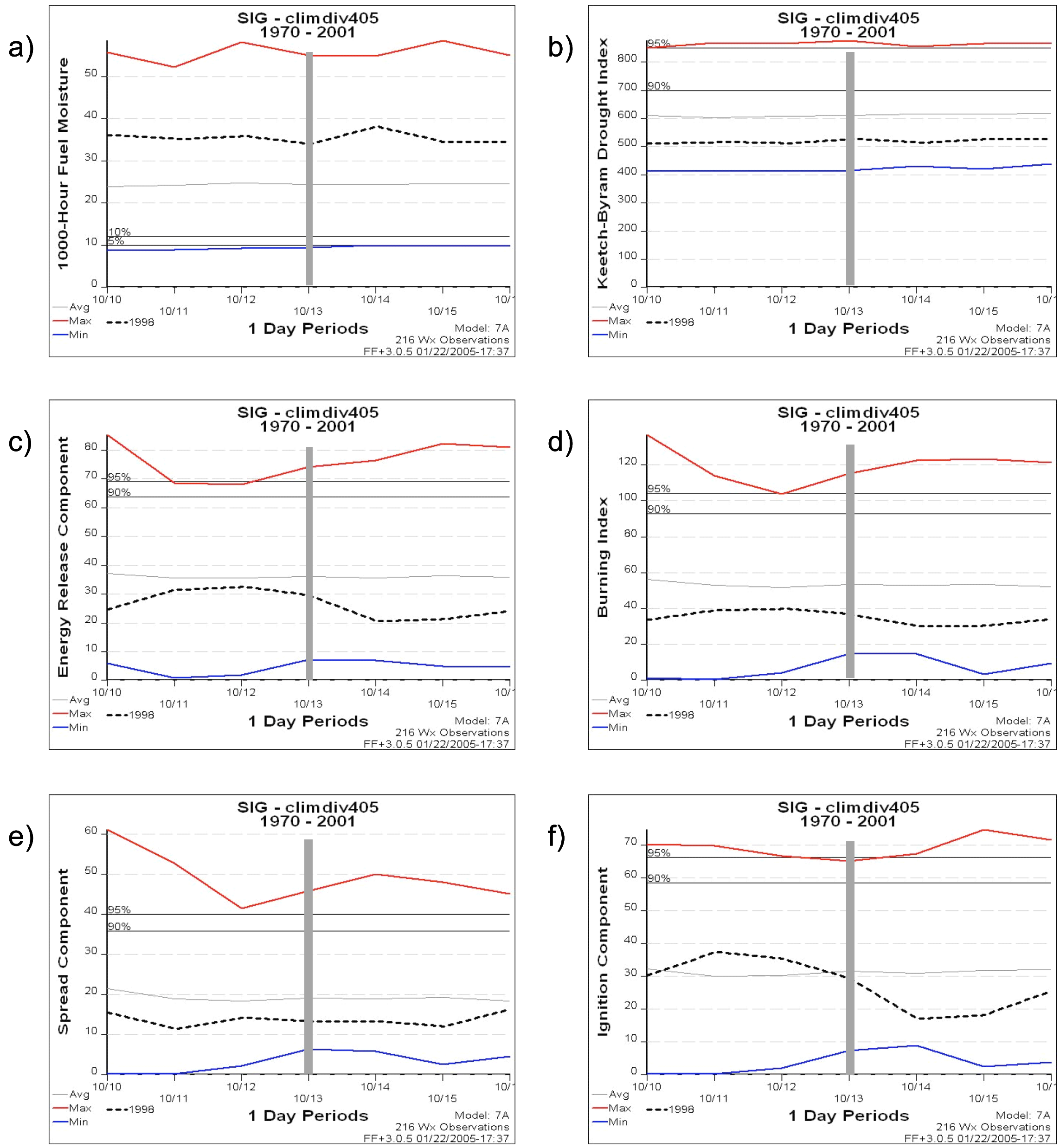
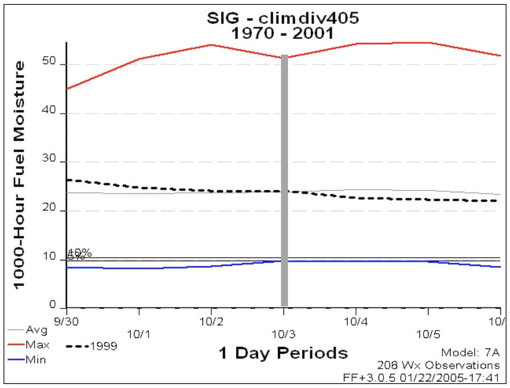


Fire Date: 10/07/98



Fire Date: 10/13/98

a)



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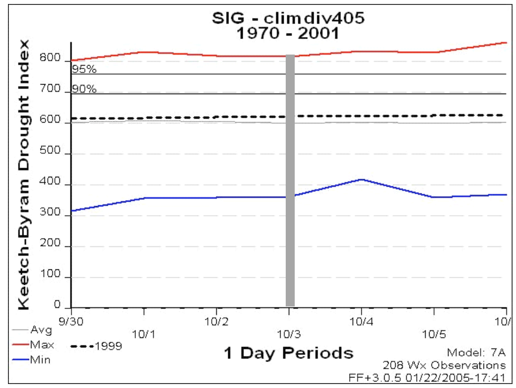

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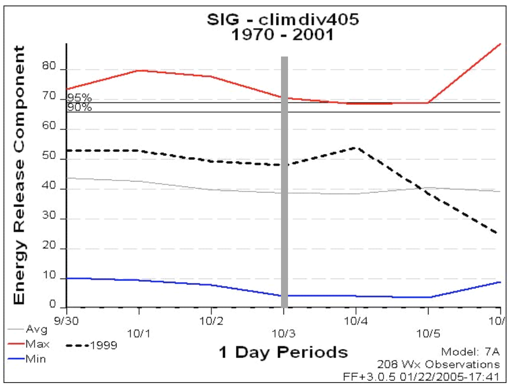

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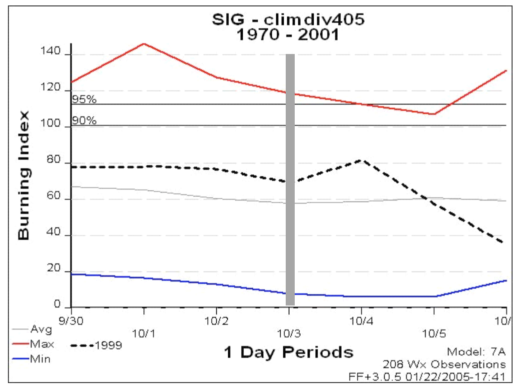

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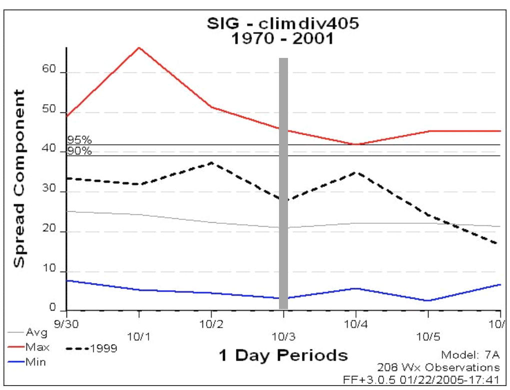

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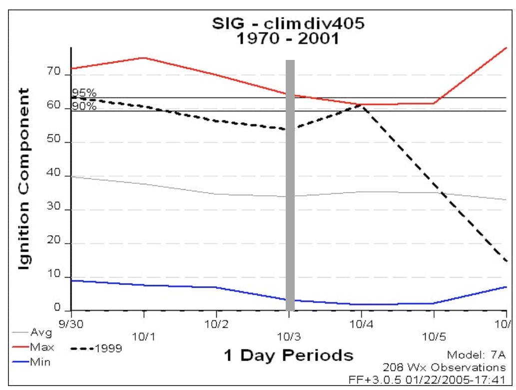
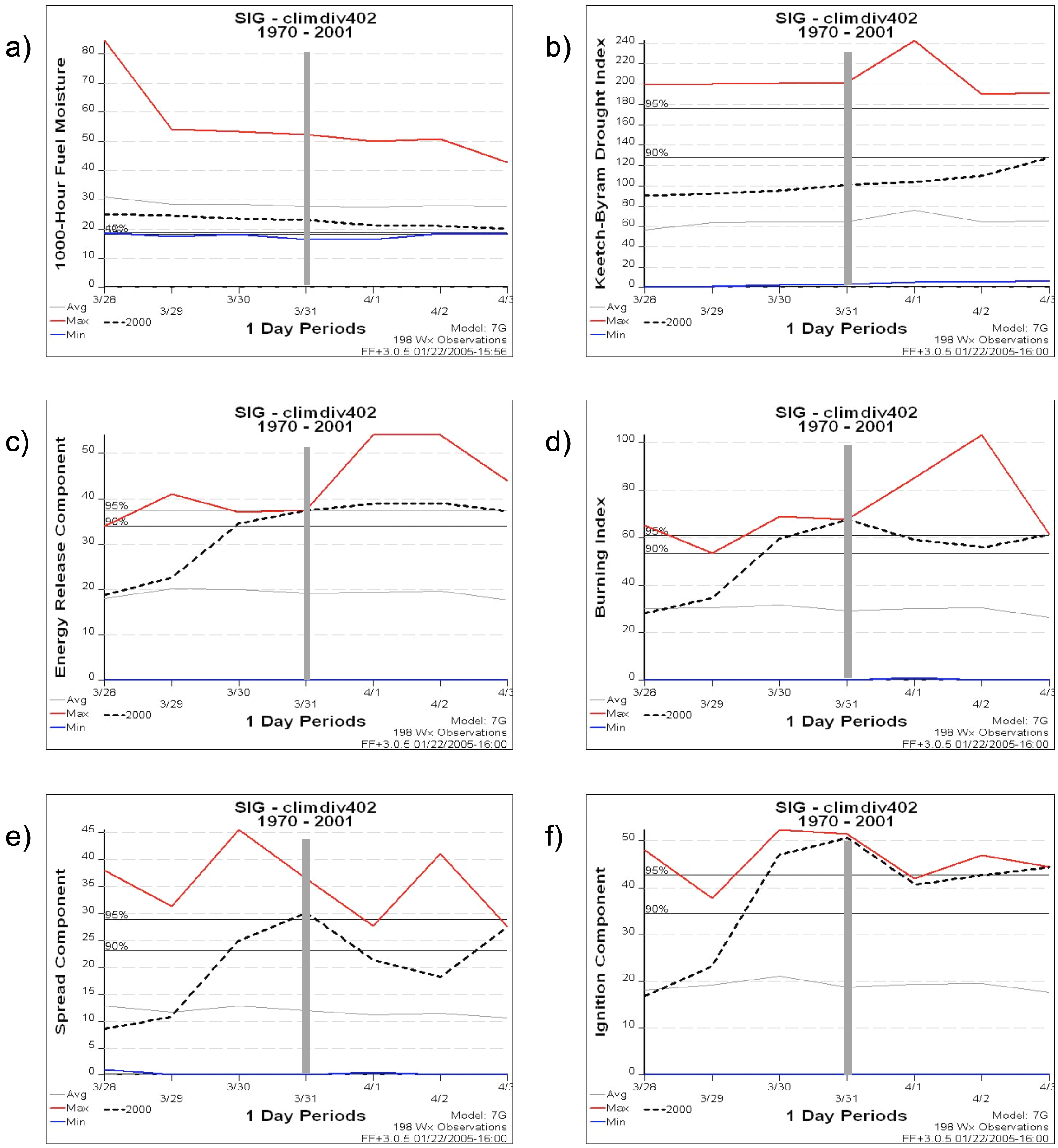
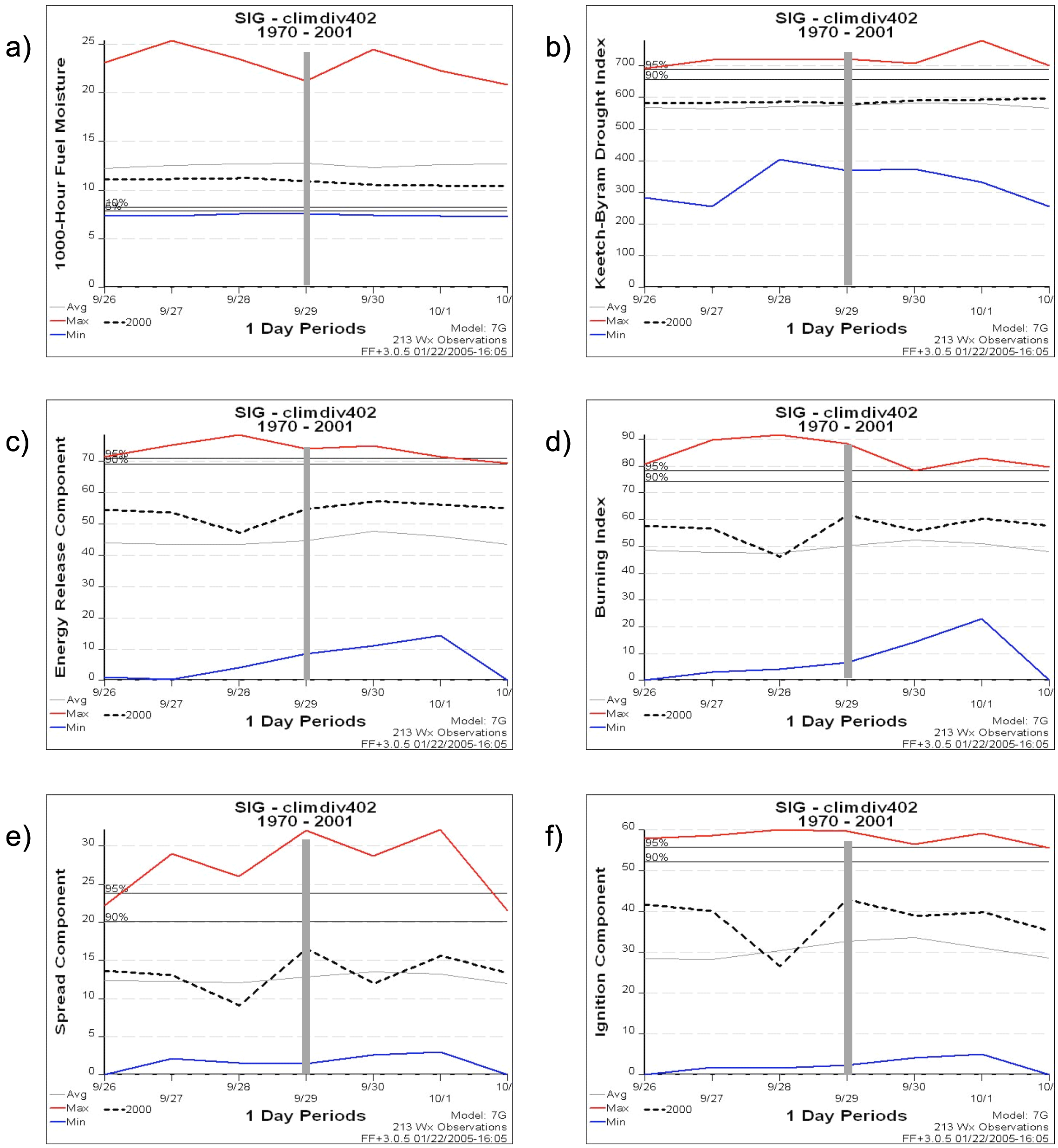


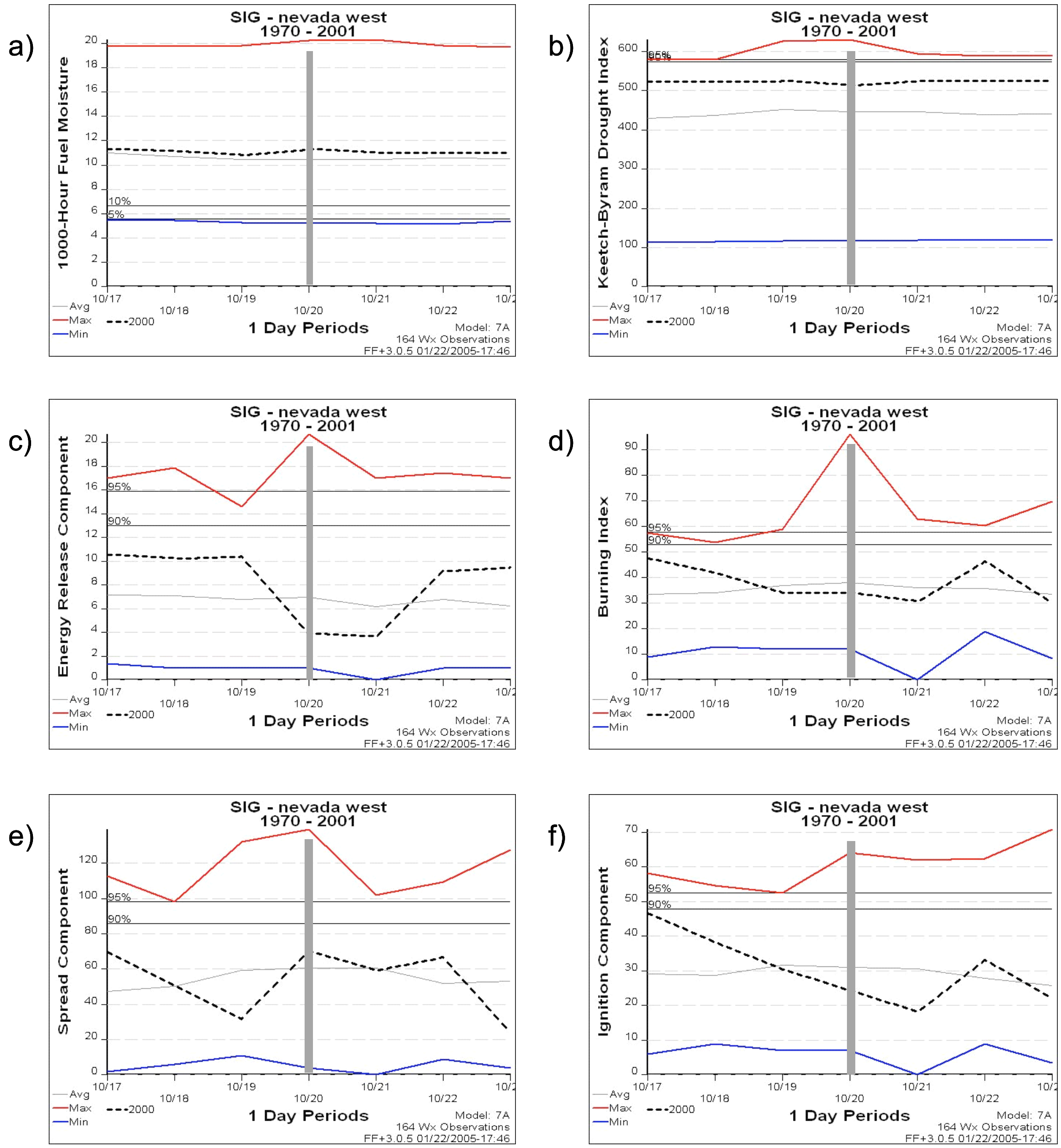
Fire Date: 10/03/99



Fire Date: 3/31/00



Fire Date: 9/29/00



Fire Date: 10/20/00