ANALYZING THE IMPACT OF METEOROLOGICAL VARIABLES ON WILDFIRES IN CALIFORNIA DURING THE 2020 FIRE SEASON

Theresa Dixon[1*], Helene Peiro[2], Steven Jester[2], Sean Crowell[2]

[1]National Weather Center Research Experiences for Undergraduates Program, University of Oklahoma
Norman, Oklahoma

[2]The GeoCarb Mission, University of Oklahoma
Norman, Oklahoma

ABSTRACT

In the past 5 years, California has experienced an increase in wildfires during the fire season, resulting from long and dry summers, and in 2020 experienced the most extreme and dangerous wildfires in its history. These 9, 917 fires recorded burned over 4 million acres, damaged over 10,000 structures, and caused 33 fatalities. This unprecedented fire event has led to increased interest in fire weather and research on the weather conditions that led to it. Fire weather is described as the meteorological conditions favorable for fire ignition and spread. Additionally, weather conditions have an impact on vegetation fuels and so on fire combustion. The purpose of this study is to focus on 10 years of climatology over northern and southern California characterized by different vegetations to find any trends and anomalies that can explain the extremity of this 2020 event. By using in situ data of temperature and precipitation, we found that 2020 was particularly characterized by an intense drought over the year which could result from a La Niña event. Drought conditions in winter and summer (with positive anomalies of temperature and negative anomalies of precipitation) seem to explain the intense temperate forest fires of the northern region. However, the same conditions in the grassland southern region suggest that other factors might have a role such as the Santa Ana wind. Future studies should hence look at wind and topography information for the grassland southern region.

1. INTRODUCTION

The impact of wildfires on climate and carbon cycle (Bowman et al., 2009) and their intensification in time, increase the scientific community's interest to study them. In 2020, California experienced the most dangerous wildfire season yet. During this season, over 9, 917 fires were reported throughout the state (CAL FIRE, 2021). Wildfires are caused mostly by human interference, but the rest are caused by natural factors. Human causes would consist of unattended campfires, discarded cigarettes, burning of land, and arson. Natural causes are typically lightning strikes (Narendran, 2001). Over the course of 4 months (August-November) of 2020, the August Complex Fire (caused by lightning in northern California) burned over 1 million acres and crossed over 7 counties, becoming California's largest wildfire in its history (CAL FIRE, 2021). Out of the top 20 most destructive California wildfires, six were from August and September of 2020 (CAL FIRE, 2021).

The climatology of northern California is known to have rainfall amounts higher than southern regions annually and typically experience hot summers and cold winters (Weather & Climate, 2021; https://studycalifornia.us/life-in-california/weather-climate/). The climatology of the southern region, however, is known to be more of a Mediterranean type of climate with rainy winters and dry summers. Droughts are a natural weather occurrence that regions in California experience regularly. The National Oceanic and Atmospheric Administration (NOAA) describes a drought as a timeframe of consistent dry weather that can cause significant problems to the land by affecting crops and creating shortages in water supply. Several factors indicate the severity of a drought such as the lack of moisture, the duration of the drought and how long the area is affected (Wilhite, 1994).

* Theresa Dixon, University of Georgia, tad18170@uga.edu

The fire season generally starts around August and last until October (the summer months of California usually characterized by droughts), but climate change has led to this season occasionally starting earlier and lasting longer (Kenward et al., 2016). Trollope et al., 2002 found that fires can be influenced by fuel types (corresponding to vegetation types) but also by weather conditions. Being able to analyze previous weather conditions of wildfires will help forecasters and fire departments with fire prediction and emergency preparedness procedure. Additionally, learning more about the climate conditions of fires from regions in California could determine the greenhouse gases emitted from these fires in order to have an idea of its implications on global warming and human health.

Particularly, fires have been found to be related to climate which impacts the fuels of an area (Carcaillet et al., 2001). Indeed, wet conditions in winter months will help shrub and grassland vegetations to grow which are good fire fuels during the summer months. On the opposite, summer drought affected forests will dry the existing vegetation and will be more favorable for fires (Littell et al., 2009). Previous research of the 2020 California wildfires conducted by Kurt et al., (2021) has been the initial start of this research. The study was focused on the concentration of carbon monoxide and nitrogen dioxide gas emitted from the fires, using the space-based instrument TROPOMI (Veefkind, 2012). It was discovered that the fires of the northern region of California, which occurred mainly over forest area, were considered smoldering, defined as slow fires with low efficiency (Rein, 2016) because of the forestry vegetations which produce higher CO emissions. The southern region fires were more of a large, open-flame type of fire because of the savanna vegetation and produced higher NO_2 emissions, characterize by flaming fires with higher combustion efficiency.

In Kurt et al., (2021) study, the Global Fire Emissions Database (GFED, van der Werf et al., 2017) was used to determine the type of vegetations over the two regions of interest. Many of California's land can fall under six vegetation classifications following this database. To account for the differing types of vegetation and investigate meteorological factors driving the fires in the northern and southern regions, observational sites near the city of Sacramento and Fresno were chosen as areas of interest, respectively.

This research is to learn of the effects the weather conditions had on the surrounding environment of the areas of interest. The weather conditions of each region of interest can provide insight to reasons the fires were so extreme compared to previous fire seasons and determine if there is an association to the different type of fuel (vegetation) of each region as well. Essentially this research is to answer the question: Could climate conditions explain the extremity of the 2020 wildfires of two different vegetation types encountered in Northern and Southern California?

The paper is structured as follows. The data and methodology used are described in section 2. The results over the northern and southern regions of California are presented in section 3. We will present time series and anomalies of temperature and precipitation and will add information of fire count as well. The results will be discussed in section 4, and we will finish by our conclusions in section 5.

2. Data and Methods

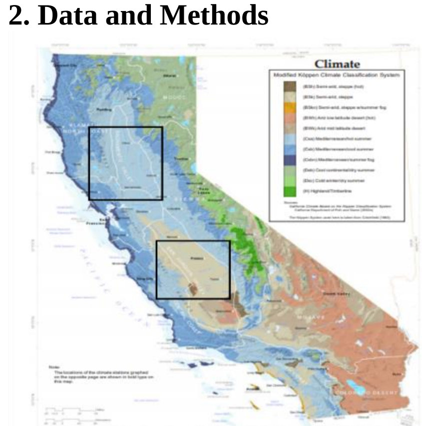

Figure 1. Climatology of California from the Atlas of the Biodiversity of California (2003) with the Koppen climate classification system (Critchfield, 1983). Squares added are to highlight northern (top square) and southern (bottom square) regions of interest.

Figure. 2 Localization of California ASOS stations in northern region (left plot) and in southern region (right plot). The arrows represent the stations selected for observation.

2.1 Description of Meteorological Variables

We acquired the data from the California ASOS (Automated Surface Observing Systems, https://mesonet.agron.iastate.edu/request/download.phtml?network=CA_ASOS) dataset. ASOS is a program developed by the National Weather Service, Federal Aviation Administration, and the Department of Defense that continuously collects weather data across the United States and is archived into the Global Surface Hourly database (Nadolski, 1992). Data was downloaded for stations within the two regions of interest (see Fig. 1) from January 2010 to December 2020. Three stations were used in the southern region: Fresno Air Terminal (FAT), Hanford (HJO), Madera (MAE); while two stations were used in the northern region: Sacramento/Executiv (SAC) and Sacramento Metro (SMF) (see Fig. 2) For our study, we used temperature and one hour precipitation data. Air temperature is reported in Fahrenheit at two meters. The one-hour precipitation is for the period from the observation time to the time of the previous hourly precipitation reset. These two variables were chosen because they give information if whether there are drought conditions or not and because they help understand the weather conditions over the two regions of interest. According to Nadolski (1992), precipitation is measured by an 8-inch gauge while the process of recording air temperature and dew point is with an hygrothermometer. Using a resistive temperature device, the hygrothermometer can quantify the ambient air temperature and the dew point is measured with a chilled mirror.

For this study, monthly averages of temperature and precipitation were created from 2010 through 2020. Yearly averages were then calculated as well as a 10-year average. The process of determining anomalies of temperature and precipitation was subtracting the 10-year average to each yearly average. Anomalies in temperature and precipitation were also calculated and observed in a seasonal aspect for Winter (DJF), Spring (MAM), Summer (JJA), and Fall (SON) of each year to determine the weather anomalies by season.

2.2 Fire Count

Fire count for each month in 2010 to 2020 was used. The fire count data came from the space-based instrument, MODIS (Moderate Resolution Imaging Spectroradiometer, Justice et al. (2002)) level 2 active fire product from TERRA Satellite with a spatial resolution of 1km. We used the monthly fire count that were averaged at a monthly time scale by the GFED analysis tool (https://globalfiredata.org/). This information was then charted alongside temperature and precipitation. Having each factor on the same chart allowed us to observe the variations in temperature and precipitation and how these weather conditions in turn affected the number of fires produced each month.

3. Results

We used the data described in our methodology (Section 2.) to look specifically at first, 10 years of climatology of temperature, precipitation, and fire count over the northern and southern regions of California. In a second part, we look at the seasonal anomalies for the areas of interest.

Looking at the regions of interest on a scale that increases in focus from 10-year climatology to seasonality to regionally in 2020 was a necessary methodology, because it allowed us to understand how climatology affected vegetation growth and decay, and in turn the susceptibility of vegetation to fires on each level of observance.

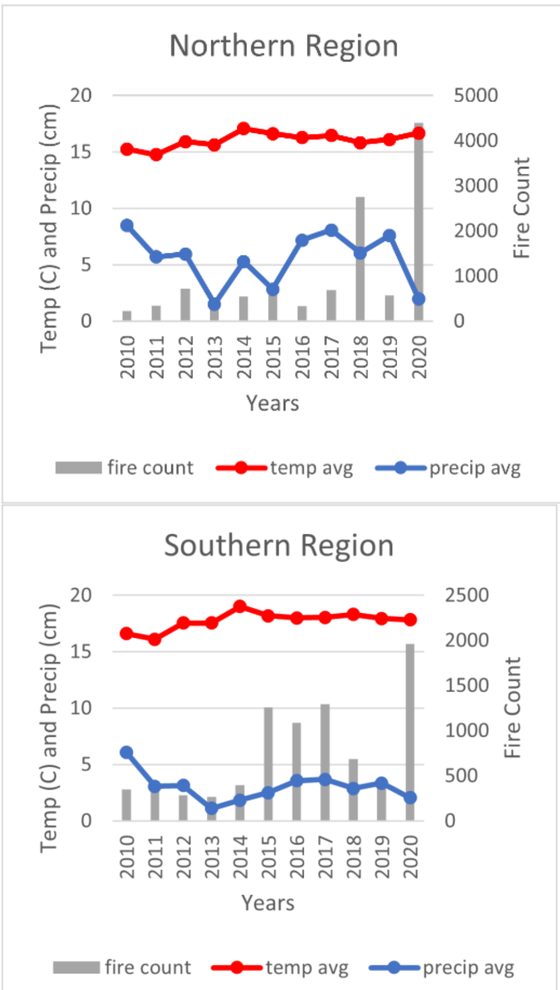

Figure 3. Yearly trend of average temperature (in red and in degree C), precipitation (in blue and in cm), and fire count (in gray, unitless) for the northern region (top plot) and the southern region (bottom plot) from 2010 to 2020.

3.1. 10 Years of Temperature and Precipitation versus Fire Count of Northern and Southern Regions

Figure. 3 represents the climatology of the northern and southern regions observed for the period 2010-2020. Further observing the temperature of the northern region, we can see that it averaged between 15 °C and 17 °C over the 10 years. There was a rise in 2014 to 17 °C from the previous year which was around 16 °C. A different range of temperature was noted for the southern region of about 16 °C to 20 °C over the 10 years. There was also a rise in temperature in 2014 to about 3 °C compared to the previous year. Now to address the precipitation of the northern region, we can observe a larger variability from year to year compared to the southern region, with an average of 9 cm of precipitation in 2010 to 2cm in 2013 and 2020. The highest precipitation averaged occurred in 2010, with 2017 and 2019 following, to be about 8 cm. A decrease in precipitation of about 2 cm can be observed in 2018 the same year as a rise in fire count. There was a sharp decrease in precipitation from 2019 to 2020 of about 6 cm, the largest decrease of precipitation over the 10 years. In 2020, there was in addition of a sharp decrease in precipitation, an increase in temperature. For the southern region, we can see less variability for the precipitation with a maximum of 6 cm reached in 2010 and a minimum of 2 cm in 2013. Even if the precipitation followed the same pattern in the northern and southern regions with a decrease in precipitation from 2010 through 2013, followed by an increase from 2013 through 2017 and finishing with a decrease through the rest of the period, the values are larger over the northern region than the southern region. Interestingly, while there was an increase in annual precipitation from 2013 to 2017 over the two regions, there was also a rise in fires over the southern region not observed for the northern region. Over the 10 years, the fire count increased progressively in the northern region while for the southern region, they increased in 2014 through 2017, decreased from 2017 through 2019 before to increase drastically in 2020 reaching about 4500 fires. Looking at the link between fire count, precipitation, and temperature, we can see that an average, when there is more precipitation than the previous year, there is less fire count for the northern region, except for some years where the increase in temperature could explain an increase in fire count. 2020 was particularly affected by both increase in temperature and decrease in precipitation. Contrasting the northern region, for the southern region, the increased in precipitation for 2014-2017 was linked with an increase in fire count while the temperature were constant around 18 °C. However, in 2020, while the temperature

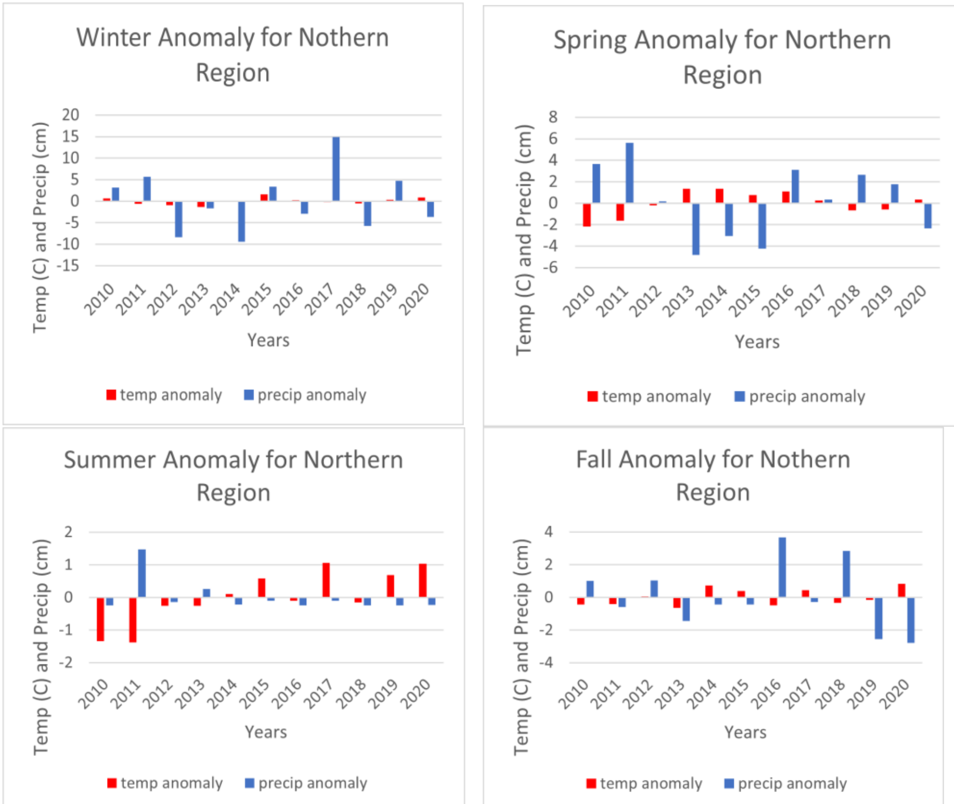

Figure 4. Seasonal anomalies of temperature (in red) and precipitation (in blue) for the northern region over 10 years. The seasons are winter (DJF, top right), spring (MAM, top left), summer (JJA, bottom right), and fall (SON, bottom left).

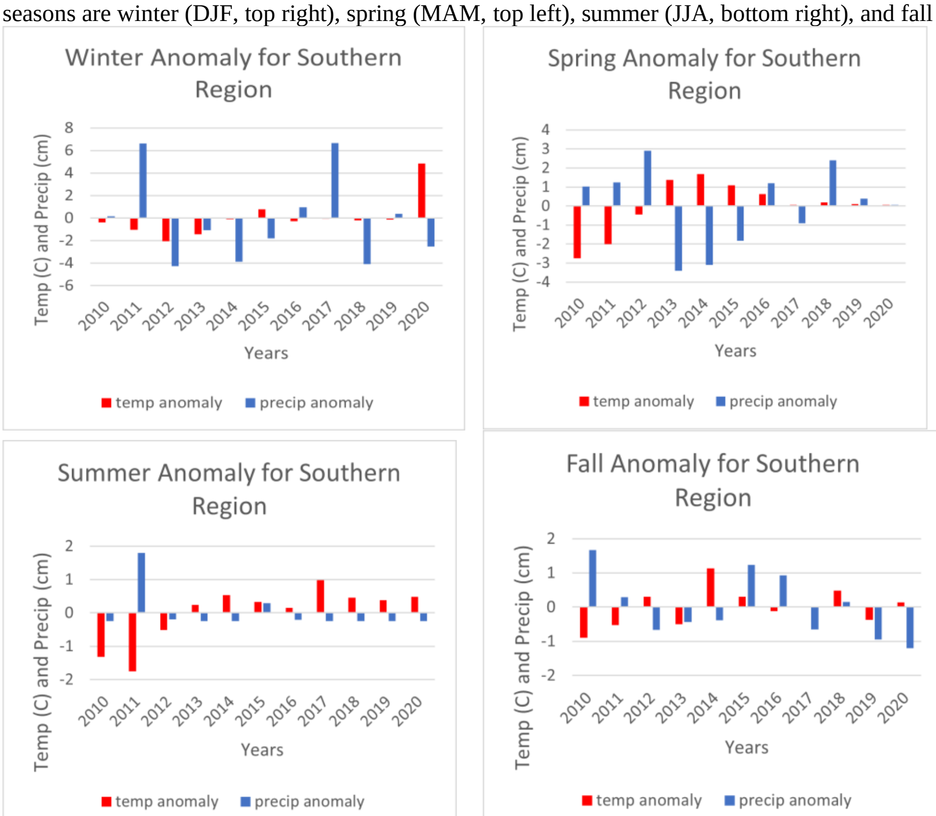

Figure 5. Seasonal anomalies of temperature (in red) and precipitation (in blue) for the southern region over 10 years. The seasons are winter (DJF, top right), spring (MAM, top left), summer (JJA, bottom right), fall (SON, bottom left).

reached about 18 °C with a decrease in precipitation of 2 cm, the fire count was the largest reaching around 2000.

3.2 Seasonal Anomalies of Northern and Southern Regions over 2010 through 2020

Figure 4 shows the seasonal anomalies of temperature and precipitation for the northern region from 2010 through 2020. Over the 10 years, the winter and spring seasons had several positive anomalies in precipitation except 2013, 2014, 2015, and 2020. Those years, precipitation was below average by about 4 cm. Those years also experienced at the same time for spring, a positive anomaly in temperature compared to the other years of that season. The precipitation anomalies of winter 2012 were below average which could correlate to the 2011-2012 La Niña event, known to cause dry conditions for northwestern regions of the United States (Gershunov and Barnett, 1998). In summer, we can see that while the temperature was below average from 2010 through 2013, it increased slowly since 2014-2015 becoming positive anomalies of temperature (2014-2015 known as the year when the most intense El Niño was ever registered (Klein, 2015)). In fall, while most of the years were having small anomalies, they became large starting 2016 with an increase of precipitation of almost 4 cm above average. The precipitation was as well important in 2018 which got 3 cm more rain. However, 2019 and 2020 are particularly highlighted because of their large negative anomalies of precipitation reaching a deficit of almost 3 cm, the largest deficit of the 10 years period. Throughout 2020, each season shows an above average increase in temperature and below average decrease in precipitation indication dry conditions of the whole year that has not been observed since 2015. This signals that the northern region experienced an intense drought throughout the year.

After looking at the seasonal anomalies of the northern region, we are now looking at seasonal anomalies for the southern region (Fig. 5). We can see that in spring, positive anomalies of precipitation were affected the region in 2010, 2011, 2012 and 2018. But from 2013 through 2015 the region experienced a deficit of precipitation with above average values of temperatures, characteristic of drought. For the summer period there was a shift in temperature. From 2010-2012, they were below average but then become above for the rest of the study period. The southern region experienced drought conditions each summer since 2016. While 2011-2012 had large negative anomalies of temperature (~ -2 °C in 2011) with large positive anomalies of precipitation in 2011 for spring and summer (but negative in 2012), 2020 was the opposite with large deficit in precipitation (-2 cm in winter and almost –1.5 cm in fall) and positive anomalies of temperature were particularly large in winter reaching around 5 °C above average. 2020 then experienced year-long drought conditions particularly severe in winter and in fall. The weather conditions observed here for 2020, indicate then that the expected cool and rainy of winter of the southern region was not particularly intense this year but was however the driest winter over the 10 past years.

3.3 2020 Seasonality of Temperature, Precipitation and Fire Count of Northern and Southern Regions

Now we take a closer look at the seasonality of 2020 for the regions of interest to gain insight of the changes in temperature and precipitation and the connection with the fire count over the months of 2020 (Fig. 6). For the northern region, by august, the fire count was already around 3000 and increased at a great rate until the end of the year. The southern region fire count was under 2000 during the same month, and its rate of increase by the end of the year was still greatly below the amount the northern region experienced (ending to be about 4500 compared to 12 000 for the northern region). While the fire season started in March for the northern region, it started one month earlier (in February) for the southern region. As mentioned by Kenward et al., (2016), fire season tends to start more earlier than previously observed. These lower fire counts in the winter months could also be explained by the precipitation from January to May, but we have previously seen that these winter precipitations were below the average (Fig. 5). The southern region experienced a higher range in temperature, by being about 25 °C from June-August while the northern region was below 25 °C during the same period. Starting from June until October, precipitation was at 0 cm, which is also seen in the chart for the southern region indicating a drought was occurring. By December, the temperature of the northern and southern region both decreased to about the same number (7 °C) and precipitation for both had increased about 3 cm for the northern and 6 cm for the southern from November to December.

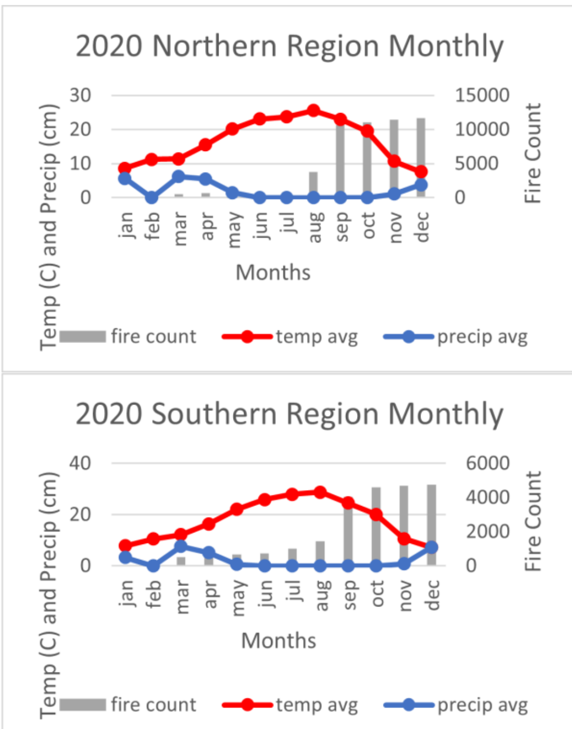

Figure 6. Monthly mean of temperature (in red and in degree C), precipitation (in blues and in cm), and fire count (in gray, unitless) for the northern region (top plot) and the southern region (bottom plot) in 2020.

4. Discussion

In this study, we focused on the weather conditions of northern and southern California over 10 years, looking at climatology, seasonal anomalies, and seasonality of 2020 to learn of the intersections between temperature, precipitation, and fire count, and to see possible explanation of the intense 2020 fire season ever recorded. We were also interested in observing characteristics of fire weather over the temperate forests of northern California and the grasslands of southern California which could explain the intense fire season and the largest fire of the northern region. The different vegetation types of the northern and southern regions were a key aspect of this research because of the differences in fire fuel each region experienced over the 10 years and especially in 2020. We observed that, by year, southern and northern California experienced drought conditions in 2010, 2017 and 2020 where 2020 was the extreme point which can explain the intensity of the fires produced during that year. The drought of these three years could be linked to an atmospheric event that occur in the Pacific Ocean (Westerling and Swetnam (2003); Gershunov and Barnett (1998)), the El Niño Southern Oscillation or also known as ENSO. Previous studies showed that the El Niño event that occurred in 2009 evolved in a strong La Niña (Bell et al., 2011; Evans and Boyer-Souchet, 2012). La Niña is particularly known to bring dry conditions in the contiguous United States (Cole et al., 2002). The 2020 La Niña was particularly intense, it started in August 2020, increased in fall and reached its maximum in DJF of 2021 (Zheng et al., 2021). The large anomalies in temperature and precipitation observed in 2020 could be explained from the 2020 La Niña and could further explain the drought that the northern and southern regions experienced. The effect of the weather phenomenon is also observed for the fires from the fire count data which were particularly huge this year for both regions. It then seems that the large fire seasons observed in 2020 over both regions of our study could be linked with the large La Niña event occurring the same year. Additionally, there is linkage between monthly fire count increasing in spring 2020 with drought conditions becoming larger by the spring then into the summer months and continuing into the fall where the fire count was at its maximum of the year. Being aware of the differing climatology of northern (high annual rainfall, hot summers) and southern (rainy winters, dry summers) California, certain weather conditions were expected to be observed from the seasonal anomalies (fig. 4 and 5). For the southern region, large precipitation during the winter months was expected to explain an increase in grassland vegetation which would have dried during the summer months favorable of fire ignition. This was not the case. We observed on the opposite, dry winter followed by dry summer for both regions. While we know that the fires over the two regions were large, the northern one was larger than the other one. The dry conditions observed for the entire year in 2020 (dry conditions not observed for the 9 previous years), could then explain the intense August Complex Fire that occurred in the temperate forest of the northern region of California. However, the conditions of the southern region suggest that other variables could explain the severity of the fires in this region, such as the Santa Ana wind. Finally, our study was also interested in a possible explanation in the shift of combustion efficiency, where fires of grassland/savanna vegetation of the southern region transition from flaming to smoldering, that Kurt et al. (2021) observed. This research expected to observe an increase in precipitation during the fall months (mainly in September) to explain shift in fires, but as observed in Fig. 6, there was no precipitation from June through October. An increase in precipitation over September could explain that the southern fire combustion efficiency shifted from flaming to smoldering. Instead, the shift in the combustion efficiency could be explained by other factors like the Santa Ana wind or a spread in the fires from savanna to temperate forest. According to Westerling et al., (2004), Santa Ana winds bring dry warm air to southern California occasionally throughout the year but peaks around winter months. The winds affect the expected precipitation of the winter months to have large variability and potentially cause droughts for the region which then dries the vegetation out leaving it to susceptible for ignition and spread during increased temperature of the summer and fall months.

5. Conclusion

California, which experienced the largest and most destructive fire season in its history in 2020, was an unprecedented weather event. The damage, intensity, and spread of this event, has elevated the interest in research on fire weather itself and specially regions of California that experience wildfires on a continual basis. This study was particularly focusing on two regions of California: the northern region characterized by temperate forests and the southern region which has some savanna/grassland vegetation. Looking at the 10-year climatology (from 2010 through 2020) of temperature, precipitation, and fire count and at seasonal anomalies, it is clear to see the drastic changes in temperature and precipitation the regions of focus experienced. A noticeable occurrence, from the seasonal anomaly, shows an above average increase in temperature paired with a below average decrease in precipitation in 2020, never experienced during the 10 previous years. We were able to observe link between the drought and large fire year in 2012, 2017 and 2020 which are known to be La Niña years. The intense drought that California experienced in 2020 could be link with the severe La Niña event recorded this year. Peaks in temperature in August with an ongoing drought at the start of fire season, means any vegetation growth from increased precipitation in spring was dried out leading to plenty of fuel to be susceptible to fire ignition. This was observed for the northern region (the temperate forest vegetation) which experienced dry conditions all year round, compared to the sparse shrub, savanna/grassland vegetation of the southern region. Over the 10 years observed, the northern region faced the drier conditions in 2020 explaining the large fires of this region. Additionally, the lack of precipitation during the summer and beginning of fall could not explain the shift in combustion that the grassland fire experienced in September 2020 as observed in a previous study. Further studies should consider using other weather variables such as winds for instance to either explain the severity of the fires in the southern region but also the shift in combustion this region experienced in September 2020.

Acknowledgements. This material is based upon work supported by the National Science Foundation under Grant No. AGS-2050267

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