**Severity of Droughtiness in California**

**Introduction.** Extreme weather events are happening more frequently due to global warming. Droughts, prolonged periods of low to none precipitation, can cause a lack of groundwater supply for ecosystems. The State of California is currently in the midst of a record-setting drought, due to its Mediterranean climate characterized by wet winters and dry summers under the influence of Ferrell cells (Diffenbaugh et al., 2015.) Drought worsened ecological costs of civilization, affects agriculture and energy production, as well as increases wildfire risks and public health problems. The drought began in 2012 and had increased in severity through time, raising concerns about the potential impact of climate change on future drought patterns. The droughtiness is measured in Palmer Modified Drought Index (PMDI), which is used to assess drought conditions by considering both precipitation and temperature data over time. Therefore, my report strives to understand the drought trend of California over time and its relationship to climate factors like temperature to make strategies for dealing with future droughts. My hypothesis is that drought tends to get worse each year in relation to the warming temperatures resulted from global warming. I also predicted that one outlier year should not cause the drought trend to fluctuate significantly.

**Methods.** External information related to drought and PMDI values are provided by Diffenbaugh et al. (2015) and Stine (1994.) PMDI values were derived from a more commonly used Palmer Drought Severity Index (PDSI), which combines monthly temperature, precipitation, soil-water holding capacity, and potential evapotranspiration data from local weather stations dating back to the late 19th century. All datasets - calpmdi23.csv file containing PMDI values for California from 1896 to 2023 - and analytical tools - drought2024.R file containing the analysis codes - used in this scientific report are provided by the EVE 101 instructors. A collection of linear regression models will be performed to test for a statistical relationship between time in years (explanatory variable) and PMDI (response variable). The p-value obtained from these linear models will be used to determine the significance of the generated models. I also aim to explore the potential effects of a Severe Wet (PMDI > 4) or Severe Drought (PMDI < -4) year in 2024 on the drought trends in California.

**Results.** The general linear model ofFigure 1 shows a decline in PMDI across the period represented by the solid black linear regression line, which indicates an increase in drought severity. The outlier PMDI value in 1983 - which corresponds to the year of La Nina - was the first point to reach PMDI < -4. The next few years experienced minimal drought, then 1988 became the first year to reach PMDI > 6. After 1988 the pattern of drought and wet began to fluctuate unevenly - multiple years of drought following multiple years of more wet. 21st century from 2001 onward tends to lean towards the negative axis of PMDI, with the highest PMDI value of approximately 2.5. The p-value of 0.00273 meaning the model confirms the correlation between PMDI and time. Figure 2A and 2B shows similar linear regression lines, regardless of the PMDI values for 2024. Both models have p-values below 0.05, which also approves the relationship between PMDI and time. It is worth noting that p-value of Figure 2A model can only reject the null hypothesis at approximately 98% confidence interval (CI), while the model in Figure 2B can further reject the null hypothesis at >99.9% CI. This may suggest that drought patterns can be explained better using model of Figure 2B, when 2024 falls more into the drought side.

**Discussion.** Observed PMDI data for the past 124 years have found signs of severe and frequent droughts in California that is associated with anthropogenic global warming. Over time, the PMDI data shows a clear trend towards more negative values, which means droughts are getting worse. While there are ups and downs in wet and dry years, the 21st century has been mostly dry with very few years having decent rainfall (Figure 1.) Diffenbaugh et al. (2015) found a strong correlation between PMDI and time, suggesting that climate change is making droughts more common. It was not clear in the dataset that less precipitation or warmer temperatures was the cause of droughts. According to Diffenbaugh et al. (2015), warming temperatures can lead to more evaporation, less soil moisture, and less snow, which has nothing to do with low precipitation. While short-term changes can be observed as normal weather fluctuations, the trend over the past century shows a major shift in California's climate. It is known that California has Mediterranean climate, with wet-dry patterns driven by atmospheric circulation patterns such as El Niño-Southern Oscillation (ENSO). But the recent warming trend seen in the climate models suggested that human actions could create new extreme droughts that have not happened before (Diffenbaugh et al., 2015.)

In general, the study shows that drought tends to worsen in California over time. There are more extreme rise and fall in both drought and wet directions in the most recent decades, which is likely the result of anthropogenic global warming. This suggests that as temperatures warm due to human activities like greenhouse gas emissions, the frequency of severe droughts is expected to increase. It is also suggested that one or two extreme wet or dry year might not significantly change this overall pattern of increasing drought severity. Also, more research is needed to understand how the expected warming could affect things like snow levels, how water flows, how much water evaporates, and how the land and atmosphere interact – all of which could interfere with drought severity (Diffenbaugh et al., 2015).

**Literature Cited**

1. Diffenbaugh, N. S., D. L. Swain, and D. Touma. (2015). Anthropogenic warming has increased drought risk in California. Proceedings of the National Academy of Sciences 112:3931-3936.

2. Stine, S. (1994). Extreme and Persistent Drought in California and Patagonia during Medieval Time. Nature 369(6481): 546-549.

A graph showing the number of years

Description automatically generated with medium confidence

Figure 1. Palmer Modified Drought Index (PMDI) values for California from the late 19th century to recent years. The time ranges from 1896 to 2023, with scales represent each year. Symbols that are used in the figure: Severe Drought is indicated by dashed red, Moderate Drought by smaller-dashed red line, Moderate Wet by smaller-dashed blue line, and Severe Wet by dashed blue line. Linear regression line for this general linear model (p-value = 0.00273) is in solid black. (Null hypothesis: no correlation between PMDI and time)

B

A

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Figure 2. PMDI values for California from 1896 to 2023, along with presumed PMDI values of 2024. (A) A general linear model assumed 2024 is Severe Wet with PMDI = 7.0 (p-value = 0.02252). (B) Another general linear model assumed 2024 is Severe Drought with PMDI = -7.0 (p-value = 0.000758). Each scale represents each year. Symbols that are used in the figure: Severe Drought is indicated by dashed red, Moderate Drought by smaller-dashed red line, Moderate Wet by smaller-dashed blue line, and Severe Wet by dashed blue line. Linear regression lines for both general linear models are in solid black. (Null hypothesis: no correlation between PMDI and time)