Investigating the Effects of Weather and Climate on Biomass Production in the Intermountain West

Rituraj Yadav[1] (yadaritu@isu.edu), Keith Weber[1] (webekeit@isu.edu), and Kurt Buffalo[2] (kurt.buffalo@noaa.gov)

1. GIS Training and Research Center, Idaho State University (ISU), Pocatello, Idaho, USA.
2. National Weather Services, National Oceanic and Atmospheric Administration, Pocatello, Idaho, USA.

Abstract

To better understand the factors driving increased wildfire frequency since 1950 across the western United States (Davis & Weber, 2018), the environmental conditions (i.e. fuel availability, hazard, and ignition source) required for a wildfire to occur were investigated. Specifically, this study investigated the effect of several weather variables (i.e. maximum and minimum monthly mean temperature, and cumulative monthly precipitation) and the El Nino Southern Oscillation (ENSO) on biomass production in the Intermountain West between 2001 and 2019. Trends in these weather variables were compared with wildfire frequency, which while quite high relative to pre-millennial, has been relatively constant over the past two decades. This study also investigated the length of the growing season over the past two decades. NOAA’s Global Hydrological Climatology Network (GHCN) Version 1 dataset was acquired for all weather variables while biomass production was estimated using Normalized Difference Vegetation Index (NDVI) data acquired from the MODIS Terra NASA Earth Observing System satellite imagery. ArcGIS Pro models were developed to perform all spatial analyses and python, excel, and Jmp were used for statistical analysis and data visualization. While the results of this study clearly show that weather variables, specifically precipitation and maximum temperature, are important drivers of vegetation production ($P < 0.05$; $R^2 = 0.69$) across the semiarid ecosystems of the intermountain west, no significant change in either of these variables was detected over the past two decades. Furthermore, no change was observed for the length of the growing season as indicated by NDVI data for this same time period. These results correspond well with the relatively constant nature of wildfire frequency over the same spatiotemporal extent.

Keywords: Wildfire, Climate, Biomass Production, Multiple Regression Analysis

Introduction

Wildfires play an important role in ecology of forest and savanna ecosystem (Brown et. al, 2000). Wildfire frequency has increased between 1950 and 2017 across the Western United States (Davis and Weber, 2018) – a region including 11 states (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming) (Figure 1).

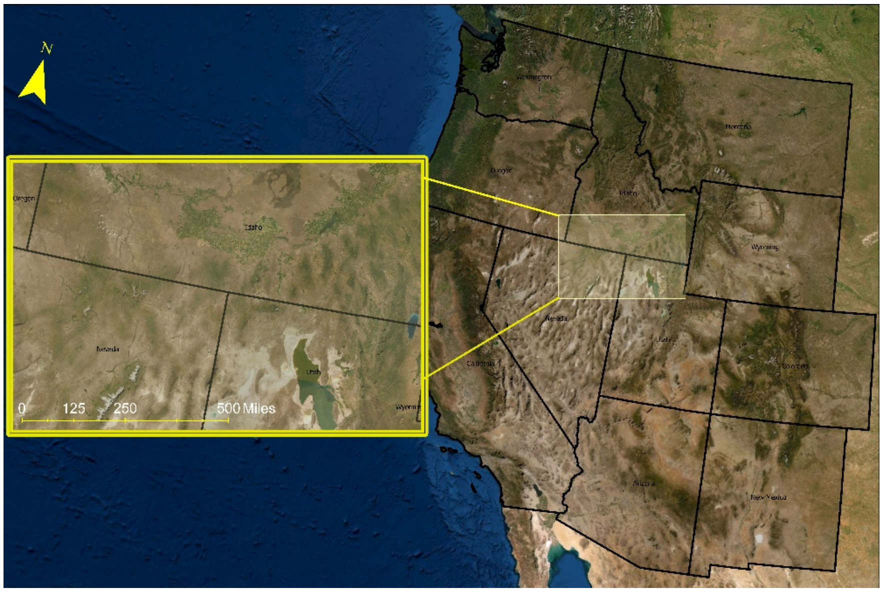

Figure 1: The Intermountain west (left box) was the focus of this study.

Many factors such as fuel load/continuity, weather (e.g., temperature and precipitation), climate (e.g., El Nino Southern Oscillation (ENSO)), and source of ignition (e.g., lightning) play a role in wildfire occurrence (Figure 2). In essence, each factor needs to exist to a sufficient degree for a wildfire to occur. Thus, these factors can be viewed as wildfire pre-requisites or precursors. Bearing this relationship in mind, this study decomposes the problem of understanding increasing wildfire frequency by exploring one of the most basic factors that directly influence wildfire, fuel load.

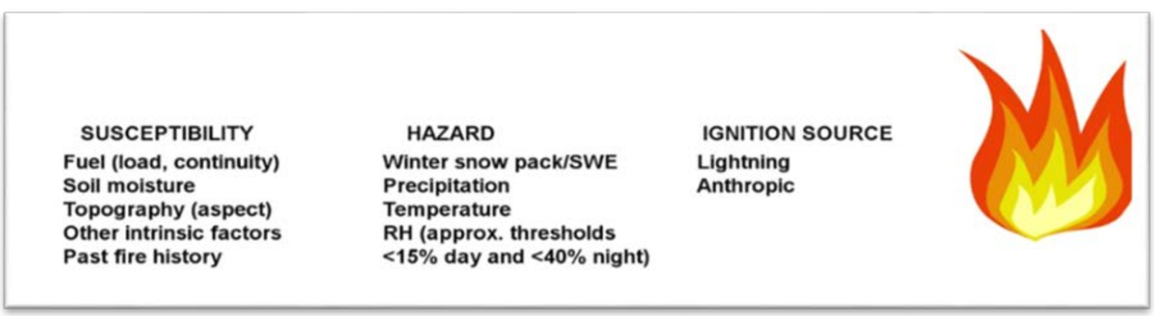

Figure 2: Conditions required for a Wildfire to occur.

Fuel load and fuel continuity are directly related to vegetation or biomass production. Increases or decreases in vegetation production affect a landscape's susceptibility to fire by affecting fuel load, continuity, and over time, its combustibility to burning. Measuring vegetation production, or in the case of this study, wildfire fuel production is very difficult to accomplish across a study area that is over 160,000 km^2 in size (Figure 1). For the purposes of this study, we will estimate fuel production using the normalized difference vegetation index (NDVI) from MODIS Terra NASA Earth Observing System (EOS) satellite imagery.

The purpose of this study was to investigate the effect of maximum, and minimum monthly temperature, cumulative monthly precipitation, and ENSO on biomass production acorss the intermountain west (Figure 1). This study used multiple regression analysis to estimate the effect of each weather variables on biomass production. This study also investigated the length of the growing season in the study region for the period of 2001 – 2019.

Methods

Data collection. Normalized Difference Vegetation Index (NDVI) data were acquired from Terra Moderate Resolution Imaging Spectroradiometer (MODIS) NASA Earth Observing System satellite imagery with all imagery available from 2001 to 2019 across the Intermountain West. These NDVI data were developed from the dataset generated by Terra MODIS MOD13Q1 Version 6 sensor. This sensor generates imagery everyday which are combined to produce a NDVI composite product at a 16-day interval with a pixel size of 250 m^2 (Huete et. al, 1999).

Weather variables (i.e. maximum, and minimum temperature, and monthly cumulative precipitation) were downloaded from NOAA’s Global Hydrological Climatology Network (GHCN) version 1 dataset in a NetCDF format and converted to a gridded (raster) 5 km monthly dataset. GHCN version 1 is a comprehensive, surface baseline climate dataset created by using with more than 6,000 temperature recording stations and 7,000 precipitation recording stations monitoring weather across the continental United States (Vose et. al, 2014). This dataset uses a monthly temporal scale and a $0.5^{o} \times 0.5^{o}$ spatial scale stored in a NetCDF raster format.

The climate variable (ENSO) was obtained from NOAA’s Physical Science Laboratory with a monthly temporal scale stored in Microsoft Excel format. ENSO data were acquired from the Multivariate ENSO Index (MEI) Version 2. This dataset combines oceanic and atmospheric variables to produce a single ENOS index value each month (Wolter et. al, 2012).

Wildfire frequency data for the time period of 2001 – 2019 were collected from the Historic Fires Database (HFD) maintained by the Idaho State University’s GIS Training and Research Center. The HFD was assembled by acquiring wildfire perimeters from authoritative sources across the western US from 1950 to 2019.

Spatial Analysis. The weather dataset was extracted into tiff raster images using “Make NetCDF a Raster Layer” in Esri’s ArcGIS Pro. The newly extracted dataset was projected to Albers Equal Area Spatial Reference System (WIKID: 102039) using the “Project Raster” data management tool. The weather, and NDVI datasets were clipped to the intermountain west study region using the “Clip Raster” data management tool. The “zonal statistics as table” tool was used to create tables with mean, median, standard deviation, and range statistics for each of these datasets. The geodatabase tables were exported to Excel using the “Table to Excel” tool for statistical analysis.

An ArcGIS Pro model was created to investigate the length of the growing season. The model ingested each 16-day composite NDVI images as an input parameter, extracting only those data with NDVI values ≥ 0.30 to create output tables showing the count of pixels that satisfied this criterion. The 0.30 threshold value was selected as NDVI values below 0.3 indicate a lack of green vegetation (Huete et. al, 1999). Summary statistics were calculated giving the sum of the NDVI pixels satisfying this criterion on each date. These tables were converted into Excel files using the "Table to Excel" tool for further statistical analysis and to determine the length of the growing season between 2001 and 2019.

Statistical Analysis. Excel was used to calculate descriptive statistics and to graph these datasets. A multiple regression analysis was performed using a 95% confidence interval with Jmp software to determine the correlation of each weather variable with NDVI. To facilitate exploratory statistical analysis, the two years with the most extreme difference in weather variables were selected and compared using single factor ANOVA.

Results and Discussion

Effect of climate, and weather variables on biomass production. Results of the multiple regression analysis indicate cumulative precipitation and maximum temperature have the greatest effect on biomass production in the intermountain region (Table 1). The R^2 (0.69) of the multiple regression model indicates that 69% of the variability in the monthly NDVI values could be predicted by the model (i.e., cumulative monthly precipitation, maximum and minimum temperature, and ENSO). Minimum temperatures and ENSO were found to have the least effect on biomass production. Higher biomass production would lead to higher fuel load, increasing the susceptibility of the area to wildfire. However, too high temperature could decrease biomass production by potentially causing higher evapotranspiration and water loss in the vegetation (Teskey et. al, 2015).

Table 1: Results of multiple regression analyses determining the effect of weather and climate variables on NDVI.

	P-Value
Precipitation	*<0.0001*
Maximum Temperature	*<0.0001*
Minimum Temperature	*0.14*
ENSO	*0.64*

Trend analysis of the cumulative precipitation and maximum temperature in the new millennium (2001 – 2019). No statistical difference was found between the trends of monthly maximum temperature (Figure 3). An insignificant P-value (> 0.05) was found for when testing the two most dissimilar years (2011 and 2012).

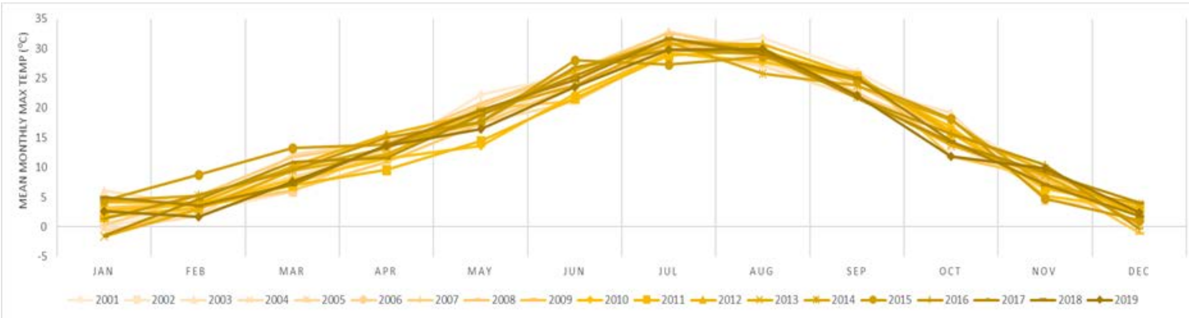

Figure 3: Visualizing the trends in maximum temperature (°C) in the new millennium across the intermountain west region

Similarly, no change in the trend of cumulative monthly precipitation was found (Figure 4). However, a significant p-value (<0.05) was found for the single factor ANOVA test between two years with high mean difference (2005 and 2013). This indicated change in patterns of the cumulative precipitation between the years 2005 and 2013.

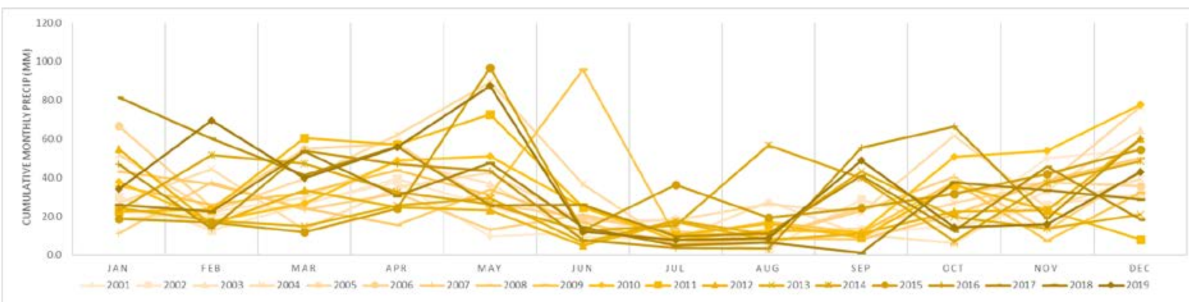

Figure 4: Visualizing the trends in cumulative monthly precipitation (mm) in the new millennium across the intermountain west region

Although these two years were different, the graph of upper and lower confidence levels confirms annual median cumulative precipitation was quite similar (Figure 5). An insignificant P-value (>0.05) was found using ANOVA for the time period (2001 – 2019).

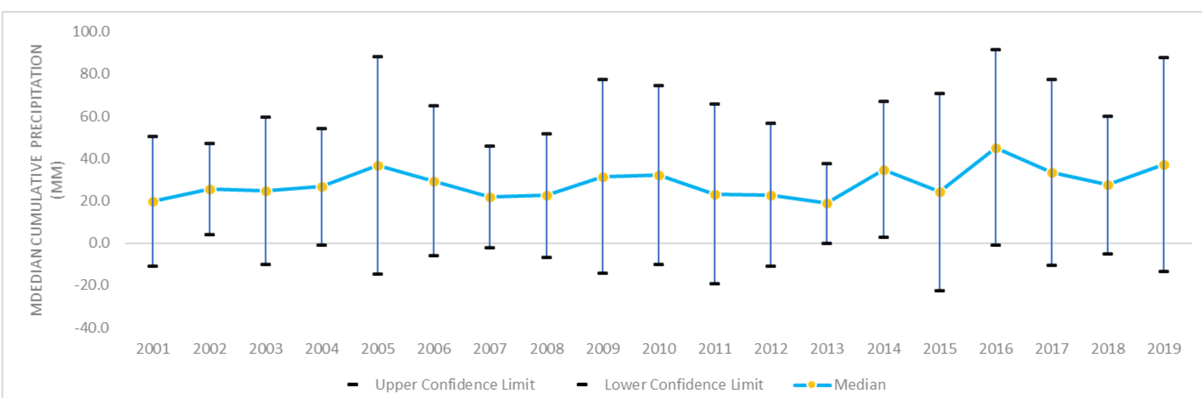

Figure 5: Upper and lower confidence limits of median cumulative monthly precipitation for each year (mm) in the new millennium across the intermountain west region.

Length of growing season in the new millennium (2001 – 2019). No change in the length of growing season between 2001 and 2019 was observed in this study (Figure 6). While some years show an earlier green up (2015) and other show a later green up (2008). These variations were found to be normal.

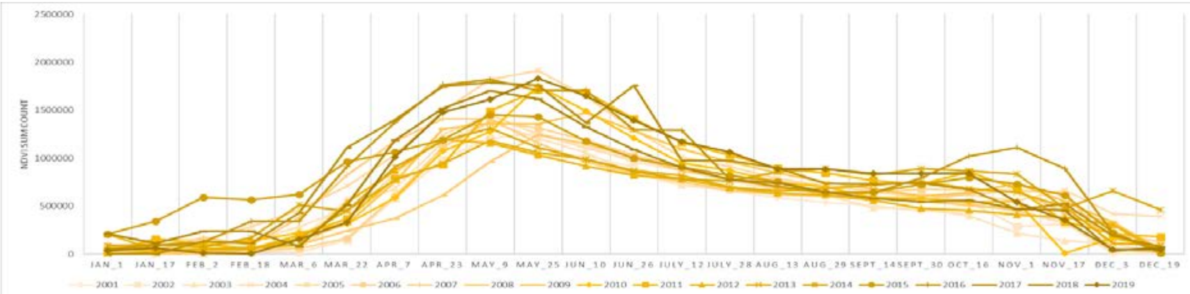

Figure 6: Visualizing green up over the study for the time period of 2001 – 2019.

A single factor ANOVA test was conducted between the year 2008 and 2015. These years were chosen because of the high difference in the annual averages of NDVI sums in the new millennium. The p-value for the ANOVA test was found to be significant (< 0.05) indicating statistical difference in green up between these two years.

Although these two years displayed variation, the upper and lower confidence limit graph confirms NDVI values (≥ 0.3) were very similar (Figure 7). This indicates no significant changes should be expected in biomass production across the intermountain west region based on these data.

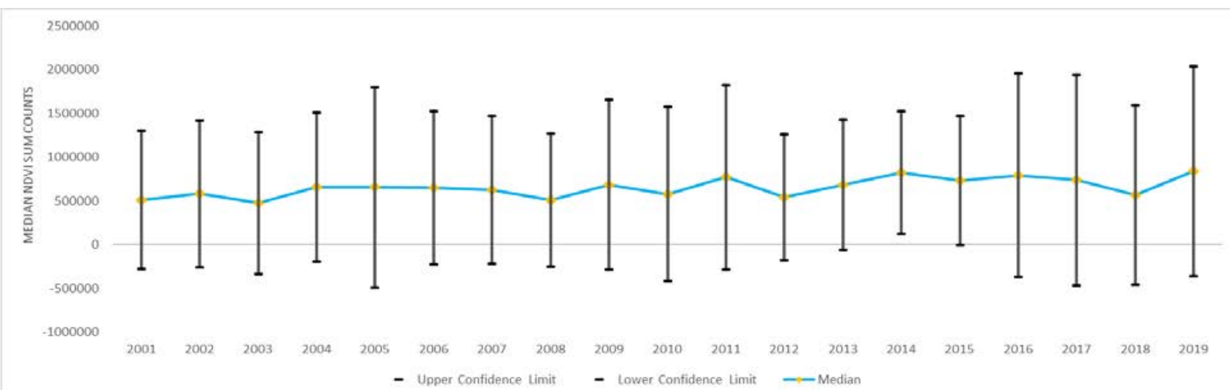

Figure 7: Visualizing the upper and lower confidence limits for the frequency of pixels exhibiting photosynthetic activity (≥0.3) across the intermountain west region between 2001 and 2019.

Trend analysis of the wildfire frequency in the new millennium at the Idaho: No significant increase in wildfire frequency was found between 2001 and 2019 (Figure 8). Some years were found to have higher wildfire frequency (e.g., 2007) than others (e.g., 2004); however, the overall trend is slightly declining over this two-decade time period (Figure 8). This follows very similar, overall constant trends in weather variables, and length of growing season as indicated by the NDVI data.

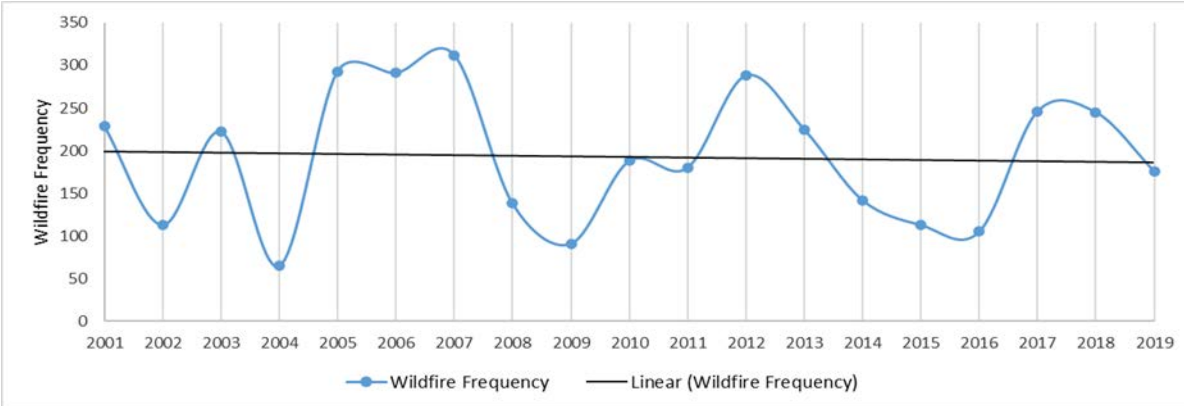

Figure 8: Visualizing the trend of the wildfire frequency in the new millennium at the Idaho. The R square and the slope of the linear trendline were found to be 0.0024 and -0.6684.

Assessment of Errors and Uncertainty

The temporal range used in this study presents a concern. Phenomenon such as change in temperature and precipitation patterns, length of growing season, and wildfire regimes take place over long time periods. The brief temporal range (i.e., 2001 – 2019) used in this study might not enable detection of change. However, studies such as this are constrained to the availability of data and specifically the MODIS NDVI product which is not available prior to 2001 (Huete et. al, 1999).

In addition, the averaging of weather and NDVI variables over a spatial scale size of this study area (i.e. 160,000 km^2) likely minimized the micro-climate effects on biomass production. A future study needs to be conducted using a more refined spatial scale to better explore changes of biomass production over longer time periods.

Conclusions

Long term changes in the wildfire regime have created the need to study the parameters driving these changes (Gorte, 2013). A pre-cursor of wildlife is the presence of sufficient fuel and its continuity. This study used multiple regression analysis to examine the effect of climate and weather variables on biomass production. Results indicate cumulative precipitation and maximum temperature are primary drivers. While these factors have been shown to drive biomass (and therefore fuel) production, no change in annual cumulative precipitation or maximum temperature was observed for the time period of this study (2001 – 2019). Furthermore, no change in the length of growing season was detected for the same time period. Similarly, no change in wildfire frequency was detected for the same time period across the study area. While it has been demonstrated previously that wildfire frequency and annual area burned has increased since 1950, since the new millennia, wildfire frequency has been relatively constant. This suggests the factor(s) responsible for the change occurred prior to the time period of this study.

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References

Brown, J. K., & Smith, J. K. (2000). Wildland fire in ecosystems: effects of fire on flora. Gen. Tech. Rep. RMRS-GTR-42-vol. 2. Ogden, UT: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 257 p., 42.

Balch, J. K., Bradley, B. A., Abatzoglou, J. T., Nagy, R. C., Fusco, E. J., & Mahood, A. L. (2017). Human-started wildfires expand the fire niche across the United States. Proceedings of the National Academy of Sciences, 114(11), 2946-2951.

Davis, J., & Weber, K. T. (2018). Spatio-Temporal Relationships of Historic Wildfires: Using the NASA RECOVER Historic Fires Geodatabase to Perform Long-term Analysis of Wildfire Occurrences in the Western United States.

Gorte, R., & Economics, H. (2013). The rising cost of wildfire protection. Bozeman, MT: Headwaters Economics.

Huete, A. R., Justice, C. O., & Van Leeuwen, W. J. D. (1999). MODIS vegetation index (MOD 13). Version 3. Algorithm theoretical basis document. Greenbelt MD NASA Goddard Space Flight Cent, Greenbelt, MD, USA.

Idaho State University GIS Training and Research Center. 2020. Historic Fires Database (HFD) version 2.0. Downloaded from http://giscenter.isu.edu/research/Techpg/HFD/ May 28, 2020.

Teskey, R., Wertin, T., Bauweraerts, I., Ameye, M., McGuire, M. A., & Steppe, K. (2015). Responses of tree species to heat waves and extreme heat events. *Plant, cell & environment*, *38*(9), 1699-1712.

Vose, R., Applequist, S., Squires, M., Durre, I., Menne, M. J., Williams Jr, C. N., ... & Arndt, D. (2014). Gridded 5km GHCN-daily temperature and precipitation dataset (nCLIMGRID), version 1. In *Maximum Temperature, Minimum Temperature, Average Temperature, and Precipitation*. NOAA Nat. Centers Environmental Information.

Wolter, K., & Timlin, M. S. (2011). El Niño/Southern Oscillation behaviour since 1871 as diagnosed in an extended multivariate ENSO index (MEI. ext). *International Journal of Climatology*, 31(7), 1074-1087.