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Climate analysis using tree-rings from the Wind River Range, Wyoming

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CLIMATE ANALYSIS USING TREE-RINGS FROM THE WIND RIVER RANGE, WYOMING

An Abstract of a Thesis

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Arts

Derek Richards

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ABSTRACT

This study utilizes tree-rings from the Wind River Range to determine past climates in this region of Wyoming and how they may have been affected by climate oscillations connected to the Pacific Ocean, such as El Nino-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO). The research considers what type(s) of past climatic cycles can be found in a roughly 500-year series of tree-rings collected from the Southeast Wind River Range using dendroclimatology and spectral analysis. It includes the reconstructed past temperature and precipitation data and how these compare with other reconstructions near the study area. The tree-rings were found to be significantly correlated to average May-through-August temperatures from the Lander airport climate station during a 424 year span from 1589 to 2013. Spectral analysis of the detrended ring-width data, as well as the reconstructed temperatures, suggests climate variations here may be associated with El Nino-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO). These analyses indicate that a tele-connection may exist between Pacific basin conditions and the climatic conditions in this region that affects tree growth in this region of Wyoming. Comparing actual El Nino/La Nina dates with precipitation and snow water equivalent values indicate that this area generally receives more moisture during El Nino periods and less moisture during La Nina periods.

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Degree of Masters of Arts

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CHAPTER 1

INTRODUCTION

Instrumental records for the Wind River Range, Wyoming lack the length needed to appropriately conduct a study of paleo-climate. Tree-rings have been shown to be useful climate proxies that record environmental changes for a long duration of time (Gray, Fastie, Jackson, & Betancourt, 2004). This means tree-rings can extend instrumental records (Gray et al., 2004). This study utilizes tree-rings from the Wind River Range to determine past climates in this region of Wyoming and how they may have been affected by climate oscillations connected to the Pacific Ocean.

Positive and negative modes of Pacific Decadal Oscillation (PDO) and El Nino-Southern Oscillation (ENSO) have been shown to influence climate in the western United States (Gray et al., 2004; McCabe & Dettinger, 1999). These oscillations can either mean an abundance of precipitation or severe drought (Gray et al., 2004). Despite these influences from the Pacific Ocean, tree-rings have not been fully utilized in the Wind River Range to determine the connection between these oscillations and climate. I attempt to use tree-rings to determine past climate conditions and if past climates here were affected by oscillation conditions (ENSO, PDO) of the Pacific Ocean. This research will consider what type(s) of past climatic cycles can be found in a roughly 500-year series of tree-rings collected from Wyoming using dendroclimatology and spectral analysis. It will include what the reconstructed past temperature and precipitation patterns look like and how these fall in line with other reconstructions that are close to the study area.

CHAPTER 2

LITERARTURE REVIEW

2.1 Why Bother with Tree-Rings

Ideally, everything that could ever be learned about climate would have been recorded by instruments, providing a perfect record of past conditions. In reality, instrumental data can be inadequate (Gray et al., 2004). This is due to the limited amount of time instruments have been used; the whole picture of climate variability cannot have been captured by instruments (Gray et al., 2004). At best, instruments only show single and multi-year anomalies as opposed to the decadal or century scale phenomena that are needed (Gray et al., 2004). Additionally, instrumental data has the limitation of being insufficient when researching the low frequency variations that often underlie climate trends (Gray et al., 2004). Luckily, there are proxy records that can be studied to illuminate past climate conditions (Gray et al., 2004). Tree-rings are one such record.

Annual tree-rings are extremely useful for climate research as proxy records because many environmental changes are reflected in the rings of a tree (Schweingruber, 1988). The widths of these rings provide long-term evidence of certain climate factors that limit growth, such as precipitation and temperature (Gray et al., 2004). This long duration can span centuries to millennia, thus, showing climate variability on the needed decadal, centennial, or millennial time scales (Brown & Wu, 2005; Gray et al., 2004). At the same time, tree-rings can provide evidence of high and low frequency variability in climate phenomena (Gray et al., 2004). Additionally, using rings means continuous data, so gaps should not be present, and dating of climate phenomena can be easily replicable (Gray et al., 2004). The results of all of this are that studying tree-rings, also known as dendrochronology and dendroclimatology, can bring to light patterns of long term climate and vegetation variability over hundreds to thousands of years (Brown & Wu, 2005).

2.2 The Process

Physiologically speaking, growth of trees occurs in the layer known as the cambium (Bradley, 1999; Gartner, 2007; Stokes & Smiley, 1996). This is a thin layer of cells sandwiched between the xylem and the phloem layers (Bradley, 1999; Gartner, 2007; Stokes & Smiley, 1996). Growth of trees in seasonal climates are restricted to certain times of year and certain climate factors such as temperature, day length, and precipitation limit this growth (Bradley, 1999; Gartner, 2007; Stokes & Smiley, 1996). Rings are sub-divided into the earlywood, first weeks of growth, and latewood, the end of growth (Bradley, 1999; Gartner, 2007; Stokes & Smiley, 1996). Earlywood is made up of large, thin-walled cells; these cells are known as tracheids (Gartner, 2007). Latewood is made up of thick-walled, flattened tracheids (Gartner, 2007). Together they make up a years’ worth of growth.

In order to study these rings, trees are cut or cored, are surfaced to make the rings visible, and the rings are counted to establish each tree's age, and so the rings can be associated with specific years, following these steps the ring-widths are measured (Cropper, 1979; Davi, Jacoby, & Wiles, 2003; Fritts, 1991; Gartner, 2007; Jacoby, Solomina, Frank, Eremenko, & D'Arrigo, 2004; Kipfmueller, 2008; Schweingruber, 1988; Stokes & Smiley, 1996). The ring-width measurements are then standardized to remove the natural growth function of the tree and to create an index that can be used to compare trees (Bradley, 1999; Cook & Peters, 1981; Salzer & Kipfmueller, 2005). A calibration model is created using regression analysis to describe the relation among the variations in the tree-ring index and climate variations (Blasing, Duvick, & West, 1981; Bradley 1999). This model is then tested with climate data that has intentionally been left out of the calibration phase to assure accuracy; this is known as verification (Blasing et al., 1981; Bradley, 1999). The results of this process lead to a reconstruction of past climate conditions that reveal variations in climate characteristics farther back in time than instrumental data.

2.3 Difference between Ring-Widths and Latewood Density

Annual ring-widths and latewood density can both be used to study climate. In some cases widths are more suitable, and in other cases density is best. Both widths and density have been found to correlate with June, July, August, and sometimes September temperatures (Davi et al., 2003; Tuovinen, 2005). However, while it has been shown that latewood density has an almost universal positive correlation with summer temperature; it does not correlate well with precipitation (Briffa, Osborn, & Schweingruber, 2004; Schweingruber, 1988; Davi et al., 2003; Tuovinen, 2005). As well, little correlation has been found between density and temperature in colder months (Briffa et al., 2004; Tuovinen, 2005). Density correlates better with temperature than ring-widths because widths are more autocorrelated; therefore, they integrate temperature over a wider span of time than a single year (Briffa, Jones, & Schweingruber, 1992). Thus, depending on the region, widths seem to vary in how well they correlate with precipitation yet, in all cases, they do better than density (Tuovinen, 2005; Woodhouse, Pederson, & Gray, 2011). For instance, widths in Finland responded poorly with July and August precipitation yet outperformed density for precipitation correlation (Tuovinen, 2005).

Despite the precipitation handicap, latewood density has been declared to be the strongest climatological signal (Tuovinen, 2005). Yet, it appears that no article studying drought or precipitation used density, instead relying on widths alone (Brown, 2006; Brown & Wu, 2005; Gray, Betancourt, Fastie, & Jackson, 2003; Gray et al., 2004; Woodhouse & Brown, 2001; Woodhouse et al., 2011). As the study area in this study is surrounded by drought and other precipitation studies, widths alone will be used.

2.4 Trees and Climate near Wyoming

Figure 2.4 is a map showing where the previous studies are located. To keep this map simple all tree-ring sites were not included. If a study had multiple locations in one state then only one location was picked as representative. The star shows the Wind River Range study area, it can be seen that no other studies are particularly close by.

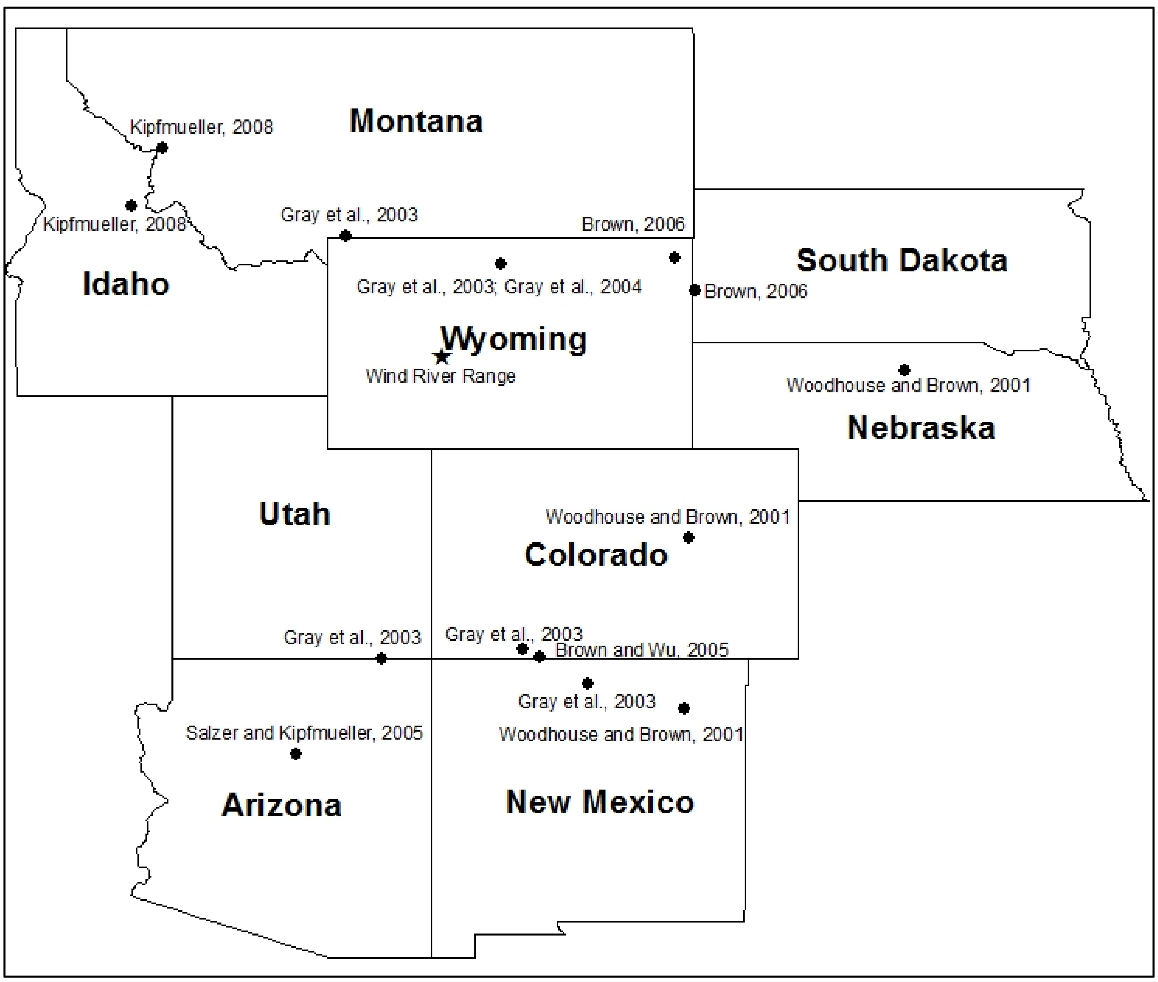


FIGURE 2.4: Locations of previous tree-ring studies applicable to the present study. If a study had multiple locations in one state then only one location is indicated.

In the Great Plains, tree chronologies extending back to the 15th century have been used to study drought (Woodhouse & Brown, 2001). Correlations with Palmer Drought Severity Index (PDSI) showed that New Mexico, Colorado, and Nebraska have the strongest and most widespread signals of drought (Woodhouse & Brown, 2001). The reconstruction for Colorado correlated best with 62% of the PDSI variance (Woodhouse & Brown, 2001).

Gray et al. (2003) used wavelet analysis to analyze ring-width measurements at multi-decadal timespans (>30-70 years) in Montana, Wyoming, Utah, Colorado, and New Mexico. They found significant multi-decadal periodicities in precipitation, especially significant were >40 year periods (Gray et al., 2003). In the Bighorn Basin (Wyoming), and the Southeast Rocky Mountains, an alternating pattern of dry and wet events occur from the 1500s to the 1850s at 30 to 60 year frequencies (Gray et al., 2003).

Gray et al. (2004) reconstructed annual precipitation in the Bighorn Basin, Wyoming from 1260 to 1998 A.D. The results were that the 20th century contained 2 of the 37 worst droughts in the past 750 years and 18 total drought years when the rest of the centuries contained 21-29 drought years (Gray et al., 2004). They also found a negative correlation with Pacific conditions; that is, dry events coincided with La Nina while wet events coincided with El Nino (Gray et al., 2004). This finding agrees with how the west normally appears to respond to ENSO forcing (Gray et al., 2004). Conditions in the north Pacific were found to have little impact on precipitation (Gray et al., 2004). Additionally, instrumental records were shown to underestimate the severity of droughts (Gray et al., 2004).

On the southern Colorado Plateau, dendroclimatology reconstructions of temperature and precipitation were used to show climate events on millennial timescales (Salzer & Kipfmueller, 2005). Thirty-five extreme dry periods and 30 extreme wet periods ranging from 5 to 26 years were discovered (Salzer & Kipfmueller, 2005). Also found were 10 cool/dry, 11 cool/wet, 12 warm/dry, and 7 warm/wet intervals greater than one year (Salzer & Kipfmueller, 2005). As well, the latter half of the 20th century was the warmest time period on record (Salzer & Kipfmueller, 2005). This presents the possibility of temperature increases outside the natural range of variability, indicating anthropogenic causes for climate warming (Salzer & Kipfmueller, 2005).

Brown and Wu (2005) compared chronologies from southwestern Colorado with various records and, specifically, two El-Nino-Southern Oscillation (ENSO) indices to study fire frequencies (Brown & Wu, 2005). The indices they used for ENSO were the primary Southern Oscillation Index (SOI) and Nino3 sea-surface temperature (SST) (Brown & Wu, 2005). SOI is the difference of surface air pressure between Tahiti and Darwin, Australia and Nino3 SST is the average temperature of the sea-surface from tropical recording stations in the Pacific (Brown & Wu, 2005). The results indicated that fire years (dry years) were associated with La Nina years (Brown & Wu, 2005). This is because La Nina is thought to bring more favorable (dry) climate conditions for burning (Brown & Wu, 2005).

In the Black Hills of South Dakota and Wyoming, chronologies have been compared with the record of regional fire years (Brown, 2006). The results show that fire years are associated with La Nina and cool phases of Pacific Decadal Oscillation (PDO; Brown, 2006). Interestingly, warm phases of Atlantic Multi-decadal Oscillation seem to add to the dryness by contributing to dry conditions created by La Nina and cool phases of PDO (Brown 2006).

In the northern Rockies, Kipfmueller (2008) used ring-widths to reconstruct past temperature and precipitation. The reconstruction was then compared with other proxy records with the results showing that decadal-scale variations in temperature were more significant than inter- annual changes or extremes in temperature (Kipfmueller, 2008). He concluded that the reconstruction show similarities with other northern hemisphere reconstructions, but also revealed the importance of local-scale variability (Kipfmueller, 2008).

2.5 Climate Oscillations in the Western United States

In the western United States, most studies suggest that variations in precipitation at inter-annual and decadal timespans are influenced by what occurs in the Pacific basin due to the relationship between El-Nino Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO; Gray et al., 2004). ENSO occurs at frequencies anywhere from around 2 to 7 years and is understood to be an atmospheric/oceanic feature in the Pacific Ocean near the equator (An & Wang, 2000; Brown, 2006). PDO has a frequency greater than 10 years, most prominent at the 15 to 25 year frequency, and is an index of warm and cool anomalies in sea surface temperatures in the North Pacific Basin (Brown, 2006).

Moisture events at greater than 10-year frequencies in the Central Rockies have been linked to both positive and negative modes of PDO (Gray et al., 2004). These links are not well-understood, only results from the lower elevations (below ~ 2500m, ~8500ft), such as Bighorn Basin, Wyoming, have been studied (Gray et al., 2004). Also, it has been noted that the effects of ENSO are more prominent during the winter than in the summer (Gray et al., 2004). This shows a weakness in our understanding of the tele-connection between the oceans and the interior that suggests the presence of a complex relationship between the Pacific and Atlantic oceans with interior North America (Gray et al., 2004).

In earlier work Gray et al. (2003), indicate that most change in sea-surface temperature occurs on the decadal (~15-25 years) timespan. This is associated with the strength and position of the Aleutian Low during winter (Gray et al., 2003). The variation is known as PDO and is linked to anomalies in U.S. winter precipitation and low frequency changes in sea-surface temperature, affecting summer rain, especially in the Great Plains (Gray et al., 2003). In the central and southern Rockies, the positive/warm phase of PDO is linked with greater precipitation during all seasons (Gray et al., 2003). Furthermore, conditions in the North Atlantic Ocean could affect climate conditions (Gray et al., 2003). Wind anomalies attributed to the Arctic Oscillation and changing sea-surface temperatures in the North Atlantic show a 65-80 year cycle named the Atlantic Multi-decadal Oscillation (AMO; Brown, 2006; Gray et al., 2003). During the warm phase of the Atlantic Multi-decadal Oscillation, the central and southern Rockies receive less summer rainfall (Gray et al., 2003). This means a cold phase PDO coupled with a warm phase AMO can result in severe droughts (Gray et al., 2003).

While tree rings have been used to study climate in the western United States and in Wyoming, none have studied in the Wind River Range. It was found by Brown, 2006, Brown & Wu, 2005, Gray et al., 2003, and Gray et al., 2004 that dry conditions were associated with La Nina and wet conditions were associated with El Nino, but the response has not been studied in the Wind River Range to see if it fits this paradigm. This study attempts to fill this gap in knowledge and illuminate what trees can reveal about climate variability in the mountains of central Wyoming.

2.6 Wind River Range

The mountains that make up the Wind River Range are oriented NW-to-SE, and reach elevations over 4200m (13,800ft; Dunwiddie, 1977; Fall 1994; Reed 1976). The climate is continental, characterized by low mean annual precipitation and large disparities in temperature (Fall, 1994). The range receives about 130-150cm (51-59in) of annual precipitation, roughly 65% of this precipitation is snow (Dunwiddie, 1977; Fall, 1994).

There seems to be some debate on the precipitation pattern. Precipitation is described as being roughly the same all year with a max in late spring/early summer, specifically in May and June (Dunwiddie, 1977; Fall, 1994). However, Reed (1976) states that on the western side of the range precipitation is even, for the most part, throughout the year with a little less in summer. On the eastern side, precipitation is uneven throughout the year with a peak in May and very low precipitation during winter (Reed, 1976). In winter, snow is from the Pacific and Arctic air masses which would explain why there is a better correlation with ENSO during the winter (Fall, 1994). Summer is dry due to the interior air masses (Fall, 1994).

The closest town to the study site is Lander, Wyoming. The elevation is roughly 1600m (5500ft; Google Maps, 2014). On average, the warmest month is July (30.5°C, 87°F) and the coolest is December (0°C, 32°F; The Weather Channel, 2012). The maximum average precipitation occurs in May (5.6cm, 2.20in) with the lowest in January (1.04cm, .41 in; The Weather Channel, 2012).

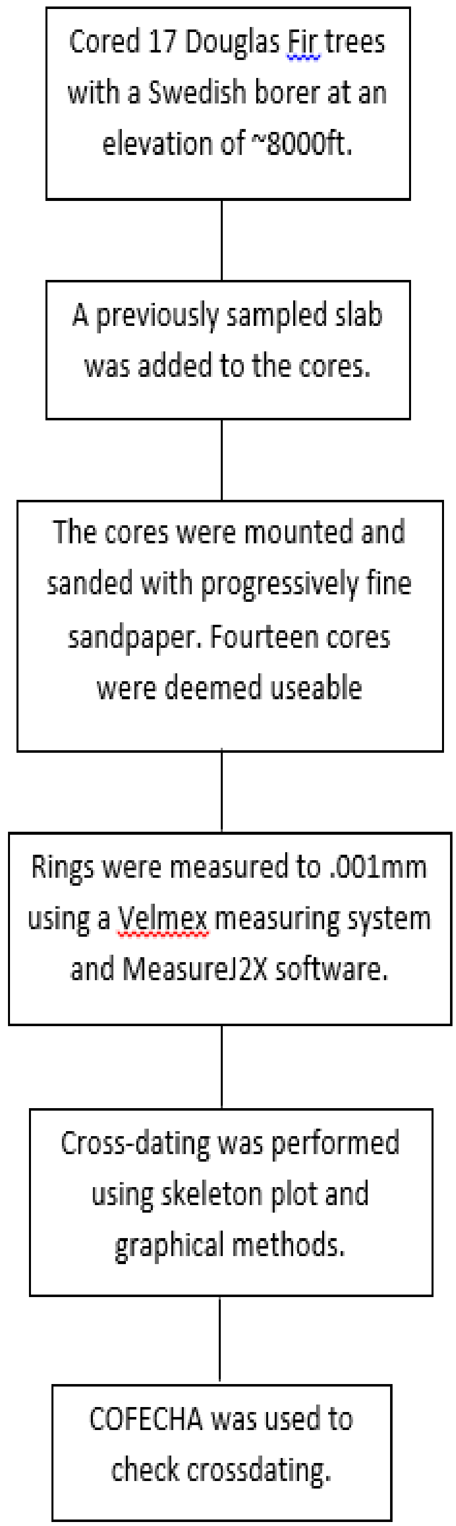
The forest is confined to a belt that is about 2500-3100m (8200-10,300ft) in elevation (Fall, 1994). The tree makeup is Aspen, Subalpine Fir, Douglas Fir, Lodgepole Pine, Engelmann Spruce, and Whitebark Pine (Dunwiddie, 1977; Fall, 1994; Reed 1976).

CHAPTER 3

METHODS

3.1 Chronology Development

Figure 3.1 is a flowchart mapping out the methods used. From June 22-29, 2013, 17 trees were cored on the southeastern bank of the Wind River Range, southwest of Lander, Wyoming above Sinks Canyon State Park at an elevation of about 8000ft. That elevation was chosen because the most appropriate trees for dendroclimatology studies grow on the edge of ecological zones, such as montane zones where trees are most stressed, and therefore, the most responsive to climate variations (Bradley, 1999; Davi et al., 2003; Salzer & Kipfmueller, 2005). At 2500m (8000ft), trees are typically stressed enough to show variability in ring growth. An aerial photograph and topographic map of the study site is shown in Figures 3.1.2. The field site is a mountainous area good for this type of study because trees should be cored from rocky hillsides and steep slopes as those environments produce maximum ring variability (Stokes & Smiley, 1996). Furthermore, there are some very large trees in this area which could be used to obtain the largest record possible. All trees cored were Douglas Fir. Douglas Fir was chosen for two reasons: first, Douglas Fir are conifers which are typically used because they dominate montane areas and the tissue makeup leads to rings that are easier to read (Gartner, 2007). Second, Douglas Fir is one of the four most commonly used tree species for dendroclimatology; the other three are Oak, Pine, and Sequoia (Walker, 2005).



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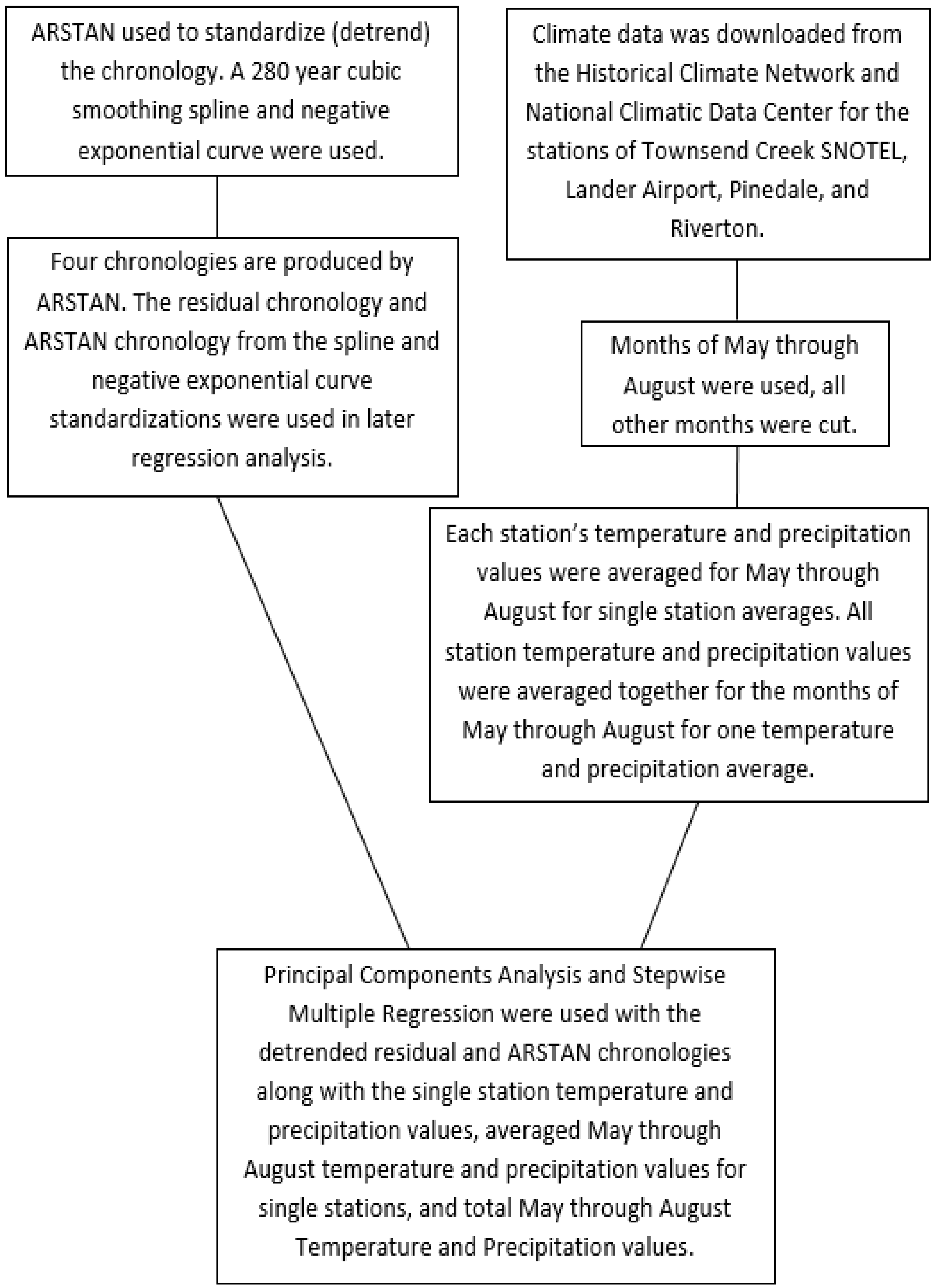

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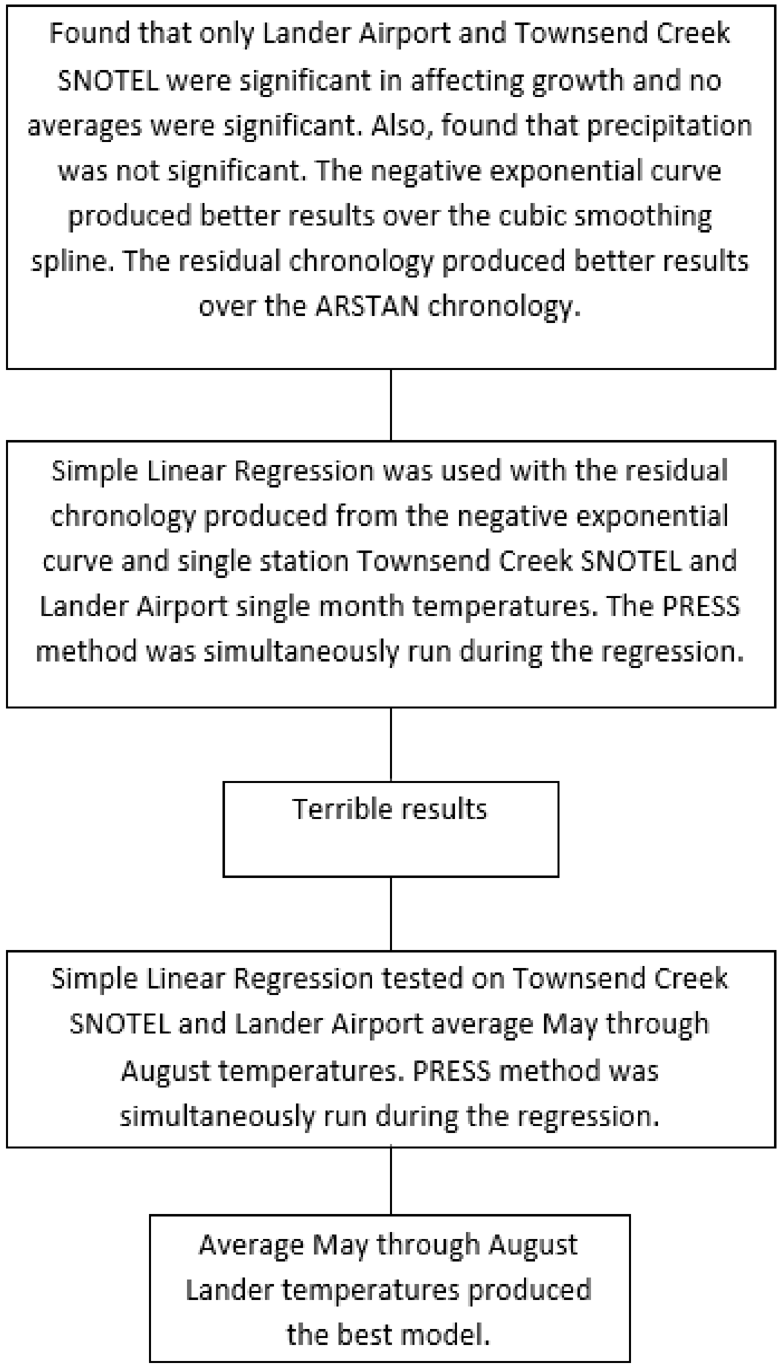

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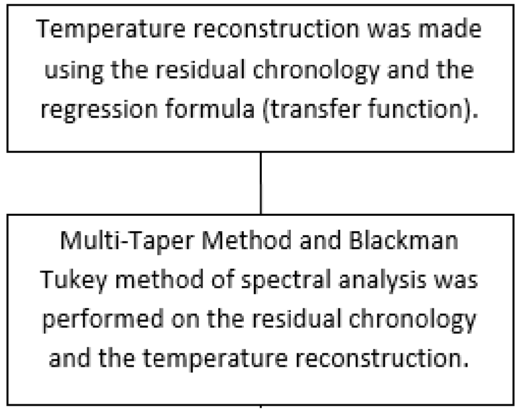


FIGURE 3.1.1: Flowchart of the methods used.

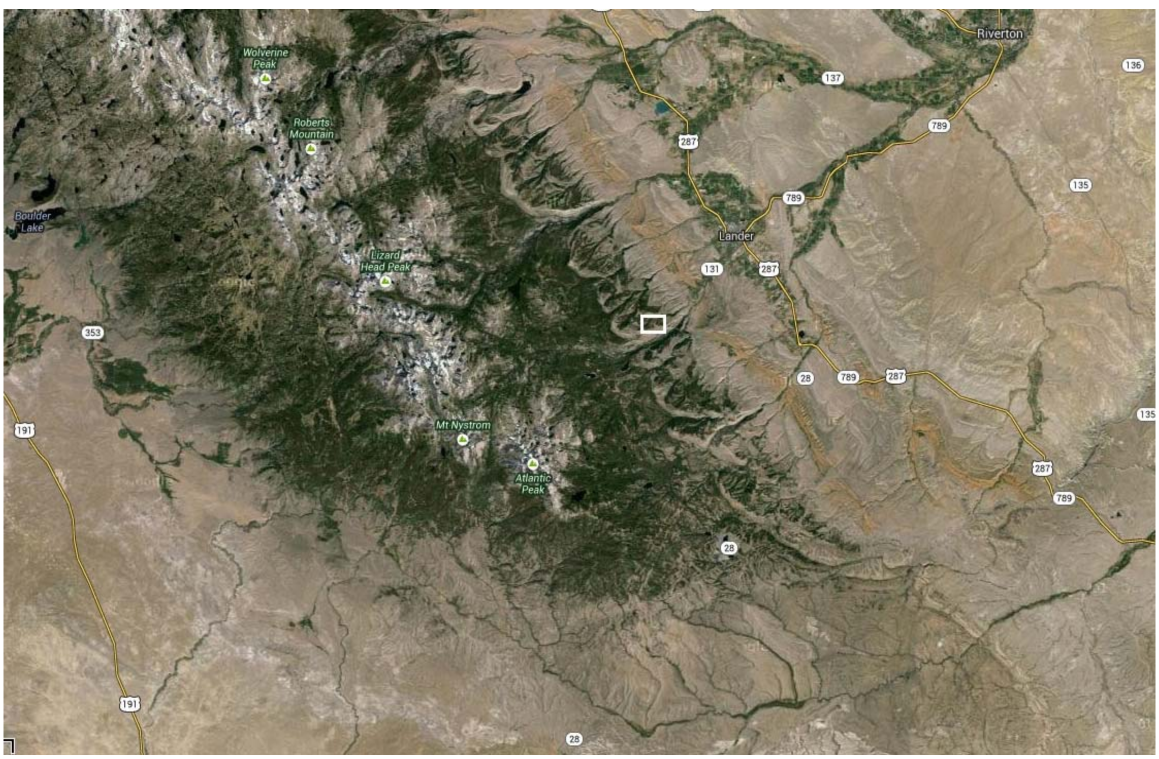


FIGURE 3.1.2: Aerial photograph of the study area used in the Wind River Range, Wyoming showing the tree-stand used. The image was obtained from Google Maps. The white box represents to rough area where trees were cored and is located approximately 12km (~7.5mi) from Lander Wyoming.

Coring was done with a 5mm Swedish borer at chest height and parallel to the contour of the slope (side slope; Davi et al., 2003; Jacoby et al., 2004; Kipfmueller, 2008; Schweingruber, 1988; Speer, 2010). Both live and dead trees were sampled. Cores were stored in straws and shipped back to Cedar Falls, Iowa. Seventeen trees were cored twice at 180° and another tree slab was added that had been previously sampled. In the lab, the cores were removed from the straws, glued to mounts, and sanded with progressively fine sand paper to make the rings visible (Fritts, 1991; Schweingruber 1988; Stokes & Smiley, 1996). Ultimately, only fourteen cores were deemed useable. The other cores showed knots in the wood which deformed the rings or the cores were too broken; a result of difficulties during coring, getting the cores into straws, and getting the cores out of straws.

The rings were measured using a Velmex measuring system and MeasureJ2X software at a resolution of 0.001mm which provided the accuracy needed to measure ring-widths. The MeasureJ2X software was used because it puts the ring measurements into a format that is useable for the COFECHA and ARSTAN computer programs (Speer, 2010).

Cross-dating was performed using both the skeleton plot and graphical methods (Cropper, 1979; Gartner, 2007; Schweingruber, 1988; Stokes & Smiley, 1996). Both methods mark pointer years, which are single years, and signatures, which are groups of two to three years, that have a small amount of growth (Cropper, 1979; Gartner, 2007;

Schweingruber, 1988; Stokes & Smiley, 1996). For skeleton plots, a piece of paper is placed under the core and a ring is compared with its neighbors: a line is drawn for narrow rings (Gartner, 2007; Schweingruber, 1988; Speer, 2010; Stokes & Smiley, 1996). The length of this line is subjective and depends on the researcher's interpretation of how narrow the ring is; the narrower the ring, the longer the line (Gartner, 2007; Schweingruber, 1988; Stokes & Smiley, 1996). The various plots are then lined up with one another to make a composite plot (Figure 3.1.3; Schweingruber, 1988; Stokes & Smiley, 1996).

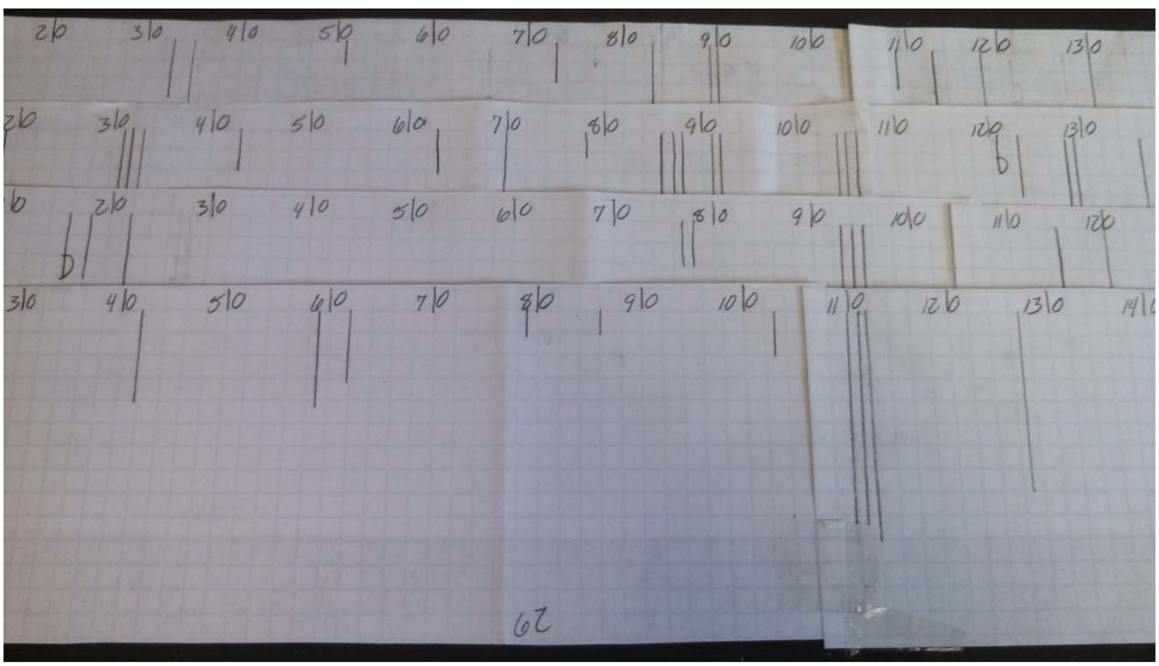


Figure 3.1.3: Example of a composite plot using the skeleton plot method.

For the graphical method, measurements of rings are graphed and then aligned visually (Schweingruber, 1988). These composite plots are then compared with a master chronology that allows for dates to be attributed to the rings (Cropper, 1979; Gartner, 2007; Schweingruber, 1988; Stokes & Smiley, 1996). In this study, both methods were used to bolster the accuracy of dating as accurate dates are needed in order to compare the rings with climate events (Speer, 2010).

COFECHA was used to check the cross-dating. COFECHA is a quality-control program that checks the accuracy of dating by comparing individual ring-widths with the master chronology of the measurements and provides the statistical match between individual cores and this master chronology (Gray et al., 2004; Speer, 2010).

Trees in open canopy locations put on naturally wide rings during their early-growth years. Overtime, the ring-widths decrease until an average level of growth is reached (Cook & Peters, 1981). These ‘anomalous’ early ring-widths must be removed from the ring series in a process known as standardization or “detrending” (Bradley, 1999; Cook & Peters, 1981; Salzer & Kipfmueller, 2005). The ARSTAN (AutoRegressive Standardization) program performs this standardization (Cook & Peters, 1981). As well as taking out the natural growth function of a tree, standardization also makes the ring-widths from different trees comparable (Bradley, 1999; Salzer & Kipfmueller, 2005). ARSTAN fits a curve to the ring-width measurements and then divides the measured width values by the expected value on the curve for each core, creating an index

(Bradley 1999; Salzer & Kipfmueller, 2005; Speer, 2010). ARSTAN then averages all the tree-ring indices to produce a stand-level chronology (Bradley 1999; Salzer & Kipfmueller, 2005; Speer, 2010).

During this study, a negative exponential curve and a 280-year cubic smoothing spline were used for standardization. The negative exponential curve was found to give better results in later regression analysis over the cubic smoothing spline. The negative exponential curve is the most conservative and probably the most widely used curve (Gray et al., 2003; Gray et al., 2004; Salzer & Kipfmueller, 2005; Speer, 2010; Tuovinen, 2005; Woodhouse & Brown, 2001). The negative exponential curve is deterministic, instead of data adaptive, so the amount of natural growth removed from each core is the same (Kipfmueller, 2008; Speer, 2010).

ARSTAN produces four chronologies for use:

- The raw chronology is the average of the raw ring-widths with no standardization being performed (Speer, 2010).
- The standard chronology is produced using the chosen standardization curve; all autocorrelation present is in this chronology, which could result in issues when running later regression analysis as regression relies on the assumption that no autocorrelation is present (Cook & Holmes, 1986; Speer, 2010).
- The residual chronology is the standard chronology with autocorrelation removed; this makes the chronology better for regression analysis, but reduces

sensitivity to climate signals because some climate signals may also be removed with the autocorrelation (Cook & Holmes, 1986; Speer, 2010).

- The ARSTAN chronology removes autocorrelation, models it, and then reintroduces the stand-level autocorrelation back to the chronology; therefore, this chronology should have the strongest climate signal (Cook & Holmes, 1986; Speer, 2010).

Theoretically, the ARSTAN chronology should have resulted in the best correlation to the instrumental climate data as individual tree autocorrelation is removed from the chronology and stand level autocorrelation (which should be a climate signal) is reintroduced (Speer, 2010). However, it was found that the residual chronology produced better correlations with the instrumental data and, thus, it was used to make the temperature reconstruction.

3.2 Climate Data

Climate data was obtained from the Historical Climate Network and National Climatic Data Center for the climate stations of Townsend Creek SNOTEL (snow telemetry; 1981-2013 for summer precipitation and winter snow water equivalent (SWE; 1990-2013 for temperatures), Lander Airport (1948-2013 for summer temperature and precipitation), Pinedale (1899-2012 for summer temperature and precipitation), and Riverton (1899-2012 for summer temperature and precipitation), Wyoming. Climate stations in this area are sparse and cover a short length of time.

Therefore, average temperature and precipitation values of all stations were calculated only for the months of May through August in an attempt to extend the instrumental record and to use data covering more than one station (Blasing et al., 1981; Kipfmueller, 2008). This strategy is assumed to increase correlation with tree rings as averages encompass more climate conditions than the localized climate at single stations (Blasing et al., 1981; Kipfmueller, 2008). The months of May through August were used as this is considered to be the growing season in this region as climate conditions during these months should have the most impact on growth (Kipfmueller, 2008). Both single month temperature, precipitation, and snow water equivalent values and the single station May through August averages along with total May through August temperature and precipitation average of all stations were used in the regression analysis to discern what affects ring growth.

3.3 Methods for Reconstructing Climate

Principal Components Analysis (PCA) and Stepwise Multiple Regression were used to explore the relationships between the detrended chronologies and climate data. PCA is the transformation of predictors (station data) to a set of orthogonal (uncorrelated) eigenvectors (Bradley, 1999; Briffa et al., 1992). The eigenvectors, in essence, are a variable that expresses part of the variance (Bradley, 1999).

Stepwise multiple regression examines a matrix of predictors and determines those that explain the most variance in descending order of significance (Bradley, 1999).

The number of predictors is set when the inclusion of additional variables does not add significant variance explanation (Bradley, 1999). Similar methods were used in Briffa et al. (1992), Gray et al. (2004), Kipfmueller, (2008), Salzer and Kipfmueller, (2005), and Woodhouse and Brown, (2001).

Simple linear regression was used in the final climate reconstruction to create a “transfer function” that connects the ring-width data with the past “unknown” climate data (temperature and precipitation; Blasing et al., 1981; Bradley, 1999; Gray et al. 2004). Simple linear regression determines a single climate variable, y, from width indices at a single site, x (Blasing et al., 1981, Bradley, 1999). Hence, it allows for the development of a reconstruction model with one climatic variable and is the easiest of the regressions to run (Blasing et al., 1981; Speer, 2010). Verification of the model was done using the Predicted Residual Sum of Squares (PRESS) method (Kipfmueller, 2008; Salzer & Kipfmueller, 2005). The PRESS method is a “leave-one-out” cross validation procedure where a model is fit leaving a year’s worth of observations out (Kipfmueller, 2008). The model then predicts the omitted observation and repeats this process for every year (Kipfmueller, 2008). This method of verification was used over the split samples method. The split samples method separates the data set into a calibration dataset and a verification dataset (Speer, 2010). Both datasets are then run through separate regression analysis and the results are compared (Speer, 2010). If both datasets produce similar results then they are recombined to form the final calibration model (Speer, 2010). The instrumental data was too short to perform split samples since the longest time covered by both the tree-rings and instruments was from 1948-2013 (65 years).

Finally, the full reconstruction was made for the timespan of the ring-width dataset by using the transfer function (regression formula) with the detrended residual chronology (Kipfmueller, 2008). This extended the reconstructed temperatures back to 1589. The reconstruction was extended back that far despite very low sample depth. The sample depth is the number of cores for each year in the chronology (Speer, 2010). Generally, a sample depth of greater than 10 is needed in order to accurately compare the ring-widths to climate (Speer, 2010). The sample depth was 10 trees at 1775 and less than 5 trees before 1649. In order to maximize the length of the reconstruction, there was no choice but to continue with the reconstruction before 1775. This low sample depth explains the relatively large variability seen in the earliest years of the reconstruction (Figure 4.4.1).

3.4 Climate Analysis

The final analysis performed was spectral analysis on both the detrended chronology and the temperature reconstruction. The Multi-Taper Method (MTM) and Blackman-Tukey (B-T) method were both used and were performed using two different computer programs, Kspecta and Analyseries (Blackman & Tukey, 1958; Paillard, Labeyrie, & Yiou, 1996). Both the MTM and B-T methods are commonly used for signal processing to determine the significant frequencies of events in annual data by separating the signals from the noise (Blackman & Tukey, 1958; Gray et al., 2003; Imbrie, McIntyre, & Mix, 1989; Mann & Lees, 1996; Schultz & Stattegger, 1997; Thomson, 1982). The analyses were performed to see if climate oscillations of known intervals, such as ENSO at 2 to 7 years or PDO at 15-25 years, might appear to influence the chronology and the reconstruction.

CHAPTER 4

RESULTS

4.1 Overview of Results

In this chapter, chronology statistics will be presented from the COFECHA output (Table 4.2). The regression output for the calibration model along with verification statistics will be reviewed (Table 4.3). Figure 4.4.1 presents the temperature reconstruction and Figures 4.4.2 through 4.4.5 present various comparisons of the temperature reconstruction to the instrumental temperatures. Basic temperature statistics are presented in Table 4.4. Lastly, the results from spectral analysis are presented and discussed (Figures 4.5A-4.5D).

4.2 COFECHA Results

The timespan covered by the tree-ring chronology is 425 years, from 1589 to 2013 (Table 4.1). The average length of time that is covered by all cores is 288 years. Series intercorrelation shows the stand-level signal in the chronology. Mean sensitivity shows year-to-year variability in width. The COFECHA program results show a series intercorrelation of 0.022 with an average of the mean sensitivities being 0.273. This means that the chronology has virtually no series intercorrelation but the rings are sensitive enough to show variability.

TABLE 4.2

COFECHA Output showing the statistics for the 14 cores used in the final chronology.

Number of Cores (Series)	14
Time Span (AD)	1589-2013
Number of Years	425
Mean Length of Series	287.9
Total Rings in all Series	4031
Total Dated Rings Checked	4019
Series Intercorrelation	0.022
Average Mean Sensitivity	0.273

4.3 Regression Results

During the exploratory Principal Components Analysis (PCA) and the stepwise multiple regression analysis, the significant correlations (p-values less than .15 show significant correlations, p-values greater than .15 show no significant correlation) found with the detrended chronology were with temperatures. No precipitation correlations were found to be significant and no averages were shown to be significant. It was also found that only two of the four climate stations any showed significance for affecting tree growth; these stations were Lander Airport and the Townsend Creek SNOTEL. Townsend Creek SNOTEL is approximately 11km (~7mi) southwest of the study site and Lander Airport approximately 12km (~7.5mi) northeast of the study site. Unfortunately, those stations had the shortest records, 1948-2013 for the Lander airport and 1990-2013 for the Townsend Creek SNOTEL.

Simple linear regression was then used with the single-month temperature data from both Lander airport and Townsend Creek SNOTEL. The results were not satisfactory as no model exceeded an r-square of 0.10. In an attempt to gain a better calibration model, the May-through-August temperature averages with the detrended chronology. The average May-through-August temperatures from the Lander airport climate station produced the best fit model. Table 4.3 presents the summary statistics for the calibration and verification process and the full output is in Appendix B. The average May-through-August temperatures show a negative sloped with tree growth; however, the temperatures are considered to be “very strongly” significant in explaining ring growth. This means that with every one degree increase in temperatures, the growth decreases by 0.0204mm. The correlation is 0.172 and the model failed the Durbin-Watson test meaning some autocorrelation remains in the model even after detrending (Kipfmueller, 2008). However, it is worth noting that the Durbin-Watson value of 1.411 just missed the pass/fail cutoff of 1.5 and the model passed tests for normality and constant variance, so the other regression assumptions held true.

TABLE 4.3

Summary table of the calibration and verification statistics for the climate reconstruction for Average May-August Temperature from the Lander Airport Climate station.

Variable	Average Lander Temperatures
Intercept	2.252
Slope	-0.0204
N	66
P-Value	<.001
Rsqr	0.172
Adj Rsqr	0.159
Stadard Error of Estimate	0.084
PRESS	0.488
Durbin-Watson Statistic	1.411 Failed
Normality Test	.706 Passed
Constant Variance	.083 Passed

4.4 The Climate Reconstruction

Figure 4.4.1 shows the temperature reconstruction for western Wyoming near Lander, based on the record of tree-ring-widths. The reconstruction is relatively uniform from the year 2013 back to around 1740, where the reconstruction becomes more chaotic. This change is caused by the low sample depth in the earliest years of the reconstruction. There were not enough (only 9) cores to average the variability in the ring-widths before 1775, thus, the chaotic nature in the earlier years of the reconstruction is reflecting the chaotic variability in those few cores.

In order to judge the accuracy of this reconstruction, Figure 4.4.2 was constructed to compare the recorded instrumental temperatures with the reconstructed temperature for the time period common to both records. Additionally, Figures 4.4.3 and 4.4.4 represent the first and second derivatives of the reconstructed versus actual temperatures. The derivation f(x) can be defined as the tangential slope across the entire range of x. By fitting a curve to the actual and reconstructed data, the values in Figure 4.4.3 were extracted and plotted as a way of normalizing the data to compare the direction of temperature change and remove absolute values. The second derivative is the rate of local change of the slope of the first derivative. Those results are shown on Figure 4.4.4 and provide a comparison of the relative degree to which the reconstructed temperatures moved in the same direction as the slope of the actual temperatures. The derivatives better show the pattern of the data, highlighting the overall match in trends between the reconstructed temperatures and actual temperatures. These derivatives remove the absolute temperature values and create a type of normalization to better highlight the changes. Figures 4.4.2, 4.4.3, and 4.4.4 have a different timespan than Figure 4.4.1 because the instrumental temperature record only goes back to 1948.

It can be seen that there are agreements and disagreements between the reconstructed and actual temperature (Figures 4.4.2-4.4.4). The figures show that the reconstruction follows the overall trend in actual temperatures since both have roughly the same peaks and troughs.

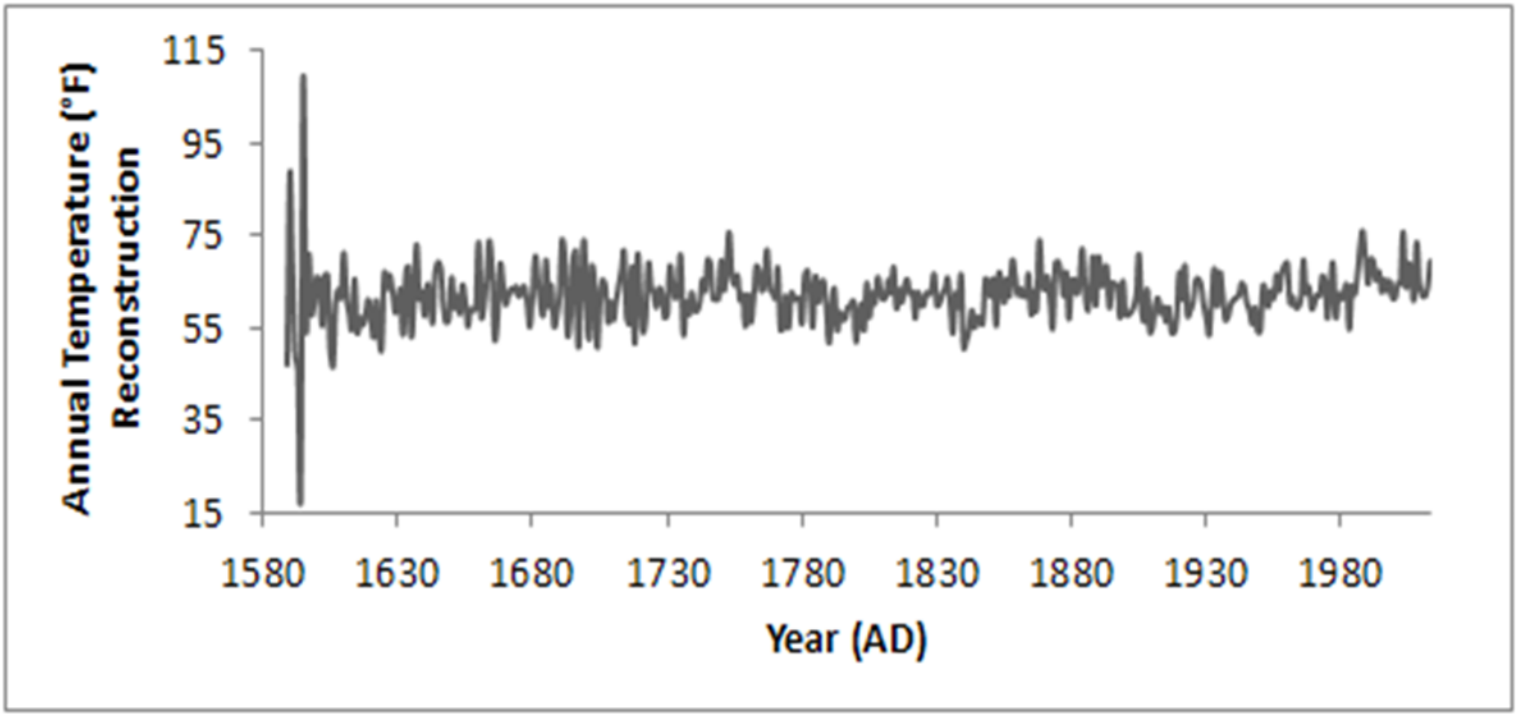


Figure 4.4.1: Reconstructed annual temperatures from 1589-2013 using the tree-rings.

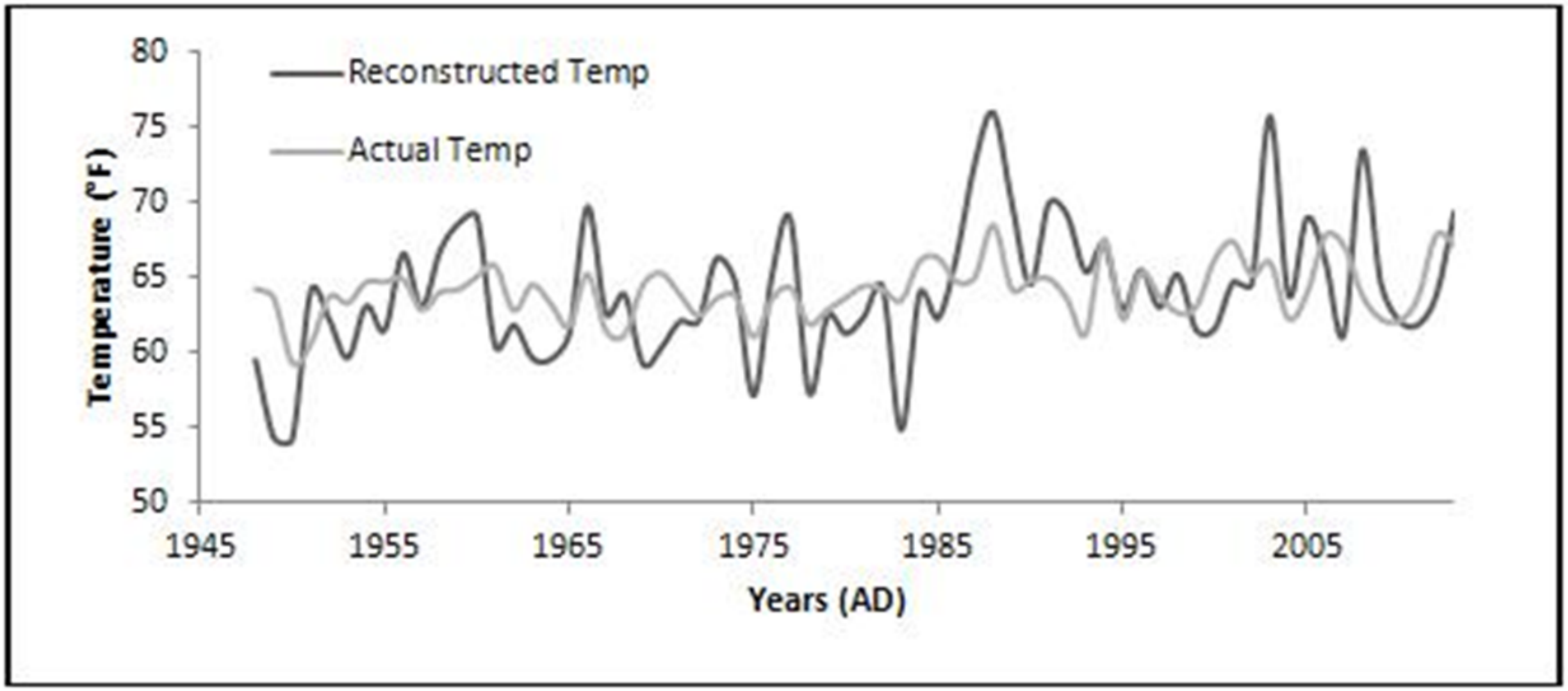


Figure 4.4.2: Instrumental temperatures overlaid on the reconstructed temperatures.

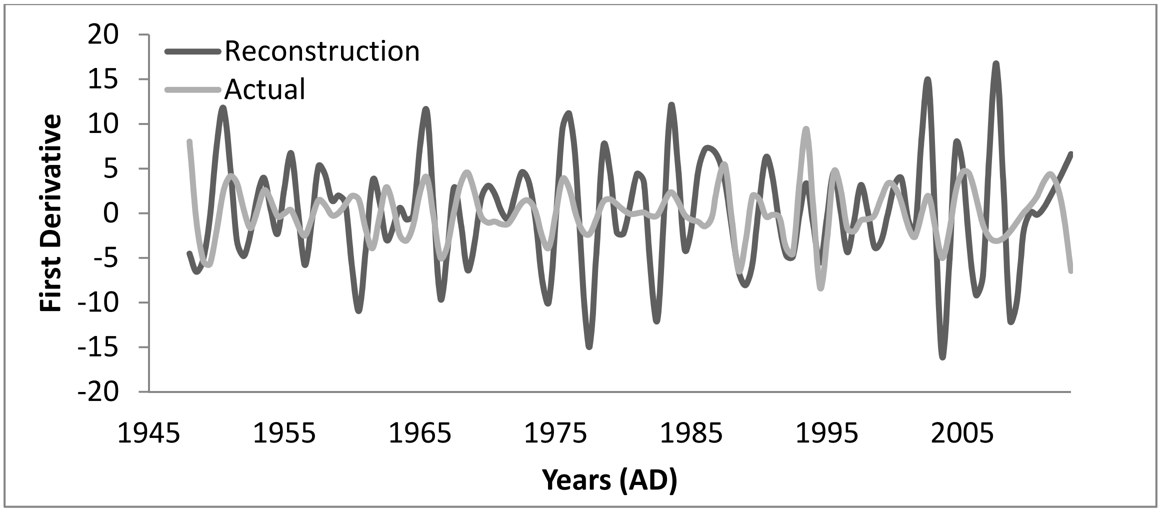


Figure 4.4.3: The first derivative from the reconstructed and instrumental temperatures.

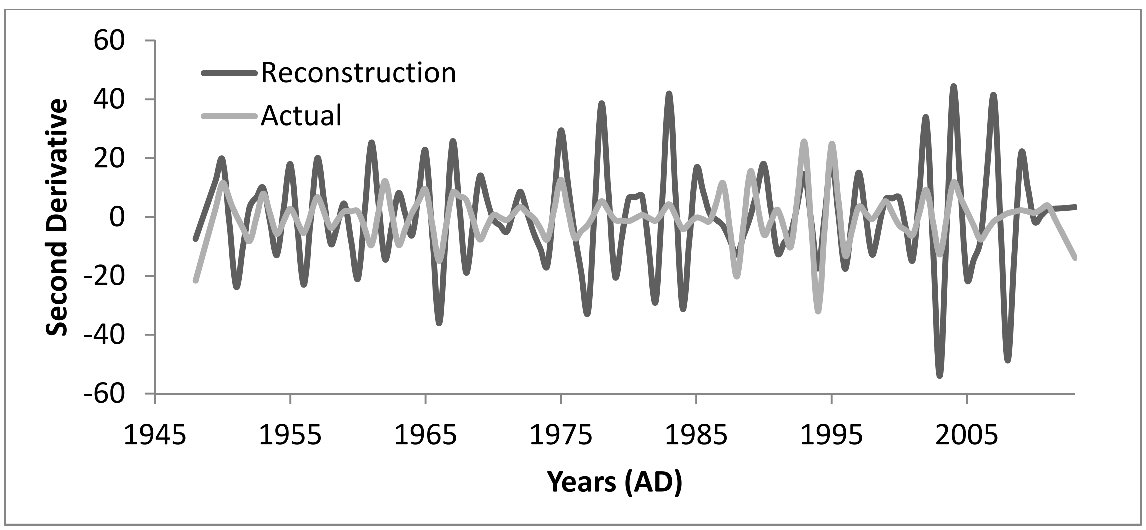


Figure 4.4.4: The second derivative from the reconstructed and instrumental temperatures.

Figure 4.4.5 better reveals how well the reconstructed temperatures and actual temperatures compare. In this graph, a line shows that the relative temperature trend matched between the actual and reconstructed temperatures. If both temperatures were increasing or decreasing together, a line is shown. No line means the temperatures moved in opposite directions. The length of the line indicates how close the reconstructed temperatures corresponded to the actual temperatures: the shorter the line the closer the correspondence.

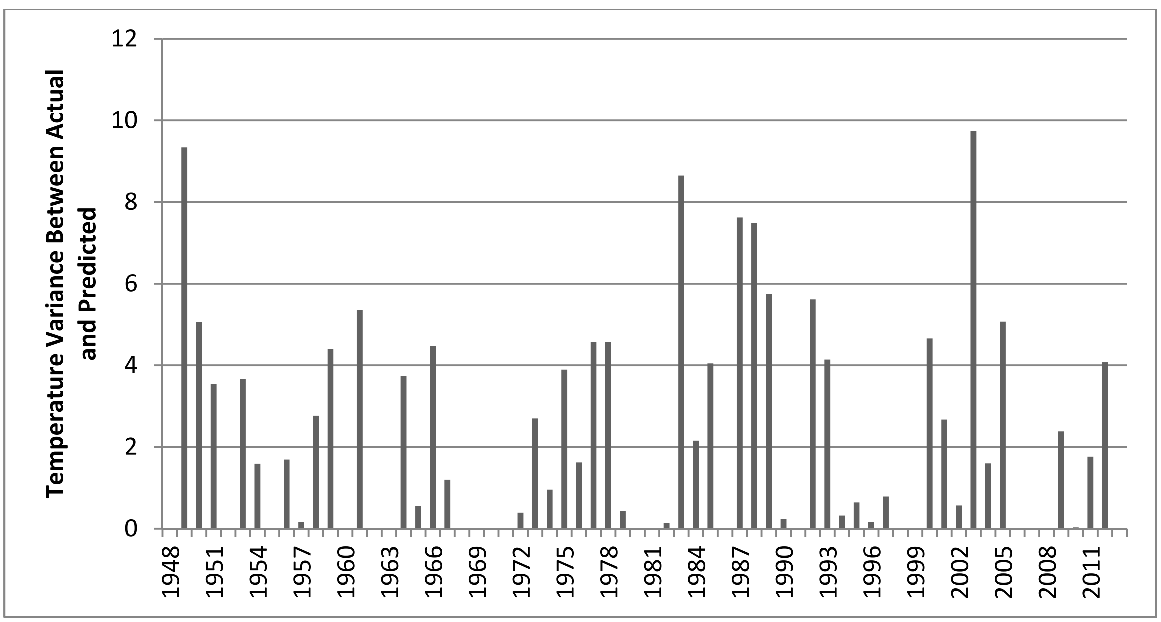


Figure 4.4.5: Chart showing the slopes in the reconstruction that match the slope in the actual temperatures. The match is 70%.

Figure 4.4.5 reveals that the reconstruction aligns most closely in the mid-1990s. While actual values are less closely aligned, the slopes trend together in the late 1940s to early 1950s, mid- 1950s, mid-1960s, the 1970s, early and late 1980s, and the early to mid-2000s. The only timespans that show significant disagreement are the late 1960s, late 1990s, and mid- 2000s. Furthermore, the reconstruction predicts the change in temperature at 70% (Figure 4.4.5) which means that while actual temperature predictions may be off the relative trend is well represented. This is especially important considering average May-through-August temperatures only explained 17.2% of the variance in the tree-rings. This is because the absolute values do not match but the trend does.

Table 4.4 shows the summary statistics for the warmer and cooler time periods in the temperature reconstruction. The average temperature and median temperature are both 62°F (16.6°C). These are the same for single years and decades. The minimum temperature for a single year is 19°F (-7°C) which occurred in 1594. However, this temperature along with the temperatures from 1593, 1589, 1592, and 1606 are considered to be outliers. Since these years are all at the beginning of the reconstruction, it is probably safe to conclude that the low sample depth is mainly responsible for these extremely low reconstructed temperatures.

TABLE 4.4

Table showing basic statistics from the temperature reconstruction.

Statistic	Temperature (°F)
Single Year Average Temp.	62
Single Year Median Temp.	62
Single Year Minimum Temp.	19
Single Year Maximum Temp.	109
Decade Average Temp.	62
Decade Median Temp.	62
Decade Minimum Temp.	57
Decade Maximum Temp.	67
Century Average Temp.	62
Century Minimum Temp.	62
Century Maximum Temp.	62

The maximum single year temperature was 109°F (43°C) which corresponds to 1595, just a year after the minimum single year temperature. Once again, this temperature is an outlier and occurs at the beginning of the reconstruction where there is a low number of cores. Other outliers for maximum temperatures occurred in 1590, 1753, 1988, and 2003. The number of cores for 1988 and 2003 is fairly high so these two years are assumed to have been genuinely warm. Both temperatures were 76°F (24°C). Looking back at average Lander airport May-through-August temperatures it can be seen that 1988 was indeed the warmest year in the record with 2003 in a five way tie for the 8th warmest year. Looking at decade averages decreased the variability that single years presented. The coolest decade, with an average of 57°F (14°C) was the 1840s. The warmest decade, with an average of 67°F (19°C) was the 2000s. Unlike the single years, the decade data had no outliers and are, therefore, considered to be relatively good indicators of warm and cool temperatures.

4.5 Spectral Analysis Results

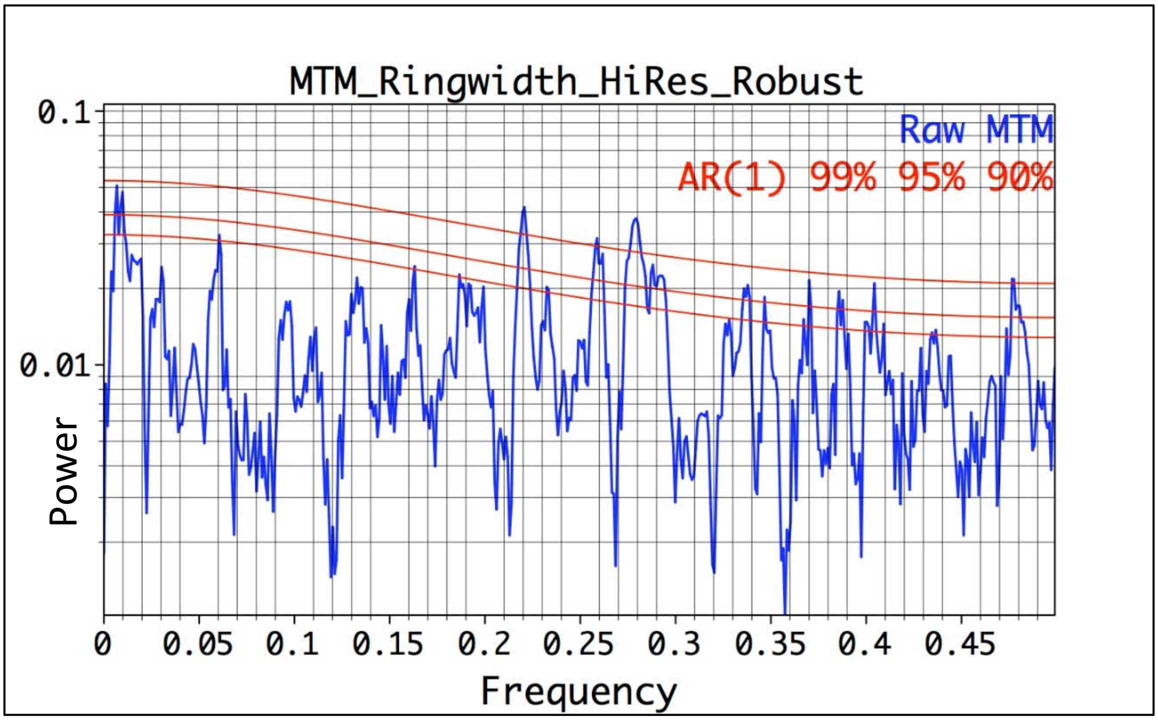
Figure 4.5A and 4.5B shows the results for both the Multi-Taper Method (MTM) and Blackman-Tukey (B-T) for spectral analysis of the detrended ring-width chronology using the Kspectra program (Blackman & Tukey, 1958; Paillard et al., 1996). The Analyseries results are included in Appendix C.

MTM analysis indicates significant (99%) frequencies are present for periods of roughly 2.5 to 4.5 years. The B-T results support the MTM results, also suggesting periods with 2-7 year significance (90%) frequencies are represented in the ring-width data. These frequencies fall in the timespan commonly associated with ENSO, suggesting the possibility of some climate tele-connection from the Pacific basin to tree growth patterns in this area of Wyoming.

Figure 4.5C and 4.5D show the results of the spectral analyses of the reconstruction for temperature. The MTM analysis results in frequencies that range between 2 to 4.5 years (99%) and show a ~16 year frequency (just under 95%). The B-T analysis results in a frequency at roughly 4.5 years (95%) and frequencies between 2 and 3.5 years and as well as a frequency at about 16 years (90% to 95%). As with the detrended chronology, these results also suggest a possible relationship climate forcing associated with ENSO. Interestingly, while present in the temperature reconstruction, the 16 year frequency associated with PDO was missing in the detrended chronology.

Lastly, there is a frequency ranging between approximately 111- 125 years in the detrended chronology and at around 160 years in the temperature reconstruction. These frequencies are between 95% and 99% significance level and show up in the MTM in the Kspectra and the Analyseries outputs, but are absent in the B-T Kspectra results. These frequencies are not attributed to any particular climate oscillation, yet the results indicate tree growth may be influenced by other unknown factors operating at these frequencies.

A.



B.

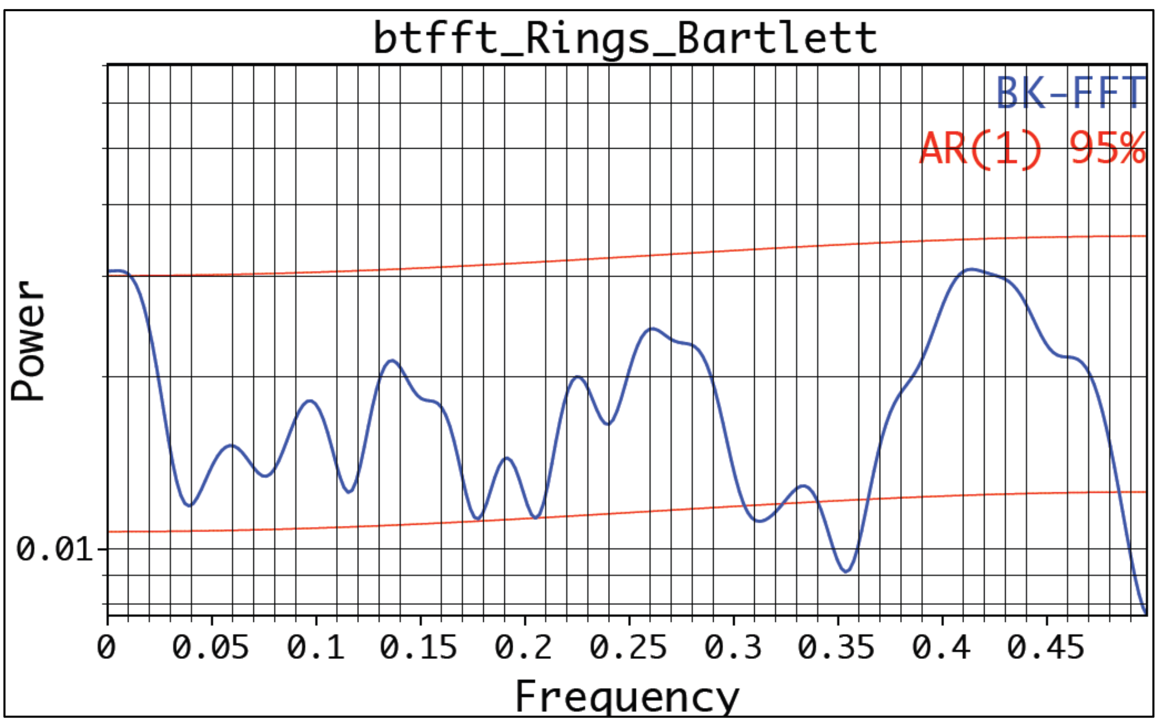
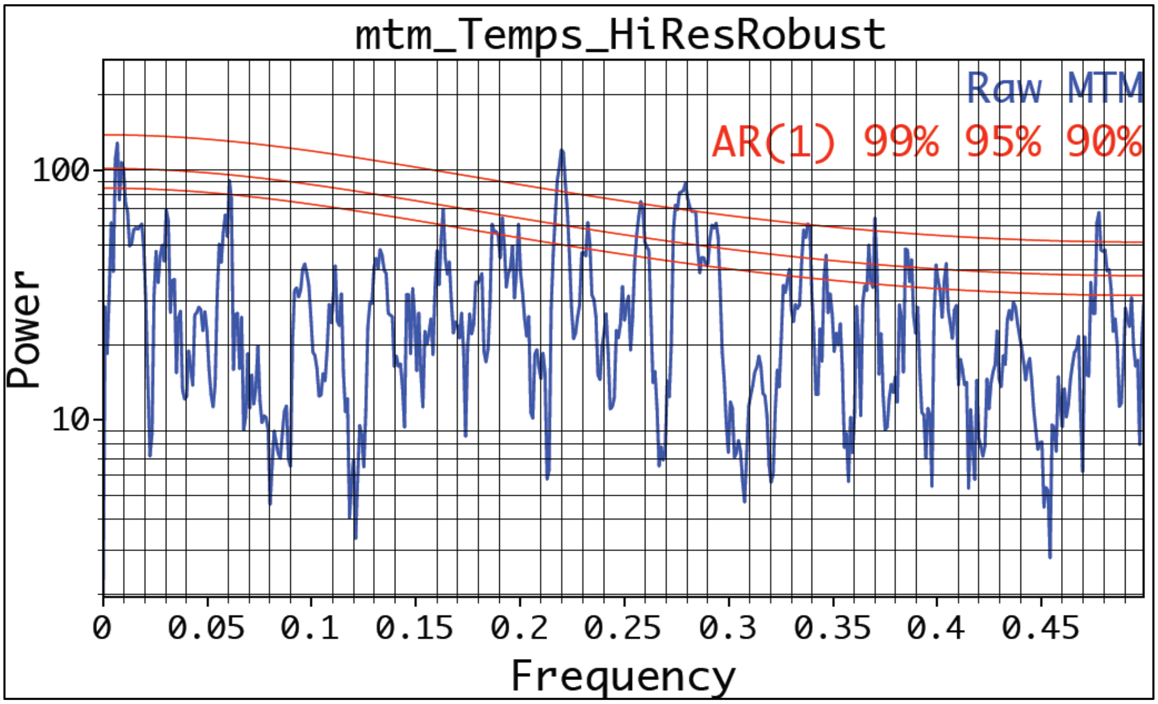


FIGURE 4.5: A. Multitaper Method Spectral Analysis results for the detrended chronology. B. Blackman-Tukey spectral analysis for the detrended chronology.

C.



D.

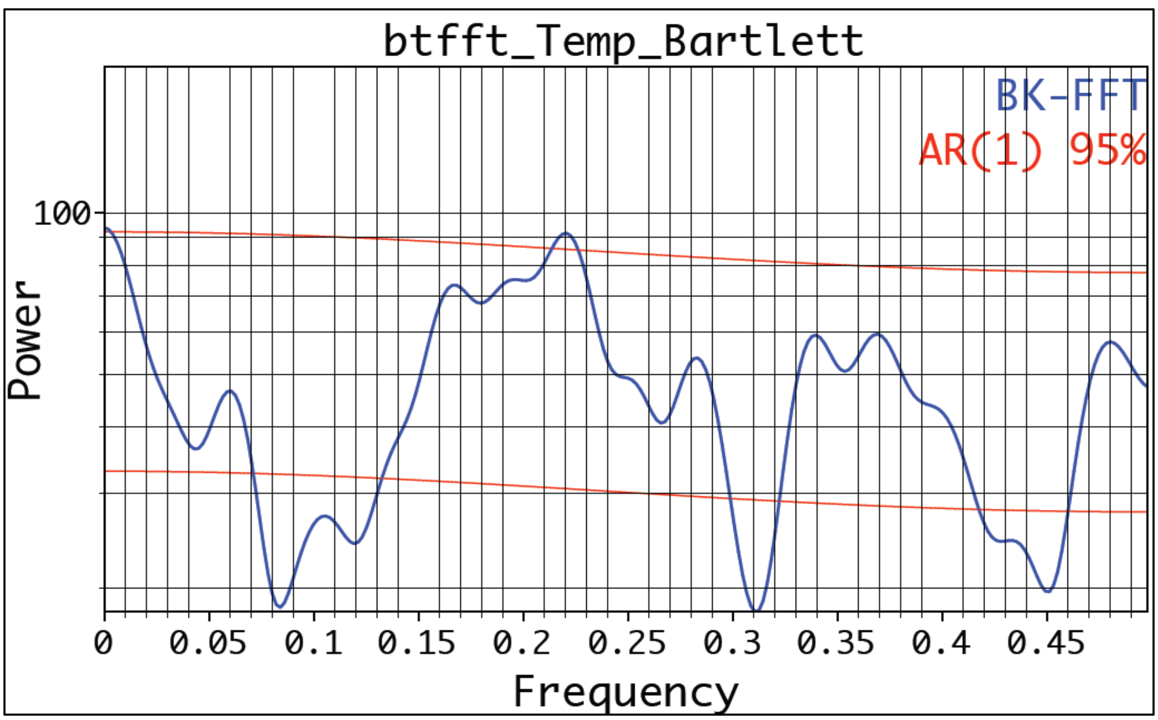


FIGURE 4.5:C. Mulitaper Method spectral analysis results for the May through August temperature reconstruction. D. Blackman Tukey spectral analysis results for the May through August temperature reconstruction.

CHAPTER 5

DISCUSSION

5.1 Limitations Associated with Chronology Development

As shown in the results section, the series intercorrelation for the final chronology is 0.022. This immediately presents limitations to this study. Series intercorrelation shows the stand-level signal in the chronology (Grissino-Mayer, 2008). The ideal range is between 0.55 and 0.75 (Grissino-Mayer, 2008). Series intercorrelation matters for two reasons: the first is that it is a way to determine if the tree-rings were correctly cross-dated because the intercorrelation shows how well the cores match each other; the second is that climate analysis performed later can be attributed to the entire sampled area instead of just one tree (Speer, 2010). The intercorrelation of 0.022 means that the chronology used here has virtually no stand-level signal so that the chronology is dominated by localized single tree conditions. The possible reasons for this are the sample depth and the varying slopes and aspects from which the trees were cored. An accurate series intercorrelation needs a sample depth of at least 10 cores, but 20 cores is preferred (Speer, 2010). Much of the present chronology was constructed from a sample depth of less than 10 cores. Thus, the requirements for an accurate series intercorrelation were evidently not met in the early years of the chronology. Additionally, cores were taken from varying slopes and aspects; thus, it was doubtful if a decent series intercorrelation could be achieved. One way to solve these issues is to cut out years where sample depth is low (Speer, 2010). This decision was not made because it would have significantly shortened the reconstruction, which would not give a reasonable time span to study climate variations.

Most of the cores used were taken from live trees; thus, the outer ring dates were already known. Although stand level events cannot be attributed to this chronology, individual tree level events can be with a fair assurance that the dating is correct (Speer, 2010).

The residual chronology was used in the climate regression analysis in this study. This was done mostly because it was found to have the highest correlation with the instrumental climate data. The residual chronology is the standardized chronology (chronology produced by the chosen detrending process) with autocorrelation removed (Speer, 2010). Although this makes the residual chronology better for regression analysis, it may have removed some climate data, making the residual chronology less sensitive to climate signals (Speer, 2010). Theoretically, the ARSTAN chronology should have been the best chronology to use because stand level autocorrelation is reintroduced back into the chronology, thus enhancing climate sensitivity (Speer, 2010). In this case, it was found that the residual chronology outperformed the ARSTAN chronology for reasons that are not quite understood.

5.2 Limitations during Climate Analysis

The results of the regression analysis that compared the detrended chronology with instrumental data yielded a model with only a 17.2% correlation. The low series intercorrelation (see section 4.2) could explain this low correlation between the chronology and instrumental data. This is because a complete stand chronology with common variability was not compared to instrumental data. Instead of a stand chronology, a group of individual trees showing individual, localized variability was compared with the instrumental data. This made it hard to compare this chronology to regional climate patterns.

It was also hard to conclude that average summer temperatures are the most important climate factor affecting trees in the southeastern Wind River Range. What can be said is that average summer temperatures affect these fourteen trees. This result is both bad and good. While this study cannot look at how a complete stand interacts with climate, it can highlight how important local variability affects conditions that determine tree growth. Furthermore, it is noted that mean sensitivity for the chronology was 0.273. Mean sensitivity shows year-to-year variability in ring-width with 0.1 being too complacent and 0.4 being considered too sensitive (Grissino-Mayer, 2008; Speer, 2010). The mean sensitivity of 0.273 is right where it should be, so while there is a low correlation among individual cores, as a collection they show that some aspect of climate is limiting growth here.

5.3 Limitations with the Reconstruction

The average May-through-August temperatures for each station (Lander airport and Townsend Creek) and the combined May-through-August summer temperatures from all stations tended not to be significant (p-value greater than .15) in affecting the tree growth during Principal Components Analysis (PCA) and Stepwise Multiple Regression. However, the average May-through-August Lander airport temperature was found to be significant during the Simple Linear Regression analysis which is interesting considering PCA and Stepwise Multiple Regression picked only single month temperatures as significant. This issue is possibly related to the low series intercorrelation. The two climate stations (Lander airport and Townsend Creek SNOTEL) that were found to significantly affect growth were the two stations closest to the study site. This highlights the importance of local climate variability. In essence, average summer temperature at the sample site appears to have muted the larger-scale regional climate controls (Kipfmueller, 2008).

Another limitation to the study that affected the temperature reconstruction revolved around the short time period that instrumental data is available for the study area. The Lander airport data only covered a time span of 65 years from 1948-2013. Due to this limited time span, the ‘split sample’ approach for verification could not be used. This only left the PRESS method as the main method used for verification. This means the understanding of how well the reconstruction actually performed is limited.

The last limitation to be addressed has to do with results of the temperature reconstruction. As is noted by Kipfmueller (2008), 20th century warming is a ubiquitous feature of climate variability. However, the present study did not identify an upward trend in warming for the 20th century, meaning that warming present in other reconstructions was not identified in this study. This is not all together unprecedented. Kipfmueller (2008) noted that his summer reconstruction and instrumental temperature data also did not show this warming trend.

Whereas the present reconstruction does not visually show 20th century warming, the warmest decade in the reconstruction was 2000-2009, with 1990-1999 and 1980-89 in a tie with 1750-1759, 1880-1889, and 1690-1699 for the second through sixth warmest decades (Appendix D). So, three of the six warmest decades occurred in the late 20th century and early 21st century. Also, when looking just from 1900 on, 8 of the top 10 warmest years have occurred since 1987 (Appendix E). So, while a visual inspection does not show a warming trend in the reconstruction, it can be seen by looking at other time scales that some warming occurred in the late 20th and early 21st century, especially since the 1980s.

5.4 Is Precipitation Actually Important?

It is uncertain as to why precipitation failed to significantly correlate to the ring-width data especially considering Gray et al. (2003), Gray et al. (2004), Salzer and Kipfmueller (2005), and Kipfmueller (2008) have all done dendroclimatology within

200km (124mi) and found precipitation to be significant. Correlation of average temperature with precipitation from the Lander dataset yielded a negative correlation of -0.672. This suggests that the temperature can be considered to be a proxy for soil moisture conditions. So, cool summer temperatures should allow for higher soil moisture conditions whereas warm summer temperatures should lead to lower soil moisture conditions (Madden & Williams, 1978). This explanation also works to reveal why average temperatures had a negative slope in the regression analysis (Table 4.3); dryer soil conditions associated with warmer temperatures limit tree growth because summer soil moisture is more a function of summer temperature than summer precipitation. Therefore, with each degree decrease in temperature the trees appear to respond by adding more cambium because of the more favorable soil conditions.

5.5 Comparison to other Reconstructions

Before comparing this study with the results of others, it should be noted that directly comparing two dendroclimatology studies is challenging because different standardization procedures produce different types of chronologies that vary in their sensitivity to climate (Kipfmueller, 2008). That being said, there are two studies that most easily compare with this one. In the northern Rocky Mountains, Kipfmueller (2008) found a 38% correlation with June through August temperature. Kipfmueller's reconstruction showed cooling in the early 1700s which is not readily noticeable in the

Lander reconstruction, but his study also did not show 20th century warming (Kipfmueller, 2008).

Briffa et al. (1992) subdivided the western United States into a number of discrete regions and found the summers in the 1630s, 1790s, 1820s, 1850s, and 1930s were warm periods in all regions. Cool summers were recorded for the 1600s, 1660s to 1680, mid-1690s to 1710, and 1870 to 1930 for all regions (Briffa et al., 1992). The coolest single years were 1601 and 1810 and the warmest single year was 1651 with notably hot years of 1646, 1649, 1653, and 1661 (Briffa et al., 1992). The present study agreed that the 1850s were warm and that the 1600s and 1920s were cool but found that the 1870s through 1890s were some of the warmest decades.

5.6 Climate Oscillations and Comparisons to Other Studies

Spectral analysis (Multi-Taper Method and Blackman- Tukey Method) showed the frequencies commonly associated with El Nino- Southern Oscillation (ENSO; 2-7 years) were present in both the detrended chronology and temperature reconstruction. Frequencies associated with Pacific Decadal Oscillation (PDO) appears to be present in only the temperature reconstruction. These results are partly reflected in previous studies. Gray et al. (2003) ran wavelet analysis for the central (Montana and Wyoming) and southern (Utah, Colorado, and New Mexico) Rocky Mountains and found frequencies at greater than 40 years. They found especially strong frequencies between 30 and 70 years at Yellowstone and the Southwestern Rocky Mountains (Gray el al.

2003). In the Bighorn Basin, Wyoming Gray et al. (2004) identified periodicities about 14 years and between 46 to 64 years. Thus, it appears high frequency periods associated with PDO appear in both major datasets (Bighorn Basin and Lander), but not the lower 30-to-70 year frequencies. Also, while neither of these studies noted frequencies associated with ENSO (~3-7 years) they were able to find a relationship between ENSO and precipitation (drought conditions). All studies that looked into the relationship between ENSO and climate noted that dry conditions were associated with La Nina and wet conditions were associated with El Nino (Brown, 2006; Brown & Wu, 2005; Gray et al., 2003; Gray et al., 2004).

It was found by looking at the actual El Nino/La Nina years and precipitation/ snow water equivalent values from the Townsend Creek SNOTEL data (Table 5.6A and 5.6B) that precipitation is greater for EL Nino during summer (2.5 in to 1.9 in) and for total precipitation (6.8 to 6.2 in; made up of summer precipitation and January snow water equivalent). However, when summer precipitation is added to maximum snow water equivalent then La Nina events have greater precipitation (24.7 in to 23.1 in). It appears that maximum snow water equivalent determines the difference in moisture in La Nina vs. El Nino years. This indicates that precipitation events during winter may be more tele-connected to Pacific basin conditions than precipitation events during the summer.

TABLE 5.6A

La Nina years obtained from Golden Gate Weather Services and precipitation values from Townsend Creek SNOTEL (Null, 2014).

Year	Summer Precip	January Snow Water Equivalent	Total Precip	Maximum Snow Water Equivalent	Summer Precip + Maximum SWE
2011	0.795	4.8	5.6	9.4	10.195
2010	0.87	4.8	5.7	11.3	12.17
2008	0.925	2.8	3.7	8.9	9.825
2007	0.95	2.8	3.8	7.8	8.75
2005	1.3675	5.5	6.9	10.4	11.7675
2000	1.8425	1.8	3.6	7	8.8425
1999	1.9675	4.5	6.5	19.7	21.6675
1998	1.975	5.6	7.6	11.9	13.875
1995	2.1925	5.1	7.3	13.6	15.7925
1988	2.895	5.1	8.0	10.6	13.495
1984	3.295	5.8	9.1	13.8	17.095
1983	3.3225	3.2	6.5	13.6	16.9225
Total	22.4	51.8	74.2	138.0	160.4
Average	1.9	4.3	6.2	11.5	24.7

TABLE 5.6B

El Nino years obtained from Golden Gate Weather Services and precipitation values from Townsend Creek SNOTEL (Null, 2014).

Year	Summer Precip	January Snow Water Equivalent	Total Precip	Maximum Snow Water Equivalent	Summer Precip + Maximum SWE
2009	0.8975	3.7	4.6	11.5	12.3975
2006	1.2975	2.8	4.1	6.7	7.9975
2004	1.4	4.3	5.7	10.2	11.6
2002	1.4975	2	3.5	5.8	7.2975
1997	2.06333333	6.2	8.3	12.7	14.76333333
1994	2.2475	4.3	6.5	9.8	12.0475
1991	2.3725	4.1	6.5	12	14.3725
1987	2.9475	6.1	9.0	12.2	15.1475
1986	3.025	6.3	9.3	14.5	17.525
1982	7.4575	3.4	10.9	6.4	13.8575
Total	25.2	43.2	68.4	101.8	127.0
Average	2.5	4.3	6.8	10.2	23.1

Results here indicate that this study area show similar or, at worst, an inconclusive response to ENSO. Findings indicate wetter conditions during El Nino for summer precipitation and dryer conditions during La Nina for summer precipitation, yet show dryer conditions for El Nino when maximum snow water equivalent is added and wetter conditions for La Nina. The western and southwestern United States usually show drier conditions during La Nina and wetter conditions during El Nino (Gray et al., 2004; McCabe & Dettinger, 1999). Thus, the southern end of the Wind River Range appears to respond to pacific conditions in a pattern similar to how the rest of the western United States.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

Tree- ring-widths measured from cores of Douglas Fir near the southern end of the Wind River Range, Wyoming were found to be significantly correlated to average May-through-August temperatures during a 424 year span from 1589 to 2013. The temperature reconstruction shows fairly uniform temperatures throughout the entire span of the reconstruction. The 20th century warming cannot easily be identified by simply observing the reconstruction. Further analysis shows that the 1980s, 1990s, and 2000s were among the hottest decades of the reconstructed record.

Spectral analysis of the detrended ring-width data, as well as the reconstructed temperatures, reveals frequencies associated with El Nino-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO). This analysis indicates that a tele-connection exists between Pacific basin conditions and the climatic conditions in this region that affect tree growth. Comparing actual El Nino/La Nina dates with precipitation and snow water equivalent values indicate that this area is wetter during El Nino and dryer during La Nina. This result falls in line with how the western United States typically responds to ENSO (Brown, 2006; Brown & Wu, 2005; Gray et al., 2003; Gray et al., 2004; McCabe & Dettinger, 1999).

In order to further investigate how climate oscillations affect the area, further research should be directed at how winter conditions interact with oscillations, as oscillations appear to be more prominent during winter (Fall, 1994; Gray et al., 2003; Gray et al., 2004). Also, collecting more cores in order to achieve a higher series intercorrelation should be under taken in order to more tightly constrain the instrumental data with the tree-rings. This study highlights how a collection of individual trees interacts with climate. What really is needed is a stand-level study. Additionally, more cores would increase the sample depth, which, in turn, would improve the series intercorrelation and make the reconstruction more accurate. This is especially important for the earlier time span of the record.

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APPENDIX A

RAW RING WIDTHS

Year	BP	DT1	DT12	DT2	DT22	J	LAT	Old1
2013	0.55					0.375	0.745	
2012	0.715					0.615	0.87	
2011	0.715					0.635	0.92	
2010	0.665					0.565	0.785	
2009	0.645					0.85	0.74	
2008	0.27					0.28	0.445	
2007	0.76					0.81	0.795	
2006	0.405					0.98	0.59	
2005	0.385					1.06	0.76	
2004	0.79	0.55	0.5			0.73	0.58	
2003	0.965	0.45	0.505			0.415	0.38	
2002	1.02	0.42	0.415			0.89	1.06	
2001	0.5	0.41	0.36			1.15	0.935	
2000	0.69	0.32	0.37			1.3	0.92	
1999	0.64	0.43	0.45			0.9	0.735	
1998	0.755	0.385	0.385			0.865	0.635	
1997	1.01	0.34	0.36			0.78	0.66	
1996	0.97	0.275	0.285			0.775	0.78	0.37
1995	0.825	0.23	0.3			1.075	0.68	0.3
1994	0.495	0.26	0.28			0.885	0.735	0.24
1993	0.675	0.33	0.36			0.67	0.81	0.295
1992	0.5	0.285	0.365			0.325	0.57	0.28
1991	0.715	0.22	0.31			0.585	0.58	0.215
1990	0.935	0.315	0.505	1.12	0.415	0.535	0.36	0.31
1989	0.685	0.425	0.495	0.905	0.415	0.625	0.335	0.285
1988	0.5	0.355	0.335	1.535	0.405	0.845	0.565	0.28
1987	0.815	0.455	0.57	1.07	0.43	0.8	0.5	0.235
1986	0.855	0.42	0.46	1.315	0.725	0.98	0.54	0.49
1985	0.785	0.5	0.62	0.795	1.09	1.575	0.8	0.435
1984	1.72	0.45	0.58	0.825	1.275	1.755	0.82	0.265
1983	0.815	0.35	0.375	0.71	1.24	2.685	0.815	0.495
1982	0.54	0.4	0.45	0.485	1.4	2.25	1.065	0.14
1981	0.69	0.465	0.45	0.92	1.09	2.21	1.03	0.215
1980	0.66	0.44	0.54	0.465	1.48	2.005	0.98	0.325

Year	BP	DT1	DT12	DT2	DT22	J	LAT	Old1
1979	0.71	0.41	0.365	0.73	1.395	0.92	0.845	0.34
1978	0.88	0.365	0.405	1.085	1.415	1.395	0.845	0.35
1977	0.65	0.24	0.275	1.19	1.015	1.195	0.915	0.195
1976	0.59	0.31	0.295	1.165	1.44	1.175	0.91	0.185
1975	0.955	0.29	0.4	1.435	1.39	1.37	0.98	0.33
1974	0.92	0.335	0.34	1.125	1.115	1.25	2.205	0.22
1973	0.865	0.265	0.21	1.645	0.73	1.195	1.135	0.255
1972	0.83	0.37	0.37	1.365	0.915	1.36	0.99	0.33
1971	0.745	0.52	0.385	1.535	0.765	2.16	1.05	0.34
1970	0.65	0.515	0.37	1.11	1.155	1.48	0.96	0.39
1969	1.885	0.645	0.405	1.535	0.9	1.42	0.985	0.25
1968	0.86	0.505	0.335	1.385	0.8	1.15	1.06	0.21
1967	1.105	0.435	0.4	1.07	0.5	1.565	0.9	0.23
1966	0.875	0.33	0.29	0.68	0.835	1.47	0.955	0.325
1965	0.725	0.45	0.325	0.925	0.91	2.38	0.9	0.46
1964	0.58	0.555	0.3	0.915	1.05	2.345	1.13	0.365
1963	0.505	0.24	0.195	1.23	0.775	2.945	1.065	0.215
1962	0.455	0.325	0.27	0.885	0.84	2.23	1.11	0.29
1961	0.17	0.175	0.22	0.83	1.4	2.08	1.11	0.25
1960	0.415	0.205	0.16	0.525	1.145	1.99	1.095	0.255
1959	0.765	0.305	0.65	0.875	0.68	2.2	0.945	0.24
1958	0.85	0.685	0.62	1.005	0.655	2.26	0.86	0.17
1957	1.05	0.95	0.62	1.09	0.97	2.495	0.925	0.47
1956	0.985	0.645	0.65	0.84	0.745	2.405	0.975	0.28
1955	1.115	0.7	0.56	0.92	0.58	2.195	1.045	0.39
1954	0.98	0.42	0.495	1.42	0.625	2.57	0.83	0.29
1953	1.16	2.715	0.69	1.255	0.575	2.49	1.01	0.295
1952	1.43	0.75	0.565	0.725	0.53	2.305	1.065	0.245
1951	0.86	0.565	0.585	0.67	0.805	2.63	1.185	0.415
1950	0.64	0.87	0.46	1.11	0.635	2.635	1.315	0.305
1949	1.135	0.545	0.48	0.765	1.205	2.71	1.085	0.52
1948	1.045	0.38	0.52	0.575	0.93	2.365	1.145	0.32
1947	0.715	0.435	0.41	0.76	1.025	1.81	1.04	0.525
1946	0.86	0.365	0.345	0.58	1.125	1.88	1.165	0.445
1945	0.905	0.345	0.395	0.5	1.015	2.465	1.17	0.37
1944	0.835	0.365	0.8	0.845	1.145	2.28	1.275	0.195
1943	1.275	0.44	0.35	0.7	1.02	2.77	0.995	0.175

Year	BP	DT1	DT12	DT2	DT22	J	LAT	Old1
1942	0.73	0.51	0.345	1.225	1.1	2.13	1.365	0.535
1941	1.45	0.6	0.33	1.01	1.055	3.165	1.33	0.355
1940	0.785	0.49	0.48	1.065	1.115	2.655	1.42	0.585
1939	1.055	0.545	0.435	1.19	0.825	3.02	1.425	0.495
1938	1.36	0.82	0.575	1.195	0.915	2.22	1.185	0.55
1937	0.89	0.705	0.5	1.21	0.84	2.35	1.245	0.535
1936	0.9	0.59	0.55	1.025	0.725	2.19	1.365	0.495
1935	1.505	0.38	0.535	1.09	0.43	2.17	1.41	0.46
1934	1.205	0.66	0.61	1.19	0.545	2.66	1.59	0.5
1933	0.73	0.565	0.43	1.23	0.605	3.03	1.67	0.425
1932	0.77	0.51	0.335	0.765	2.055	2.95	1.77	0.29
1931	1.03	0.54	0.595	0.975	1.08	2.82	2.03	0.515
1930	0.795	0.4	0.43	0.87	0.615	3.715	1.73	0.625
1929	0.98	0.375	0.39	0.655	0.9	3.69	1.39	0.425
1928	0.95	0.565	0.415	0.355	0.485	3.84	1.41	0.56
1927	0.745	0.46	0.34	0.64	0.515	3.005	1.66	0.445
1926	0.79	0.82	0.35	0.655	0.74	3.03	1.815	0.47
1925	1.34	0.63	0.535	0.83	1	3.475	1.875	0.39
1924	1.1	0.765	0.39	1.02	0.705	3.225	1.755	0.48
1923	1.41	0.84	0.795	0.995	0.89	3.58	1.7	0.45
1922	1.315	0.695	0.64	0.615	0.25	3.85	1.38	0.75
1921	1.3	0.57	0.75	0.855	0.7	3.64	1.685	0.525
1920	0.975	0.61	0.79	0.435	0.555	4.485	1.405	0.595
1919	1.14	0.78	0.66	0.53	0.31	4.03	1.84	0.855
1918	1	0.915	0.475	0.81	0.42	5.45	2.485	0.69
1917	1.02	0.94	0.59	0.96	0.41	5.22	2.405	0.495
1916	0.985	0.715	0.79	0.765	0.585	3.875	1.94	0.775
1915	1.175	0.72	1.045	0.85	0.615	4.11	1.69	0.665
1914	1.195	0.66	1.12	0.305	0.34	3.785	1.695	0.635
1913	1.1	0.435	0.85	0.615	0.2	3.86	1.805	0.785
1912	1.135	0.16	0.845	0.49	0.79	3.83	1.68	0.61
1911	0.985	0.605	0.665	0.265	0.465	3.11	1.955	0.62
1910	0.73	0.505	0.425	0.415	0.495	3.925	2.125	0.595
1909	0.485	0.52	0.275	0.335	0.66	4.03	2.18	0.865
1908	1.065	0.63	0.585	0.135	0.605	3.68	1.555	0.695
1907	2.415	0.66	0.615	0.495	0.47	3.39	1.585	0.625
1906	1.645	0.735	0.52	0.465	0.66	3.18	1.205	0.585

Year	BP	DT1	DT12	DT2	DT22	J	LAT	Old1
1905	1.43	0.49	0.705	0.515	0.61	2.95	1.015	0.855
1904	0.97	0.54	0.54	0.75	0.575	2.055	1.475	1.17
1903	1.185	0.54	0.31	0.4	0.48	3.24	2.01	0.695
1902	0.875	0.535	0.54	0.415	0.775	3.915	2.03	0.85
1901	0.745	0.585	0.32	0.665	0.22	3.475	2.13	0.64
1900	1.01	0.225	0.495	0.56	0.56	4.52	1.64	0.675
1899	0.895	0.675	0.595	0.455	0.34	5.47	1.49	0.52
1898	0.225	0.565	0.58	0.595	0.415	3.95	1.645	0.925
1897	1.04	0.315	0.61	0.625	0.31	4.02	1.68	0.5
1896	0.895	0.355	0.54	0.55	0.365	3.025	1.76	0.76
1895	0.49	0.23	0.335	0.425	0.765	2.205	1.925	0.76
1894	1.14	0.135	0.59	0.855	0.72	2.67	1.195	0.71
1893	0.555	0.44	0.565	0.185	0.63	2.96	1.03	0.675
1892	0.645	0.565	0.36	0.52	0.525	5.225	1.21	0.41
1891	1	0.555	0.51	0.4	0.25	3.2	1.405	0.35
1890	1.39	0.33	0.29	0.43	0.865	1.695	1.26	0.48
1889	0.495	0.445	0.165	0.28	0.57	2.73	1.91	0.575
1888	0.28	0.26	0.53	0.575	0.49	2.06	1.875	0.735
1887	0.995	0.385	0.865	0.705	0.6	1.43	1.525	0.34
1886	1.11	0.345	0.64	0.87	0.435	1.5	1.355	0.395
1885	1.125	0.29	0.535	0.67	0.8	1.675	1.305	0.335
1884	0.94	0.25	0.525	0.545	0.4	1.235	1.535	0.28
1883	1.275	0.42	0.375	0.205	0.58	1.605	1.605	0.33
1882	0.885	0.37	0.47	1.025	0.425	5.69	1.885	0.28
1881	0.945	0.28	0.385	0.69	0.26	1.97	1.575	0.32
1880	1.275	0.255	0.325	0.51	0.745	2.065	1.75	0.21
1879	1.07	0.365	0.39	0.625	1.415	1.55	1.7	0.245
1878	0.91	0.155	0.61	0.465	0.235	1.09	1.28	0.23
1877	1.39	0.285	0.485	0.765	0.89	1.33	1.145	0.54
1876	0.96	0.215	0.4	0.355	0.895	1.435	1.225	0.425
1875	0.7	0.315	0.265	0.625	1.345	1.71	1.35	0.255
1874	0.605	0.05	0.355	0.465	1.28	1.885	1.7	0.67
1873	0.87	0.47	0.175	0.325	1.05	2.01	1.82	0.24
1872	0.38	0.395	0.345	0.87	0.77	1.695	1.585	0.86
1871	0.72	0.385	0.26	1.39	0.92	1.455	1.42	0.36
1870	0.67	0.35	0.445	0.235	1.04	1.825	1.745	0.63
1869	0.615	0.28	0.44	0.835	1.25	1.09	1.685	0.695

Year	BP	DT1	DT12	DT2	DT22	J	LAT	Old1
1868	0.885	0.11	0.52	1.035	0.755	3.58	1.325	0.54
1867	0.67	0.55	0.515	1.525	0.945	3.425	1.78	0.61
1866	0.925	0.47	0.32	1.405	0.685	2.86	1.79	0.67
1865	1.165	0.355	0.355	1.13	0.825	3.02	1.755	0.665
1864	0.955	0.345	0.125	0.71	0.88	2.88	1.545	0.425
1863	0.785	0.375	0.585	0.925	0.84	2.105	1.5	0.475
1862	0.325	0.465	0.405	0.885	0.64	2.37	1.195	0.685
1861	1.05	0.33	0.315	1.215	0.625	2.445	1.24	0.55
1860	0.93	0.45	0.28	0.68	0.52	1.835	1.3	0.345
1859	0.79	0.445	0.32	0.875	0.77	1.07	1	0.605
1858	0.915	0.255	0.45	0.77	0.44	3.135	0.85	0.6
1857	0.82	0.83	0.23	0.85	0.84	2.26	1.5	0.505
1856	1.225	0.81	0.355	0.975	0.66	2.745	1.295	0.48
1855	0.885	0.25	0.405	0.875	0.975	2.875	1.515	1.48
1854	1.005	0.79	0.18	0.68	0.85	2.655	1.665	1.165
1853	1.07	0.765	0.705	0.665	1.02	2.38	1.46	0.875
1852	0.81	1.125	0.685	0.525	1.355	2.185	1.655	1.06
1851	1.245	0.92	0.205	0.61	1.05	2.205	1.68	1.23
1850	1.72	0.895	0.705	0.37	1.21	2.105	1.37	1.18
1849	0.59	0.69	0.795	0.885	1.055	2.125	1.495	0.535
1848	1.56	0.89	1.02	0.65	0.815	2.505	1.74	0.95
1847	1.485	0.97	0.945	0.935	0.925	3.495	1.785	0.83
1846	2.26	1.05	0.73	0.81	0.71	1.875	2.115	1.175
1845	2.155	0.91	0.565	0.96	0.48	3.25	1.61	0.91
1844	2.01	0.695	0.78	1.32	1.105	2.005	2.195	0.835
1843	1.325	0.67	0.885	1	0.69	1.915	2.69	0.775
1842	1.15	1.06	0.915	1.02	0.36	1.645	3.045	1.005
1841	1.43	0.755	0.69	1.12	0.37		2.435	0.91
1840	1.495	0.705	0.59	0.78	0.94		2.435	0.87
1839	0.405	0.485	0.51	0.96	0.995		2.2	0.605
1838	0.37	0.605	0.72	0.61	0.965		2.21	0.855
1837	1.395	0.48	0.735	0.465	0.695		2.435	0.52
1836	1.605	0.56	0.515	0.775	1.11		2.7	0.805
1835	1.75	0.29	0.46	0.565	1.075		2.605	0.435
1834	1.625	0.635	0.445	0.285	0.61		2.105	0.64
1833	1.585	0.45	0.43	0.365	1.345		2.29	0.635
1832	1.12	0.655	0.7	0.895	1.135		2.705	0.83

Year	BP	DT1	DT12	DT2	DT22	J	LAT	Old1
1831	1.19	0.725	0.515	0.88	1.06		2.82	0.92
1830	1.8	0.8	0.46	0.845	1.685		2.4	1.08
1829	0.705	0.905	0.61	0.65	1.31		2.49	1.12
1828	1.23	0.645	0.695	0.94	1.6		1.69	0.805
1827	1.775	0.585	0.8	0.915	0.82		1.63	0.915
1826	3.27	0.505	0.825	0.535	1.205		1.69	0.765
1825	1.485	0.505	0.65	1.24	0.68		2.08	0.65
1824	2.05	0.425	0.56	1.055	1.105		2.87	0.76
1823	2.93	0.295	0.515	1.11	1.305		2.575	0.685
1822	1.64	0.285	0.54	1.57	1.15		2.75	0.53
1821	1.76	0.355	0.36	1.245	1.03		2.025	0.695
1820	1.85	0.23	0.295	1.425	1.305		2.3	0.665
1819	1.49	0.195	0.28	0.84	2.395		3.335	0.31
1818	1.485	0.225	0.375	0.925	0.98		2.075	0.36
1817	1.625	0.455	0.32	0.58	1.105		2.2	0.81
1816	1.575	0.495	0.195	1.055	1.285		2.455	0.76
1815	2.345	0.47	0.26	1.095	1.35		2.08	0.78
1814	1.275	0.445	0.525	0.965	0.69		1.675	0.56
1813	1.135	0.58	0.655	0.945	0.975		1.555	0.68
1812	1.2	0.46	0.49	1.07	1.105		1.645	0.8
1811	2.04	0.335	0.44	0.875	1.255		2.745	0.62
1810	1.96	0.695	0.495	0.94	1.415		1.685	0.735
1809	2.51	0.525	0.395	0.57	1.235		1.84	1.105
1808	2.805	0.545	0.395	1.175	1.33		1.6	0.96
1807	2.3	0.68	0.63	0.895	1.33		1.98	1.225
1806	2.115	0.94	0.52	1.025	1.6		1.805	1.09
1805	1.96	1.025	0.62	1.405	1.375		2.27	1.275
1804	2.95	0.865	0.735	1.24	1.235		2.53	0.945
1803	3.235	0.74	0.87	0.775	1.235		2.69	1.035
1802	2.265	0.535	0.925	0.86	1.35		2.64	0.795
1801	2.965	0.7	0.76	1.13	1.405		2.81	0.93
1800	2.39	0.755	0.715	1.195	1.3		2.695	1.12
1799	3.17	0.68	0.415	1.355	0.82		2.725	0.795
1798	2.495	0.66	0.62	1.12	1.465		2.19	0.835
1797	0.655	0.715	0.735	1.31	1.455		2.805	0.79
1796	2.235	0.605	0.74	1.425	0.695		2.745	0.815
1795	2.895	0.54	0.72	1.535	1.57		2.52	0.55

Year	BP	DT1	DT12	DT2	DT22	J	LAT	Old1
1794	4.68	0.56	0.745	1.475	1.54		2.245	0.615
1793	2.325	0.74	0.72	1.51	0.765		2.42	0.81
1792	2.47	0.51	0.62	1.245	0.77		2.29	0.58
1791	1.775	0.76	0.57	1.415	1.58		1.935	0.85
1790	2.9	0.855	0.8	1.26	2.41		2.605	0.77
1789	2.655	0.56	0.475	1.23	2.08		2.195	0.7
1788	3.11	0.525	0.86	0.83	1.59		1.87	0.475
1787	2.22	0.725	0.81	1.485	2.38		2.085	0.515
1786	3.005	0.845	0.545	1.33	1.565		2.25	0.64
1785	1.815	0.93	0.47	0.69	1.4		2.62	0.78
1784	2.72	1.18	0.66	1.55	1.085		2.225	0.61
1783	3.4	0.9	0.735	1.49	0.805		2.715	0.665
1782	3.68	0.885	0.805	0.675	0.71		2.21	0.745
1781	2.48	0.885	0.94	0.545	0.8		2.505	0.66
1780	2.46	1.27	0.775	1.36	0.945		2.885	0.695
1779	5.67	0.94	0.7	1.965	0.835		2.73	0.505
1778	2.92	1.07	0.79	1.515	0.97		2.42	0.595
1777	7.94	0.815	1.13	1.295	0.975		2.915	0.47
1776	3.3	0.82	0.97	1.76	1.385		2.565	0.435
1775	7.28	0.93	1.055	1.105	1.035		2.695	0.4
1774		0.685	0.865	1.08	0.925			0.31
1773		0.535	0.805	0.795	1.745			0.59
1772		0.665	0.91	0.615	1.74			0.59
1771		0.445	0.62	0.56	1.345			0.325
1770		0.525	0.55	0.66	1.94			0.3
1769		0.705	0.595	0.705	1.235			0.26
1768		0.925	0.39	0.57	1.33			0.33
1767		0.44	0.505	0.645	1.355			0.22
1766		0.71	0.68	0.78	1.215			0.175
1765		0.94	0.47	0.76	1.245			0.4
1764		0.99	0.36	0.795	1.185			0.495
1763		1.055	0.46	0.73	1.475			0.315
1762		1.015	0.65	1.385	1.595			0.25
1761		0.64	0.88	1.57	1.645			0.25
1760		0.455	0.81	1.245	1.885			0.245
1759		0.32	0.99	1.64	1.945			0.165
1758		0.26	0.94	1.29	1.42			0.1

Year	BP	DT1	DT12	DT2	DT22	J	LAT	Old1
1757		0.295	0.65	1.285	1.17			0.095
1756		0.295	0.51	1.055	0.635			0.17
1755		0.39	0.365	1.145	1.795			0.095
1754		0.325	0.39	1.11	1.55			0.125
1753		0.38	0.3	0.97	1.42			0.15
1752		0.465	0.3	1.455	1.275			0.33
1751		0.68	0.395	1.765	0.995			0.43
1750		0.635	0.355	1.58	0.99			0.23
1749		0.885	0.41	1.945	0.91			0.41
1748		0.79	0.55	1.925	0.77			0.445
1747		0.8	0.79	1.44	0.775			0.33
1746		0.67	0.765	1.195	0.81			0.24
1745		0.925	0.9	0.66	0.455			0.385
1744		0.785	0.845	1.815	0.475			0.44
1743		0.865	0.845	1.455	0.495			0.445
1742		1.035	0.74	1.425	0.67			0.59
1741		0.88	0.845	1.44	1.25			0.615
1740		1.195	0.765	1.265	0.725			0.715
1739		1.245	0.76	1.13	1.28			0.56
1738		1.61	0.915	1.09	3.055			0.46
1737		1.32	0.91	1.055	2.235			0.5
1736		1.895	1.035	1.08	1.92			0.41
1735		2.03	0.945	1.24	1.1			0.265
1734		2.105	1.37	1.11	1.29			0.39
1733		1.235	0.96	1.495	1.695			0.27
1732		0.935	1.55	1.105	1.25			0.38
1731		0.935	1.775	1.34	1.33			0.31
1730		1.385	1.355	1.815	1.485			0.19
1729		1.475	0.895	2.5	0.99			0.19
1728		1.38	0.835	2.785	1.245			0.29
1727		1.17	0.85	1.96	0.96			0.2
1726		1.05	1.325	1.625	1.025			0.29
1725		0.965	1.44	1.11	1.4			0.28
1724		0.73	1.335	1.425	1.035			0.525
1723		0.705	1.18	1.55	1.17			0.35
1722		0.975	1.11	1.525	1.795			0.445
1721		1.02	0.875	1.15	2.015			0.32

Year	BP	DT1	DT12	DT2	DT22	J	LAT	Old1
1720		0.8	0.755	1.455	1.83			0.575
1719		0.925	0.73	1.09	1.235			0.685
1718		1.01	0.99	1.035	2.425			0.845
1717		1.07	0.94	0.855	1.065			0.73
1716		1.44	0.94	1.47	1.545			0.365
1715		1.525	1.155	1.535	1.065			0.5
1714		1.59	0.91	1.035	1.76			0.475
1713		0.825	1.32	1.085	1.125			0.425
1712		0.585	1.52	1.655	1.225			1.08
1711		0.31	1.235	2.105	1.28			0.94
1710		0.855	1.185	1.79	1.5			0.76
1709		0.78	0.945	1.615	0.675			0.72
1708		1.03	0.93	2.265	1.505			0.42
1707		0.835	0.88	1.205	2.245			0.495
1706		0.8	0.935	1.91	1.91			0.325
1705		0.54	1.09	1.575	1.625			0.585
1704		0.59	1.095	2.165	2.24			0.645
1703		0.525	0.89	1.4	1.985			0.405
1702		0.76	0.84	1.395	1.09			0.31
1701		0.7	0.5	1.76	1.765			0.925
1700		0.47	0.575	1.625	1.955			0.74
1699		0.445	0.505	0.625	2.14			0.655
1698		0.755	0.735	1.425	1.895			0.65
1697		0.61	0.59	2.085	1.765			1.14
1696		0.73	0.435	1.355	2.1			0.625
1695		0.925	0.485	1.405	1.735			0.655
1694		1.055	0.86	2.045	1.58			0.625
1693		0.64	0.755	1.79	2.31			0.925
1692		0.615	0.81	1.1	0.765			0.66
1691		0.545	0.685	1.6	1.39			0.665
1690		0.85	0.94	2.4	1.725			0.6
1689		0.625	0.71	2.355	2.865			0.925
1688		0.875	0.805	2.175	1.855			0.69
1687		0.595	0.595	1.995	0.49			0.835
1686		0.61	0.985	2.02	1.98			0.57
1685		0.24	0.665	1.98	2			0.48
1684		0.62	0.865	1.9	1.745			0.865

Year	BP	DT1	DT12	DT2	DT22	J	LAT	Old1
1683		0.78	0.51	1.55	2.445			0.76
1682		0.63	0.5	0.89	2.915			0.575
1681		0.48	0.23	1.355	2.605			1.105
1680		0.91	0.515	1.385	2.87			1.02
1679		0.75	0.645	1.7	3.31			1.235
1678		0.58	0.505	1.125	2.71			1.035
1677		1.07	0.46	1.905	2.48			0.885
1676		1.265	0.695	0.595	1.665			1.215
1675		1.35	0.675	2.5	0.93			0.92
1674		0.925	0.505	2.19	1.46			0.965
1673		0.9	1.025	1.53	2.1			0.93
1672		1.065	1.01	2.545	0.955			0.705
1671		1.175	1.165	2.515	0.825			0.795
1670		1.215	0.795	2.91	0.605			0.89
1669		0.835	0.805	3.17	0.72			0.725
1668		0.555	0.95	2.91	1.12			0.625
1667		0.75	0.925	2.51	0.595			1.16
1666		1.045	0.875	3	1.26			1.2
1665		0.715	0.53	1.17	1.04			1.065
1664		0.52	0.395	3.785	1.57			0.95
1663		1.005	0.61	1.645	1.615			1.32
1662		1.24	0.92	1.15	1.755			1.39
1661		1.21	0.595	2.405	3.695			1.225
1660		1.05	0.44	1.195	1.845			1.36
1659		1.425	0.68	1.57	2.6			1.8
1658		1.59	0.205	1.915	4.555			1.525
1657		1.845	1.015	0.82	2.935			1.065
1656		1.99	1.105	1.87				1.14
1655		2.1	0.965	2.34				1.42
1654		1.58	1.345	2.36				1.21
1653		1	1.52	2.075				1.635
1652		0.845	1.68	3.245				1.8
1651		1.03	1.995	2.055				1.265
1650		0.885	2.4	6.8				0.905
1649		1.02	1.805					1.21
1648		1.15	1.09					1.09
1647		0.815	1.015					1.135

Year	BP	DT1	DT12	DT2	DT22	J	LAT	Old1
1646		0.63	1.055					0.645
1645		0.65	0.86					0.935
1644		0.55	1.18					1.23
1643		0.715	1.315					1.02
1642		0.415	0.83					1.655
1641		0.47	0.61					1.905
1640		0.885	0.71					1.79
1639		0.6	0.47					1.835
1638		1.015	0.715					1.815
1637		1.095	0.485					1.29
1636			0.72					1.645
1635			0.61					2.115
1634			0.53					1.6
1633			0.95					1.545
1632			1.135					2.23
1631			0.865					2.06
1630			0.965					2.2
1629			0.895					2.36
1628			0.655					2.19
1627			1.025					2.3
1626			1.155					2.575
1625			1.11					2.275
1624			1.305					2.83
1623			1.57					2.29
1622			1.28					2.73
1621			1.665					2.985
1620			1.47					3.1
1619			1.485					2.495
1618			1.5					2.305
1617			1.55					1.625
1616			1.34					2.75
1615			1.36					2.81
1614			1.41					2.28
1613			1.56					2.54
1612			1.655					2.32
1611			1.705					2.13
1610			1.22					1.83

Year	BP	DT1	DT12	DT2	DT22	J	LAT	Old1
1609			1.155					2.36
1608			0.99					2.37
1607			1.885					2.41
1606			2.365					2.25
1605			2.07					2.69
1604			1.515					2.16
1603			1.27					2.585
1602			2.035					2.49
1601			1.86					1.785
1600			1.685					
1599			1.875					
1598			1.945					
1597			1.59					
1596			2.41					
1595			1.105					
1594			4.645					
1593			3.03					
1592			2.57					
1591			2.03					
1590			1.91					
1589			3.78					

Year	Old2	OTE2	OTE	TT2	TT	WIA2
2013		0.75	0.74	2.73	0.71	0.26
2012		0.8	0.87	1.22	0.645	0.275
2011		0.965	0.79	1.035	0.465	0.43
2010		0.94	0.59	0.835	0.655	0.39
2009		0.92	0.565	0.45	0.565	0.345
2008		0.955	0.225	1.325	0.64	0.485
2007		0.275	0.535	0.73	0.6	0.265
2006		0.845	0.275	0.615	0.49	0.565
2005		0.545	0.365	0.495	0.645	0.33
2004		0.55	0.135	0.455	0.96	0.45
2003		0.35	0.205	0.755	0.825	0.395
2002		0.435	0.565	3.57	0.825	0.35
2001		0.99	0.685	0.715	0.625	0.695
2000		1.46	0.565	0.745	0.66	1.115
1999		2.09	0.385	0.955	1.13	0.845
1998		0.76	0.385	0.495	1.435	0.54
1997		0.79	0.38	0.52	0.735	0.61
1996	0.325	0.9	0.37	0.46	0.46	0.575
1995	0.42	1.23	0.58	0.42	0.445	0.61
1994	0.405	1.14	0.305	0.305	0.33	0.89
1993	0.39	0.875	0.3	0.32	0.34	0.565
1992	0.7	0.665	0.325	0.345	0.465	0.615
1991	0.605	1.17	0.145	0.355	0.475	0.47
1990	0.25	1.075	0.27	0.53	0.65	0.565
1989	0.35	0.835	0.21	0.78	0.405	0.53
1988	0.19	0.895	0.275	0.81	0.355	0.445
1987	0.77	0.94	0.265	1.04	0.845	0.48
1986	0.29	1.47	0.51	2.035	1.32	0.395
1985	0.51	1.105	0.905	1.12	1.095	0.495
1984	0.245	1.83	0.685	0.565	0.88	0.63
1983	0.88	1.925	1.035	0.645	1.77	0.495
1982	0.48	1.645	1.225	0.295	0.845	0.88
1981	0.56	1.855	0.825	0.18	0.82	0.885
1980	0.56	1.125	1	0.485	0.85	0.945
1979	1.015	1.44	0.55	0.845	0.705	1.095
1978	0.63	1.37	0.93	0.655	0.85	0.65

Year	Old2	OTE2	OTE	TT2	TT	WIA2
1977	0.675	1.41	0.87	0.925	0.315	0.94
1976	0.445	1.59	0.98	1.35	0.37	0.97
1975	0.43	1.37	1.15	1.355	0.635	1.105
1974	0.36	1.175	1.11	0.87	1.005	1.075
1973	0.385	1.84	1	0.78	1.035	1.005
1972	0.52	1.8	1.56	0.8	0.98	0.73
1971	0.37	1.535	1.565	0.805	0.925	1.105
1970	0.48	1.565	1.21	0.565	0.76	1.325
1969	0.31	1.76	1.075	0.925	0.9	0.91
1968	0.25	1.565	1.095	0.795	0.67	0.785
1967	0.485	1.495	1.17	1.14	0.915	0.895
1966	0.375	2.045	0.95	0.7	0.95	0.84
1965	0.63	1.735	1.21	0.655	1.79	0.815
1964	0.415	1.985	0.97	0.71	0.91	1.245
1963	0.61	1.57	1.085	0.66	1.01	1.17
1962	0.385	1.24	0.765	0.51	0.975	1.28
1961	0.575	1.24	0.905	0.475	0.92	0.97
1960	0.56	0.93	0.72	0.57	0.735	0.9
1959	0.38	0.665	0.57	0.83	0.675	0.775
1958	0.69	0.6	0.57	1.44	0.815	0.745
1957	0.555	0.66	0.425	1.435	1.115	0.83
1956	0.84	1.165	0.47	2.63	1.36	1.15
1955	0.94	1.815	0.875	1.255	1.955	1.155
1954	0.735	1.6	1.27	1.345	1.6	1.11
1953	0.975	2.025	1.07	1.075	1.495	1.88
1952	0.69	2.565	1.645	1.135	2.12	1.55
1951	0.69	2.285	1.575	1.17	2.945	1.32
1950	0.825	3.21	1.525	1.44	1.45	1.825
1949	0.82	2.3	1.755	1.375	0.805	1.685
1948	0.7	2.185	1.445	0.895	1.095	1.835
1947	0.835	1.695	1.57	1.885	1.215	2.075
1946	0.6	2.275	1.34	1.255	1.135	1.88
1945	0.515	2.065	1.43	1.295	0.96	1.815
1944	0.355	1.58	1	0.715	0.82	2.405
1943	0.65	1.51	0.89	0.825	1.39	1.97
1942	0.625	1.845	0.88	0.625	1.795	1.605
1941	0.67	1.37	1.005	0.8	2.69	1.275

Year	Old2	OTE2	OTE	TT2	TT	WIA2
1940	0.53	2.285	1.03	0.79	1.1	1.92
1939	0.445	1.305	1.265	1.02	1.115	1.795
1938	0.47	1.68	0.585	0.805	0.735	2.07
1937	0.665	1.335	1.02	1.03	1.07	1.305
1936	0.605	1.565	0.65	3.47	0.935	1.155
1935	0.58	1.915	1.115	0.655	1.08	0.88
1934	0.53	1.975	1.295	1.115	1.015	1.16
1933	0.525	1.77	1	0.985	1.095	1.19
1932	0.92	1.67	1.12	1.29	1.655	3.14
1931	0.575	2.525	1.68	1.4	1.08	1.37
1930	0.575	1.975	1.555	0.945	1.275	1.655
1929	0.685	1.59	0.945	0.935	1.53	1.405
1928	0.66	1.6	0.92	1.3	2.05	0.84
1927	0.635	1.945	1.025	3.74	1.135	0.975
1926	0.765	1.425	0.715	1.015	0.885	1.295
1925	0.735	1.46	1.025	1.14	0.46	0.98
1924	1.215	1.51	0.87	1.27	1.73	0.92
1923	0.69	1.1	0.58	1.465	1.55	0.995
1922	0.54	0.995	0.585	1.635	1.415	0.89
1921	0.935	1.64	1.21	1.495	2.215	0.94
1920	0.835	1.56	1.135	3.865	1.745	1.235
1919	0.885	2.33	1.925	2.31	2.345	0.935
1918	0.975	2.245	1.385	1.825	1.61	1.615
1917	1.05	1.83	1.39	1.735	1.535	1.675
1916	0.62	2.04	1.425	1.29	1.445	1.425
1915	0.765	1.85	1.325	1.33	1.7	1.42
1914	0.79	1.685	1.245	0.83	1.78	1.63
1913	0.835	1.87	1.43	1.42	1.385	1.55
1912	0.95	1.9	1.465	2.415	1.47	1.885
1911	0.84	2.6	2.1	2.01	2.125	1.53
1910	0.76	2.835	2.075	3.22	2.21	1.925
1909	0.76	2.1	1.485	2.495	1.905	2.435
1908	0.505	1.83	1.405	1.435	1.755	1.965
1907	0.605	1.665	1.045	2.61	1.695	4.245
1906	0.68	1.285	1.07	1.605	1.455	2.02
1905	0.565	0.775	0.68	1.055	0.745	1.535
1904	0.805	1.63	1.36	1.73	1.705	2.27

Year	Old2	OTE2	OTE	TT2	TT	WIA2
1903	0.37	1.98	1.705	1.495	2.33	3.285
1902	0.325	1.49	1.425	0.43	2.69	2.62
1901	0.525	1.74	1.85	0.44	3.035	2.765
1900	0.5	1.425	1.655	1.055	1.5	2.275
1899	0.29	0.93	1.195	1.11	1.14	1.4
1898	0.42	1.12	1.09	0.65	1.74	1.84
1897	0.45	0.545	0.45	2.075	0.93	1.37
1896	0.58	0.72	0.645	1.975	0.745	0.835
1895	0.56	0.995	0.73	1.81	1.035	1.22
1894	0.435	0.975	0.34	3.09	0.985	1.085
1893	0.635	0.26	0.235	2.8	0.585	0.94
1892	0.67	0.99	0.615	1.175	0.975	1.045
1891	0.36	0.78	0.405	1.395	1.19	1.54
1890	0.45	0.34	0.205	2.21	0.78	0.465
1889	0.5	1.085	0.785	3.015	0.55	2.38
1888	0.27	0.685	0.415	2.995	0.52	1.91
1887	0.575	0.83	0.365	4.055	0.545	1.285
1886	0.59	1.265	0.68	2.74	0.625	2.08
1885	0.465	1.28	0.8	1.83	0.535	2.615
1884	0.28	0.945	0.35	1.74	0.725	1.21
1883	0.59	1.845	1.315	1.53	0.66	2.02
1882	0.285	2.57	1.89	1.695	0.65	1.495
1881	0.195	2.695	1.955	2.17	0.655	1.53
1880	0.315	2.175	1.27	2.73	0.805	1.365
1879	0.3	2.655	2.04	1.545	0.43	2.57
1878	0.265	2.055	1.57	1.805	0.31	2.07
1877	0.3	2.035	1.155	1.455	0.355	1.81
1876	0.335	1.785	1.43	0.675	0.245	2.095
1875	0.31	1.585	1.355	1.24	0.355	1.87
1874	0.195	1.635	1.265	1.54	0.785	1.675
1873	0.68	2.355	1.84	2.53	0.79	1.985
1872	0.235	2.01	1.74	2.47	0.295	2.03
1871	0.26	1.315	1.335	2.025	0.535	1.71
1870	0.18	1.26	1.145	1.98	0.385	1.6
1869	0.215	1.12	1.125	2.24	0.34	1.52
1868	0.2	0.72	0.605	1.365	0.46	0.57
1867	0.52	0.755	0.545	1.45	1.365	0.315

Year	Old2	OTE2	OTE	TT2	TT	WIA2
1866	0.455	0.47	2.485	0.65	1.205	1.53
1865	0.495	0.26	1.535	3.755	1.245	1.75
1864	0.39	0.21	1.84	3.34	0.8	1.735
1863	0.645	0.635	1.425	2.12	1.255	1.68
1862	0.69	1.715	0.995	2.26	1.24	1.605
1861	0.715	2.085	0.61	1.575	0.885	0.96
1860	0.53	1.665	2.095	3.18	0.87	2.53
1859	0.415	1.345	1.56	2.345	0.485	2.445
1858	0.565	0.73	1.175	1.935	1.495	1.855
1857	0.71	2.72	1.255	2.82	1.32	1.7
1856	0.485	1.895	0.83	2.53	0.8	1.52
1855	0.67	1.445	1.25	3.85	0.905	2.09
1854	0.625	1.6	0.89	5.08	0.775	1.53
1853	0.56	1.18	1.145	2.73	1.24	1.725
1852	0.97	2.06	1.29	4.62	0.885	1.77
1851	1.23	1.2	1.08	3.22	0.925	1.375
1850	0.395	1.2	1.68	5.345	1	1.705
1849	1.165	1.25	1.895	6.045	0.975	2.17
1848	0.905	0.99	1.215	5.595	1.36	1.165
1847	1.155	1.86	1.96	4.925	2.125	2.085
1846	1.07	2.34	1.82	4.63	1.205	1.555
1845	0.95	1.365	3.135	5.36	1.955	2.37
1844	0.675	2.435	2.685	5.475	1.785	2.78
1843	0.88	2.175	2.49	4.535	2.65	2.18
1842	0.81	3.54	1.935	4.105	2.885	2.12
1841	1.015	3.225	1.93	4.16	3.225	1.56
1840	0.885	2.765	2.47	5.225	2.065	2.645
1839	0.735	2.585	2.45	2.805	1.61	2.27
1838	0.81	2.275	2.125	5.29	1.995	2.02
1837	0.74	2.935	2.17	3.525	1.755	1.905
1836	0.71	3.305	2.19	2.215	1.265	8.75
1835	0.695	2.75	2.565	3.82	1.145	1.925
1834	0.49	2.25	2.71	4.57	1.185	1.435
1833	0.605	2.43	2.04	6.555	1.285	1.575
1832	0.465	2.84	1.455	6.755	1.375	0.845
1831	0.58	3.01	1.405	5.155	1.365	1.455
1830	0.36	0.305	0.99	4.49	1.075	1.925

Year	Old2	OTE2	OTE	TT2	TT	WIA2
1829	0.59	0.255	0.8	2.77	1.01	2.07
1828	0.47	2.16	1.215	3.16	1.31	2.6
1827	0.81	2.365	1.89	3.295	0.72	1.795
1826	0.625	1.98	1.815	2.435	1.565	3.1
1825	0.9	1.575	2.07	2.81	2.935	2.77
1824	0.95	0.935	2.395	3.015	2.505	1.61
1823	0.595	1.58	2.37	2.24	2.375	2.705
1822	0.78	2.015	2.97	1.635	1.75	3.735
1821	0.68	1.71	2.01	2.045	2.04	2.67
1820	0.6	1.785	2.295	2.375	4.755	3.03
1819	0.61	2.15	2.285	3.03	2.01	2.725
1818	0.64	2.195	2.18	1.75	2.35	2.875
1817	0.735	2.845	1.92	1.615	2.085	3.195
1816	0.775	1.9	1.685	1.65	1.805	2.56
1815	0.595	2.615	1.86	2.845	2.24	2.405
1814	0.355	2.37	2.415	3.59	2.17	2.705
1813	0.38	2.12	1.455		2.83	3.66
1812	0.83	1.38	0.885		1.835	4.64
1811	0.705	1.895	1.55		2.445	4.725
1810	0.76	1.66	2.315		2.045	4.07
1809	0.565	0.99	2.91		3.4	3.345
1808	0.6	0.335	3.095		3.14	4.695
1807	0.695	1.48	2.745		4.875	3.815
1806	0.485	0.83	2.81		4.305	4.81
1805	0.58	1.38	3.31		4.26	4.33
1804	0.86	1.88	1.61		2.46	4.39
1803	0.705	2.92	5.01		5.54	7.935
1802	0.89	2.77	3.45		1.605	8.51
1801	0.99	2.1	3.35		1.595	
1800	0.865	3.01	3.805		2.15	
1799	0.73	3.095	2.46		2.205	
1798	0.775	1.845	3.83		2.94	
1797	0.59	2.85	3.285		2.585	
1796	0.71	2.645	3.785		3.62	
1795	0.73	2.77	3.69		3.875	
1794	0.66	2.455	3.535		3.495	
1793	0.58	3.06	3.97		4.075	

Year	Old2	OTE2	OTE	TT2	TT	WIA2
1792	0.505	2.79	3.545		4	
1791	0.69	2.37	2.825		3.065	
1790	0.5	1.78	3.08		2.805	
1789	0.58	1.41	2.925		2.775	
1788	0.705	2.15	2.375		1.26	
1787	0.61	2.325	2.08		0.695	
1786	0.695	2.23	2.685		0.73	
1785	0.68	2.115	2.195		0.605	
1784	0.71	2.255	1.995		3.375	
1783	0.54	2.075			0.595	
1782	0.55	1.98			1.865	
1781	0.78	1.565			3.46	
1780	0.72	2.195			5.59	
1779	0.645	1.625			1.79	
1778	0.755	1.88			1.72	
1777	0.57	1.345			2.225	
1776	0.575	1.54			2.48	
1775	0.575	1.67			3.68	
1774	0.655	1.17			3.535	
1773	0.485				3.595	
1772	0.2				2.55	
1771	0.505				1.3	
1770	0.585				2.005	
1769	0.505				2.495	
1768	0.405				3.095	
1767	0.33				3.16	
1766	0.535				3.36	
1765	0.36				5.885	
1764	0.24				2.185	
1763	0.435				1.47	
1762	0.425					
1761	0.195					
1760	0.45					
1759	0.45					
1758	0.375					
1757	1.26					
1756	0.28					

Year	Old2	OTE2	OTE	TT2	TT	WIA2
1755	0.265					
1754	0.28					
1753	0.18					
1752	0.185					
1751	0.335					
1750	0.3					
1749	0.325					
1748	0.335					
1747	0.305					
1746	0.385					
1745	0.425					
1744	0.62					
1743	0.575					
1742	0.64					
1741	0.615					
1740	0.435					
1739	0.44					
1738	0.445					
1737	0.325					
1736	0.355					
1735	0.265					
1734	0.26					
1733	0.305					
1732	0.335					
1731	0.35					
1730	0.29					
1729	0.43					
1728	0.425					
1727	0.39					
1726	0.395					
1725	0.265					
1724	0.34					
1723	0.405					
1722	0.63					
1721	0.62					
1720	0.585					
1719	0.33					

Year	Old2	OTE2	OTE	TT2	TT	WIA2
1718	0.79					
1717	0.5					
1716	0.745					
1715	0.515					
1714	0.45					
1713	0.65					
1712	0.485					
1711	0.365					
1710	0.395					
1709	0.605					
1708	0.56					
1707	0.39					
1706	0.31					
1705	0.705					
1704	0.73					
1703	0.66					
1702	0.56					
1701	1.15					
1700	0.445					
1699	0.51					
1698	0.5					
1697	0.825					
1696	0.37					
1695	0.325					
1694	0.49					
1693	0.595					
1692	0.495					
1691	0.65					
1690	0.355					
1689	0.305					
1688	0.535					
1687	0.715					
1686	0.4					
1685	0.81					
1684	0.955					
1683	1.235					
1682	0.815					

Year	Old2	OTE2	OTE	TT2	TT	WIA2
1681	0.695					
1680	0.795					
1679	0.815					
1678	0.965					
1677	0.54					
1676	0.435					
1675	0.435					
1674	1.465					
1673	0.455					
1672	0.32					
1671	0.8					
1670	0.875					
1669	0.95					
1668	0.76					
1667	1.18					
1666	1.08					
1665	1.245					
1664	1.25					
1663	1.57					
1662	1.18					
1661	0.855					
1660	1.005					
1659	1.175					
1658	1.055					
1657	1.325					
1656	1.515					
1655	1.01					
1654	0.745					
1653	1.035					
1652	0.99					
1651	0.96					
1650	0.8					
1649	0.82					
1648	0.945					
1647	0.72					
1646	1.105					
1645	1.325					

Year	Old2	OTE2	OTE	TT2	TT	WIA2
1644	1.21					
1643	1.565					
1642	1.575					
1641	1.37					
1640	1.475					
1639	1.585					
1638	1.31					
1637	1.385					
1636	1.795					
1635	1.82					
1634	1.71					
1633	1.755					
1632	1.665					
1631	1.54					
1630	1.26					
1629	1.41					
1628	1.705					
1627	1.585					
1626	1.94					
1625	1.92					
1624	2.335					
1623	2.26					
1622	2.055					
1621	1.085					
1620	2.305					
1619	2.15					
1618	2.42					
1617	2.46					
1616	2.05					
1615	2.195					
1614	1.51					
1613	2.195					
1612	1.95					
1611	2.005					
1610	1.77					
1609	2.425					
1608	2.545					

Year	Old2	OTE2	OTE	TT2	TT	WIA2
1607	2.485					
1606	2.69					
1605	2.35					
1604	0.875					
1603						
1602						
1601						
1600						
1599						
1598						
1597						
1596						
1595						
1594						
1593						
1592						
1591						
1590						
1589						
1588						
1587						
1586						

APPENDIX B

REGRESSION OUTPUT

Res_Detrend = 2.252 - (0.0204 * AverageLanderTemp)

N = 66 R = 0.414 Rsqr = 0.172 Adj Rsqr = 0.159 Standard Error of Estimate = 0.084

	Coefficient	**Std. Error**	**t**	**P**	**Std. Coeff.**	**VIF**
Constant	2.252	0.359	6.270	<0.001		
AverageLanderTemp	-0.0204	0.00560	-3.641	<0.001	-0.414	1.000

Analysis of Variance:

	DF	**SS**	**MS**	**F**	**P**
Regression	1	0.0947	0.0947	13.260	<0.001
Residual	64	0.457	0.00714		
Total	65	0.551	0.00848		

The dependent variable Res_Detrend can be predicted from a linear combination of the independent variables:

	P
AverageLanderTemp	<0.001

All independent variables appear to contribute to predicting Res_Detrend (P < 0.05).

PRESS = 0.488

Durbin-Watson Statistic = 1.411 Failed

Normality Test (Shapiro-Wilk) Passed (P = 0.706)

Constant Variance Test: Passed (P = 0.083)

Power of performed test with alpha = 0.050: 0.938

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Regression Diagnostics:

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Row	Predicted	Residual
1	0.942	0.0962
2	0.955	0.189
3	1.043	0.102
4	1.016	-0.0732
5	0.953	0.0305
6	0.961	0.0738
7	0.933	0.0314
8	0.933	0.0644
9	0.929	-0.0356
10	0.970	-0.00435
11	0.946	-0.0574
12	0.943	-0.0908
13	0.925	-0.0830
14	0.911	0.108
15	0.971	0.0186
16	0.936	0.0988
17	0.962	0.0753
18	0.993	0.0102
19	0.921	-0.0924
20	0.999	-0.0254
21	1.005	-0.0570
22	0.936	0.107
23	0.920	0.101
24	0.949	0.0361
25	0.978	0.00701
26	0.955	-0.0561
27	0.951	-0.0205
28	1.008	0.0785
29	0.956	-0.0341
30	0.940	-0.0943
31	0.990	0.0923
32	0.970	0.00765
33	0.954	0.0480

Row	Predicted	Residual
34	0.938	0.0403
35	0.943	-0.00383
36	0.958	0.175
37	0.904	0.0429
38	0.900	0.0815
39	0.932	-0.0361
40	0.926	-0.157
41	0.855	-0.154
42	0.942	-0.118
43	0.931	0.00389
44	0.928	-0.103
45	0.956	-0.116
46	1.003	-0.0855
47	0.875	0.00546
48	0.983	-0.0141
49	0.919	-0.00439
50	0.951	0.0150
51	0.974	-0.0534
52	0.966	0.0312
53	0.901	0.0940
54	0.878	0.0534
55	0.923	0.0105
56	0.906	-0.200
57	0.983	-0.0336
58	0.948	-0.104
59	0.869	0.0336
60	0.882	0.121
61	0.950	-0.198
62	0.983	-0.0496
63	0.986	-0.00164
64	0.955	0.0349
65	0.869	0.0821
66	0.882	-0.0457

=================

Influence Diagnostics:

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Row	DFFITS
1	0.143
2	0.300
3	0.470
4	-0.244
5	0.0458
6	0.119
7	0.0484
8	0.0998
9	-0.0570
10	-0.00776
11	-0.0846
12	-0.135
13	-0.139
14	0.219
15	0.0337
16	0.150
17	0.122
18	0.0249
19	-0.162
20	-0.0677
21	-0.164
22	0.163
23	0.179
24	0.0533
25	0.0139
26	-0.0857
27	-0.0306
28	0.235
29	-0.0524
30	-0.141
31	0.217

Row	DFFITS
32	0.0137
33	0.0728
34	0.0602
35	-0.00563
36	0.282
37	0.0942
38	0.192
39	-0.0561
40	-0.266
41	-0.656
42	-0.177
43	0.00608
44	-0.168
45	-0.179
46	-0.243
47	0.0178
48	-0.0299
49	-0.00780
50	0.0224
51	-0.101
52	0.0528
53	0.217
54	0.168
55	0.0178
56	-0.449
57	-0.0709
58	-0.156
59	0.117
60	0.363
61	-0.309
62	-0.105
63	-0.00360
64	0.0533
65	0.289
66	-0.136

=================

% Confidence Intervals:

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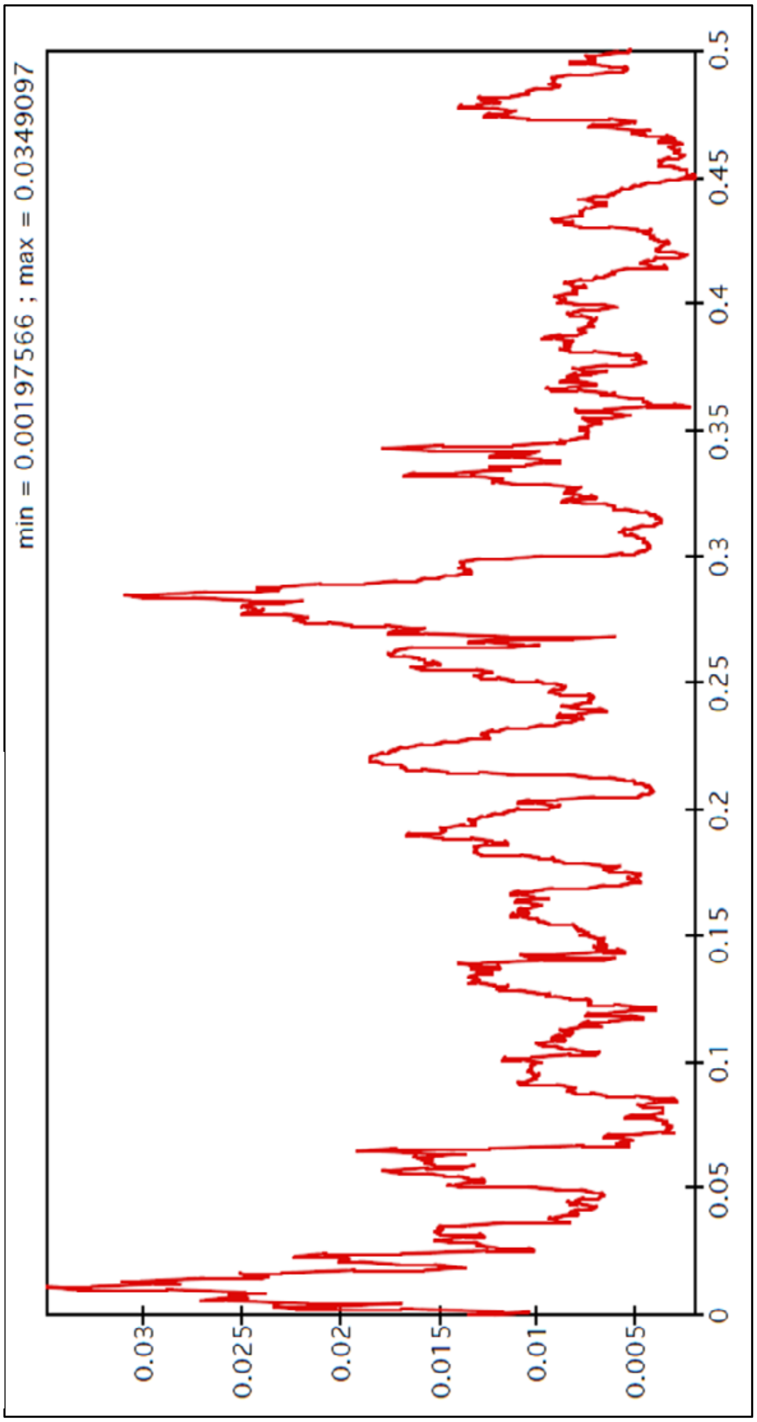
Row	Predicted	80% Conf-L	80% Conf-U	80% Pred-L	80% Pred-U
1	0.942	0.928	0.955	0.832	1.052
2	0.955	0.941	0.968	0.844	1.065
3	1.043	1.005	1.080	0.927	1.158
4	1.016	0.987	1.045	0.903	1.129
5	0.953	0.939	0.966	0.842	1.063
6	0.961	0.946	0.976	0.851	1.072
7	0.933	0.919	0.947	0.822	1.043
8	0.933	0.919	0.947	0.822	1.043
9	0.929	0.914	0.943	0.818	1.039
10	0.970	0.954	0.987	0.860	1.081
11	0.946	0.933	0.960	0.836	1.057
12	0.943	0.929	0.956	0.833	1.053
13	0.925	0.910	0.940	0.815	1.035
14	0.911	0.893	0.929	0.800	1.022
15	0.971	0.955	0.988	0.861	1.082
16	0.936	0.922	0.950	0.826	1.046
17	0.962	0.947	0.976	0.851	1.072
18	0.993	0.971	1.015	0.881	1.104
19	0.921	0.906	0.937	0.811	1.032
20	0.999	0.976	1.023	0.887	1.111
21	1.005	0.980	1.030	0.893	1.117
22	0.936	0.922	0.950	0.826	1.046
23	0.920	0.904	0.936	0.810	1.031
24	0.949	0.935	0.962	0.839	1.059
25	0.978	0.960	0.996	0.867	1.089
26	0.955	0.941	0.969	0.845	1.065
27	0.951	0.938	0.965	0.841	1.062
28	1.008	0.981	1.034	0.895	1.120
29	0.956	0.942	0.970	0.846	1.066
30	0.940	0.927	0.954	0.830	1.051
31	0.990	0.969	1.011	0.878	1.101
32	0.970	0.954	0.987	0.860	1.081
33	0.954	0.940	0.968	0.844	1.064
34	0.938	0.924	0.951	0.827	1.048
35	0.943	0.929	0.956	0.833	1.053

Row	Predicted	80% Conf-L	80% Conf-U	80% Pred-L	80% Pred-U
36	0.958	0.943	0.972	0.847	1.068
37	0.904	0.884	0.924	0.793	1.015
38	0.900	0.879	0.920	0.788	1.011
39	0.932	0.918	0.946	0.822	1.042
40	0.926	0.910	0.941	0.815	1.036
41	0.855	0.820	0.889	0.740	0.969
42	0.942	0.929	0.956	0.832	1.053
43	0.931	0.917	0.945	0.821	1.041
44	0.928	0.913	0.942	0.817	1.038
45	0.956	0.942	0.970	0.845	1.066
46	1.003	0.979	1.028	0.891	1.116
47	0.875	0.846	0.903	0.762	0.988
48	0.983	0.964	1.002	0.872	1.094
49	0.919	0.903	0.936	0.809	1.030
50	0.951	0.937	0.965	0.841	1.061
51	0.974	0.957	0.992	0.864	1.085
52	0.966	0.950	0.981	0.855	1.076
53	0.901	0.880	0.922	0.790	1.012
54	0.878	0.850	0.905	0.765	0.990
55	0.923	0.908	0.939	0.813	1.034
56	0.906	0.886	0.925	0.795	1.017
57	0.983	0.964	1.002	0.872	1.094
58	0.948	0.935	0.962	0.838	1.059
59	0.869	0.839	0.899	0.756	0.983
60	0.882	0.856	0.908	0.770	0.995
61	0.950	0.937	0.964	0.840	1.061
62	0.983	0.964	1.002	0.872	1.094
63	0.986	0.966	1.005	0.874	1.097
64	0.955	0.941	0.969	0.845	1.065
65	0.869	0.839	0.899	0.755	0.982
66	0.882	0.856	0.908	0.769	0.994

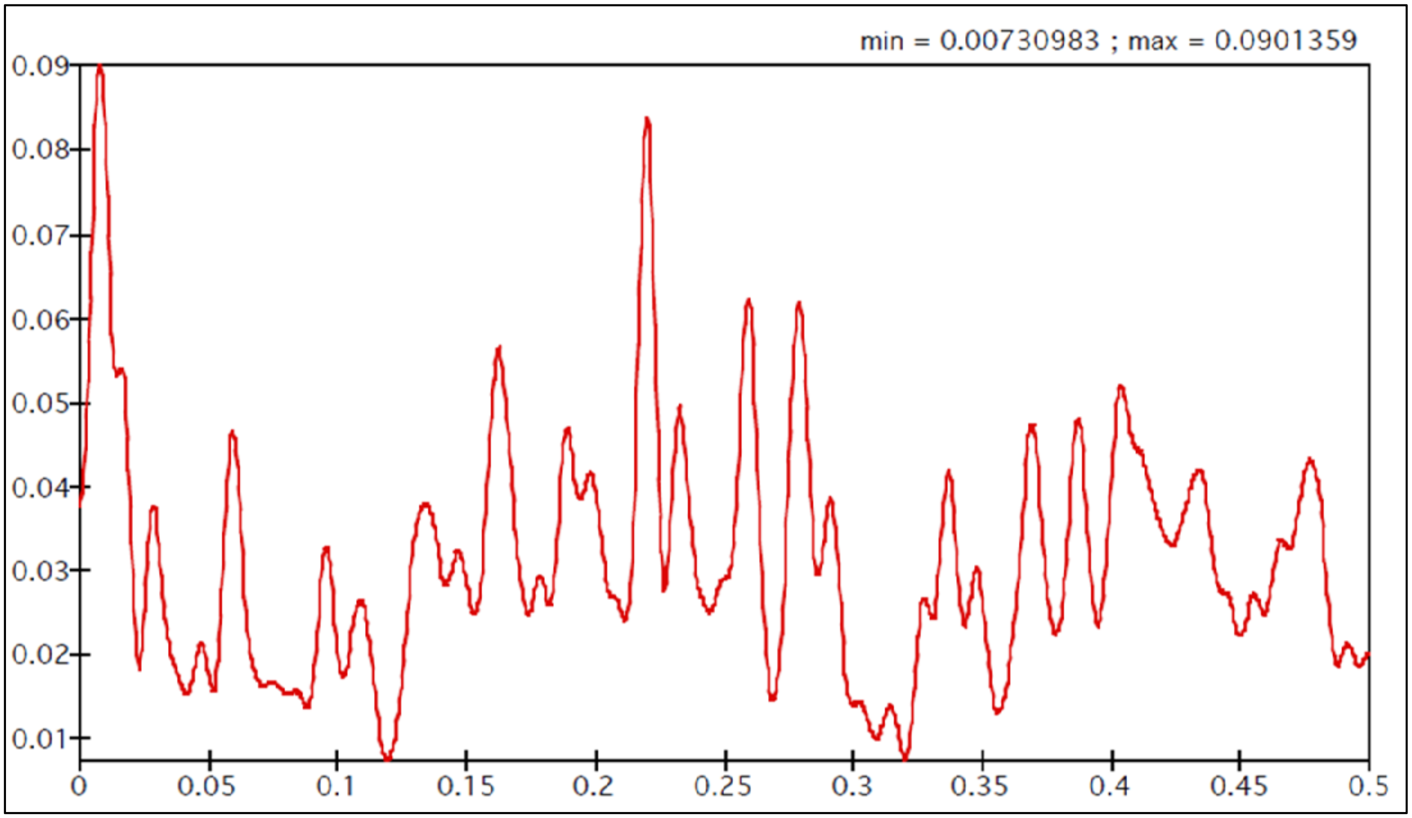
APPENDIX C

ANALYSERIES OUTPUT

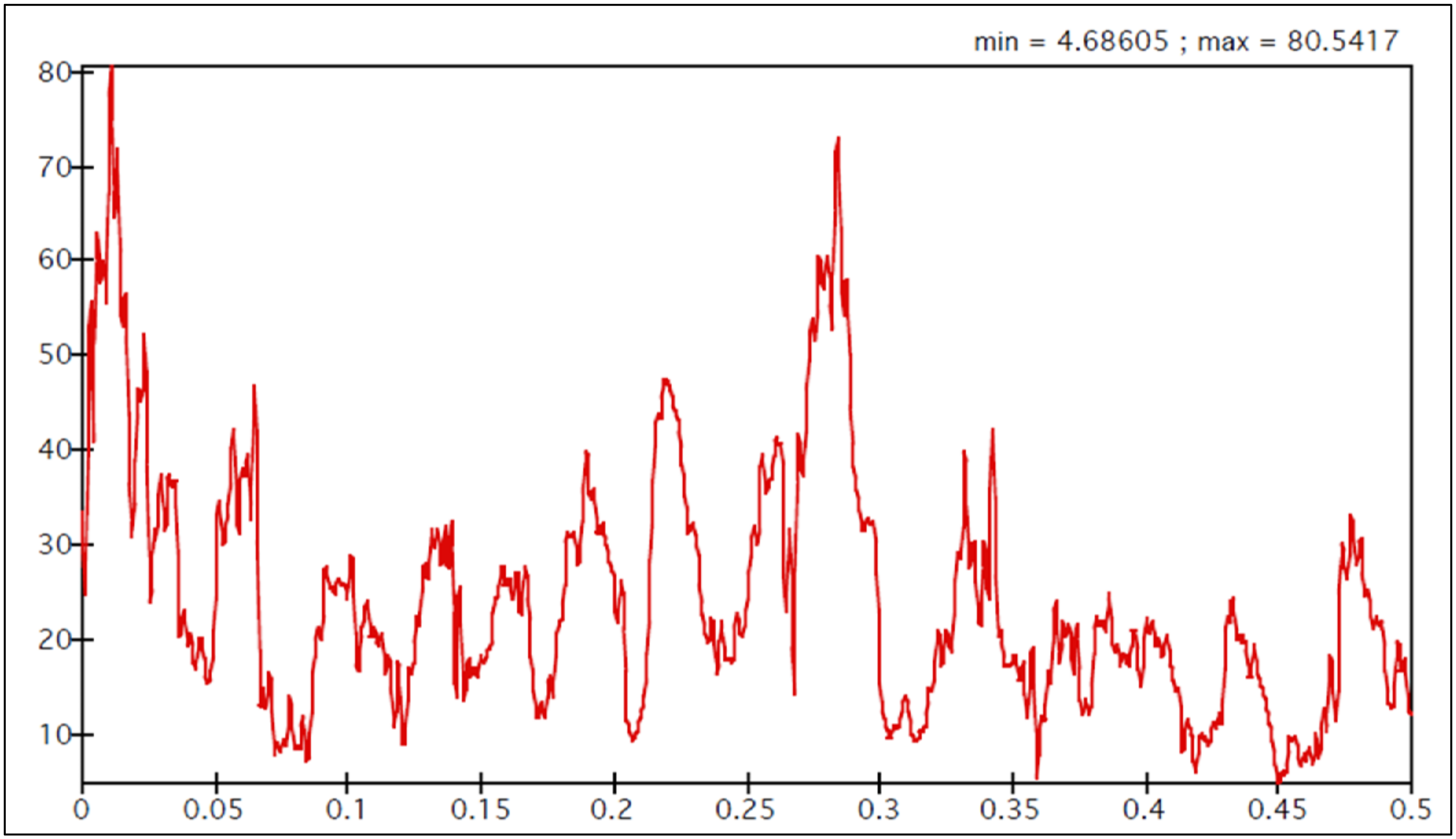
Multi-taper Method- Detrended Chronology



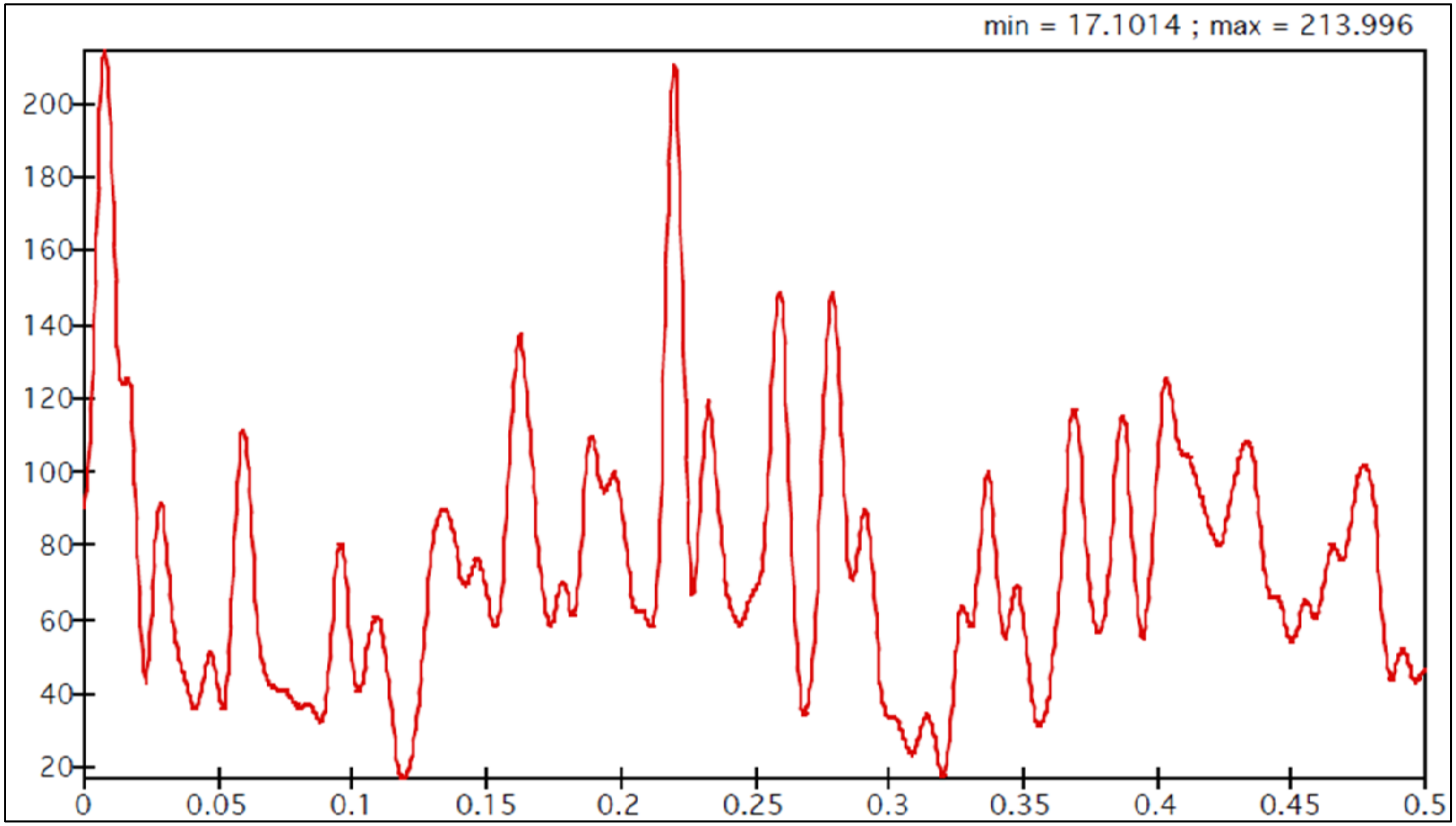
Blackman-Tukey Detrended Chronology



Multi-taper Temperature Reconstruction



Blackman-Tukey Temperature Reconstruction



APPENDIX D

DECADE TEMPERATURES

Decades	Decade Temperature (°F)	Decades	Decade Temperature (°F)
1840-1849	57	1780-1789	62
1910-1919	58	1680-1689	62
1790-1799	58	1710-1719	62
1620-1629	59	1970-1979	63
1590-1599	60	1960-1969	63
1610-1619	60	1740-1749	63
1800-1809	60	1920-1929	63
1900-1909	60	1950-1959	63
1600-1609	60	1810-1819	63
1940-1949	60	1860-1869	64
1770-1779	60	1870-1879	64
1930-1939	60	1850-1859	64
1650-1659	60	1760-1769	64
1700-1709	61	1660-1669	64
1720-1729	61	2010-2013	64
1830-1839	61	1890-1899	64
1640-1649	62	1690-1699	65
1670-1679	62	1880-1889	65
1820-1829	62	1750-1759	65
1730-1739	62	1980-1989	65
1630-1639	62	1990-1999	65
		2000-2009	67

APPENDIX E

SINGLE YEAR TEMPERATURES

Year	Reconstructed Temperature (°F)	Year	Reconstructed Temperature (°F)
1931	54	1934	60
1918	54	1929	60
1909	54	1911	60
1917	54	1939	60
1950	54	1970	60
1949	54	1961	60
1983	55	1945	61
1910	55	1925	61
1947	56	1940	61
1907	56	1965	61
1915	56	2007	61
1937	57	1921	61
1930	57	1932	61
1919	57	1980	61
1975	57	1912	61
1978	57	1955	62
1938	58	1999	62
1923	58	1941	62
1901	58	2000	62
1900	58	1962	62
1913	58	2011	62
1902	58	1942	62
1906	59	1971	62
1924	59	1972	62
1946	59	2010	62
1969	59	1952	62
1916	60	1904	62
1948	60	1985	62
1964	60	1979	62
1914	60	1981	62
1953	60	1967	63
1963	60	1936	63

Year	Reconstructed Temperature (°F)	Year	Reconstructed Temperature (°F)
1957	63	1973	66
1997	63	1986	66
1954	63	1956	67
1908	63	1958	67
2012	64	1935	67
2004	64	1920	67
1968	64	1994	67
1984	64	1933	68
1944	64	1922	69
1951	64	1959	69
1928	64	1977	69
1982	64	2005	69
1990	65	1960	69
2002	65	1992	69
2009	65	2013	69
1943	65	1966	70
1974	65	1991	70
2001	65	1989	70
1976	65	1905	71
1998	65	1987	73
1926	65	2008	74
1993	65	2003	76
1996	66	1988	76
1927	66		