A Comparison of Paleoclimate Reconstructions for a Variety of Climate Proxies in North America and Europe

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March 02, 2015
1. Introduction

Scientists have been trying to understand the natural variability of Earth’s climate for many years. The most common method to developing a paleoclimate record is with the use of various proxy data. A focal point for understanding the natural variability of the climate system is global and regional temperature anomalies. Observations from climate proxies do not directly compute temperature anomaly, but instead are regressed with a temperature observational record to reconstruct a paleoclimatic temperature record. While paleoclimate reconstructions from climate data are insightful for understanding the evolution of Earth’s climate, the accuracy of the proxy data and the regression model constructed to develop the paleoclimate temperature record are critical for qualitatively assessing the veracity of the derived climate record.

Many regional, hemispheric, and global temperature reconstructions have been developed using climate proxy data, but the calculated temperature anomalies don’t always agree between methods. The variability between proxies and statistical approaches is widely recognized, but not yet understood. This project was designed to look at various climate proxies and their resulting temperature reconstruction in comparison with each other and peer-reviewed climate reconstructions for the same domain.

2. Previous Work

The work for this project was based off the work of Büntgen et. al (2011) and Viau et. al (2006). Between these two studies, multiple climate proxies were used. The first project reconstructed temperature anomalies in Central Europe for the last 2500 years using a collection of tree ring data with 2619 samples in Southeast Germany (SEG), 1775 samples in Northeast Germany (NEG), and 2880 samples in Northeast France (NEF). Tree ring segments from historical oak datasets in three distinct regions were used from ∼500 B.C. to 1936 to create a single temperature reconstruction from 500 B.C. - 2008 A.D. The samples were collocated temporally using the innermost ring for alignment with other tree ring samples. Different species were used to complete the recent portion of the temperature reconstruction; however, raw data from these cores was not readily available. In this study, tree ring width was used to derive a regression algorithm that was tweaked to include

Viau et. al (2006) recreate North American mean July Temperatures using pollen records; however, the reconstruction is compared to higher resolution paleoclimate data to identify trends in the variability. While the raw data was not provided for the pollen samples, raw values were provided for the nine other climate proxies, five of which were used in this project. A combination of ice cores, sediment cores, and tree ring data were utilized as a metric for the performance of the temperature reconstruction developed from pollen samples.

The ice core proxy data used for this project is over 3,000 meters in depth and was extracted as a part of the Greenland Ice Sheet Project Two (GISP2) project located at 72.6 °N and 38.5 °W (Mayewski et al., 1994). Ice core proxies preserve past climate conditions through annual snow accumulation, which contains temporal information on ion species composition. For this project, ratios of δ18O and concentrations of Na were used to develop a linear regression model. δ18O represents the ratio of oxygen isotopes 16O and 18O and uses the fact that water with higher concentrations of 16O is easier to evaporate than water with 18O. During ice ages, more water is locked up in ice caps on land and therefore, concentrations of δ18O are higher during ice ages in the ocean. Concentrations of sea salt are also contained in the ice core record and similar to δ18O, sea salt concentrations increase during ice ages in the ocean (Mayewski et. al, 1994).

Sediment core proxy data used in this project are located near 55 °N and 14 °W at the MC52-VM29-191 site. The sediment cores provide information on the North Atlantic drift ice and δ18O ratios (Bond et. al, 2001). δ18O ratios were discussed in the previous paragraph and the same information can be obtained from the ocean bed sediment. In the ocean, however, 18O and 16O are deposited by sea creatures that use H₂O to make CaCO₃ in their shells. When these creatures die and their shells fall to the sea floor, temporal information of δ18O ratios can be obtained. North Atlantic drift ice proxies utilize concentrations of three petrologic tracers (Hematite-stained grains, Icelandic glass, and Detrital carbonate) transported by icebergs. These tracers are sensitive to the amount of global ice concentrations being advected on the ocean surface by ocean currents. Sediment core temporal resolution is not as great as in ice cores and is typically used for more longer paleoclimate temperature reconstructions.
Width of tree rings can be used to discern paleoclimate conditions, but atmospheric $^{14}C$ production can also be derived from tree rings. Changes in $^{14}C$ concentrations in the tree cores provide a record of $^{14}C$ production; however, the data provided was “corrected for marine and terrestrial reservoir effects. (Bond et. al, 2001)”. For atmospheric $^{14}C$ production, higher production rates are associated with glacial periods (Bond et. al, 2001). The $^{14}C$ production data has a temporal resolution of 70 years.

3. Methods

Temperature reconstructions were developed for each of the seven proxy datasets described above using temperature records from the Hadley Centre for Climate Research CRUTEM4 dataset. The CRUTEM4 dataset is a gridded $5^\circ \times 5^\circ$ dataset of near-surface air temperature anomalies. Monthly-averaged temperature anomaly records are available from January 1850-present (Jones et. al, 2010). For both of the datasets, observed monthly temperature anomalies were averaged over respective sample domains as seen in Figure 1. The domain-averaged observed temperature anomalies are used to develop regression models for each of the proxies.

Temporal resolution of proxy data is much less than the CRUTEM4 dataset; therefore, regression models were constructed using only the nearest temperature point in the time series. For simplicity purposes, only first-order regression models were analyzed. Proxy data from the Viau et. al (2006) paper is provided in time steps of “years to present”. The GISP2 ice core completed drilling in July 1993 and the data from Bond et. al (2001) was adjusted to match the start time of the GISP2 ice core (Mayewski et. al, 1994; Viau et. al, 2006). Therefore the proxy data extends through year 1993.5 and is aligned to the CRUTEM4 observations accordingly.

The poor temporal resolution of the North Atlantic drift ice and the $^{14}C$ production lead to poor sample size and misleading coefficients of determination. The regression model for each proxy is provided in Figure 2. From Figure 2, the regression equations are noisy in general with very little correlation to the observed data points. The highest correlation with a sample size greater than three, is the $\delta^{18}O$ ratio from the GISP2 ice core with an coefficient of determination of 0.50. All of the other proxies with sample sizes larger than three have coefficients that
are less than 0.20. This suggests the temperature reconstructions from these linear regression models contain uncertainties that could lead to large errors in the paleoclimate temperature record.

Tree ring data was provided annually; however, the datasets do not extend beyond 1936. The tree ring dataset is a collection of samples from oak trees in northeast France and northeast Germany with proxy data available from 587 B.C. to 1915 A.D. for northeast France and 317 B.C. to 1936 A.D. in northeast Germany. Although available data does not extend through the 2nd half of the 20th century, the high temporal resolution of the tree ring data provides the largest number of samples for the linear regression models. From the regression curves in Figure 2, the width of the tree ring segments does not appear to have any correlation with temperature anomalies with coefficients of determination of less than 0.10 for both regions. Temperature reconstructions compared to the observational record can be seen in Figure 3 for both the Viau et. al (2006) and Büntgen et. al (2011) datasets.

Figure 1: Domain for temperature averages for North Atlantic temperature reconstruction (green) and Central European temperature reconstruction (red).
Figure 2: Linear regression models and analysis for all proxy temperature reconstructions

(a) North Atlantic

(b) Central Europe

Figure 3: Linear regression model overlaid on observations of domain-averaged temperature for all proxies

(a) North Atlantic

(b) Central Europe
4. Results

The temperature reconstructions vary significantly between the different proxies and even with the two different regions using tree ring segments. The full temperature reconstructions are in Figure 4 for both the North Atlantic and the Central Europe domain. Figure 4 provides an indication of the sensitivity of each of the proxies with respect to temperature anomalies. For the analysis, we will assume the linear regression models are somewhat accurate and provide meaningful results fully aware that the results are strongly dependent upon the accuracy of the model which has already been shown to be incorrect.

First, the results from the North Atlantic domain will be discussed. From Figure 4a, the response of the climate proxies to changes in near-surface air temperature is highly variable with some dependence upon temporal resolution of the proxy data. The most sensitive proxy is the GISP2 ice core $\delta^{18}O$ ratio with a range in temperature anomaly from -4 to 4°C. The $\delta^{18}O$ ratios from the North
Atlantic sediment core also appears to be sensitive relative to the other proxies in this data set; however, the range in temperature anomalies is nearly the same for both proxies obtained from the sediment core. The trends between these two proxies are fairly well matched despite the difference in temporal resolution and the limited number of data points for the drift ice. The sea salt concentrations were the highest temporal resolution proxy available in the data set. From the linear regression model, temperature reconstruction from sea salt concentrations appears to be quite noisy with little response to temperature anomalies. While it’s noted that the sea salt concentrations are obtained from a land locked ice core, results from this study suggest obtaining temperature information from this proxy requires either a more complex regression model or more data points. In addition, the range of reconstructed temperature anomalies is between -1 and 0, which is known to be inaccurate. The poor performance of this proxy is undoubtedly related to the very low correlation of the data to the linear regression model and it should be noted this was the least correlated proxy among all of the datasets evaluated in this study. Finally, the $^{14}$C proxy shows a very flat temperature record, with slight fluctuations in temperature on the order of $\pm 0.5 \degree C$ around 8000 B.C. However, it is should be noted that the $^{14}$C data had the poorest temporal resolution of all of the datasets evaluated so it’s possible that some of the temperature trends were smeared out of the reconstruction.

The tree ring segments seem to be much more sensitive to near-surface air temperature fluctuations as seen in Figure 4b. Both temperature reconstructions show similar magnitudes of temperature anomalies; however, they are of opposite sign. The cluster of tree rings in NEG show a slightly higher sensitivity to temperature fluctuations than those in NEF. The NEG temperature trend shows an overall cooling trend from $\sim$ 300 B.C. to 1900 A.D. with most rapid cooling occurring between 700 and 900 A.D. After 1900 A.D., the temperature trend turns toward more of a warming trend as was seen in the observations. The opposite trend is observed in the NEF temperature reconstruction with a gradual warming event taking place from $\sim$ 500 B.C. The warming trend continues into the observational temperature domain and seems to follow the general trend line of the observed temperature data despite the extremely low coefficient of determination. The opposite trends between the two clusters of tree ring data can possibly be explained by the fact that the NEF dataset had fewer observations after 1850 A.D. than did the NEG dataset.
5. Comparison to Previous Work

Since both of these cases were regional temperature reconstructions over different time periods, different sources were used to evaluate the performance of the linear regression models. Temperature anomalies from the North Atlantic domain were compared with climate reconstructions of Mann and Jones (2003), Moberg et. al (2005), and Viau et. al (2006). Temperature anomalies from these reconstructions were available from 200 - 1980 A.D., 1 - 1979 A.D., and 1000 B.C. to 1955 A.D. respectively. The temperature anomalies from this study are compared to the temperature anomalies in the Mann and Moberg studies without standardization or statistical manipulation. Mann and Moberg reconstructions provide temperature anomalies annually, whereas the Viau reconstruction provides data every century. Temperature reconstructions between this study and the three published works range from 0 to 1980 A.D. to account for the different temporal ranges of the different climate reconstructions.

Figure 5: Comparison of linear regression model derived temperature anomalies with other climate reconstructions.
The comparisons for the North Atlantic domain are shown in Figure 5a. Since the peer-reviewed temperature reconstructions are quite flat, the regression models derived from proxies with less sensitivity to temperature fluctuations performed better. Although the GISP2 $\delta^{18}O$ ratios had the highest correlated linear regression model, the reconstructed temperature anomalies from this proxy are exaggerated compared to other climate reconstructions. The other proxies represent the other climate reconstructions much better; however, the proxies from the sediment core and the sea salt concentrations from the GISP2 ice core show a cooling trend in the 1900s. The other reconstructions suggest a warming trend during this time period and this trend is only represented in the $^{14}$C proxy. It is important to note, however, that the $^{14}$C dataset has a temporal resolution of 70 years and therefore, there is only a single point suggesting the warming trend.

The comparisons for the Central Europe domain are shown in Figure 5b. Temperature anomalies in the Central Europe domain were compared with the temperature reconstruction of Büntgen et. al (2011). As expected, the two tree ring datasets are on opposite sides of the Büntgen temperature reconstruction. The Büntgen temperature reconstruction is a blended average of all of the tree ring datasets in the Central European domain to develop a single temperature reconstruction for the entire domain. The two linear regression models developed here fail to represent the trends observed in the Büntgen model except for in the most recent part of the reconstruction. In addition, the linear regression models overestimate the magnitude of the temperature anomalies with respect to the Büntgen model. As noted before, the NEG dataset shows a cooling trend from $\sim 4^\circ C$ to near 0 in 1936 and the NEF dataset shows a warming trend from $\sim -4^\circ C$ to near 0 in 1915.

6. Conclusions

The results of the temperature reconstructions are fairly uncertain and difficult to quantify. The lack of correlation in the regression models suggest the temperature reconstructions should not be well represented by the proxy data provided; however, the temperature reconstructions in the North Atlantic were not too far off those of Mann and Jones (2003), Moberg et. al (2005) and Viau et. al (2006). This can likely be attributed to the fact that the temperature anomalies for this region were typically less than 0.5 °C in magnitude. To gain a better understanding of
regression model performance, a statistical standardization approach might be better to help draw the trends in the reconstruction from the noise. Additionally, the GISP2 δO18 proxy, which had the highest performing regression model, performed the worst with respect to the other temperature reconstructions.

The Central Europe domain results were similar to that of the North Atlantic; muddy and inconclusive. The two tree ring datasets produced completely different temperature reconstructions. Even though the tree ring data was only available until 1936 and 1915 for the two datasets, there were sufficient data points to make a linear regression model; however, both of these models had very weak coefficients of determination with values less than 0.06. The tree ring data provided showed virtually no correlation as seen in Figure 2b and the two datasets showed two different relationships to temperature anomaly leading to conflicting results. Results might be improved with more recent data points; however, Büntgen et. al (2011) adapted the tree ring data which was not performed here. In general, it seems that reconstructing temperature anomalies from proxy data is difficult and requires more meticulous data analysis than was performed here.
References


