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NORTHERN HEMISPHERE SUMMER SEA LEVEL PRESSURE RECONSTRUCTED FROM PROXY-CLIMATE DATA

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1. INTRODUCTION

The global instrumental record of weather observation provides information about climate over the past century. Farther back into time, however, it becomes more difficult to draw conclusions about large-scale trends and patterns in the climate. For this reason, reconstruction of climatic parameters using proxy data is employed. The temporal resolution of climatic reconstructions is often limited by the proxy data. Some proxy sources, though, can provide high temporal resolution records. Here we employ some of these data, specifically, tree-rings and ice cores, to reconstruct long series of sea level pressure patterns for the northern hemisphere at an annual resolution.

In general, climate reconstruction is based on the premise that aspects of climate have a direct influence on many systems, both organic and non-organic. If climate imprints a record of its existence on a natural system that system can be used for proxy climate reconstruction work. In the case of tree-rings, temperature and precipitation have a clear impact on the growth of the tree. Similarly, winter precipitation and summer temperatures affect the layers laid down by ice caps. Numerous studies have illustrated the use of tree rings and ice-core layers to reconstruct climatic parameters (e.g. Schweingruber et al. 1993, Cook 1992, Koerner and Fisher 1990, Kutzbach and Guetter 1980, Fritts 1976, 1991).

Proxy sources have been widely used to reconstruct a variety of climatic parameters, most often temperature and precipitation. Many of these studies focus on specific regions, such as the western United States (Fritts, 1991), and often they employ one type of proxy data. Few studies have attempted to reconstruct past circulation patterns (e.g. Luterbacher et al., 2002a, b).

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This objective of this study is to use high temporal-resolution proxy data sources, including tree-ring width indices and oxygen isotope data from ice cores, to reconstruct summer mean sea level pressure fields for the northern hemisphere for the period 1750 - 1945. This effort differs from previous work because it targets atmospheric pressure, it is hemispheric in scope, and it directly combines multiple proxy data sources. Pressure was selected, rather than temperature or precipitation, since atmospheric circulation is a synthesis of many atmospheric phenomena (Kutzbach and Guetter, 1980). It was also felt that pressure is a useful tool for the atmospheric researcher.

2. DATA

The proxy data used for this project consisted primarily of tree-ring data, as these are available from around the hemisphere with some ice core data. Tree-ring data came from the International Tree Ring Data Base (ITRDB) (Contributors to the International Tree-Ring Data Bank, 2002). Tree ring data from a large data set contributed more recently by Schweingruber et al. (2000) were also employed, and filled a critical gap in the ITRDB data in the central and eastern Siberian region. Raw standardized indices of ring width were used in the reconstructions. A tree-ring “series” consists of as many as 40 separate cores taken from different trees in the same area that have been combined and cross-validated (Fritts 1976).

Data series were included based on the length of record and the absence of missing data. A series had to have a complete data sequence for the entire period of reconstruction, with no missing data. Estimates to fill in individual missing points were not made. Based on this, a total of 378 series were available, representing the major terrestrial regions of the Northern Hemisphere (Fig. 1). The proxy series were cut off at 1989 and not at the end of the available SLP data in 1994 to maximize the number of sites that could be included (Table 1).

Ice core data were also obtained from the WDC-A and consisted of $d^{18}O$ time series from the GRIP and GISP2 ice cores from Greenland (Grootes et al. 1993), and Agassiz Ice Cap ice cores from the Canadian Arctic Archipelago (Koerner and Fisher 1990). The inclusion of ice core data provided information north of treeline.

Sea-level pressure data were obtained from the National Center for Environmental Prediction gridded northern hemisphere data set 1946 – 1994 (NCAR 1996). These are arrayed on a 47x51 octagonal grid draped over a projected representation of the Northern Hemisphere (Fig. 2).

Table 1: Number of tree ring sites available from the WDC-A for Paleoclimatology by source.

Year	ITRDB stations	Schweingruber stations
1971	923	426
1972	879	426
1973	832	426
1974	823	424
1975	800	419
1976	778	403
1977	741	390
1978	736	374
1979	720	340
1980	269	340
1981	249	316
1982	244	287
1983	229	279
1984	228	213
1985	226	213
1986	223	213
1987	220	209
1988	219	209
1989	214	164
1990	8	164
1991	8	100
1992	8	62
1993	6	51
1994	6	48

3. METHOD

The dimensionality of both the proxy and the climate data are first reduced, because both sets possess large degrees of spatial autocorrelation. Transfer functions are then developed, a reconstruction is performed, and finally original data values are recovered (Kutzbach and Guetter 1980). Specific details follow.

Dimensionality is typically reduced using an eigenmode analysis such as principal components analysis (PCA, Kutzbach and Guetter 1980), although canonical correlation can also be used (Fritts 1976). For this study PCA was used. A PCA results in a set of surrogate variables, equal in number to the original number of variables; in this case, sites for the proxy data and grid points for the SLP data. Each variable represents a successively decreasing amount of common variance in the data, the amount of which is indicated by a resultant eigenvalue. The elimination of co-linearity serves two purposes. It removes the considerable redundancy that can be present in these types of data sets, establishing their orthogonality, and it simplifies the building of transfer functions in the subsequent regression analysis by reducing the number of predictor and predictand variables that must be considered.

3.1 *Determining the number of components*

Regression of climate components on the proxy components is then performed. As indicated, not all components go into this process; rather, a subset must be extracted. The selection of components is a crucial step. It does not have a clear physical basis, yet the efficacy of the reconstruction depends on reasonable selections being made, because usually only the first few represent signals prevalent throughout the data set (e.g. Fig. 3). There have been attempts to objectify the process, such as use of a “scree” plot of eigenvalues to identify a logical cut-off point. Such methods, however, often do not necessarily have clear application between different types of studies and what works well for one type of study may not yield acceptable results for another. Kutzbach and Guetter (1978), for example, based their selection on the amount of explained variance the components represented, although this was not guided by a determination of a “break point” in the explained variance values.

In the case of a climatic parameter reconstruction, if there are too few components, such that they do not represent sufficient variability, the resulting reconstructions may lack useful detail. If there are too many components, especially among the proxy-data, excessive local variability may cause the resulting reconstructions to suffer from ranges that exceed that which is naturally observed (e.g. Fig. 4). For this study the decision of component retention was made by subjectively harmonizing five indicators of reconstruction effectiveness, including:

- An examination of how the mean RMSE values (by year, during the calibration period) varied under reconstructions using different numbers of retained components;

- Inspection of the mean spatial residuals fields to visually assess when variability was becoming excessive;
- Generation of time series plots for the calibration period contrasting reconstructed vs. original NCEP SLP values for several selected grid points;
- Generation of time series plots for the entire reconstruction period contrasting range and variability of the reconstructed vs. original NCEP SLP values, and;
- Examination of the success with which an index of summertime NAO could be reproduced.

These indicators are gathered for various “experiments” consisting of trial runs with differing sets of retained components. For each experiment 44 separate reconstructions were conducted. In each run a single year of SLP data was left out and was reconstructed based on predictor equations developed by training on the 43 years remaining in the training set. Results from all 44 reconstructions for a given experiment were aggregated to generate the indicators of effectiveness described here. Specific considerations and objectives applied to the various indicators are presented below.

Use of the mean RMSE values provides an indication of overall departure of the observed values from the reconstructions. Although the variation among various experiments is small, it can still provide an indication of general success. A spatial plot of mean residual fields over the calibration period gives an indication of regions that tend to be poorly captured. In some cases the addition of components can noticeably decrease the accuracy of the reconstructed fields. Time series plots from selected grid points facilitated comparison between reconstructed and observed for individual years. This allowed an assessment of the ability of the reconstruction to reproduce both the timing and magnitude of observed SLP trends at selected sites. As well, the entire reconstructed time series for selected grid points was plotted and compared to the original data from the grid point. The objective in this case was to ensure the reconstructed grid did not vary too far from the range and variability observed in the original data. Finally, a time series of the summer NAO index was generated and contrasted with that available from the Climate Research Unit (CRU), East Anglia.

All of these factors were taken into consideration in the following manner. The importance of each factor varied: the RMSE field was of moderate importance because it showed relatively little variation between runs. Also of moderate importance was the year-by-year time series comparison between observed and reconstructed series. Although desirable to have well correlated series for all grid points examined, the fact that not all variability can be captured when some components are rejected means that the time series will not always match. Greater importance was placed on the visual inspection of the mean spatial residual fields, and the highest importance was placed on the range and variability of the reconstructed data. Both of these gave a good indication of a poor reconstruction, as would occur when too many tree-ring components were retained. As well, high importance was placed on the ability of the reconstruction to reproduce major trends in the NAO index. Given the fundamental nature of this mode of variability in the northern hemisphere SLP field - it is recovered at the level of the first principal component of pressure - it was felt that a requirement of any reconstruction of SLP should be the recovery of a reasonable approximation of the NAO index.

Based on the work listed it was decided to retain 10 proxy data components and 15 SLP components for the final reconstruction.

3.2 *Calibration*

Calibration of the proxy components on the SLP components was then performed, resulting in equations that represent the climate components in terms of the proxy components resulting. The transfer functions were then solved for the reconstruction period using the proxy components, and finally climate data are recovered from the reconstructions.

4. RESULTS

The result is a series of summer mean SLP grids for each year 1750 through 1945 (e.g., Fig 5). Generally the major patterns of the summer Northern Hemisphere surface pressure field are well represented. The mean RMSE value for the 44 years of the calibration period, averaged over the 1977 point grid, is 1.22mb. For comparison, the same RMSE statistic for the excessive component example is 28.02 mb. Examining the spatial distribution of standard deviation and range of the reconstructed grids for the calibration period (Figs. 6, 7) with respect to the same plots for the observed data (Figs. 8, 9) gives an indication of how well the reconstruction fared with respect to observed.

Smoothed time series plots of individual grid points provide indices of variability such as the NAO (Fig. 10). The reconstructed NAO index correlates with the CRU NAO index at R=0.74 after both time series have been put smoothed with a nine-point running average filter.

5. CONCLUSION

This study has utilized high temporal resolution proxy data to reconstruct mean summer surface pressure fields at a similar temporal resolution for the northern hemisphere from 1750 through 1945. It has demonstrated that stable results can be obtained at a hemispheric scale. It has also demonstrated how a new, multi-faceted approach to determine retained components can reduce the subjectivity of the process, normally a difficult problem, but one that forms an important underpinning of this type of reconstruction work. Utilizing a more thorough component selection process has also shown that proxy data pre-processing, which is a common feature of other high temporal resolution studies, may not be necessary.

Regions of greatest range and variability in the reconstructions, the western Arctic Ocean and the North Atlantic north of Iceland, are also regions of greatest natural variability and the reconstructed variability does not exceed observed. As well, the essential patterns of a major mode of northern hemispheric pressure variability, the NAO, are adequately captured.

6. REFERENCES

Contributors to the International Tree-Ring Data Bank, 2002. IGBP PAGES/World Data Center for Paleoclimatology, NOAA/NGDC Paleoclimatology Program, Boulder, Colorado, USA.

Cook, E.R., 1992: Using tree rings to study past El Nino/Southern Oscillation influences on climate. *In* Diaz, H.F. and Markgraf, V. (eds,), *El Nino: Historical and Paleoclimatic Aspects of the Southern Oscillation.* Cambridge: Cambridge University Press, 203-214.

Fritts, H.E., 1976: Tree rings and climate. Academic Press, New York.

Fritts, H.E., 1991. Reconstructing large-scale climatic patterns from tree-ring data. University of Arizona Press, Tucson.

Grootes, P.M., M. Stuiver, J.W.C. White, S.J. Johnsen, and J. Jouzel. 1993: Comparison of oxygen isotope records from the GISP2 and GRIP Greenland ice cores. *Nature,* **366**, 552-554. Data archived at the World Data Center for Paleoclimatology, Boulder, Colorado, USA.

Koerner, R.M., and Fisher, D.A., 1990: A record of Holocene summer climate from a Canadian high-Arctic ice core. *Nature*, **343**, 630-631.

Kutzbach, J.E. and Guetter, P.J., 1980: On the design of paleoenvironmental data networks for estimating large-scale patterns of climate. *Quaternary Research*, **14**, 169-187.

Luterbacher, J., and 10 others. 2002a. Extending North Atlantic Oscillation reconstructions back to 1500. *Atmospheric Science Letters* 2:114-124.

Luterbacher, J and 8 others. 2002b. Reconstruction of sea level pressure fields over the eastern North Atlantic and Europe back to 1500. *Climate Dynamics* 18: 545-561.

NCAR. 1996: Compact Disc of the National Meteorological Center Grid Point Data Set: Version IIi. Department of Atmospheric Sciences, University of Washington and the Data Support Section, National Center for Atmospheric Research.

Schweingruber, F.H., Briffa, K.R., and Nogler, P. 1993: A tree-ring densiometric transect from Alaska to Labrador. *International Journal of Biometeorology,* **37**, 151-169.

Schweingruber, F.H., et al. 2000. WSL-Birmensdorf Tree Ring Data 2000. IGBP PAGES/World Data Center for Paleoclimatology, NOAA/NGDC Paleoclimatology Program, Boulder, Colorado, USA.

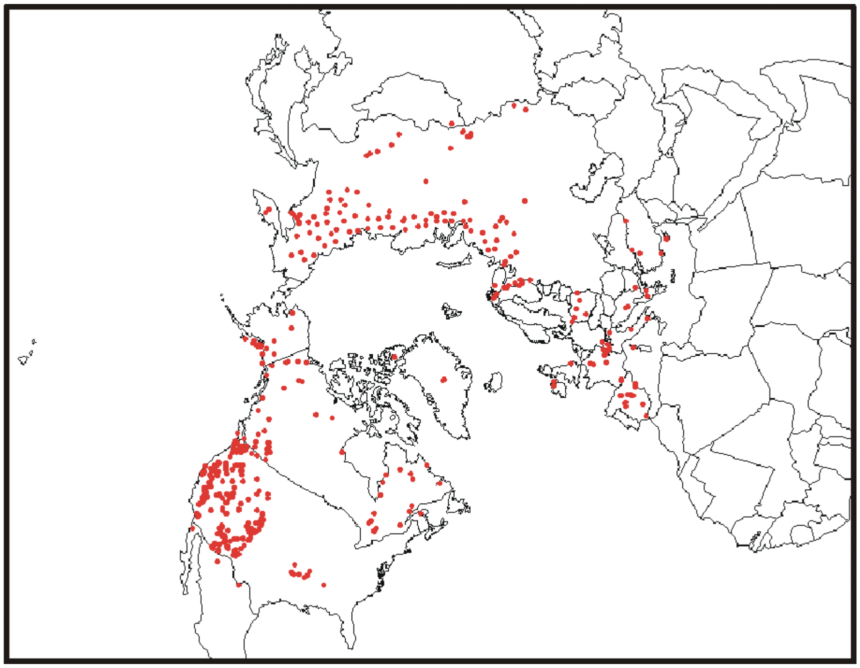

Figure 1: Location of proxy data sites used for the reconstruction over the period 1750 – 1989.

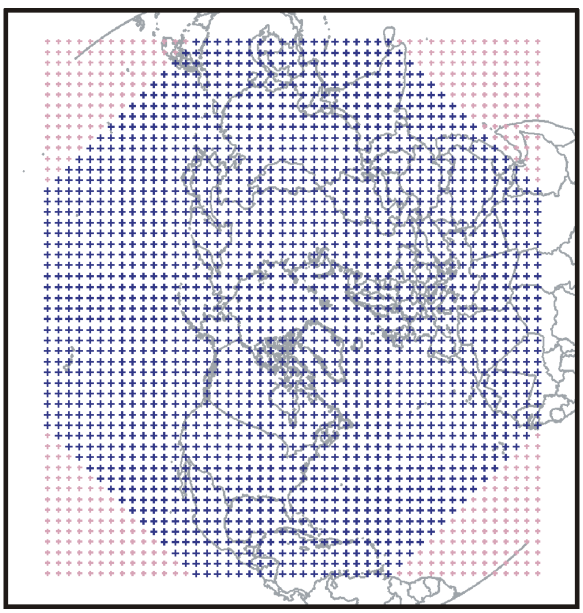

Figure 2: NCEP 47x51 octagonal grid.

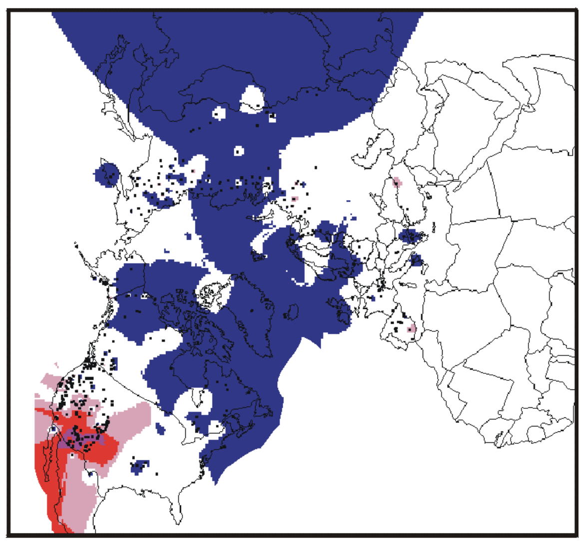

Figure 3: Example of the factor 1 loading on the proxy data. Color representation of loading values is as follows: Dark blue = -0.2 – 0, white = 0 - 0.2, light red = 0.2 – 0.4, dark red = 0.4 – 0.6, purple = 0.6 – 0.8. A loading is a correlation between the series at the site and the time series of the component score.

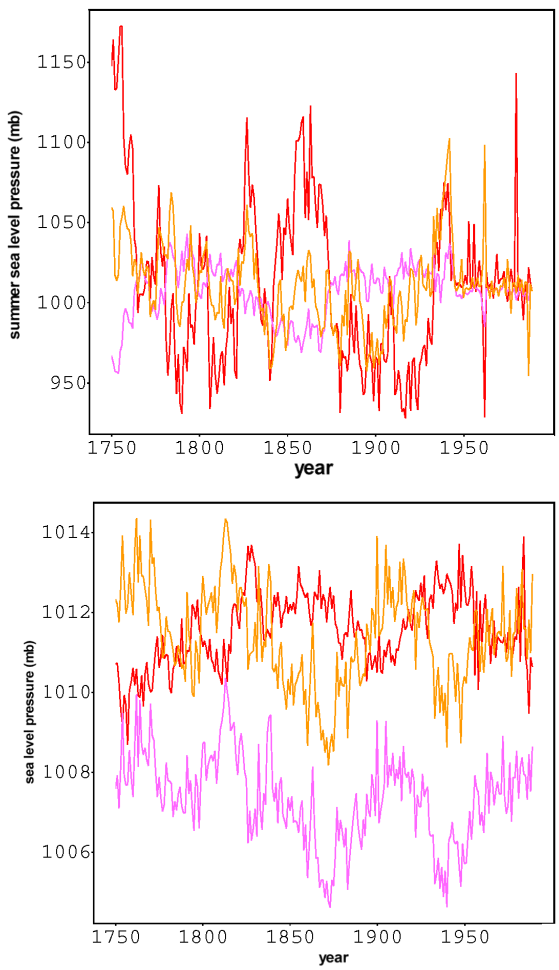

Figure 4: Reconstructed time series of summer SLP for individual grid points, TOP: showing excessive range resulting from inclusion of too many components, and BOTTOM: showing a more acceptable range. On both plots the red line is a grid point in the western Arctic Ocean, the purple line is a grid point in eastern Siberia, and the orange line is a grid point near Iceland.

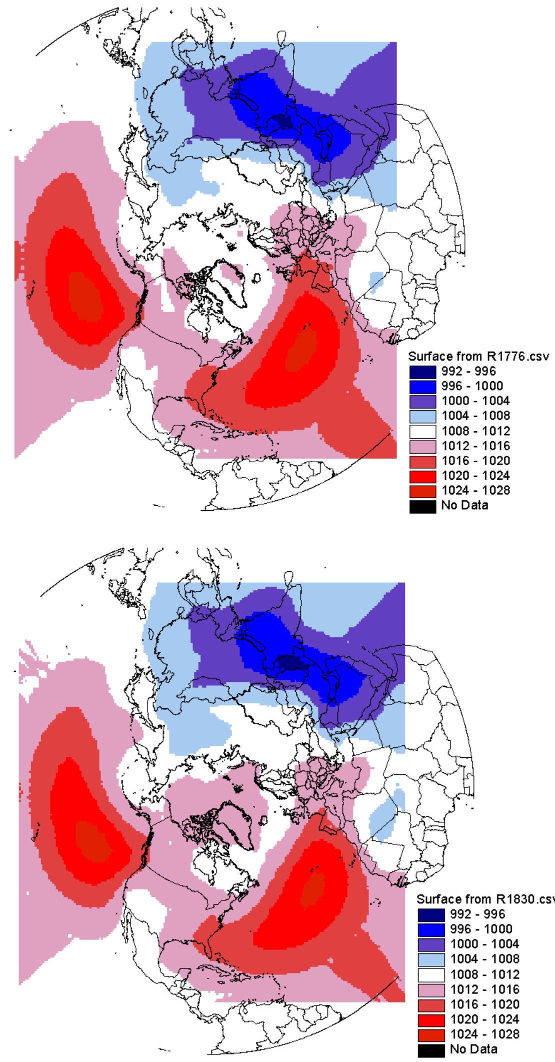

Figure 5: Reconstructed summer mean SLP field for TOP: 1776 and BOTTOM: 1830. Contour interval is 4 mb.

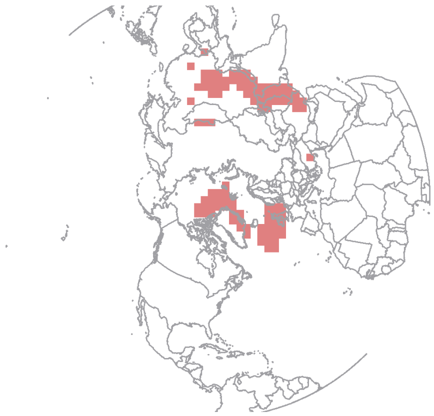

Figure 6: Standard deviation of reconstruction for calibration period. n=44. Contour interval is 1 mb; first colored zone = 1 – 2 mb.

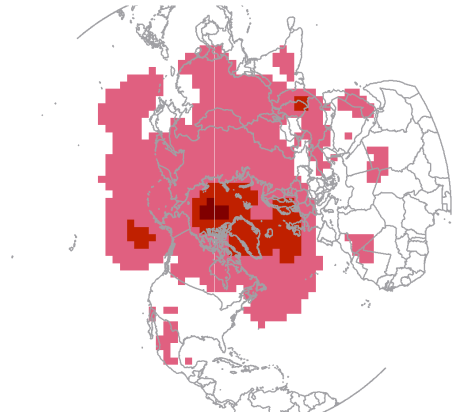

Figure 8: Standard deviation of observed for calibration period. n=44. Contour interval is 1 mb; first colored zone = 1 – 2 mb.

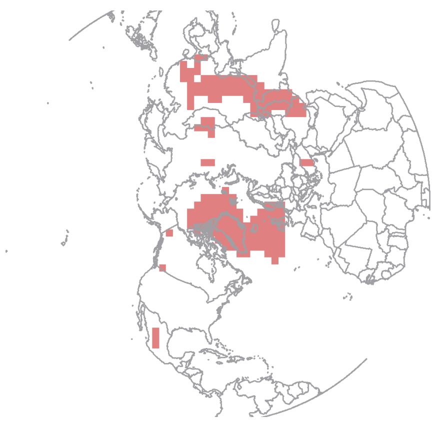

Figure 7: Range of reconstruction for calibration period. n=44. Contour interval is 4 mb; first colored zone is 4 – 8 mb.

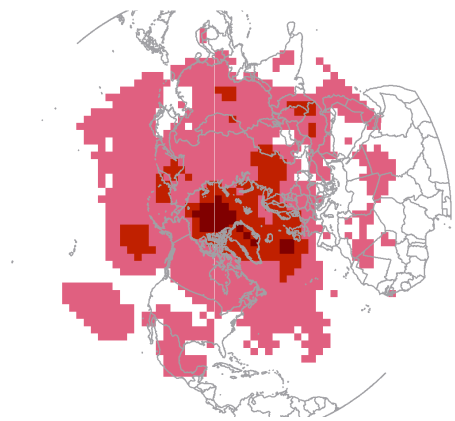

Figure 9: Range of observed for calibration period. n=44. Contour interval is 4 mb; first colored zone = 4 – 8 mb.

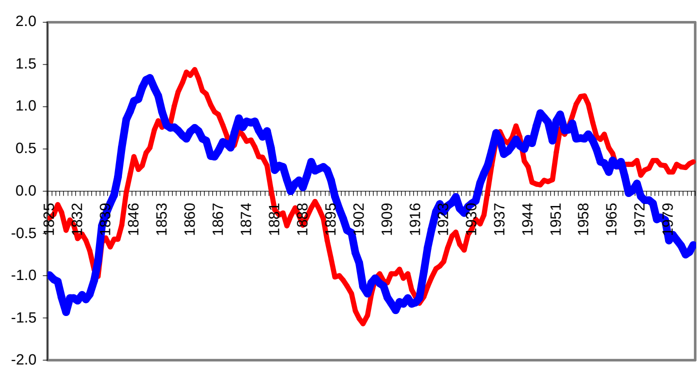

Figure 10: Reconstructed summer index of the North Atlantic Oscillation (Iceland grid point minus Azores grid point) in blue; the similar index from the Climate Research Unit, East Anglia, in red. Both series have been smoothed with a nine-point running mean. R value between the two is 0.74.