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Tree ring-based temperature reconstruction, and the influence of the NAO on growth patterns of scots pine in west central Jämtland

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Abstract

The development of tree ring chronologies is an important process in research of past climates. In this study a new tree ring width (TRW) chronology from west central Jämtland is presented with the aim of reconstructing a series of a climate variable, together with an analysis of the influence of Atmospheric Circulation, specifically of the North Atlantic Oscillation (NAO) on the growth patterns of sampled trees. A significant mean temperature-growth relationship for June-July was found and a new temperature series was subsequently reconstructed. The reconstructed temperature series showed interdecadal variability consistent with previous tree ring studies in Jämtland. However, it did not capture the observed warming trend of the 20th century, a problem which can occur in tree ring studies carried out at high latitudes. Significant, but not very strong statistical relationships were found between the NAO, as well as the summer North Atlantic Oscillation (SNAO), and the tree growth. Running correlation analysis between the SNAO-index and the chronology demonstrated that the strength of their relationship is not stable through time.

Keywords: Jämtland, Dendroclimatology, TRW, NAO, SNAO, PCA

Sammanfattning

Utvecklandet av trädringskronologier är en viktig del inom forskningen om klimathistoria. I detta arbete presenteras en ny trädringsvidd (TRW) -kronologi från västcentrala Jämtland med målet att återskapa en serie av en klimatvariabel, samt att undersöka påverkan av Atmosfäriska Cirkulationen, med fokus på Nordatlantiska Oscillationen (NAO), på tillväxten i trädringsproverna. En signifikant relation mellan juni-juli medeltemperatur och tillväxt hittades och en temperaturserie återskapades därefter. Den nya temperaturrekonstruktionen visade interdekadal variabilitet som stämmer överens med tidigare forskning i Jämtland. Rekonstruktionen lyckades dock inte återskapa uppvärmningstrenden under 1900-talet, vilket är ett problem som kan uppstå vid studier utförda på högre latituder. Signifikanta, men inte särskilt starka statistiska förhållanden hittades mellan NAO, samt sommar Nordatlantiska Oscillationen (SNAO), och trädtillväxten. Löpande korrelationsanalys mellan SNAO-indexen och TRW-kronologin visade att styrkan av deras förhållande varierar genom tiden.

Nyckelord: Jämtland, Dendroklimatologi, TRW, NAO, SNAO, PCA

1. Introduction

Tree ring science has broad applications, one of which, is the study of past climates. This scientific subfield is known as dendroclimatology and it can provide information on the natural variability of the climate system. Advantages in using tree rings as indicators for past climate is the spatial availability of sites to collect samples, as well as the high temporal resolution it offers (National Research Council, 2007). The knowledge obtained from dendroclimatological studies is not only important for understanding past variability, but it can also be used for predicting the climate's response to future natural and anthropogenic processes (Linderholm et al., 2010).

In the province of Jämtland, dendroclimatological research stretches as far back as to the 1970s and from the 1990s and onwards the area has been the subject of many studies reconstructing climate. Parameters reconstructed have mainly been temperature, but also lake level fluctuations have been reconstructed using subfossil wood found in lakes (Linderholm et al., 2010; Linderholm & Gunnarsson, 2019). The western part of the province is located in the central Scandinavian Mountains and provides ideal conditions for tree ring research where scots pines (*Pinus sylvestris*) can reach ages up to 700 years and can be found at the tree line of natural forests (Linderholm et al., 2010). As these sites are situated in close proximity to the main divide of the central Scandinavian mountains there can be influences both from the maritime climate found to the west in Norway in addition to the continental climate of inland Sweden. It has been suggested by Linderholm & Gunnarsson (2019) that due to the above-mentioned conditions that characterise this part of Jämtland, the climate could be sensitive to changes in the atmospheric circulation and direction of winds associated with the North Atlantic Oscillation (NAO). Large scale atmospheric circulation patterns such as the NAO have an influence on weather conditions in large parts of the northern hemisphere and there have been studies in Scandinavia where links have been found between the NAO and the tree growth (Linderholm et al., 2010).

Here, a new Jämtland TRW-chronology is presented with the aim of analysing the tree growth relationship to climate variables, and given that a relationship is found, reconstruct a series of that variable. In addition, the influence of the atmospheric circulation, specifically of the NAO, on the patterns of tree growth will be investigated. With this, the study aspires to expand on the knowledge of past climate variability as well as the impact that the NAO may have on the regional tree growth.

2. Background

2.1. Dendroclimatology

Dendrochronology is the scientific discipline that engages with the dating of annual tree ring layers by analysing the growth characteristics of the tree rings. More specifically, this is achieved through cross-dating, a technique where individual tree rings are assigned to the correct year of formation by matching the patterns of narrow and wide rings as well as performing statistical quality control of the dating (Sheppard, 2010; Smith & Levis, 2007).

As mentioned, dendroclimatology is a subfield of dendrochronology that uses dated tree rings as indicators for climate parameters. There are however several factors that can influence the width of tree rings, one of which is climate. Cook & Kairiūkštis (1990) provides a linear aggregate model to explain these influences:

$$R_t = A_t + C_t + D1_t + D2_t + E_t$$

R_t is the observed ring width, A_t the age-related trend where the ring width decreases from pith to bark, C_t the climate signal, $D1_t$ the local endogenous disturbance, $D2_t$ the standwide exogenous disturbance and E_t is the unexplained variability that is not related to the other signals. By collecting many samples and selecting a site that is undisturbed by processes such as wildfires or human activity, the local and external influences $D1_t$ and $D2_t$ can be minimized (Cook & Kairiūkštis, 1990). Instead, when selecting sample sites where the tree growth is highly dependent on the influence of climatic parameters such as temperature or precipitation, the tree ring width (TRW) or maximum latewood density (MXD) of the tree rings can be examined along with meteorological data to construct records of past climate exceeding instrumental observations (Sheppard, 2010). By doing so, dendroclimatology follows the principle of uniformitarianism and assume that the relationship between climate and tree growth has remained constant from past to present (Linderholm et al., 2010).

2.2. The North Atlantic Oscillation

The North Atlantic Oscillation (NAO) is a recurring pattern of variability in the atmospheric circulation which exerts a strong influence over winter climate and weather patterns in the North Atlantic region. It can be described as a fluctuation in the distribution of atmospheric mass between the Arctic and subtropical Atlantic (Hurrell et al., 2003). There are several ways of measuring the NAO where two common methods are either decomposing the variability of the sea level pressure (SLP) into spatial patterns or describing the strength of the variability in a time series index where the difference in SLP between the Icelandic low and the Azores high is measured (Wanner et al., 2001). The NAO consists of two phases where the positive phase is characterized by well-developed low SLP over the Icelandic region coinciding with high SLP in the Azores. This pressure gradient increases the strength of the westerly winds which bring warm and moist weather conditions over northern Europe (Wanner et al., 2001; Visbeck, 2001). In the negative phase the pressure systems are less developed thus weakening the westerlies. As a result, colder winds from Russia and the Arctic are prone to sweep in over Scandinavia (SMHI, 2015).

While the effects of the NAO are most noticeable during the winter months, it can still be observed throughout the year. Studies have found that the spatial pattern of SLP over the Atlantic vary seasonally. The summer North Atlantic Oscillation (SNAO) have therefore been characterized somewhat differently, with a smaller spatial extent and located further north.

Here, the positive phase is linked to warm, dry, and cloud-free conditions over large parts of Scandinavia (Linderholm et al., 2008, Linderholm et al., 2009).

3. Material & Methods

3.1. Site description

Tree ring samples were collected by prof. Hans Linderholm from Gothenburg University and Björn E. Gunnarsson from Stockholm University in west central Jämtland close to the Norwegian border (*figure 1*). The tree species sampled was *Scots pine (Pinus sylvestris)* growing sparsely on thin layers of soil at an elevation of approximately 520-550 m.a.s.l. (*figure 2*). Average temperature in Storlien (ca. 37 km from study site) is -7.1 °C in January, 11.5 °C in July and the total annual average rainfall is 947.2 mm (1900-2020, data obtained from the Swedish Meteorological and Hydrological Institute). As mentioned, the climate of this region in Jämtland is influenced by the proximity to the Norwegian ocean and the humid weather conditions to the west as well as the relatively dryer conditions and continental climate found in the Swedish inland to the east (Linderholm & Gunnarsson, 2019).

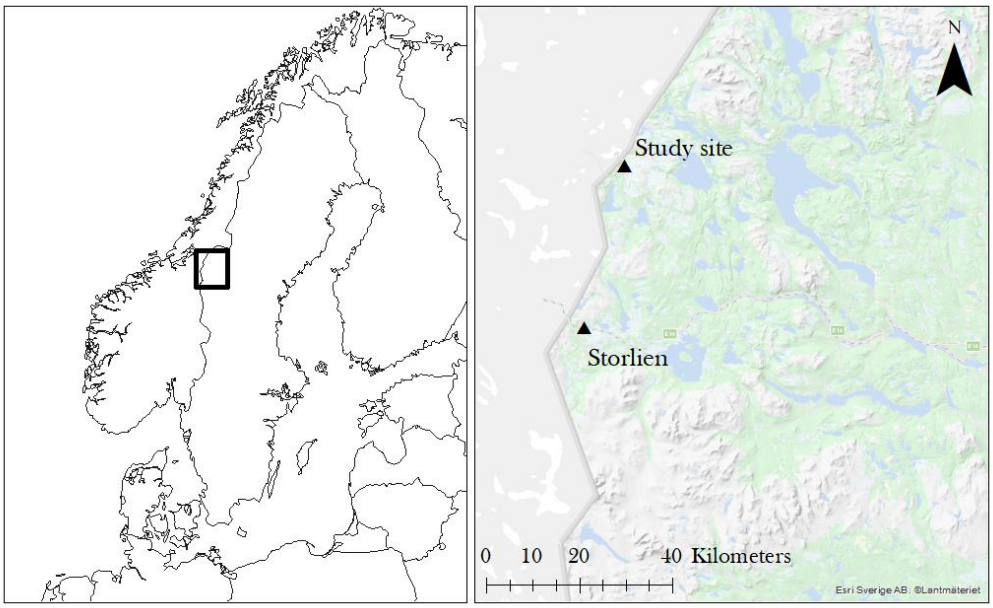

Figure 1 *Overview map showing the location of the study site, along with Storlien where the meteorological data originates from. Data obtained from ESRI Sweden & Lantmäteriet.*

Figure 2 *Picture of the study site where the tree ring samples were collected.*

3.2. Chronology building

The annual TRW of the samples was measured with a precision of 0.001 mm using a LINTAB 5 measurement station and the software TSAP-Win™. Cross-dating was performed by visually inspecting pointer years, i.e., years of relatively wide and narrow rings in TSAP to correct dating errors. The series were then run in the program COFECHA (Holmes, 1983) to assess the quality of the cross-dating through intercorrelation. Samples from 8 trees were excluded from the study on the basis of receiving a low R-value and/or showing a deviating growth pattern. The remaining 18 trees received a series intercorrelation of 0.63 in COFECHA. The final TRW chronology was developed in the software ARSTAN (Cook, 1985). There the series were standardized by fitting negative exponential curves or straight lines with the purpose of removing the biological growth trend while preserving variations likely associated with climate. The valid period of the chronology was assessed by subsample signal strength (SSS), which is a measure used to determine the year where the accuracy of the record is reduced as a result of decreased sample size (Cook & Kairiūkštis, 1990). For this study, a threshold value of 0.8 was used for the SSS. Statistics for the standardized chronology is presented in *table 1*.

Table 1
Statistics of the standardized chronology.

Autocorrelation (-1)	Mean correlation (1681-1935)	Signal-to-noise ratio (1681-1935)	Subsample Signal Strength (SSS) of 0.8 (number of trees)	Subsample Signal Strength (SSS) of 0.8 (year)
0.456	0.435	4.620	6	1678

3.3. Climate reconstruction

Monthly mean temperature and precipitation data were obtained from the Swedish Meteorological and Hydrological Institute's (SMHI) open data service, and the meteorological stations used were Storlien (1900-1963, 595 m.a.s.l., 63.3158 °N 12.1009 °E), Storlien-Visjövalen (1964-2010, 642 m.a.s.l., 63.3028 °N 12.1253 °E) and Storlien-Storvallen A (2011-2020, 583 m.a.s.l., 63.2826 °N 12.1218 °E). The relationship between the standardized TRW-chronology and the climate variables was analysed in MATLAB by performing correlations over different monthly to seasonal scales in order to determine which period of the year the relationship is strongest. There was no notable connection found to the precipitation data, however, the temperature series revealed a significant relationship during the summer months where the strongest correlation was found in the June-July mean temperature with an R-value of 0.55 ($P < 0.01$) (*figure 3*).

The mean temperature for June and July was subsequently reconstructed by using a linear regression model ($Y = 4.408X + 5.823$) with a calibration period covering the years 1900-2020. To evaluate the stability of the model, and make sure that it does not have an underestimated prediction error, calibration-verification statistics was summarized for two periods, 1900-1959 and 1959-2020 (*table 2*). Statistics used for the calibration periods were Pearson correlation coefficient (R), the coefficient of determination (R^2), adjusted coefficient of determination (R^2 Adjusted), and F-test (F), while statistics used for the verification periods were the coefficient of determination (R^2), reduction of error (RE) and coefficient of efficiency (CE). RE and CE assesses the predictive accuracy of the reconstruction where a positive RE- and CE-value is an indicator for a valid model (National Research Council, 2007).

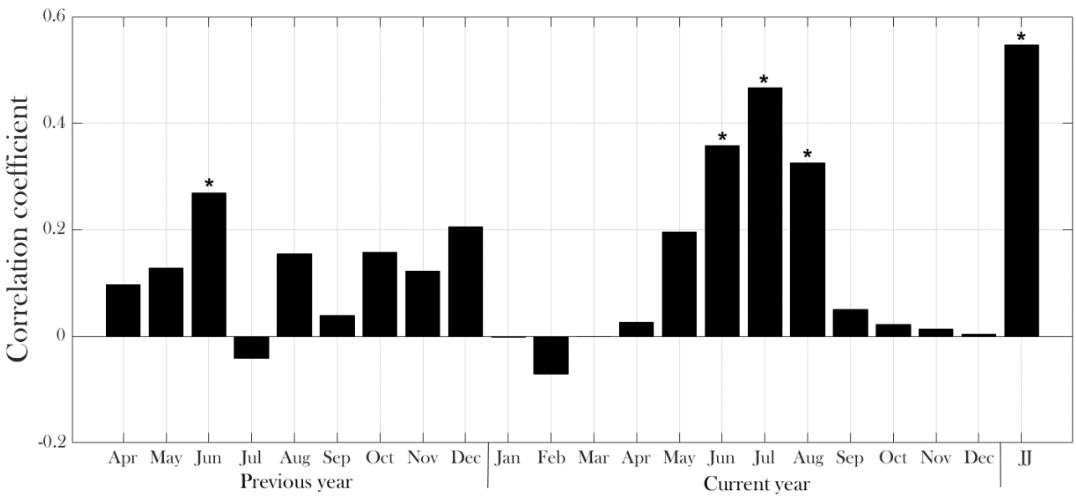

Figure 3 *Correlation analysis between the tree ring chronology and monthly mean temperature.*
** P < 0.01*

3.4. PCA & NAO-analysis

To investigate the influence of atmospheric circulation patterns to the tree growth a principal component analysis (PCA) was carried out using the PCA-function in MATLAB. This is a statistical technique that can be used to extract important information from a larger set of data by computing principal components (PC). These components represent the explained variance of the dataset where the first PC contains the largest amount of variance, followed by the second and so forth (Abdi & Williams, 2010). The input variables for the PCA were 13 individual and standardized tree ring series for the period 1955-2020. The four PCs with largest explained variance were then correlated to the June-August SNAO-index provided by prof. Hans Linderholm. In addition, a running correlation with a 15-year window were performed between the main TRW-chronology and the SNAO-index in its full length, 1836-2020. The monthly NAO-index, which is based on the SLP differences between the subtropical high and subpolar low obtained from the first mode of an Empirical Orthogonal Function (EOF) analysis, was also correlated to the four PCs for every month of the year. This data was obtained from the National Oceanic and Atmospheric Organization (NOAA) (at: https://www.ncdc.noaa.gov/teleconnections/nao/).

4. Results

4.1. Temperature reconstruction

The new TRW-chronology spans the years 1582-2020. From 1678 and onwards the series could be considered reliable based on the SSS threshold value of 0.8 when the sample size exceeded 6 cores. In *table 2* the statistics for the calibration-verification is presented. The linear regression model used to reconstruct temperature explained 30 % (29 % adjusted) of the variance in the observed data. Values from the calibration-verification statistics revealed that both examined periods, 1900-1959 and 1960-2020, showed a significant correlation to the observed temperature data. The validation statistics RE and CE received positive values for both intervals which indicates that the model is statistically valid for predicting temperature. While both periods received significant values, the first performed better than the second period with higher R, R^2, F as well as RE and CE. This can also be observed when plotting the reconstruction and observed temperature data (*figure 4*). The reconstruction is doing quite well at recreating variations in temperature, however, during the last decade there is a negative trend in the reconstruction which differs from the observed data.

The reconstructed temperature series (*figure 5*) displays a decadal to multidecadal fluctuation between colder and warmer periods. Warm intervals, defined as extended periods of time where the smoothed temperature series (15-year window length) rises above the reliable period mean, were C.E 1690s-1700s, 1720s-1740s, 1750s-1780s, 1800s-1830s, 1850s-1860s, 1870s-1900s, 1940s-1950s and 1960s-2010s. There were however small dips below the series mean in the periods 1800s-1830s and 1960s-2010. Disregarding these dips, the most prolonged warm period was 1960s-2010s, while the warmest temperature values in the smoothed reconstruction were found in the 1750s-1780s. The colder periods lasted C.E. 1700s-1720s,

1740s-1750s, 1780s-1800s, 1830s-1850s, 1860s-1870s, 1900s-1930s, 1950s-1960s and 2010s-present. Here the longest period was 1900s-1930s and the coldest temperature was found in the 1700s-1720s.

Table 2

Statistics of calibration and verification for the new June-July temperature reconstruction.

Calibration period	1900-1959	1960-2020	1900-2020
R	0.65	0.40	0.55
R^2	0.42	0.16	0.30
R^2 Adjusted	0.41	0.15	0.29
F	41.99*	11.55*	50.92*
Verification period	**1900-1959**	**1960-2020**	
R^2	0.42	0.16	
RE	0.37	0.09	
CE	0.36	0.06	

* *P < 0.01*

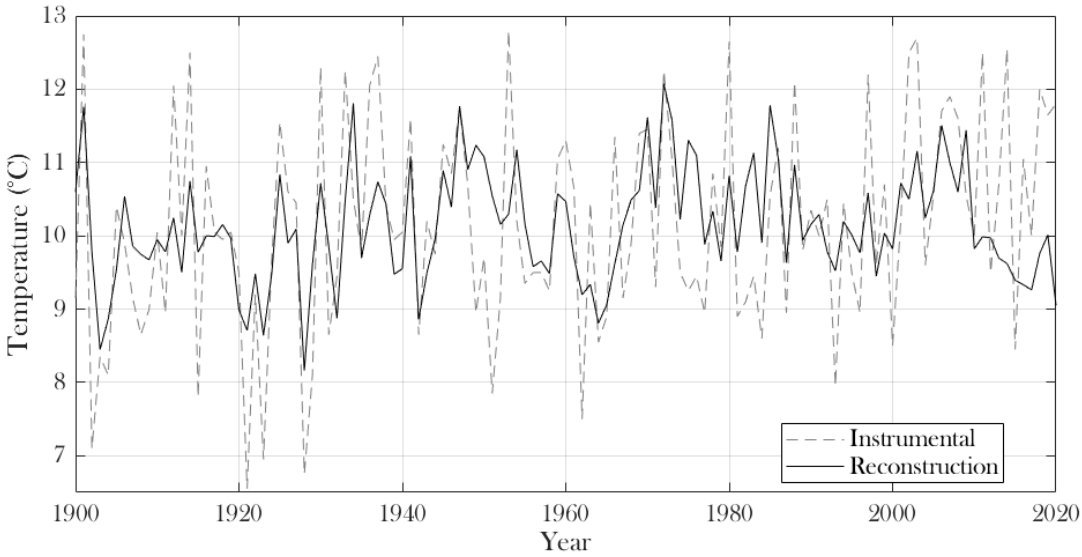

Figure 4 *Comparison of reconstructed June-July temperature and actual instrumental data from Storlien during the period 1900-2020.*

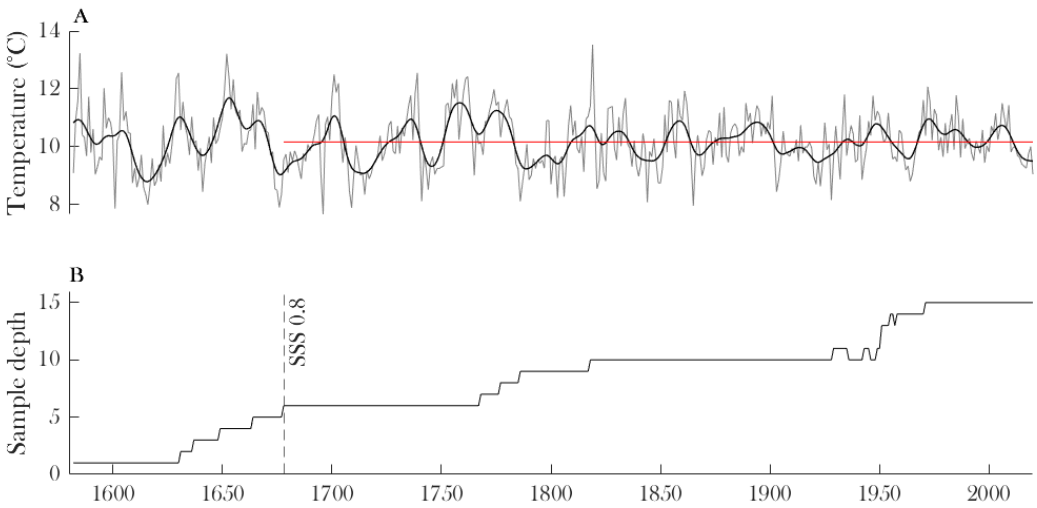

Figure 5 *Temperature reconstruction for June-July in west-central Jämtland.* **A** *Temperature plotted annually from 1582-2020 along with a smoothed gaussian filter with a 15-year window length. The red line represents the mean of the reliable period (1687-2020).* **B** *Sample depth, i.e., the amount of tree cores used in the chronology during the full period 1582-2020.*

4.2. NAO

The statistics from the correlation analysis between the PCs and the SNAO-index is presented in *table 3*. In the period 1955-2020, using 13 samples of mostly younger trees, the first component seems to dominate with an explained variance of 51.29 %. It received an R-value of 0.25 ($P < 0.05$). The running correlation analysis (*figure 5*) between the TRW-chronology and the SNAO-index demonstrates that there is a variability in correlation between the two variables where there is a stronger positive relationship during 15-year windows starting in 1840s, 1900s and 1960s-1970s as well as a negative relationship in the 1870s.

In *table 4* the results from the correlation analysis between the monthly NAO-index and the PCs are summarized. Index values from July showed a significant correlation to the first PC with an R-value of 0.25 ($P < 0.05$). There was also a significant relationship found with December and January where both months received an R-value of 0.25 ($P < 0.5$) when correlated with the second PC (13.31 explained variance). However, when correlating the mean of these two months, there was an R-value of 0.32 ($P < 0.01$). In November and February there was also significant negative correlations found to the fourth PC (5.9 % explained variance) of -0.27 ($P < 0.05$) and -0.34 ($P < 0.01$) respectively.

Table 3
Correlation analysis between SNAO-index and the PCs in the period 1955-2020.

	PC1	PC2	PC3	PC4
Exp. variance	51.23	13.31	8.02	5.90
R-value	0.25 *	0.15	-0.03	-0.02

* *P < 0.05*

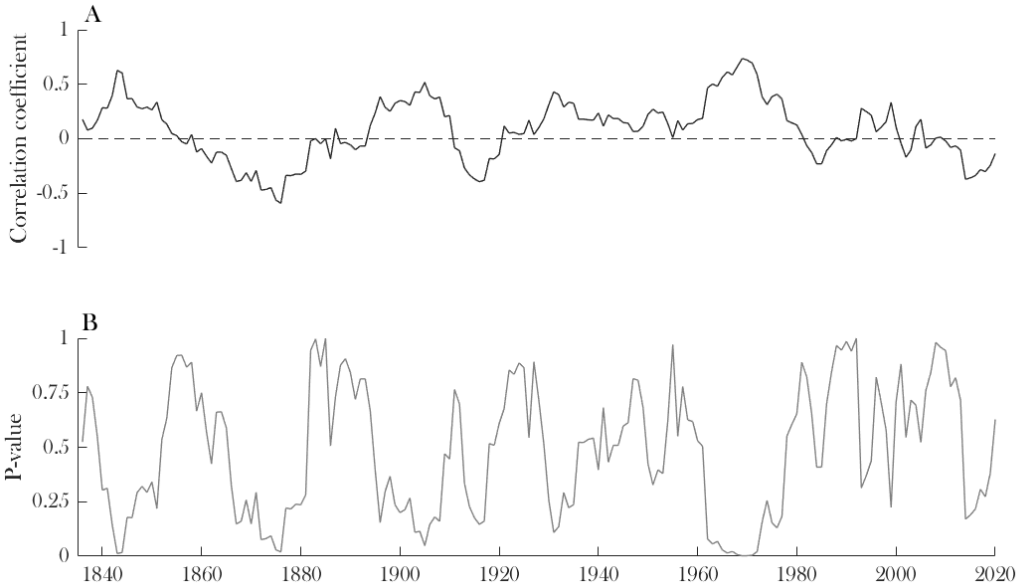

Figure 6 *Running correlation between the SNAO-index and the TRW-chronology.* **A** *The R-value for the period 1836-2020.* **B** *The P-value for the period 1836-2020. The values were calculated using the movcorr function in MATLAB (Mack, 2021), with a 15-year window length.*

Table 4
Correlation analysis between the monthly NAO-index and the PCs in the period 1955-2020.

	Exp. Variance	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	Dec	Dec / Jan
PC1	51.23	-0.03	-0.02	0.08	-0.18	0.08	0.11	0.25 *	0.13	-0.05	-0.14	-0.08	-0.08	-0.07
PC2	13.31	0.25 *	0.03	-0.03	0.08	-0.24	0.23	0.17	-0.04	0.05	-0.03	0.02	0.25 *	0.32**
PC3	8.02	-0.12	-0.11	-0.18	-0.07	-0.04	0.02	0.07	-0.16	-0.18	-0.10	-0.02	0.07	-0.03
PC4	5.90	-0.04	-0.34 **	-0.20	-0.09	-0.03	-0.00	-0.09	-0.15	-0.00	0.01	-0.27 *	-0.20	-0.17

* *P < 0.05* ** *P < 0.01*

5. Discussion

To assess if the new reconstruction shows a coherence with previous research in Jämtland a comparison was made with the summer temperature reconstruction by Linderholm & Gunnarsson (2019) (*figure 7*). In their reconstruction there are dips in temperature centred around early 1700s, 1740, late 1700s and 1900 that coincide with the new June-July series. Warm episodes such as mid-1700s, early 1800s and later 1900s are also in agreement. However, the 20th century warming is more pronounced in Linderholm & Gunnarsson (2019). Indeed, there is no distinct transition from the Little Ice Age (1450-1850, IPCC 2013) to the industrial warming that usually characterize late 19th to 20th century in the new reconstruction. Differences between the series could to some degree be related to the method, as the Linderholm & Gunnarsson (2019) reconstruction is based on MXD in contrast to this study which used TRW to reconstruct temperature. This is important as the temperature signal is generally stronger in MXD data compared to TRW (Ljungqvist et al., 2020). For this reason, a comparison with the Linderholm & Gunnarsson (2005) chronology was included (*figure 7*), as it also uses ring width as a measure for changes in temperature. Multidecadal variability consistent with the June-July series was found here as well. Periods with low values centred on early 1700s, 1740 and late 1700s agree with the cold periods presented in this study, along with higher temperature in mid 1700s, early 1800s and the later 1900s. Just as the MXD based reconstruction, the warming is more noticeable in the Linderholm & Gunnarsson (2005) chronology.

One explanation as to why the new reconstruction does not show a strong 20th century warming trend could be that it is affected by the phenomenon known as the divergence problem. This is an observed weakening in the mean temperature sensitivity of tree growth in northern forests during the last decades. The mechanisms behind the divergence problem are not fully understood but possible explanations are regional causes such as drought stress or that the warming exceeds the physiological threshold. Theorised hemispheric to global causes include global dimming and changes in ozone levels. Including values affected by the divergence in the calibration period of a reconstruction could lead to an underestimation of 20th century temperatures as well as an overestimation of past temperatures (D'Arrigo et al., 2008). Seeing as the trees sampled for this study were growing on quite thin layers of soil it could limit the grounds moisture content and leave the trees vulnerable to prolonged dry periods. Moreover, the majority of the samples from this period consisted of younger trees which might be more sensitive to potential changes in soil moisture induced by 20th century warming. This is one possible factor that could contribute to the divergence seen in temperature when comparing to previous studies as well as observed temperature. Given that this project was not as time-constrained, one might have revisited the method of reconstructing temperature. Excluding data from the last decades in the calibration period might have resulted in a more accurate reconstruction. However, it is argued by Loehle (2009) that using tree ring data that clearly displays divergence could be considered poor practice as it questions the linearity of the tree growth's response to temperature.

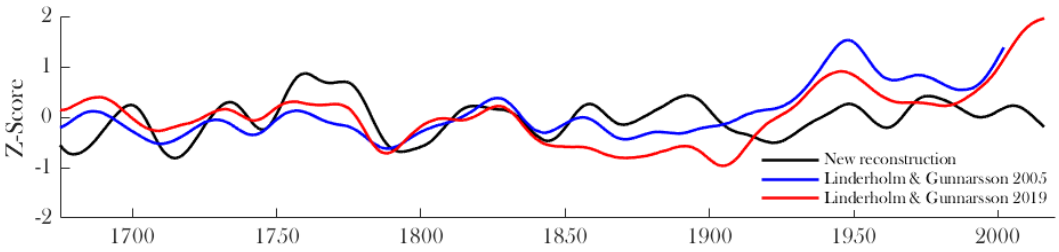

Figure 7 *Comparison between temperature reconstructions in Jämtland. The series were standardised using the zscore-function in MATLAB over the common period 1582-2016 except for Linderholm & Gunnarsson 2005 which was standardized over 1582-2002. A gaussian filter with a 30-year window length was applied to the series.*

Results from the PCA and correlation analysis suggests that the NAO could have some influence in the tree growth. The correlation between the SNAO-index and the first PC (*table* 2) was not that strong, yet significant. As the first PC contains 51.23 % of the explained variability one would reasonably assume that temperature is a large factor in this component. Considering that the SNAO exerts influence over temperature patterns in Scandinavia it is not entirely unexpected for there to be some correlation to this PC. The running correlation between the SNAO-index and the TRW-chronology (*figure 6*) showed that there is a periodic correlation between these two. While the positive phase in summer generates higher temperatures, it is also linked to dry conditions which might not be favourable for tree growth. This could be one of the contributing factors as to why there is a weaker covariance in certain periods, as well as the negative relationship found in the 1870s. Also, in Polyakova et al. (2006) it is demonstrated that the strength of the relationship between the NAO and climate variables over the North Atlantic are not stable through time, but rather fluctuate at an interdecadal timescale. It is possible that the effects of the SNAO vary in a similar manner in regard to climate conditions that affect the tree growth in west-central Sweden. However, further studies are required to draw any strong conclusions.

The connection to the NAO-index is somewhat more ambiguous. Index values from July received a similar value to the SNAO-index. However, there were also significant positive correlations found in December-January in the second PC as well as significant negative correlations in November and February in the fourth PC. These are more complicated to explain as none of these months are included in the growing season. In winter, the positive phase brings humid conditions and the negative phase dry conditions. The connection between the NAO-index in December-January and growth patterns could be that higher winter precipitation yields higher productivity in the early growing season while dry winters decreases the production. This would however contradict the signal found in the fourth PC. Nonetheless, the result from the analysis suggests that there could exist some relationship between growth patterns of the tree rings and the larger atmospheric circulation.

6. Conclusion

A new reconstruction of Jämtland June-July temperature based on TRW-data was presented in this study, as well as an analysis of the influence of the NAO on the growth patterns of the sampled trees. The reconstruction, which was reliable for 1678-2020, showed variability consistent with previous studies reconstructing temperature in Jämtland. However, it fails to capture the warming trend of the 20th century, which can be attributed to the phenomenon known as the divergence problem where the growth patterns of northern forests have lost sensitivity to the mean temperature for the last decades. Significant correlations were found between the SNAO- and NAO-index and PCs of 13 individual trees but the correlation coefficients were not of strong values. Running correlation between the SNAO-index and the TRW-chronology revealed that there is a stronger covariance in certain periods between these variables. These findings suggest that the growth pattern of the trees could have a connection to the NAO, and that there might be some potential for the sample site to be used for research on past atmospheric circulation.

7. References

Abdi, H., & Williams, L. (2010). *Principal component analysis.* Wiley Interdisciplinary Reviews: Computational Statistics, 2(4), 433-459.

Cook, E. R. (1985). *A Time Series Analysis Approach to Tree-Ring Standardization.* Ph.D. dissertation, The University of Arizona, Tuscon.

Cook, E., & Kairiūkštis, L. (1990). *Methods of dendrochronology : Applications in the environmental science.*

D'Arrigo, R., Wilson, R., Liepert, B., & Cherubini, P. (2008). *On the 'Divergence Problem' in Northern Forests: A review of the tree-ring evidence and possible causes.* Global and Planetary Change, 60(3-4), 289-305.

David J. Mack (2021). movcorr(x, y, k, varargin): *Compute windowed correlation coefficient* (https://www.mathworks.com/matlabcentral/fileexchange/65342-movcorr-x-y-k-varargin-compute-windowed-correlation-coefficient), MATLAB Central File Exchange. Retrieved May 24, 2021.

Folland, Chris K., Knight, J, Linderholm, Hans, Fereday, D, Ineson, S, & Hurrell, James. (2009). *The Summer North Atlantic Oscillation: Past, present and future.* Journal Of Climate, 22(5), 1082-1103.

Holmes RL (1983). *Computer-assisted quality control in tree-ring dating and measurement.* TreeRing Bull 43:69–78

Hurrell, J.W & Kushnir, Yochanan & Ottersen, Geir & Visbeck, Martin. (2003). *The North Atlantic Oscillation: Climatic Significance and Environmental Impact.* 10.1029/GM134.

Linderholm, H., & Gunnarson, B. (2005). *Summer temperature variability in central scandinavia during the last 3600 years.* Geografiska Annaler. Series A, Physical Geography, 87(1), 231-241.

Linderholm, H., & Gunnarson, B. (2019). *Were medieval warm-season temperatures in Jämtland, central Scandinavian Mountains, lower than previously estimated? Dendrochronologia (Verona), 57*(October), Dendrochronologia (Verona), October 2019, Vol.57.

Linderholm, H., Folland, C., Walther, A., Robertson, I., Froyd, C. A., Gagen, M., & Hicks, S. (2009). *A multicentury perspective on the summer North Atlantic Oscillation (SNAO) and drought in the eastern Atlantic Region.* Journal of Quaternary Science, 24(5), 415-425.

Linderholm, Hans W., Folland, Chris K., & Hurrell, James. (2008). *Reconstructing Summer North Atlantic Oscillation (SNAO) variability over the last five centuries.* Tree Rings In Archaeology, Climatology And Ecology, 2008, Vol. 6, Pp. 8-.16, 6, 8-16.

Liu, Y., Jeong, J-H, Drobyshev, I., Grudd, H., Gunnarson, B.E., Seftigen, K., . . . Bjorklund, JA. (2010). *Dendroclimatology in Fennoscandia – from past accomplishments to future potential.* Climate Of The Past, 6, 93-114.

Ljungqvist, Fredrik Charpentier, Thejll, Peter, Björklund, Jesper, Gunnarson, Björn E., Piermattei, Alma, Rydval, Miloš, . . . Büntgen, Ulf. (2020). *Assessing non-linearity in European temperature-sensitive tree-ring data.* Dendrochronologia, 2020, Vol. 59, 59, Dendrochronologia, 2020, Vol. 59.

Loehle, Craig. (2009). *A mathematical analysis of the divergence problem in dendroclimatology.* Climatic Change, 94(3), 233-245.

Martin H. Visbeck, James W. Hurrell, Lorenzo Polvani, & Heidi M. Cullen. (2001). *The North Atlantic Oscillation: Past, present, and future.* Proceedings of the National Academy of Sciences of the United States of America, 98(23), 12876-12877.

Masson-Delmotte, V., M. Schulz, A. Abe-Ouchi, J. Beer, A. Ganopolski, J.F. González Rouco, E. Jansen, K. Lambeck, J. Luterbacher, T. Naish, T. Osborn, B. Otto-Bliesner, T. Quinn, R. Ramesh, M. Rojas, X. Shao and A. Timmermann, 2013: Information from Paleoclimate Archives. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

National Research Council. (2007). *Surface Temperature Reconstructions for the Last 2,000 Years.*

Polyakova, E., Journel, A., Polyakov, I., & Bhatt, U. (2006). *Changing relationship between the North Atlantic Oscillation and key North Atlantic climate parameters. Geophysical Research Letters, 33*(3), N/a.

Sheppard, P. (2010). *Dendroclimatology: Extracting climate from trees.* Wiley Interdisciplinary Reviews: Climate Change, 1(3), 343-352.

SMHI. (2010). *Nordatlantiska oscillationen (NAO).* Retrieved 2021-04-21 from: https://www.smhi.se/kunskapsbanken/meteorologi/nordatlantiska-oscillationen-nao-1.13984

Smith, & Lewis, D, D. (2007). *Dendrochronology.* 459-465.

Wanner, H., Brönnimann, S., Casty, C., Gyalistras, D., Luterbacher, J., Schmutz, C., . . . Xoplaki, B. (2001). *North Atlantic Oscillation – Concepts And Studies.* Surveys in Geophysics, 22(4), 321-381.