# Heterogeneous climate signal in *Pinus sylvestris* tree-ring chronologies from southern Finland

**E.Düthorn[1], J.Lindén[1], M.Timonen[2], S.Gläser[1] & J.Esper[1]**
[1] *Department of Geography, Johannes Gutenberg University, Mainz, Germany*
[2] *Finnish Forest Research Institute, Rovaniemi. Finland*
*E-mail: duethorn@uni-mainz.de*

## Introduction

Northern Europe is often considered to be a hotspot for proxy-based climate reconstructions, especially when considering tree-ring chronologies (Eronen et al. 2002; Helama & Lindholm 2003; Büntgen et al. 2005; Büntgen et al. 2008; Nicolussi et al. 2009; Esper et al. 2012). Typically, the growth pattern found in tree-ring width (TRW) chronologies from high latitude areas, such as northern Scandinavia, correlate well with summer temperatures (Helama et al. 2009; Grudd 2008; Gouirand et al. 2008). The climate signal changes with decreasing latitudes, from the arctic area to more moderate climate regions, from growing-season temperature towards precipitation, drought and non-climatic factors such as stand dynamics (Lindholm et al. 2000). A drought signal has been found in chronologies from southern Finland (Lindholm et al. 2000; Helama & Lindholm 2003; Helama et al. 2005; Helama et al. 2009) and Sweden (Drobyshev et al. 2011). These studies all point to the importance of tree-ring chronologies from lower latitude sites in Scandinavia to reconstruct long-term drought and precipitation variability.

In general, spatial analyses are necessary to increase the validity of climate signals in tree-rings (Gouirand et al. 2008; Treydte et al. 2007). Tree ring climate signals are affected by the age of the trees (Carrer & Urbinati 2004; Esper et al. 2008; Linan et al. 2012) as well as the sampling strategy (Tegel et al. 2010). Also more statistical processes, as RCS detrending, could influence the chronologies and therefore the correlation coefficients between the time-series and the climate target (Briffa & Melvin 2011). Düthorn et al. (2013) showed that trees growing in differing micro-sites produce different regional curves and contain differing climate signals.

Here, we assess the homogeneity of the climate signal and the signal strength across a network of 28 *Pinus sylvestris* tree-ring chronologies in southern Finland (60-65°N/23-33°E) and examine the influence of chronology characteristics such as mean replication, mean age, growth rate and latitude on the retained climate signal.

## Tree-ring proxy and climate target data

The location of the 28 tree-ring sites herein examined is shown in Figure 1. Twenty-four chronologies were downloaded from the ITRDB and expanded by four recently sampled sites, considering ecological differences as moist soil conditions directly at lakeshores and drier soil conditions a few meters away from the lakeshore (Düthorn et al. 2013). The chronologies differ in length (119 to 395 years), replication (21 to 134 series) and were sampled in different years (1978 to 2011). Biological age trends were removed using 67% splines (as in Lindholm et al. (2000), Helama and Lindholm (2003)). This means that the rigidity of the spline is 2/3 of the length of every single time-series with a 50% frequency cut-off (Cook & Peters 1997). For calibration , we used monthly precipitation data from the GPCC V6 2.5°grid (Schneider et al. 2011) over the 1902-1978 period common to all tree-ring chronologies. The average of four grid points was considered and might best represent the widely distributed station data from Punkaharju, Lappeenranta, Helsinki, Tampere, Jyväskylä, Kajaani, Turku and St. Petersburg used in previous studies.

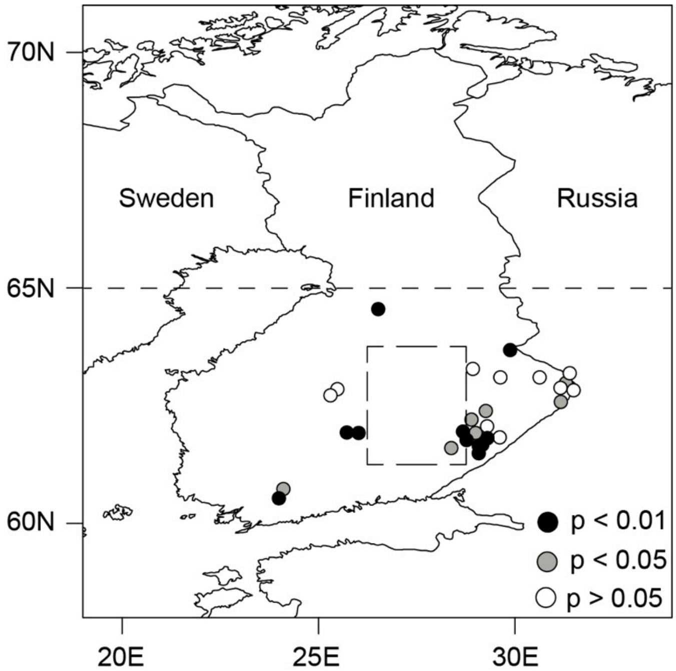


*Figure 1: Location and climate signal strength of the 28 Pinus sylvestris tree-ring sites located south of 65°N in southern Finland. The colours (black, grey, white) indicate differing significance levels of the correlation of tree-ring chronologies with the sum of previous year May and June (pMJ) and current year May and June (MJ) precipitation calculated over the 1902-1978 common period.*

**Results**

*Growth pattern*

The correlation matrix in figure 2 shows the inter-site correlations among all 28 TRW chronologies. Correlation coefficients range from -0.24 to 0.88 indicating no homogeneous growth pattern throughout the region. The matrix does not contain spatial patterns, i.e. neighboring chronologies do not necessarily correlate better than distant chronologies. The matrix also highlights the chronologies deviating from the general pattern, e.g. F24 showing low and negative correlation values with all other tree-ring sites. Other chronologies, e.g. F13 and F15, indicate rather high inter-site correlation. The mean correlation of all sites is 0.36.

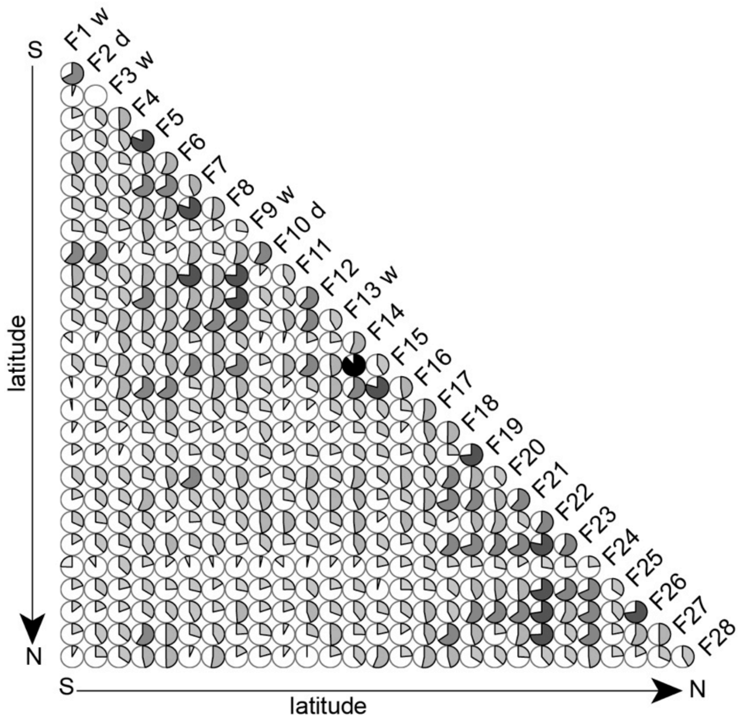


*Figure 2: Correlation matrix of 28 tree-ring sites (F1-F28) ordered in south-north direction. Pies filled in clockwise direction indicate positive correlation. Pies filled counter clockwise indicate negative correlation. The darker the colour of the pie the stronger the correlation is. The extensions "w" and "d" indicate chronologies sampled at a lakeshore and drier inland micro-sites, respectively.*

*Growth-climate response patterns*

The relatively moderate climate in southern Finland is expected to decrease the strength of the climate signal, because the limiting factor is likely to be less strong as compared to semi-arid or very cold areas (Linderholm et al. 2010; Speer 2010). In order to determine growth-climate relationships of the 28 sites, correlations between monthly precipitation and the single tree-ring chronologies were calculated (Fig.3a). Highest correlation values were found with previous year May-June (pMJ) and current year May-June (MJ) precipitation. In general, the climate signal is not uniform throughout the study area (Fig.3b). Eighteen of the 28 tree-ring sites (black and grey bars) show significant ($p$ <0.05) correlations with early summer precipitation, and most significant responses were found with pMJ and MJ precipitation. The sum of these two seasons (pMJMJ) is thus considered in further analysis in order to assess the strongest common climate signal.

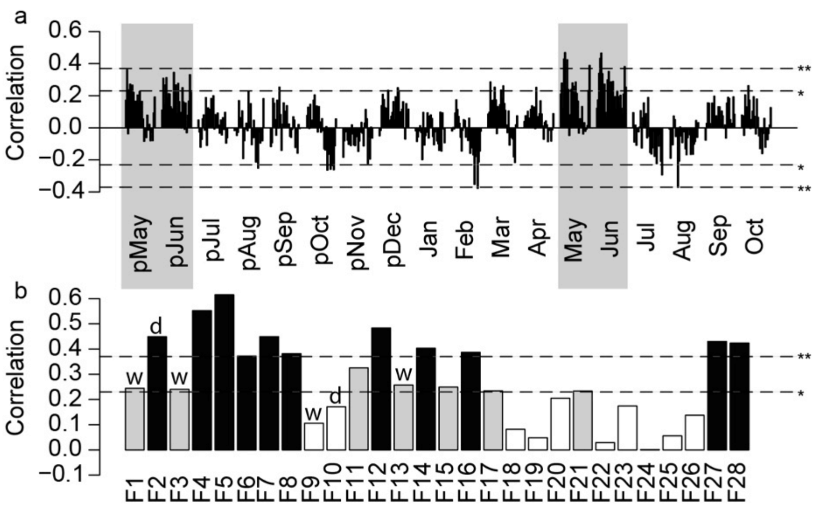


*Figure 3: (a) Correlation coefficients of every tree-ring site (F1-F28) with monthly precipitation data of previous year May to current year October over the 1902-1978 common period. (b) Correlation results with pMJMJ precipitation sums over 1902-1978. Colour denotes the statistical significance reaching from p<0.01 (black) to p<0.05 (grey), and p>0.05 (white). Dotted lines indicate estimates of the 99% (**) and 95% (*) confidence level. Sites are ordered from lower (F1) to higher (F28) latitudes.*

Differences in growth patterns between the sites are reflected in the high variability in significance of correlations. Figure 4 shows the 11 chronologies with the highest correlation (*p*<0.01) with pMJMJ (top) and the 10 chronologies with the lowest correlation (*p*>0.05) with pMJMJ (bottom). The correlation between the mean of these chronologies with pMJMJ reach $r_{p<0.01}$=0.63 in figure 4a and $r_{p>0.05}$=0.16 in 4b.

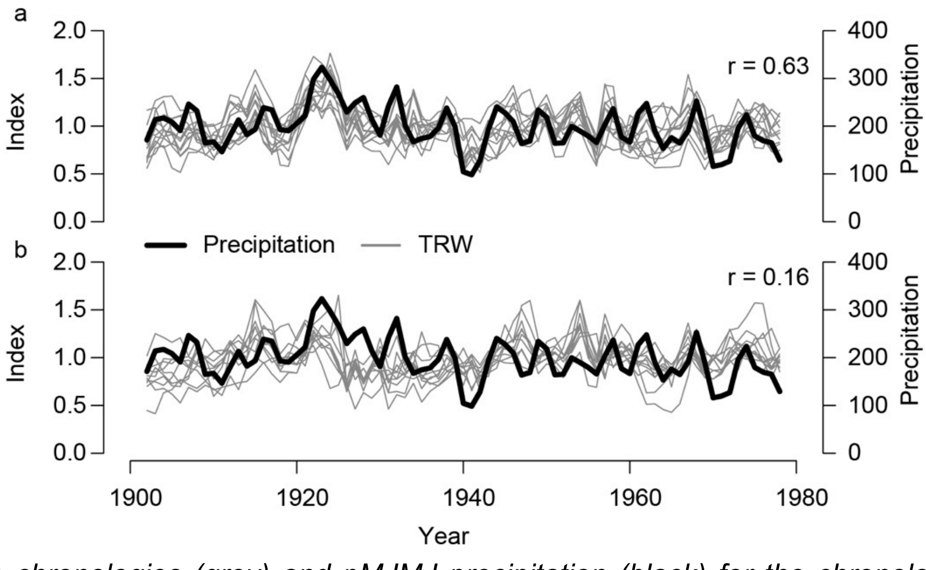


*Figure 4: Site chronologies (grey) and pMJMJ precipitation (black) for the chronologies reaching (a) highest significance (p<0.01) and (b) lowest significance (p>0.05). Correlation coefficients derived from the mean of the site chronologies in the top and bottom panels with pMJMJ precipitation over the 1902-1978 period.*

*Correlation analysis*

Due to different contributors of TRW data in the International Tree Ring Data Bank (ITRDB) and our own sampling strategy, the complete dataset is rather heterogeneous in terms of site-specific replication, age structure and location. Correlations between TRW and pMJMJ range from 0.001 (F24) to 0.62 (F5). In order to examine the possible causes of the large inter-series variability of the correlation coefficients, the influence of replication, mean age, growth rate (common period as well as the first 80 years), and latitude, on the climate correlation coefficient was tested (Fig. 5).

The chronologies of southern Finland show mean replications for the common period (1902-1978) between 18 and 120 samples. In Fig. 5a the mean replication for the series, especially when <70, are widely distributed and show no significant influence on the correlation with the climate parameter. A similar pattern is shown in figure 5b, where large differences between the lowest mean age of 23.2 years and the highest mean age of 335.8 years show very little influence on the obtained climate correlations. The influence of growth rate on these relationships is further tested in two different ways: The mean growth rate for the 1902-1978 common period (Fig. 5c) and the mean growth rate for the cambial age 1-80 (Fig. 5d). Both parameters are widely distributed and no significant pattern could be found. Figure 5e shows all tree-ring sites as black dots except for the two northernmost sites, which are plotted in grey. When including all sites, no significant influence of latitude can be found. However, a significant decrease of the climate-growth relationship is shown for the observed sites if the two sites located in the north are excluded. None of the tested statistical factors have a significant effect on the strength of the climate signal, indicating that other factors are causing the heterogeneity of the climate signal of the examined series.

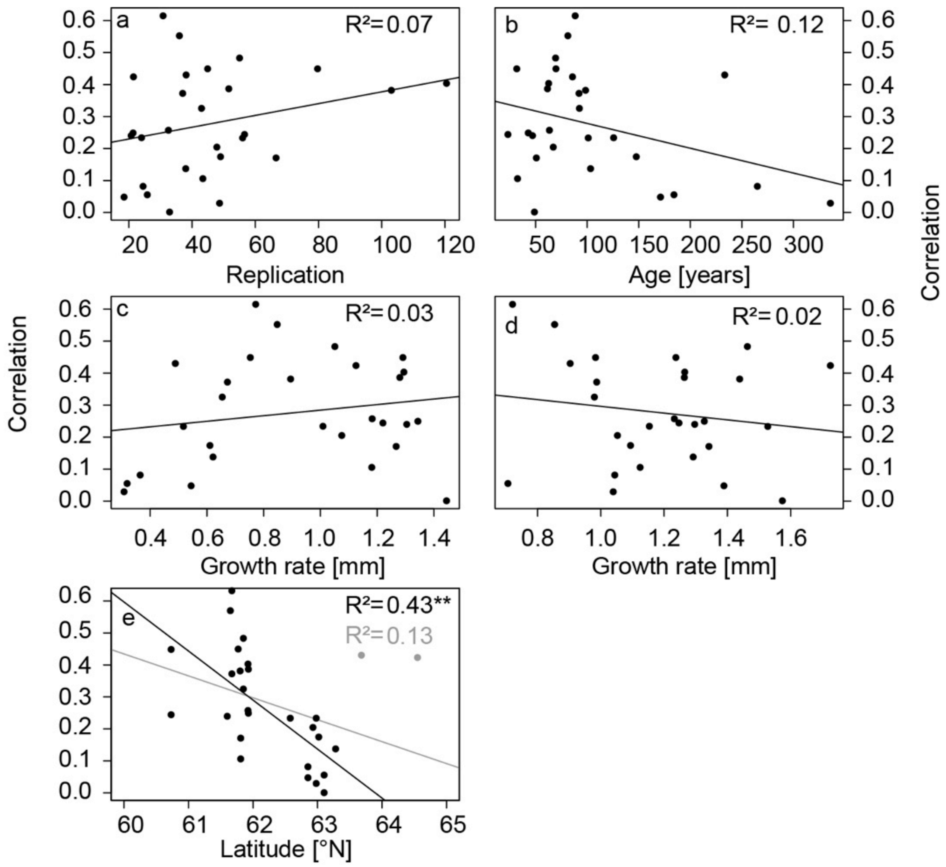


*Figure 5: XY-Plots showing the pMJMJ correlations (1902-1978) of the site chronologies ordered by different chronology parameters: (a) replication, (b) age, (c) growth rate, (d) growth rate of the first 1-80 years of tree age, (e) geographical latitude.*

**Discussion**

The relationship between tree growth and summer temperature in the northern part of Europe is considered to be very stable and thus commonly utilized for temperature reconstructions (Gouirand et al. 2008). However, the robustness and spatial extension of the climate signal in southern Scandinavia is less well understood. While several studies present drought or precipitation reconstructions from this region (Lindholm et al. 2000; Helama & Lindholm 2003; Helama et al. 2009), our analyses showed strong variations in the growth-climate response patterns among sampling sites in southern Finland. In previous studies, the strongest climate signal in tree ring chronologies is MJ precipitation (Lindholm et al. 2000; Helama & Lindholm 2003). We increased the importance of the climate signal using the sum of previous year and current year MJ precipitation.

Twenty-four chronologies from the ITRDB, and four chronologies sampled in 2012, were analysed with regard to the spatial validity and the stability of the climate signal over a larger area. The climate growth relationship of pines from the 28 sites with pMJMJ showed strong variations over the common period, with correlations ranging from 0 to 0.62. To find the cause for this inhomogeneity, various parameters that may have influenced tree-growth were tested. Some uncertainties exist due to missing meta-data about the chronologies (e.g. pith-offset, ecological conditions), and the sampling design (e.g. all trees, dominant trees, age structure). The analysis also could identify the most valuable trees or sampling areas for climate-growth relationships.

The spatial distribution of sites and signals revealed no clear pattern. Though a lot of samples are from the area of Punkaharju in the southeast, the variation in climate signal in this area is large. Helama et al. (2005) showed that inter-site correlation decreases with increasing distance. However, the here tested pine chronologies do not show this trend. Chronologies from south-eastern Finland (Fig.2: sites F3-F13, F15) differed substantially, although the region is part of the Saimaa Lake Complex with comparable climate and ecological conditions. In contrast, there are sites with high inter-site correlation in spite of geographical distance (Fig. 2: F2 and F27).

The generally low inter-site correlation indicates that the coherence among site chronologies is likely associated to other parameters, such as changing micro-site conditions or the general sampling design. Therefore, the assumption that trees of the same area respond similar to a limiting climate factor does not apply here. The four micro-site chronologies (F1d, F2w, F9d, and F10w) indicate that the difference between dry and wet sites might be important for the climate signal although the difference is only significant in F1 and F2. Due to missing meta-information, this could unfortunately not be tested for the remaining sites since only two other sites in the ITRDB (F3w and F13w) contain information on micro-site conditions (marked as “lakeshore trees” and “trees sampled at the lakeshore”). Since the heterogeneity in the climate signal could not be explained by spatial or ecological variations, the differences among the chronologies is likely associated with the multiple approaches of sampling strategies used.

An important parameter for the development of tree-ring time series is the replication of the chronologies. Although the replication among the examined chronologies varied substantially, all chronologies exceed a minimum sample size of 5 series, and this parameter showed no influence on the correlation with climate elements. Similarly, mean age and growth rate did not influence the signal strength of the examined chronologies. In general, the climate signal changes from the southern part of Scandinavia to the north from predominantly drought and precipitation signals toward temperature sensitivity (Lindholm et al. 2000; Düthorn et al. 2013). The spatial distribution of the tree-ring sites reaches from 60.73°N to 64.55°N, but the latitude of the sample sites showed no significant relationship with the signal strength if all samples were included. However, if we exclude the two northernmost sites we see a relatively strong relationship characterized by decreasing correlation values for precipitation with increasing latitude. However, if including all sites available in this region, only a very slight trend towards a decreasing climate signal with increasing latitude, indicating the importance of representative selection of the sites for statistical analyses.

The difficulty to determine the origin of the variation in climate signal between the different sites results in the problem of choosing a site representative for the calibration period. As the trees in southern Finland do not show the same climate signal, selecting a site with the best climate-growth relationship would likely not represent the population of pines in the region. Another important factor for climate reconstructions is time. The results presented here indicate strong temporal variations in climate signal strength. This problem also applies when updating existing historical chronologies (Tegel et al. 2010). Meta data about the location of the sampling site, the growth behavior and the chronology development are necessary information for increasing accuracy (Düthorn et al. 2013).

**Conclusion**

The examination of 28 TRW chronologies from southern Finland revealed strong variation in the detection of a common climate signal (temperature or precipitation) and in the manifestation of the intensity of climate-growth relationships. This study could not detect a systematic pattern of correlation coefficients, neither for large-scale spatial aspects nor for chronology development practices. This indicates that the difference among TRW chronologies has to be directly connected to site-specific aspects, including ecology and climatology. In general, this variation causes problems in the calibration of tree ring chronologies with climate targets in order to get robust spatial information for long-term reconstructions. It seems important for spatial climate reconstructions to use trees that best represent the climate-growth relationship of the investigated area. This does, however, not imply to solely consider the sites with the highest correlation if the climate signal is heterogeneous over a certain area. We therefore recommend an analysis of the historical material, e.g. origin of the wood (micro-site) and growth-climate relationship to support calibration/verification exercises. In this way, chronologies from areas where the climate signal strength is not as strong as in extreme tree-line areas could perhaps be improved.

## References

Briffa, K. R., & Melvin, T. M. (2011). A Closer Look at Regional Curve Standardization of Tree-Ring Records: Justification of the Need, a Warning of Some Pitfalls, and Suggested Improvements in Its Application. In M. K. Hughes, T. W. Swetnam & H. F. Diaz (Eds.), *Dendroclimatology* (Vol. 11, pp. 113-145): Springer Netherlands.

Büntgen, U., et al. (2005). A 1052-year tree-ring proxy for Alpine summer temperatures. Climate Dynamics. *25*(2-3): 141-153. DOI 10.1007/s00382-005-0028-1

Büntgen, U., et al. (2008). Long-term summer temperature variations in the Pyrenees. Climate Dynamics. *31*(6): 615-631. DOI 10.1007/s00382-008-0390-x

Carrer, M., & Urbinati, C. (2004). Age-dependent tree-ring growth responses to climate in Larix decidua and Pinus cembra. Ecology. *85*(3): 730-740. Doi 10.1890/02-0478

Cook, E. R., & Peters, K. (1997). Calculating unbiased tree-ring indices for the study of climatic and environmental change. Holocene. *7*(3): 361-370.

Drobyshev, I., et al. (2011). Reconstruction of a regional drought index in southern Sweden since AD 1750. Holocene. *21*(4): 667-679. Doi 10.1177/0959683610391312

Düthorn, E., et al. (2013). Influence of micro-site conditions on tree-ring climate signals and trends in Central and Northern Sweden. Trees-Structure and Function doi: 10.1007/s00468-013-0887-8.

Eronen, M., et al. (2002). The supra-long Scots pine tree-ring record for Finnish Lapland: Part 1, chronology construction and initial inferences. Holocene. *12*(6): 673-680. Doi 10.1191/0959683602hl580rp

Esper, J., et al. (2012). Orbital forcing of tree-ring data. Nature Climate Change. *2*(12): 862-866. Doi 10.1038/Nclimate1589

Esper, J., et al. (2008). Climate signal age effects - Evidence from young and old trees in the Swiss Engadin. Forest Ecology and Management. *255*(11): 3783-3789. DOI 10.1016/j.foreco.2008.03.015

Gouirand, I., et al. (2008). On the spatiotemporal characteristics of Fennoscandian tree-ring based summer temperature reconstructions. Theoretical and Applied Climatology. *91*(1-4): 1-25. DOI 10.1007/s00704-007-0311-7

Grudd, H. (2008). Tornetrask tree-ring width and density AD 500-2004: a test of climatic sensitivity and a new 1500-year reconstruction of north Fennoscandian summers. Climate Dynamics. *31*(7-8): 843-857. DOI 10.1007/s00382-007-0358-2

Helama, S., & Lindholm, M. (2003). Droughts and rainfall in south-eastern Finland since AD 874, inferred from Scots pine ring-widths. Boreal Environment Research. *8*(2): 171-183.

Helama, S., et al. (2005). Multicentennial ring-width chronologies of Scots pine along a north-south gradient across Finland. Tree-Ring Research. *61*(1): 21-32.

Helama, S., et al. (2009). Multicentennial megadrought in northern Europe coincided with a global El Nino-Southern Oscillation drought pattern during the Medieval Climate Anomaly. Geology. *37*(2): 175-178. Doi 10.1130/G25329a.1

Linan, I. D., et al. (2012). Age effects and climate response in trees: a multi-proxy tree-ring test in old-growth life stages. European Journal of Forest Research. *131*(4): 933-944. DOI 10.1007/s10342-011-0566-5

Linderholm, H. W., et al. (2010). Dendroclimatology in Fennoscandia - from past accomplishments to future potential. Climate of the Past. *6*(1): 93-114.

Lindholm, M., et al. (2000). Climatic signals extracted from ring-width chronologies of Scots pines from the northern, middle and southern parts of the boreal forest belt in Finland. Silva Fennica. *34*(4): 317-330.

Nicolussi, K., et al. (2009). A 9111 year long conifer tree-ring chronology for the European Alps: a base for environmental and climatic investigations. Holocene. *19*(6): 909-920. Doi 10.1177/0959683609336565

Schneider, U., et al. (2011). GPCC Full Data Reanalysis Version 6.0 at 2.5°: Monthly Land-Surface Precipitation from Rain-Gauges built on GTS-based and Historic Data. DOI: 10.5676/DWD_GPCC/FD_M_V6_250

Speer, J. H. (2010). Fundamentals of tree-ring research: University of Arizona Press. xvi, 333 p.

Tegel, W., et al. (2010). Updating historical tree-ring records for climate reconstruction. Quaternary Science Reviews. *29*(17-18): 1957-1959. DOI 10.1016/j.quascirev.2010.05.018

Treydte, K., et al. (2007). Signal strength and climate calibration of a European tree-ring isotope network. Geophysical Research Letters. *34*(24) Artn L24302
Doi 10.1029/2007gl031106