High frequency coherence of temperature and solar radiation reconstructions over the past millennium in northern Fennoscandia

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Introduction

Tree growth is a complex process influenced by many different factors (Fritts 1976). Especially at extreme sites, with limiting climatic factors, the production of wood and the carbon isotope fractionation notably depends on external influences, e.g. vegetation period temperatures, precipitation, snow cover, or radiation variations. Due to the measurement of various parameters, including tree ring width (TRW), maximum latewood density (MXD) and stable isotope ratios ($\delta^{13}C$, $\delta^{18}O$), trees offer the possibility for multi-proxy analyses (McCarroll et al. 2013). In northern Europe, MXD and carbon isotope records have been used to reconstruct several climate parameters over the last millennium (Esper et al. 2014, Esper et al. 2012, Gagen et al. 2011, Loader et al. 2013, Melvin et al. 2013, Young et al. 2012). All these reconstructions display the variability of a climate parameter over at least the last 1000 years. Studying the association between these might improve our understanding of the complex interaction between tree growth and atmospheric conditions. The relationship between radiation, estimated by using sunshine hour and cloud cover reconstructions, and temperature has been discussed in several recent papers (Gagen et al. 2011, Loader et al. 2013, Young et al. 2012). These studies indicated temperature versus cloud cover homogeneity at higher frequencies, but also a decoupling between these elements at lower frequencies, enabling reconstructions of prolonged periods with sunny and cold as well as cloudy and warm conditions, respectively. We here build on these results and compare summer temperature reconstructions, derived from MXD time series, with reconstructions of solar radiation (cloud cover and sunshine hours), derived from $\delta^{13}C$ time series. We assess inter- and intra-proxy similarities focusing on high and low frequency domains as well as possible effects of macro-climate conditions.

Data and Methods

In northern Europe, several climate reconstructions have been developed, based on long tree-ring records, with annual resolution, and covering the last millennium (Overview in McCarroll et al. 2013). Beside multi-proxy analyses, also intra-proxy relationships are important to understand. A recent study showed the similarity between the MXD based temperature reconstructions from Torneträsk (Melvin et al. 2013, Schweingruber et al. 1988) and northern Fennoscandia (Esper et al. 2012). They combined the two time series to a single record representing summer temperature variations in northern Europe (N-Eur; Esper et al. 2014).
There are two long term carbon isotope records with an annual resolution from Torneträsk and Forfjorddalen (Loader et al. 2013, Young et al. 2012). Both records are proxies for solar radiation, with the Torneträsk isotopic data representing summer sunshine hours, and the Forfjorddalen data representing cloud cover changes.
All proxy records cover the last millennium (1000-2001AD). Standardization over this common period allows comparisons between the reconstructions. For inter-proxy comparisons we use the N-Eur temperature reconstruction. Cloud cover and sunshine hours are inversely connected to each other: if it is cloudy, the sunshine hours are reduced. Hence, the cloud cover record was

inverted enabling the comparability of the reconstructions. The low-frequency relationship between the two climate parameters was tested by calculating residuals between the temperature and the radiation record. A 10-year spline spots periods of positive and negative alterations. For tests on high frequencies we calculated the first differences of the reconstructions. This method allows us to test the relationship on a year-to-year perspective. 51-year running correlations with a centrally weighted filter help to detect the constancy of the high-frequency relationship over time.

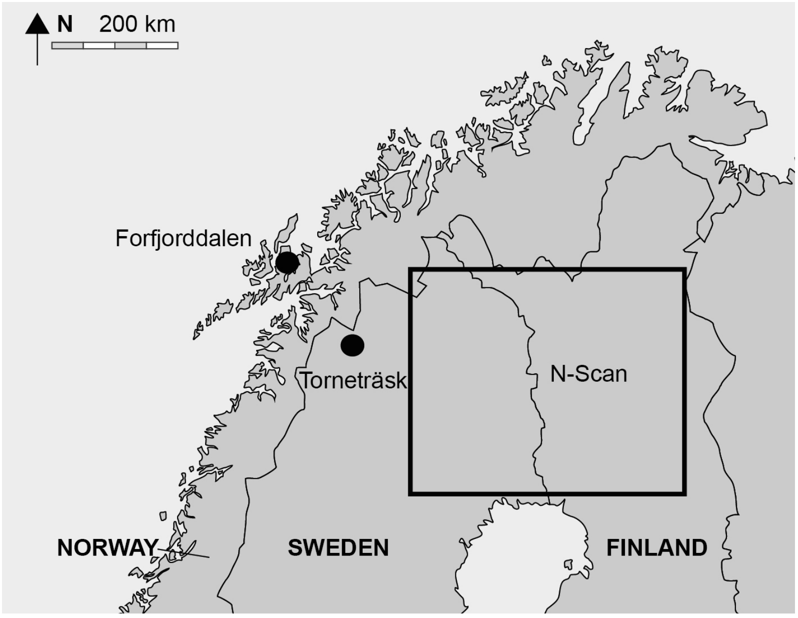

Figure 1: Map of northern Fennoscandia. Dots display sites of millennial long tree-ring records. N-Scan (black box) cannot be determined with one point due to a large extension of the different sampling sites over this northern region.

Results

The described homogeneity of the Torneträsk and N-Scan temperature reconstructions is displayed in the upper panel of figure 2 and the correlation coefficient of 0.72 over the last millennium highlights this close relationship. The radiation records (Fig.2, bottom panel) correlate at 0.48 over the past millennium, though include periods of obvious coherence (e.g., 1600-1800) and divergence (e.g., around 1100 and 1500).

The inter-proxy relationship at lower frequencies is shown in figure 3. The residual time series indicate periods with dominating warm and cloudy conditions, alternating with cool and sunny conditions. Considering the Torneträsk record, the residuals show warmer conditions at the beginning of the last millennium followed by a colder/sunnier period in the 13th century. The most distinct and persistent era of cooler and sunnier conditions is around the Little Ice Age (LIA) in the 17th and 18th century. The results are quite similar with the residual time series derived using the Forfjorddalen record. The key periods are the same as with the Torneträsk data, but there are more distinct warmer periods (e.g., around 1400 AD), as well as clearer changes in the atmospheric conditions in the early 12th and mid-15th century when the climate turned cool and cloudy.

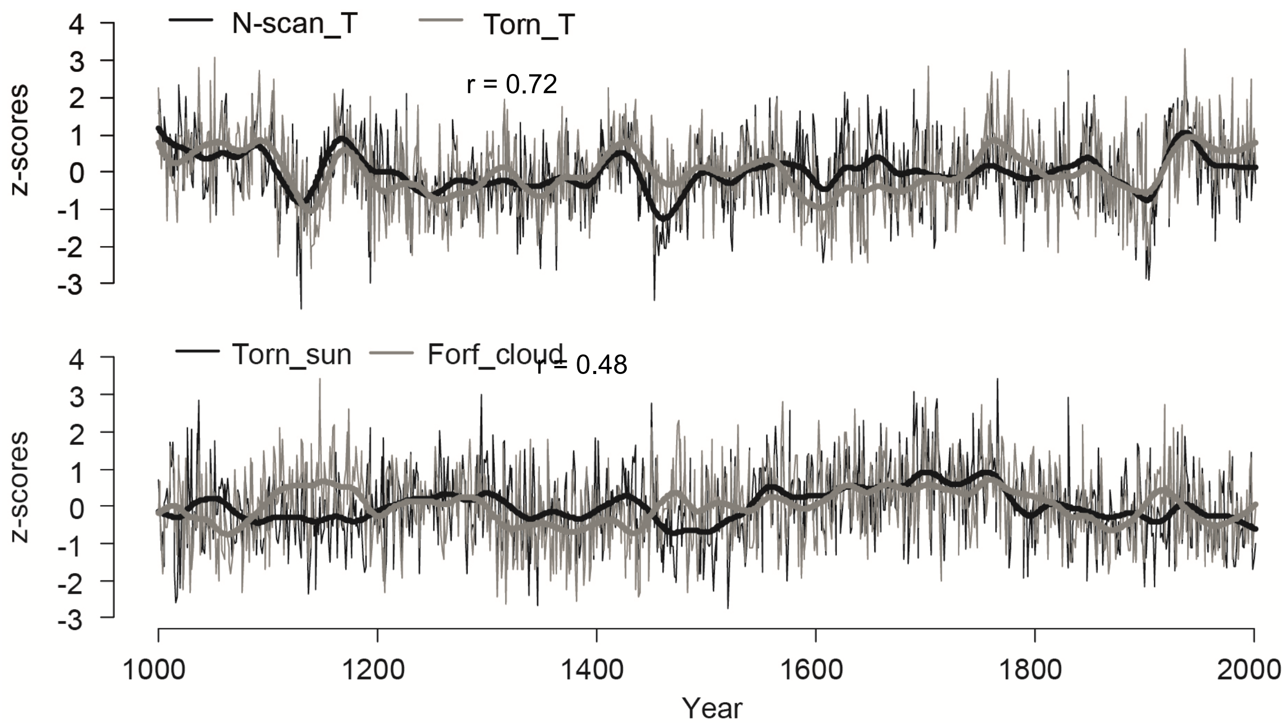

Figure 2: Millennial long climate reconstructions with annual resolution in northern Fennoscandia. Upper panel shows summer temperature reconstructions based on MXD chronologies. Lower panel shows sunshine hour/cloud cover reconstructions. The common period is 1000 - 2001 AD. All data were z-transformed over this common period. The cloud cover reconstruction is inverted to simplify comparison with the other reconstructions. Thicker lines are 50 year spline.

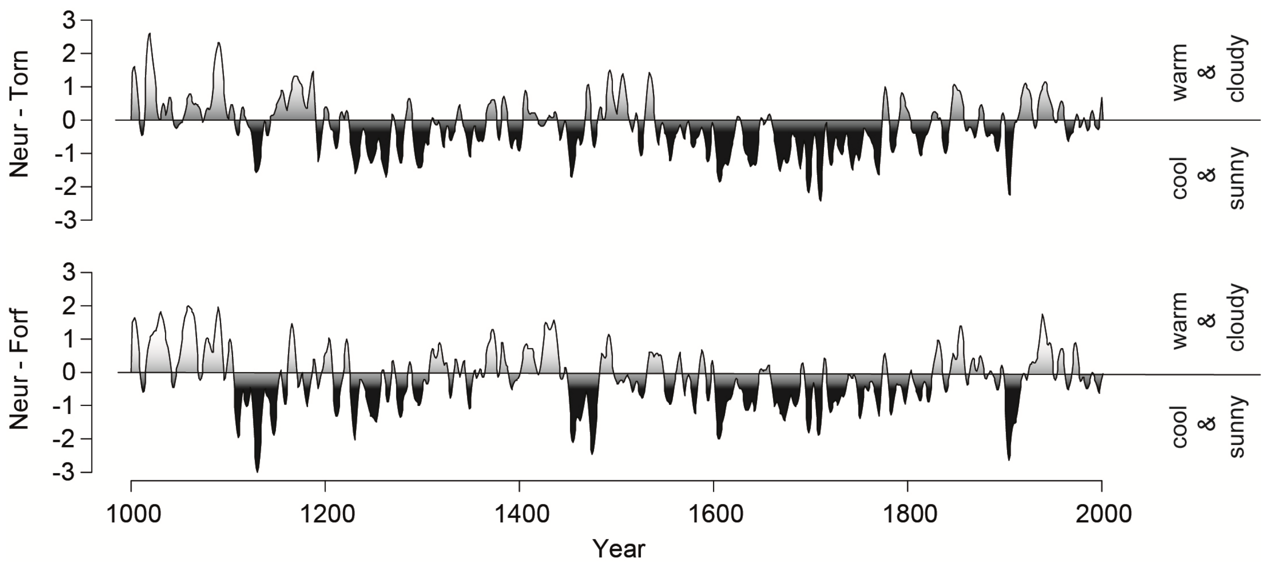

Figure 3: Relative differences between the combined temperature reconstruction (N-Eur) and sunshine hour/cloud cover reconstructions (upper panel: Torneträsk; lower panel: Forfjorddalen). Differences are smoothed with a 10 year spline. Warm and cloudy conditions are represented by positive values (grey), negative values indicate cool and sunny atmospheric conditions (black).

51-year running correlations indicate similar patterns among the three records (Fig.4). The relationship between temperature and radiation (sunshine/cloud cover) is positive throughout the entire millennium and varies around 0.5. The most striking deviation occurred in the late 16th century when correlation drop below 0.2 in all cases. The correlation drops in the 11th century using Torneträsk data, though this feature is not revealed in the Forfjorddalen data nor in the combined record (bottom panel in Fig.4)

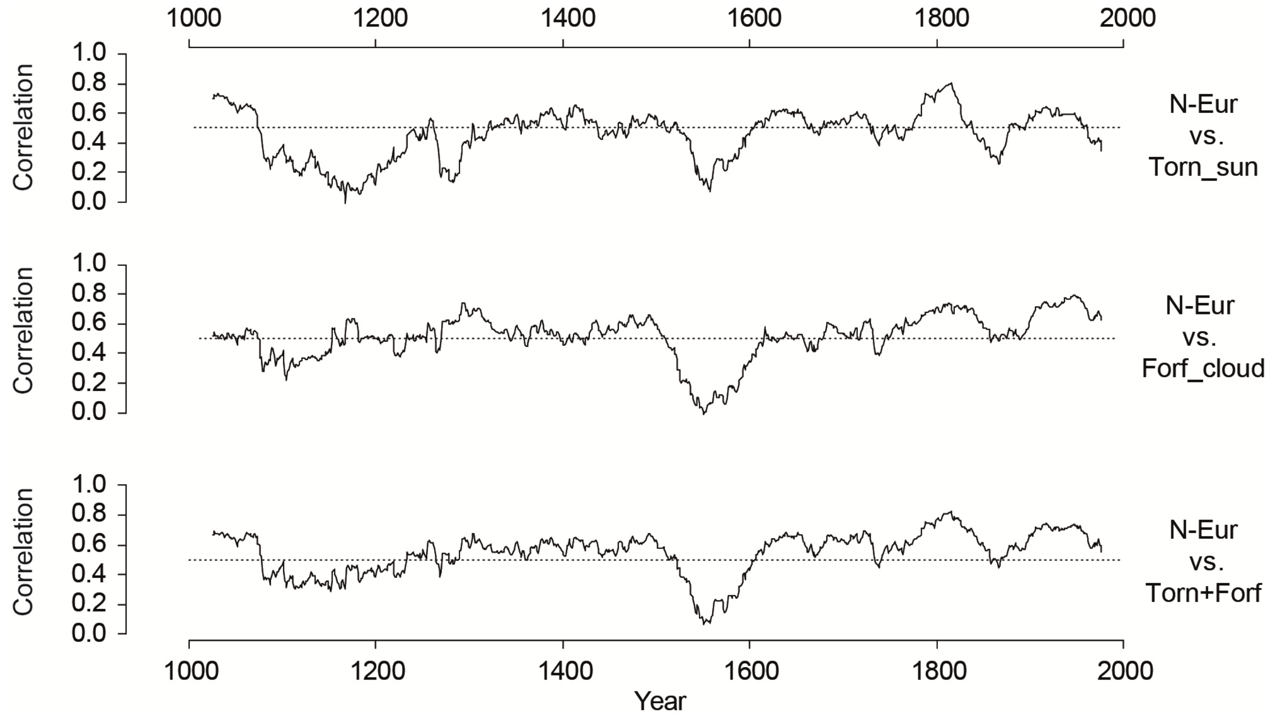

Fig.4: Inter-proxy high frequency analysis. 51-year running correlation of the first differences of temperature and radiation reconstructions. Upper (middle) panel shows the correlations of N-Eur and Torneträsk (Forfjorddalen). Lower panel shows the running correlations of a combined record of Torneträsk and Forfjorddalen versus N-Eur. Dotted line is r= 0.5.

Discussion

The similarity of the MXD-based temperature reconstructions (Torneträsk and N-Scan) enables merging these records into a single temperature reconstruction for northern Fennoscandia (Esper et al. 2014). A similar combination of the stable carbon isotope-based radiation reconstruction (sunshine hour and cloud cover) from nearby Forfjorddalen and Torneträsk would increase replication and likely advance the spatial expansion of the radiation signal. In general, discrepancies between these records (see lower panel in Fig.2) could be related to the location in the luv (Forfjorddalen) and lee (Torneträsk) of the Scandinavian Mountains. The coastal site is influenced by a higher atmospheric moisture content due to the Atlantic Ocean. The Scandinavian Mountains serve as orographic border where the air masses rise. During the movement the air masses are transformed into precipitation, fog and clouds (Young et al. 2012). The phenomenon of the foehn provides drier and warmer conditions in the continental Torneträsk area (Holmgren and Tjus 1996). While these site effects appear important to understand differences between the carbon isotope records, the overall coherence is still striking. Also the spatial importance is unclear due to the strong effect of macro-climatic influences.

Changing connections of temperature and radiation proxies at differing frequencies (Fig.3 and Fig.4) have already been addressed by Gagen et al. (2011) detailing co-variance at high frequency and divergence at decadal to centennial time scales. We here provide more detail on these changes. First of all the relationship between temperature and sunshine hour is positive over the last millennium (Fig.4), indicating that warmer temperatures coincide with more hours of sunshine (Loader et al. 2013). This positive relationship on a high frequency level is accompanied by an opposite relationship at lower frequencies. The residual time series (Fig.3) point out changing conditions and a decoupling of the positive relationship between temperature and sunshine hours during the last 1000 years. As the high frequency shows robust results of a positive relationship, we will discuss the possible causes for the divergence at lower frequencies.

Next to annual information tree-rings also store low frequency trends. Depending on the measured parameter and the statistical treatment, the low frequency capacity of the time series could vary.

The low frequency content in the temperature reconstructions depends on the detrending method of the raw MXD measurements. The applied detrending technique on the MXD-measurements is the RCS detrending as it is known to keep the low frequency in the tree-ring data (Briffa et al. 1996, Esper et al. 2003). MXD-data also shows similar frequencies as the target parameter and is very suitable for temperature reconstructions (Franke et al. 2013). Some studies propose that carbon isotope records also contain low frequency information even without detrending (Young et al. 2011) but the relationship of the frequencies of the proxy and target data is unclear and depends strongly on the trend caused by the CO_2 corrections of the carbon isotope data (Konter et al. 2014). These differences also could bias the low frequency relationship between temperature and radiation, as well as the link of MXD and carbon isotope records, respectively.

Another approach to explain the divergence of temperature and radiation over time was discussed by Loader et al. (2013). They point out that a change of the dominant air masses could cause this divergence. Their results are based on the residual time series (Fig.3) where on the one hand positive differences are indicated to be warm and cloudy and on the other hand negative values point out cool and sunny conditions. This simple way to calculate differences is not very robust as it does not consider the extreme years of the climate reconstructions and therefore a misinterpretation could be the consequence. Hence, a more complex analysis of differences and of the low frequency relationship is needed to verify if there is a change in the air masses.

The high frequency relationship of temperature and radiation is very stable over the last millennium. A decoupling between both proxies is only indicated by the drop of running correlations shown in figure 4. The positive relationship between the first differenced temperature and sunshine hour time series breaks down in the 16^{th} century. We exclude an error of dating of the temperature time series as it fits quite well to other existing independent temperature reconstructions in this area. Dating problems of the radiation records are also unlikely due to the appearance of the drop at both sampling sites. Also woodland clearance as a factor for the decrease in correlation appears unlikely. Even if this effect would result in more light and increased growth, the thinning must have taken place at both sites. Helama et al. (2009) reconstructed a dry period around 1500 AD, indicating that increased drought stress could have influenced tree growth in the North and affected the temperature signal in the MXD measurements. Furthermore, this also could affect the radiation reconstructions as they are established under the condition that the carbon isotope fractionation takes place in moist environments and that the photon flux (Hari et al. 1981) is responsible for the assimilation in the tree-rings. But very dry years can change this main factor for carbon fractionation and stomata conductance controls the fractionation (McCarroll and Loader 2004). Therefore, in dry years water availability and not sunshine is influencing the signal in the carbon isotope time series.

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