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A POSSIBLE PALEOCLIMATIC IMPLICATION OF A RECENT CHANGE OF CORRELATIONS BETWEEN THE TREE-GROWTH AND THE CURRENT WARMING

ABSTRACT. Recent studies have revealed a reduced sensitivity of tree-growth to temperature at high Northern Hemisphere (NH) latitudes during recent decades. Causes of this reduction are not known, but it seems to be for certain that this reduction has important implications for paleoclimatic reconstructions based on tree-rings because there is a risk that warmer phases of paleoclimates can be essentially underestimated if the problem is not taken into account. We add some more observational evidences of the reduction and argue: it is a signal that temperatures recently have reached above optimum levels for the tree-growth in some areas of NH. If such equally warm, or warmer, phases existed in the past, and if tree-growth responded negatively to temperatures during these phases, it would be necessary to apply separate transfer functions to calibrate tree-ring records in terms of temperature for warmer and colder phases of the past climates.

KEY WORDS: dendroclimatic reconstruction, recent reduction of tree-growth, wavelet analysis.

INTRODUCTION

Much focus has been placed on reconstruction of hemispheric mean air temperature variations during the latest millennia. A number of reconstructions were published based on calibrations of various, but mainly high-resolution, climate proxy data series (tree-rings, corals, historic documents, etc.) against available instrumental surface air temperature observations in the XIXth and XXth centuries (e.g., Jones et al. [1998]; Mann et al. [1998, 1999]; Crowley and Lowery [2000]; Moberg et al. [2005]). Tree ring data (either ring widths or ring densities) are the particularly often used type of climate proxy data (Briffa et al. [2001]; Esper et al. [2002]) due to their well studied properties: exact dating, annual resolution, and more or less strong correlation with either near surface air temperatures or local precipitations. It has been noted (e.g. Briffa et al. [1998a] Wilmking et al. [2005] and many others) that the sensitivity of tree-growth to local temperatures seems to be reduced in many geographic areas during the second half of the XXth century compared to the earlier part of the period when overlaps with instrumental observations exist, i.e. often back to the middle of the XIXth century. Instead of a positive correlation with temperatures, many regional correlations became to be unessential or even negative during recent decades. Causes of this phenomenon, called the divergence problem in dendrochronology (see: D'Arrigo et al. [2007]; Loehle [2009]), are unknown

(Rutherford et al. [2005]), but a number of factors (e.g. increasing atmospheric CO_2, higher levels of pollutants, changes in soil chemistry etc.) might be involved (Briffa et al. [1998b]). It has been also recognized (Briffa et al. [1998a and 1998b]; Rutherford et al. [2005]) that some implications of this phenomenon are important and must be taken into consideration in dendroclimatic reconstructions. In this paper, we add some points to the evidences of the divergence problem and discuss the implications.

DATA SELECTION AND ANALYSES

To begin, we present some additional analyses of correlations between regionally grouped tree-ring width series and the Northern Hemisphere (NH) annual mean near surface air temperatures after 1856, emphasizing a general change in correlation during the last few decades. For this goal, we screened several hundred tree-ring width records from the World Data Centre for Paleoclimatology (http://www.ngdc.noaa.gov/paleo/data.html). Tree-ring series that start at or before the middle of the XIXth century and end at or later 1980 have been chosen for 57 regions of NH. All of these 57 NH-temperature sensitive records are mainly located within the Northern parts of Euro-Asia and Northern America, although some records are located in mountain areas further south. All these series are standardized by the classical method that damps the low-frequency (centennial and longer) climate-dependent tree growth variations. We had to choose this method because tree-ring series standardized with more perfect methods, like RCS and age-banding, which better preserve low-frequency variability (Briffa et al. [2001]; Esper et al. [2002]), exist for a few regions only. But, these latter few series that we have in our disposal reveal the same time-dependent character of their responses to temperature variations that is shown below for the classic standardized series.

The instrumental temperature data used were obtained from the web site of the Climatic Research Unit, University of East Anglia, U.K. (http://www.cru.uea.ac.uk/cru/data/temperature/), discussed by e.g. Jones et al. [1999, 2001]. Although tree rings essentially respond to local summer temperatures rather than to local annual mean temperatures, we perform our calculations using the NH annual mean temperature series. The first rationale is that the final goal of the paleoclimatic reconstructions consists in the global or hemispheric scale reconstruction. The traditional way to reach this goal consists in averaging a number of local dendroclimatic reconstructions previously calibrated by instrumental near surface air temperature data of some neighbouring meteorological stations. Unfortunately, in many cases, such station data records cover shortened time intervals: from the beginning of the XXth century only and with some gaps; besides, they are inhomogeneous. At the same time, the hemispheric mean temperatures of CRU are available from the middle of the XIXth century; they are without any gaps and more or less homogeneous. Therefore, bearing in mind that the tree-ring reconstruction calibration and these reconstructions' average are both linear mathematical procedures, so they can be changeable in their ordering, one can average all local dendrochronologies first, and then calibrate the result in terms of the hemispheric mean temperatures, either warm-season or the annual mean. The second rationale is that the vegetation period is different for different regions, and so it would be difficult to compare our result related to different regions with each other. Using the NH annual mean temperature we can overcome this difficulty.

To obtain an overall view of correlations between tree-ring width series from various regions and the NH mean temperatures, we grouped the individual tree-ring width index series located within a region and then averaged the index values for each calendar year of the series, producing one regional index-mean series for this region. A correlation graph was produced for each region, showing correlations between regional index-mean series and the NH annual mean temperatures for each of three periods: 1856–1960, 1960–1980, and 1980 to the end of a respective tree-ring series. The temperature dependence of 10 index-mean series is of the same strength over all of these three calendar periods, but the correlations with temperatures of other 47 index-sum series are different for different calendar periods.

In Fig. 1, we show examples of such correlations for 4 regions (Alaska, Finland, Russia, and Norway) with significant positive correlations (22–25% variance explained) during the 1856–1960 period. The intermediate period 1960–1980 shows significant positive correlation (18% variance explained) only for Alaska, but insignificant positive correlations for other three regions. Correlations calculated for the period from 1980 to the end of the respective tree-ring series are negative in all 4 cases, with significant values for Alaska and Norway (19% and 45% variance explained). In Figure 2, we show examples of other 4 regions (Japan, Netherlands, Poland, and Mongolia) where there is no significant correlation between the Northern Hemisphere temperature and tree-ring width.

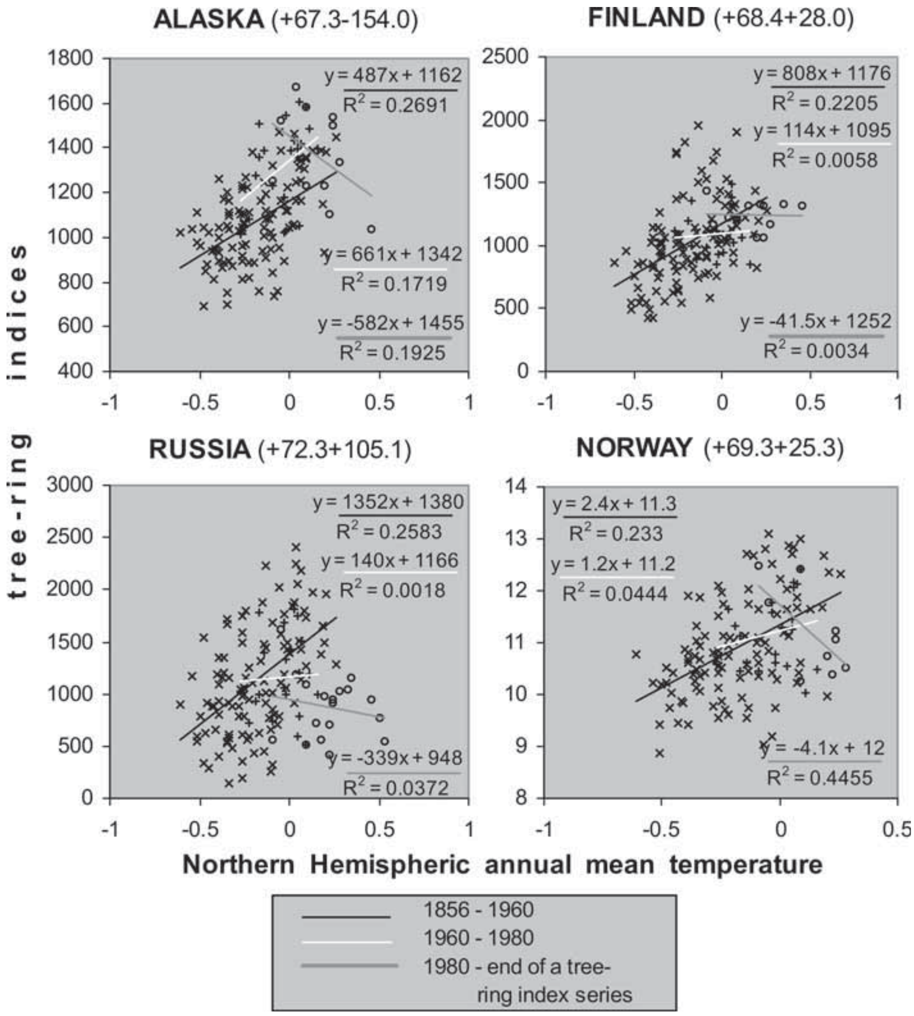

Fig. 1. Correlations between the Northern Hemisphere annual mean near surface air temperatures and regionally grouped tree-ring series from Alaska, Finland, Russia, and Norway for three periods: *1856–1960 (symbol: x), 1960–1980 (symbol: +), and 1980 – the end of the record (symbol: o).*

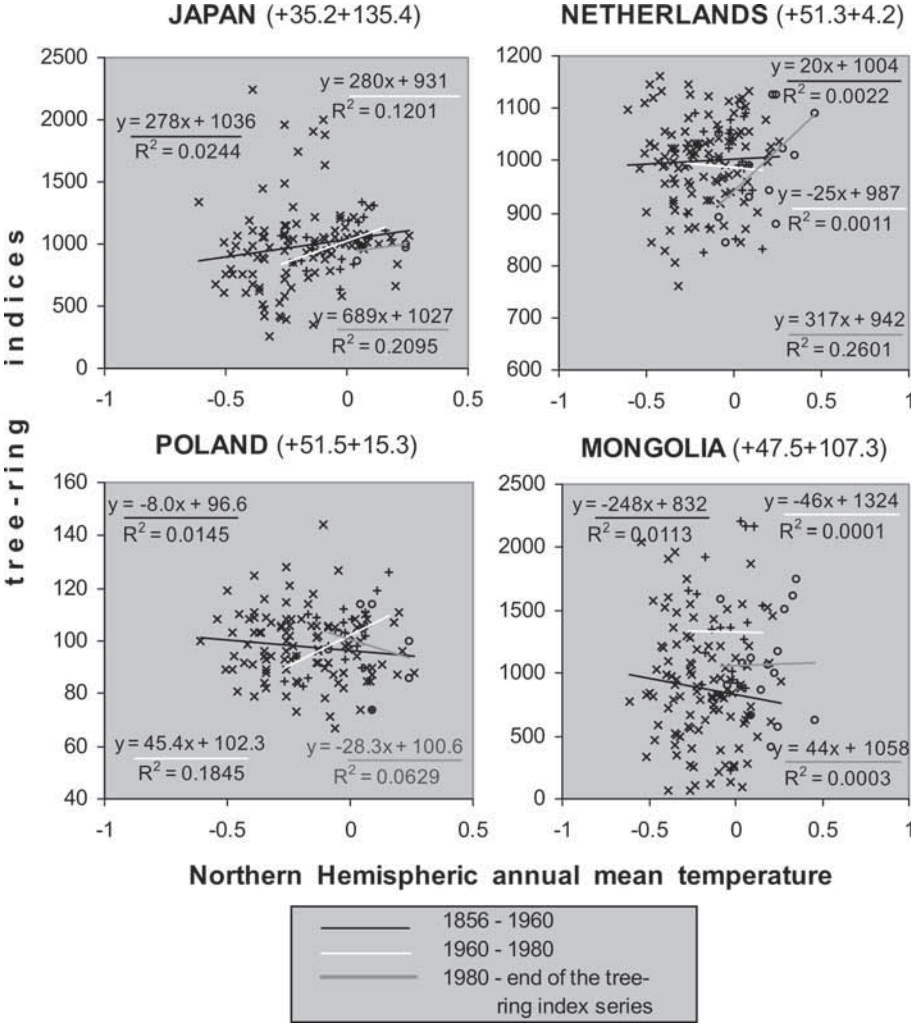

Fig. 2. Correlations between the Northern Hemisphere annual mean near surface air temperatures and regionally grouped tree-ring series from Japan, Netherlands, Poland, and Mongolia for three periods: *1856–1960 (symbol: x), 1960–1980 (symbol: +), and 1980 – the end of the record (symbol: o)*

AN EXAMPLE OF THE TIME-DEPENDENT TREE-RING WIDTH CALIBRATION

How is it possible to use the divergence phenomenon of the correlation between temperatures and tree-ring width? We have in our disposal an extended tree-ring width series from Scandinavia (Tornetresk) developed by the so-called Regional Curve Standartization (RCS). It is widely accepted that RCS preserves possible centennial and possibly multi-centennial tree growth trends due to climate, and so one can expect to see the divergence phenomenon more clearly (if it exists in reality) in the RCS-created tree-ring series than in the classic standardized series. A preliminary analysis of the divergence phenomenon on the example of the Tornetresk series has been published in Datsenko [2005]. In this paper, unfortunately available in Russian only, it was also shown (by means of a wavelet analysis) that there exists a rather close coherence between near surface air temperatures averaged over April – September measured at the station Chaparanda (not fare from the Tornetresk area) and the NH annual mean near surface air temperatures (Jones et al. [1999]). Taking into consideration, we limited our analysis here to comparison of the Tornetraesk tree-ring series with this latter temperature series.

We divided the calendar period of the Tornetresk series overlapping with the NH series into three time intervals (before 1960, 1960–1980, and 1980 – the end of the Tornestraesk series in 1997), i.e. this division is exactly the same as the one used in the previous Section. Fig. 3 (upper part) shows that the divergence problem exists for the RCS processed tree-ring records too. The correlation is positive for the first calendar period considered (before 1960). This correlation is essentially deteriorated during the second calendar period (1960–1980), and becomes to be negative during the period after 1980.

We changed the axis of the correlation graph shown in Fig. 3 (upper part) to the form shown in Fig. 3 (lower part) in order to use this time dependent correlation as a tool of the Tornestresk series calibration in terms of the NH annual mean near surface air temperature. Considering this new correlation graph, one can see that the correlation between tree-ring width and the Northern Hemisphere temperature is not one-to-one relationship. For this reason it is necessary to choose one of the three possible calibrating graphs in Fig. 3 (lower part) in order to calibrate each of year-points of the Tornetresk series.

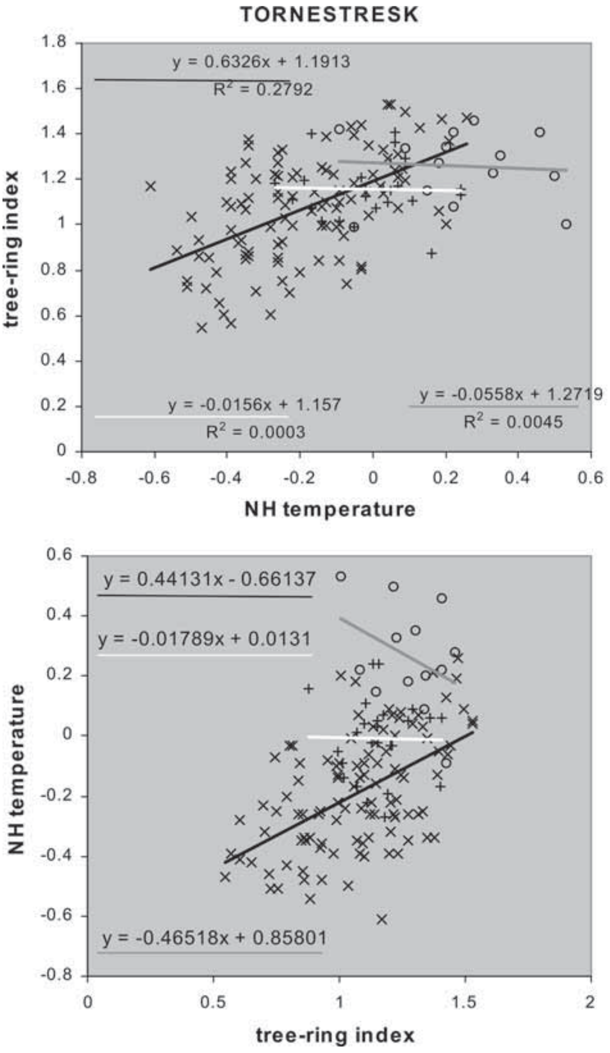

Fig. 3. Correlations between the Tornestraesk tree-ring width series (Scandinavia) and the Northern Hemisphere annual mean near surface air temperature for three periods: *1856–1960 (symbol: x), 1960–1980 (symbol: +), and 1980–1997 (symbol: o) (upper part). The same correlations with the axis changed for the Tornestraesk record time-dependent calibration is shown in the lower part*

In general, different kinds of other proxy climatic information may be used for this selection. Some discussion of this point can be found in Loehle [2009]. But here, we limit ourselves to the illustrative examples of this problem solving. Our approach is simply to choose only the information contained in the tree-ring series itself. We just take into account the hypothesis that the tree growth divergence can be observed either after or before the time moment when climate crosses the temperature optimal for the respective tree species growth. Such transition can be observed either if climate warming reaches this optimal temperature and continues to warm further or if climate cooling, from the higher to lower than the optimal temperatures, takes place. If such a transition year-point exists indeed, it must be seen in a tree-ring record as a year-point of a tree index maximum in the tree-ring series considered. The only maxima that may be identified as transition points are the values similar to the tree index value near the intersection of the correlation graphs of the respective tree series calibration like those shown in Fig. 3.

In Fig. 3 (lower part), the intersect value of the Tornestresk tree index is near 1.5. Therefore, the maximal year-points of the Tornestresk series (Fig. 4 (upper part)) located near the calendar years of 935, 1000, 1070, 1090, 1311, 1411, 1450, 1760, 1830, and 1851 AD are the candidates for the transition year-points. Two latest year-points must be rejected from this listing for certain because extensive early instrumental and proxy data indicate that the XIXth century climate was rather cold. Among other candidate year-points, the 935 and 1000 year-points seem to be the year-points in the beginning of the Medieval Warm Period (see; Hughes and Diaz, 1994). For example, if the 935 (or 1000) year-point is the first transition year-point indeed, the year-points of the Tornetresk tree-ring series before 935 (1000) AD must be calibrated according to the first correlation graph of Fig 3 (lower part). It means the correlation between the tree-ring indices and the NH annual mean near surface air temperatures must be considered positive for the previous calendar period. Instead, the subsequent (after the 935 or 1000 AD) tree-ring indices must be negatively correlated with the respective NH annual mean near surface air temperatures. Therefore, these index-points must be calibrated by the third correlation graph shown in Fig. 3 (lower part). This calibration must be used up to a calendar year when climate returned to the lower than the optimal for the Tornetresk tree growth temperature conditions. The most recent, among such candidate year-points, are the 1411 (or 1311) years. The choice of one of these calendar years as the year of a transition to lower than optimal temperatures may be made based on numerous publications indicating that the end of the Medieval Warm Period took place near the mid-XVth century (Hughes and Diaz, 1994). Certainly, it is quite possible that there are some intermediate transition years within the calendar period between 935 and 1411 AD. So, alternating calibrations by the first and third graphs must be used. Indeed, there are published data (for example: Shiyatov, [1993]) that the upper limit of timberline varied essentially during the entire Medieval

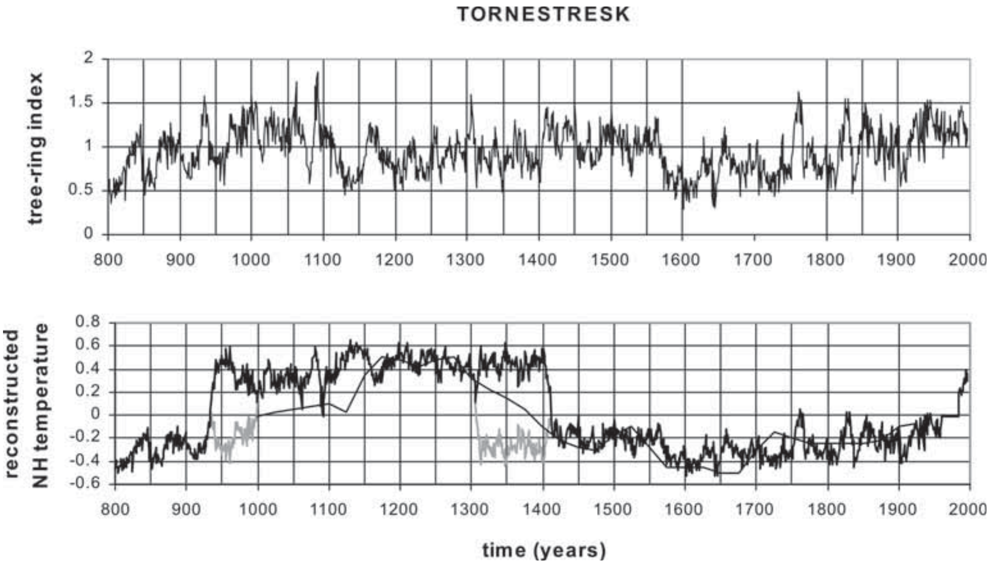

Fig. 4. The original tree-ring width series of Tornetresk (Scandinavia) (upper part), and the Northern Hemisphere annual mean near surface air temperature reconstructed by means of two alternative designs of the time-dependent calibration of the original record (lower part).

The historic reconstruction of the North Atlantic – Europe region [Lamb, 1977] is shown by thin line for comparison

Warm Period – the Little Ice Age period. Thus, it seems, when the timberline limit was higher than now, temperatures were higher than the optimal value for the tree growth in sites lower than the upper tree limit. Unfortunately, the existing evidence of the timberline dynamics is too fragmentary in order to accept their use for the quantitative identification of transition year-points in the Tornestresk series. Therefore, we limit ourselves to delineating the Medieval Warm Period as a whole without analyzing any details of this period despite some essential heterogeneity of this Period already indicated [Hughes and Diaz, 1994]. Even in this generalized form, our reconstruction seems to reproduce the well-known Lamb's temperature reconstruction for the North Atlantic – Europe region (based on historic documents mainly [Lamb, 1977]) quite satisfactory (thin line imposed on our reconstruction in Fig. 4).

ANOTHER EXAMPLE OF THE HEMISPHERIC MEAN TREE-RING BASED RECONSTRUCTION

For another illustration of our time-dependent tree-ring calibration, we use a millennial reconstruction of the NH temperature based on tree-rings [Esper et al., 2002]. The time-dependent correlation of this reconstruction with the NH annual mean near surface air temperature [Jones et al., 1999] is shown in Fig. 5. The divergence phenomenon is quite clearly seen. One of the most evident features of this reconstruction (shown in the upper part of Fig. 6) in comparison with the Tornestresk series and also with other well-known millennial temperature reconstructions, consists of an essential lowering of the tree-ring index value during the XII–XIVth centuries. This lowering contradicts to the widely accepted idea of the Medieval Warm Period. At the same time, some transition year-points can be seen during the IX–Xth and XIV–XVth centuries respective to such transition year-points in the Tornestresk series.

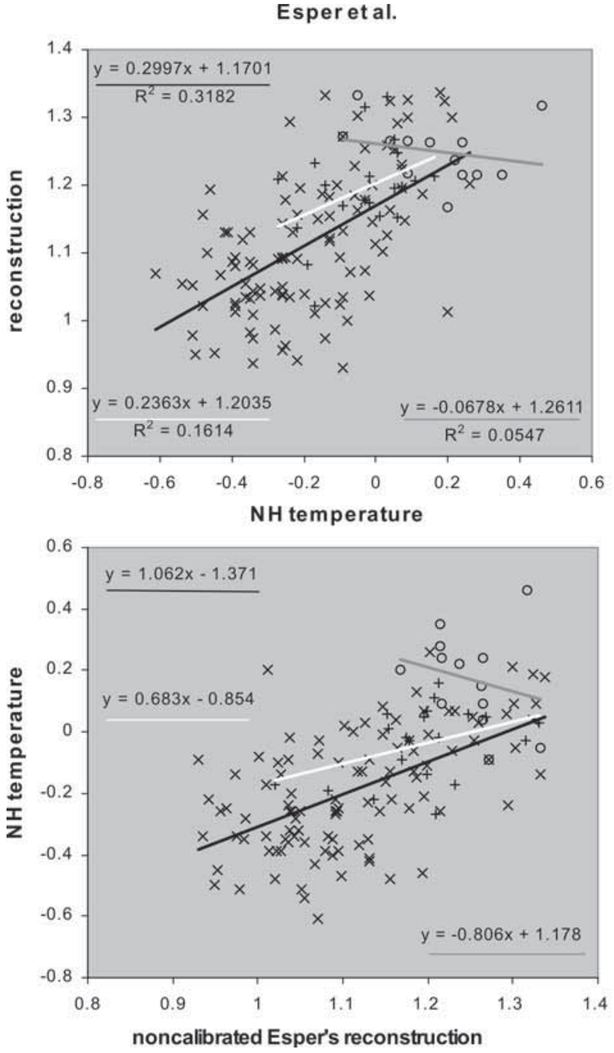

Fig. 5. Correlations (upper part of the figure) between the millennial hemispheric mean reconstruction of the tree growth [Esper et al., 2002] and the Northern Hemisphere annual mean near surface air temperature for three periods: *1856–1960 (symbol: x), 1960–1980 (symbol: +), and 1980–1997 (symbol: o) (upper part). The same analysis with the axis changed for the time-dependent calibration of the reconstruction (lower part)*

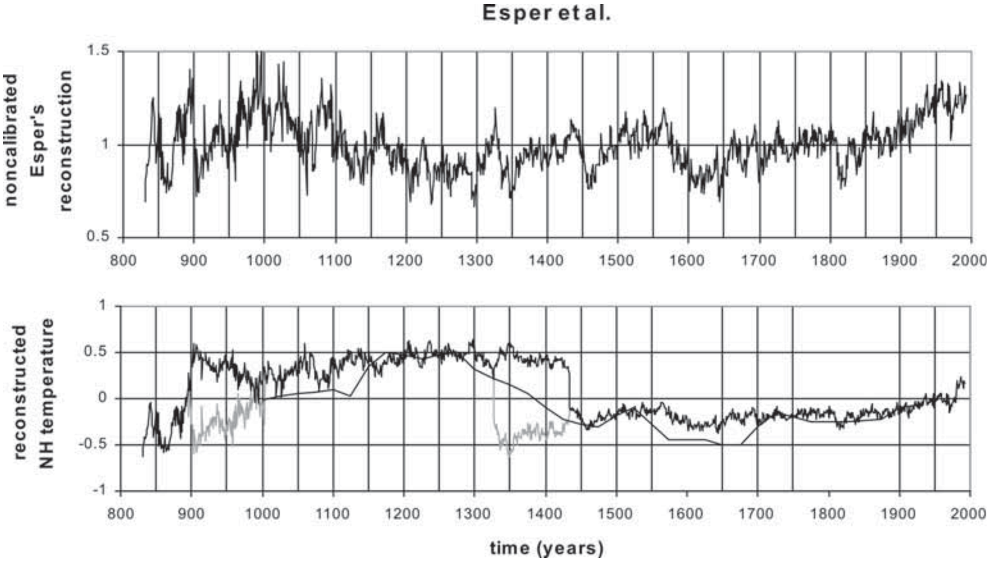

Fig. 6. The millennial hemispheric mean tree growth reconstruction [Esper et al., 2002] (upper part), and the Northern Hemisphere annual mean near surface air temperature reconstructed by means of two alternative designs of the time-dependent calibration of the tree growth reconstruction (black and grey lines in the lower part).

The historic reconstruction of the North Atlantic – Europe region [Lamb, 1977] is shown by thin line for comparison

Therefore, one can propose two alternative calibrations of this reconstruction based on these candidate year-points (see Fig. 6 (lower part)). It is necessary to indicate that temperature changes in close vicinities of the transition year-points seem to be too strong and of the same strength as the current warming or even stronger. It may be possibly explained by the fact that some transitions certainly existed within the Medieval Warm Period.

Comparison of such calibrated hemispheric reconstruction with the above created on the basis of the Tornestresk tree-ring series shows their general similarity within the multi-centennial time scale. The multi-centennial variations of both reconstructions also seem to be rather similar to the well-known Central England temperature variations during the last millennium created by Lamb (see in: Crowley and Lowery, [2000]) and to some other subjective temperature reconstructions created by Western climatologists for the XIXth and the first half of the XXth centuries. Thus, peak-to-peak variations of our NH temperature reconstructions during the entire time period from the IXth up to XXth century are about 1°C. The Medieval Warm Period is about 0.5–0.6°C higher and the Little Ice Age is about 0.4–0.5°C cooler than the mean temperature of 1961–1990 taken as the normal period in the NH annual mean near surface air temperature series. Consequently, we obtained the Medieval Warm Period to be slightly warmer (at 0.1–0.3°C) than the current warming as it is seen for the period before 1990.

DISCUSSION AND CONCLUSIONS

Certainly, we are not the first who noted the phenomenon of the tree growth divergence in respect to temperature variations and, moreover, we are not the first who recognized the importance of this phenomenon for paleoclimatic reconstructions based on tree-ring records. We only argue that this phenomenon occurred in many places of NH over the 1960–1980 time interval. Certainly, our simple analysis is not capable to accurately detect the exact year-point when the positive correlations begin to deteriorate.

As mentioned in the Introduction, many factors have a potential to cause this change of correlations, for example, increased environmental pollution. Another possible cause that has not, to our knowledge, been discussed much is the recent warming of the hemispheric mean temperatures. It is possible that the optimal large-scale temperature conditions for the tree growth were reached during 1960–1980 for forests in the Northern parts of Euro-Asia and America. The damped tree growth after this time interval may thus be due to higher than optimal temperatures for the tree growth. The divergence may thus be directly related to the recent apparently unprecedented global warming. In connection with this, one can mention a paper of Rutherford et al. [2005] whose authors calibrated their ~600-year long NH temperature field reconstruction (beginning from 1400 BP) using correlations between tree growth and temperatures estimated for the time interval before 1960 only. These authors stated, "In developing large-scale reconstructions... we have chosen to exclude any values (tree-ring data) after 1960 because of uncertainty about the cause of this divergence". It is just because the Current Warming would be essentially underestimated in another case. But, these authors did not mention that the divergence could exist during some warm phases of past climate.

The main issue that we would like to address is the possibility that trees that lived in earlier periods of the Medieval Times could also been responding negatively to increasing temperatures. If such periods of negative tree – temperature correlations really existed in these past times, then this imposes a restriction, or at least a complication, to the usefulness of the tree-ring width data for reconstruction of past climatic variability. To reconstruct the full range of the past temperature variations (for example the difference between temperatures of the Medieval Warm Period and the Little Ice Age), it would be necessary to apply different transfer functions: one function for the colder and another function for the warmer times. Two major problems would arise in such a case: 1) to determine different transfer functions to be used for different climatic states, and 2) to determine what sort of transfer functions must be used for each time interval.

Our intention here is only to indicate a possibility that any tree-ring data calibration may be a major problem if the full range of the climatic variations over millennia is considered, and to point out that this problem should not be neglected in future research. In contrast to a conclusion of Briffa et al. [1998a, 1998b] that past temperatures could be overestimated by the reason of the divergence, we stress that a risk exists that temperatures during the warmest past times are underestimated rather than overestimated in the millennial tree-ring based reconstructions created to this date.

Certainly, the method that we use to illustrate this risk is oversimplified, and so the results demonstrated in this paper may be aggravated by serious shortcomings. Despite these shortcomings, we hope that the examples we demonstrate provide new important information for quantitative comparison of the Current Climate Warming with the Medieval Warm Period.

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