Source: Elferts D, Brumelis G, Gärtner H, Helle G, Schleser G (eds.) (2008) TRACE - Tree Rings in Archaeology, Climatology and Ecology, Vol. 6: Proceedings of the DENDROSYMPOSIUM 2007, May 3rd – 6th 2007, Riga, Latvia. GFZ Potsdam, Scientific Technical Report STR 08/05, Potsdam, p. 31 - 36.

A challenge for spatially explicit reconstructions: the climate response of trees is a function of climate

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Introduction

It is well known that ambient climate conditions, modulated by site ecology, place limitations on tree growth (Fritts 1976). Year-to-year variations in local climate result in more or less severe growth constraints that typically are reflected as narrower or wider annual rings. Accordingly, dendroclimatic investigations target sampling locations where the limitation from one climatic element -- the reconstruction target -- is dominant. Thus skillful temperature reconstructions from tree-ring width (TRW) require data from trees growing near the theoretical thermal limit sufficient for survival, i.e., the elevational or latitudinal treeline. For these reasons, local, regional, and hemispheric temperature reconstructions are weighted towards the high latitudes or mountainous areas. These biogeographic and plant physiological constraints may hinder efforts to develop spatial reconstructions seeking to utilize data well distributed over the earth's land surface.

Within the European region, significant progress has been made in understanding longer-term, spatially-resolved, climate variations via multi-proxy studies (Luterbacher et al. 2004). Such efforts rely heavily upon long-instrumental series (Auer et al. 2007) and documentary evidence (Brazdil et al. 2005; Pfister 1999), which are either non-existent or increasingly scarce prior to about 1500 AD. Over longer time scales, the relevance of natural proxies increases for understanding climate variations across Europe. In this regard, and in line with the previously stated limitations, successful long-term efforts utilizing TRW data include temperature reconstructions for Scandinavia (Grudd et al. 2002), the European Alps (Büntgen et al. 2005), and the Carpatian Arc (Büntgen et al. 2007). In contrast, long precipitation or drought reconstructions have been developed for southern Germany (Wilson et al. 2005) and Morocco (Esper et al. 2007) and in the Mediterranean basin (Griggs et al. 2007).

It would obviously be desirable to fill the large spatial gaps that exist between current local reconstructions, so that more meaningful assessments of spatial climate variability can be derived. This could either be achieved by determining suitable locations, which have not yet been targeted for sampling, and/or finding proxy-types or parameters, such as isotopic data (Treydte et al. 2006) or quantifiable wood anatomical features (Fonti et al. 2007) that most skillfully serve in all regions.

Herein we compile a network of TRW data and analyze the climatic response as a function of the climate itself. We attempt to characterize the importance of forcing factors on growth for the European region in terms of geographic position and climatic state-space. Broad concepts analyzed herein are well known from dendrochronological principles, large network analysis (Neuwirth et al. 2007), and modeling studies (Nemani et al. 2003), however, implications for spatially-resolved climate reconstructions, especially in consideration of recent and rapid warming, may make such a compilation relevant.

Data and Methods

The compiled network consists of nearly all sites available from the International Tree Ring Databank within the European Region (10°W- 20°E, 30°N-70°N). Tree-ring data were detrended on a site-by-site basis in ARSTAN (Cook 1985) using both 32-year splines to emphasize decadal

to interannual scale variation and Regional Curve Standardization (RCS; Esper et al. 2003) to preserve inter-annual to centennial-scale variability. It should be noted that the predominant nature of the network (low sample replication and sites with only living trees) adds uncertainties particularly to the RCS results.

A biweight robust mean (Cook 1985) was used to average the detrended series together for each site, and the variance was subsequently stabilized to prevent artifacts related to changes in sample replication (MEANr correction as in Frank et al. 2007). Initial screening and quality control resulted in the identification of 403 sites with data in the 20th century. Chronologies were truncated at a sample replication of >4 series and were additionally required to have at least 60 years of data (after truncation) within the 1901-2002 period. This second step resulted in 376 sites for the final analysis.

All detrended data were correlated with various monthly and seasonal gridded temperature and precipitation data from the nearest gridpoint of the CRUT2.1 0.5° x 0.5° dataset (Mitchell & Jones 2005). In addition to computations with the raw data, correlations were also calculated for high and low-pass filtered (30-year spline) TRW and instrumental series.

For analyses related to absolute climatic conditions, we calculated the elevational difference between tree-ring sites and the elevation corresponding to the CRUT2.1 grid-cell. A lapse rate of 6.5 °C/km was utilized to adjust the instrumental mean temperature. For the five cases where elevation data were not available, no adjustments were made. Precipitation data were not adjusted.

Results

Correlations, expressed as grey shades, between mean June-August (JJA) temperature and RCS TRW data (both high-pass filtered) were plotted as a function of the mean annual temperature (y-axis) and mean monthly precipitation (x-axis) for each site (Fig. 1, upper panel). It is evident that the highest correlations are obtained for sites with low mean annual temperatures, with relatively little dependence upon summer precipitation. Geographically, sites with highest correlations are found in Scandinavia and along the Alpine arc (Fig. 1, lower panel).

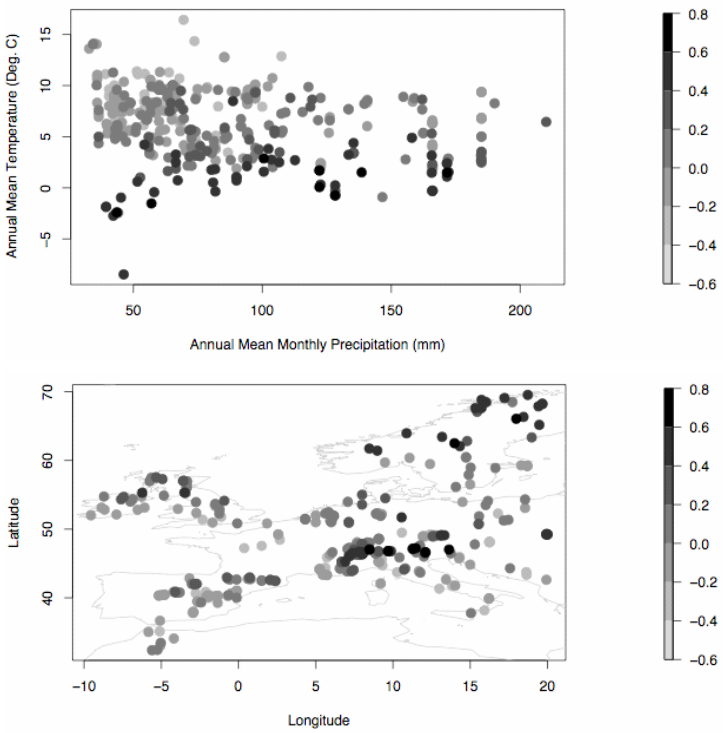

Figure 1: Correlations between TRW chronologies and JJA temperature data, plotted as a function of annual mean temperature and monthly mean precipitation at each site (upper) and according to geographic position (lower).

The Northern UK and the Pyrenees mountains also contain sites with moderately high correlations to summer temperature. A similar but opposite pattern is observed for JJA precipitation with highest correlations obtained for sites with low mean annual precipitation and high mean annual temperatures (Fig. 2, upper panel). Compared to the temperature response patterns, sites with highest correlations to precipitation data are more widely distributed, and in fact, cover most areas of Europe except for the northern United Kingdom, northern Scandinavia, and surprisingly much of Italy (Fig. 2, lower panel). Similar results were obtained with the unfiltered and spline-detrended chronologies (not shown).

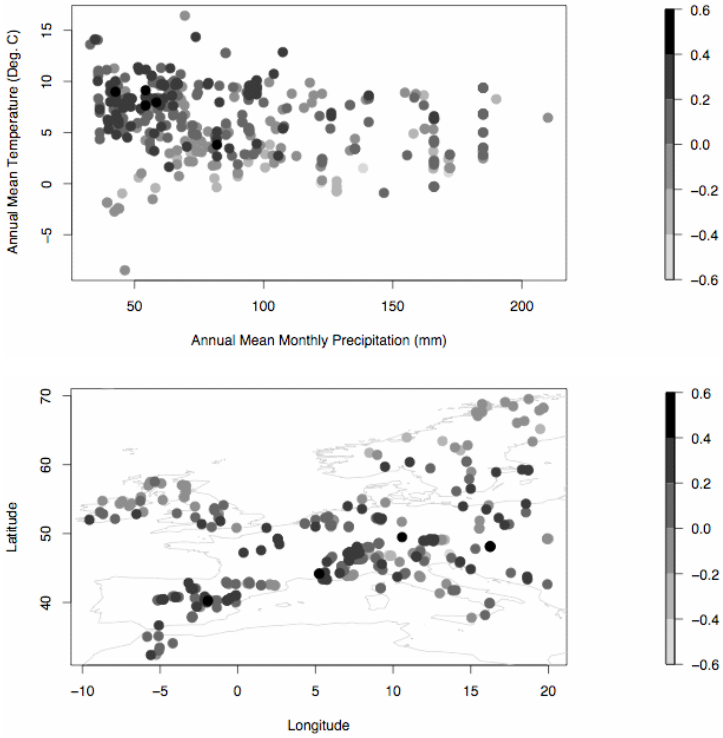

Figure 2: As figure 1, except for correlation between TRW chronologies and JJA precipitation data.

Given the apparent spatial constraints for temperature sensitive TRW data, it might be relevant to ask how spatially representative would the average of two reconstructions, one from Scandinavia and one from the Alps, be for the European landmass. To provide a simple assessment, we averaged JJA station temperature data from Haparanda (65.83N, 24.15E; Sweden) and Säntis (47.25N,9.35E; Switzerland) and correlated the mean series with all JJA CRUT2.1 gridpoints. As expected, this average has two correlation epicenters: northern Scandinavia and along and north of the Alpine arc (Fig. 3). However, what is perhaps surprising, especially when considering that this result is derived from instrumental series free of any proxy noise, is that the variance explained for most of Europe is rather low and is in fact only > 50% for only a small region in Scandinavia. This has to do with the broad independence -- at least in the frequency domains represented by the summer season instrumental data -- for temperatures between the Alpine and Scandinavian regions. The correlation between the JJA instrumental series from these regions is only 0.07. The development of two regional reconstructions or a more generalized point-by-point approach (Cook et al. 1994), possibly represent reasonable and simple solutions to increasing the explained variance for most European areas.

However, it should be noted, if we do not care about spatially resolved reconstructions, and seek to reconstruct European average temperatures, a simple average of the JJA temperatures from the 5637 gridpoints within the European region bounded by 30-70° N and -10-40°E correlates with the Säntis-Haparanda mean at .791 (> 60% variance explained) over the 1901-1991 common period.

This result demonstrates increased skill of these two locations (and methodology) for assessing average European temperatures, although with the caveat that this mean is spatially biased in accordance with figure 3.

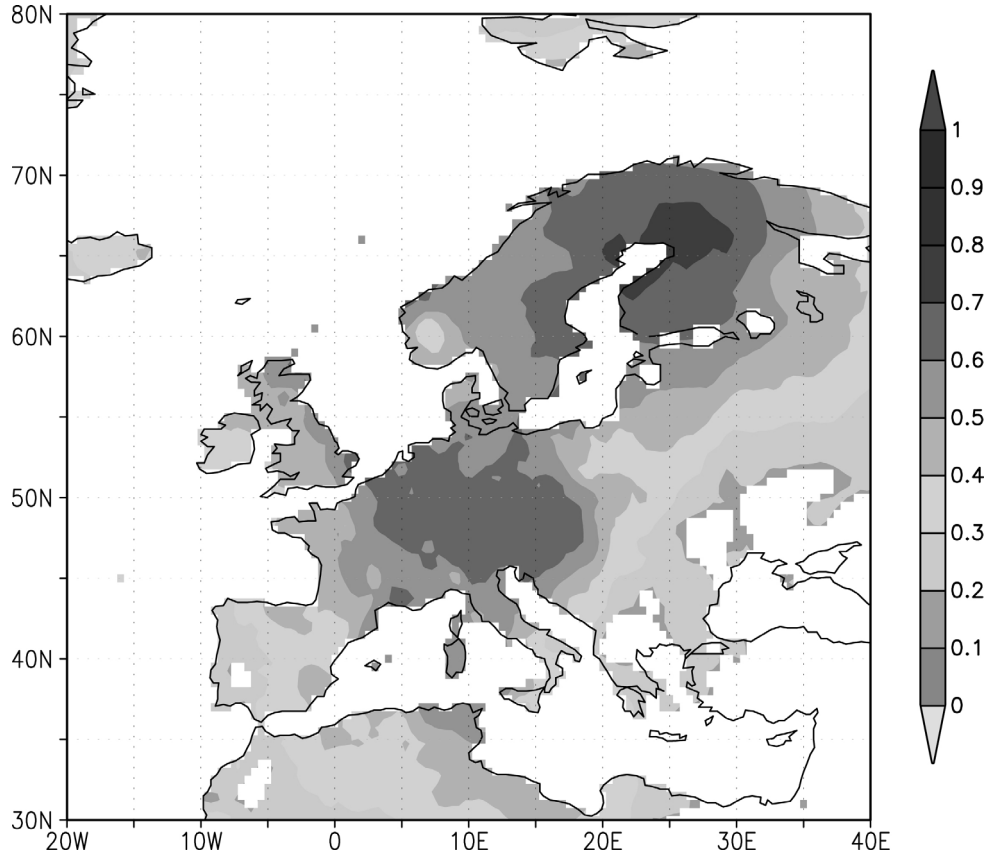

Figure 3: Correlation between the mean of Säntis and Haparanda JJA temperatures and JJA temperature from the CRUT2.1 dataset computed over the 1901-1991 period.

Discussion and Conclusions

Using a large European network, we have demonstrated how the climate response of TRW data is closely related to climate itself. This fact, although well-established in the dendrochronological literature, has implications for the spatial reconstruction and representation of climate variability. Additional assessment of other tree-ring parameters, including maximum-latewood density, earlywood/latewood width, isotopic composition, and vessel data will help determine the possibilities and limitations for dendroclimatic efforts within Europe and beyond. It has been shown, for example, that maximum latewood density generally has a stronger climatic response with a more “forgiving” climatic and ecological range than TRW data (Frank and Esper, 2005; Kienast et al. 1987).

Our results have quantified the well known dendrochronological principle -- the need to go to the elevational or latitudinal treeline for most skillful temperature reconstructions -- based on numerous sites across Europe. While maximum JJA correlations are lower for precipitation than for temperature, better quantification of the optimal target season is needed. It is likely that a dendroclimatic year spanning previous August to current July is a more appropriate season for precipitation reconstructions (not shown). The broader spatial area of tree-ring sites that correlate significantly with precipitation variations is promising for the development of spatially resolved precipitation or drought reconstructions. This is critical because of the much lower spatial autocorrelation for precipitation than for temperature. The length of most currently existing records will place limitations on the length of any such reconstructions, however.

If we assume that the response-gradients demonstrated, represent physiological limitations for trees to respond in the same way to a variable climate, the ability of TRW data to serve as a valid predictor across a wide range of climate conditions is perhaps limited. This might serve as a conceptual basis for concerns of reductions in temperature sensitivity (e.g., D'Arrigo et al. 2007) and demonstrate the utility of pointer-year analysis (Schweingruber 1986) and/or forward growth modeling studies (Anchukaitis et al. 2006) to understand the suite of climatic parameters that jointly act in forcing wide and narrow sequences in tree-ring data. Further studies along elevational transects (Wilson & Hopfmueller 2001) or using growth-climate response surfaces may also provide insight into the climate forcing of forest growth across a wide-range of climate conditions.

Acknowledgements

We thank Anne Verstege for help in compiling this dataset and Gerd Helle for comments on an earlier draft. This research is supported by the Swiss National Science Foundation (NCCR-Climate), the EU (Millennium #017008-2), and the MAIF foundation (project ECLID).

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