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# Interannual climate/growth-relations of Central European tree rings - A dendroecological network analysis

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## Introduction

A comparison of dendrochronological data from different sources mostly deals with various problems. Due to missing standards in respect to sampling strategies, ecological site conditions, statistical and indexation methods, etc., interregional differences in tree-ring chronologies need not be the results of changing ecological or climatological forcings. This problem can be solved by excluding all the aspects influenced by varying strategies and methods. Additionally, more than one tree species should be investigated to find out their common/true climatological signals. By using a unique statistical homogenization and a bio-geographical stratification of all data big datasets make it possible to reconstruct climatic influences as well in temperate zones (Schweingruber and Nogler 2003).

The main objective of this network analysis is the evaluation of the potentials of tree-ring analytical investigations in the temperate midlatitudes of Europe for reconstructing the climate conditions of historical time periods. Therefore we analyse the interannual climate/growth-relations of Central European tree rings in a dendroclimatological network combining tree-ring data from 377 sites with climatological data. Additionally the network includes modules to edit and to analyse the data, and to present the results.

## Data and methods

This dendroclimatological network includes more than 1.25 million values of tree-ring width of the principal forest tree species (see Tab. 1) in Central Europe (defined as the area from 5° to 15°E and 42.5° to 52.5°N) from 377 sites (Fig. 1).

The network combines the tree-ring data with climatological data (temperature, precipitation, and air pressure expressed by the North Atlantic Oscillation (NAO). Temperature and precipitation values are gridded data in a spatial resolution of 10 minutes for the time period from ad1901 to 2000 (Mitchell et al. 2003).

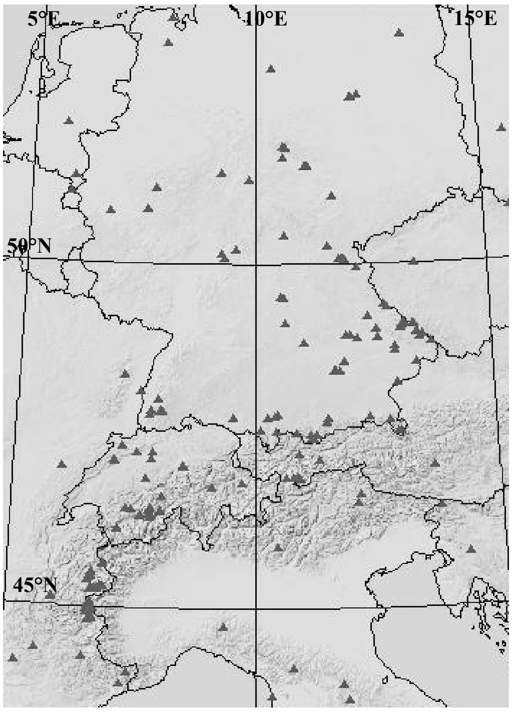

*Figure 1: Sites of tree-ring width chronologies in Central Europe.*

The NAO is represented by three indices: PON and GIB for the air pressure gradients between the Icelandic climatic stations [Akureyri (65.7°N/18.1°W) or Stykkisholmur (65.0°N/22.8°W)], and Ponta Delgada (37.7°N/25.7°W) at the Azores (van Loon and Rogers 1978, Rogers 1990) and Gibraltar (36.1°N/5.1°W) in Southern Spain (Jones et al. 1997), respectively (Neuwirth et al. 2004). The third NAO index is called PAE and describes the minima and maxima in the air pressure field between 70° and 20°N as zonal mean values (Glowienka-Hense 1990, Paeth 2000). The PAE-index takes into account the spatial movements of the air-pressure centres. The common overlap of all datasets determines the investigation period of this study from ad1901 to 1971.

The raw tree-ring widths of all dendrochronological sites were checked for their suitability by the dendrostatistical parameters like Gleichläufigkeit GLK (Schweingruber 1983), interseries correlation $r_{xy}$ (Fritts 1976), and signal strength parameter NET (Esper et al. 2001). After building sitewise mean curves for the 377 sites the calculation of pointer values expressed by z-transformations according to Cropper (1979) leads to time series illustrating the anomalies against the mean radial growth for every site. The resulting z-transformed Cropper values $C_z$ are grouped into weak ($C_z > 1$), strong ($C_z > 1.28$), and extreme ($C_z > 1{,}645$) pointer values. The chosen thresholds correspond to the probability, that the pointer year event is rarer than 33%, 20%, or 10% respectively.

Using the multivariate techniques factor-, cluster-, and discriminance analysis the 377 sites were reduced to 59 clusters combining all sites with similar growth anomalies over the investigation period.

Temperature and precipitation anomalies were derived from the long time mean of the period ad1901 to 1971 for every month from September of the year before to August of the year of tree-ring growth. The NAO indices represent anomalies and will be used after a ztransformation. The synthesis of the climatological interpretation of extreme growth values with the results of correlations between climatological and tree-ring datasets is the base of the analysis of climate/growth-relations follows from the synthesis of.

## Results

### *Radial growth*

The mean radial increment derived from all 7,708 Central European trees during the investigation period is 1.42 mm/a. Fir, spruce, and beech are the fast growing species (Tab. 1). In this dataset three species - larch, mountain pine and stone pine - are only located in high mountain regions above 1500m a.s.l.. Larch and mountain pine grow less than 0.9 mm/a. Additionally, the high mountain species show with more than 0.44 mm/a the largest variances in radial growth while the other species spread with less than 0.4 mm/a around the mean.

Gleichläufigkeit GLK (Schweingruber 1983), signal strenght parameter NET combining the variance v with GLK (Esper et al. 2001), and Pearsons coefficient of correlation t-value (Schönwiese 1992) give an impression about the quality of the site chronologies. All values are better than the defined thresholds (GLK > 70%; NET < 0.8, t > 10). Therefore the mean curves represent the common signals of the single tree curves for all species. Regarding the three parameters in detail we find out that the mountain pine chronologies have the lowest and beech the highest common signals.

*Table1: Statistical features of central European tree-ring width from ad1901 to 1971 as mean over all tree sites and seperated into species.*

Abbreviations:

ABAL = *Abies alba*, fir;
PCAB = *Picea abies*, spruce;
PISY = *Pinus sylvestris*, Scots pine;
FASY = *Fagus sylvatica*, beech;
YRG = yearly radial growth;
GLK = Gleichläufigkeit;
t-value = coefficient of correlation; after Pearson

LADE = *Larix decidua*, larch;
PICE = *Pinus cembra*, stone pine;
PIUN = *Pinus uncinata*, mountain pine;
QUSP = *Quercus petraea* & *Qu. robur*, oak;
v = varinace;
NET = signal strength parameter;
AK 1 = autocorrelation lag 1

| | all | tree species | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **ABAL** | **LADE** | **PCAB** | **PICE** | **PISY** | **PIUN** | **FASY** | **QUSP** |
| number of sites | 377 | 76 | 17 | 129 | 27 | 22 | 21 | 38 | 47 |
| YRG | 1.42 | 1.82 | 0.88 | 1.48 | 1.16 | 0.99 | 0.76 | 1.63 | 1.30 |
| v | 0.39 | 0.38 | 0.44 | 0.37 | 0.44 | 0.43 | 0.45 | 0.37 | 0.35 |
| GLK | 0.77 | 0.78 | 0.79 | 0.76 | 0.78 | 0.76 | 0.70 | 0.80 | 0.76 |
| NET | 0.62 | 0.60 | 0.65 | 0.61 | 0.67 | 0.67 | 0.75 | 0.57 | 0.56 |
| t-value | 13.2 | 13.0 | 16.2 | 12.4 | 11.9 | 15.4 | 10.1 | 13.4 | 13.9 |
| AK 1 | 0.63 | 0.68 | 0.56 | 0.65 | 0.62 | 0.64 | 0.65 | 0.57 | 0.56 |

The autocorrelation of lag 1 separates the species into two groups. Deciduous species (larch, beech and oak) show significant smaller autocorrelations than the other species. Tree-ring growth of evergreen trees depend more on the conditions during the year before than the others.

*Pointer values*

Figure 2 shows the masterplot of central European pointer values calculated on the base of 59 dendroclusters (black bars in figure 2).

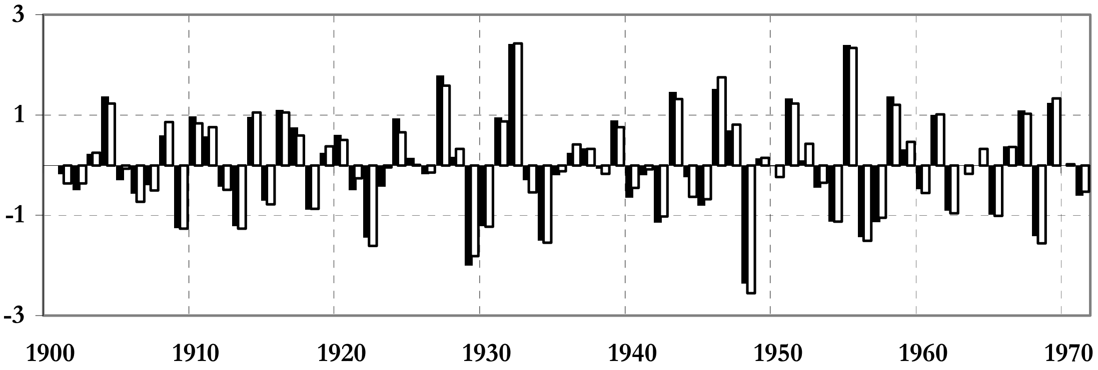

*Figure 2: Central European masterplot for the period ad1901 – 1971 derived from 59 dendroclusters (black) and 377 sites (white).*

There are 12 years with $C_z$-values above the threshold 1 and also 13 years with values lower than -1. The positive pointer values are classified into 4 weak (1916, 1961, 1967, and 1969), 6 strong (1904, 1927, 1943, 1946, 1951, and 1958) and 2 extreme (1932 and 1955) pointer years. For the negative growth reactions we can find out 7 weak (1909, 1913, 1930, 1942, 1954, 1957, and 1965), 4 strong (1922, 1934, 1956, and 1968) and 2 extreme (1929 and 1948) pointer years. Comparing this with the masterplot deviated from the 377 sites, (white bars in figure 2) there is no important difference between both plots. In all years the black and white bars tend into the same direction with nearly the same values. Therefore we can conclude that there is no modification by using the dendroclusters as calculation base.

Valuable advices about growth determining factors can be obtained either by differentiating the various ecological sites, in the following expressed by elevation zones, or by regarding the species specific growth reactions (Neuwirth 2005). The subtraction of z-transformed Cropper values $C_z$ averaged over the sites with elevations lower than 750m a.s.l. from the means of the sites above 1500m a.s.l. leads to a modified masterplot (Fig. 3).

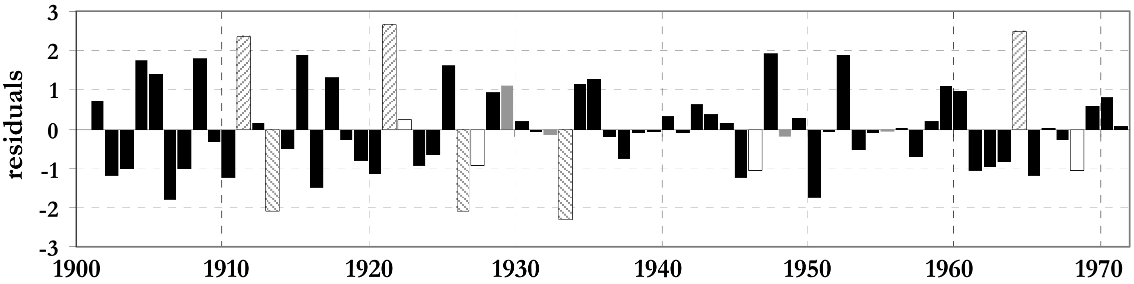

*Figure 3: Masterplot for the period ad1901 - 1971 of the residuals from the z-transformed croppervalues of the high- (>1500m a.s.l.) and the low- (<750m a.s.l.) elevated sites in Central Europe. Emphasized are years with extreme pointer values (grey), species specific pointer values (white), and elevation depending pointer values (hatched bars).*

Positive pointer years in the highlands and negative pointer values in the lowlands result in positive orientated bars, whereas negative highland values and positive lowland values lead to negative orientated bars. If high and low elevated sites have nearly the same values the residual bars are located nearby the zero line.

In the years ad1911, 1913, 1921, 1926, 1933, and 1964, the strongest differences between low and high elevated sites can be found (hatched bars in figure 3). In these years, the signs of pointer values are changing with the elevation gradient. In 1911 and 1964 the differences are so decisive that in highlands as well as in lowlands, the pointer values are above the thresholds 1 and -1 respectively. The four extreme central European pointer years (1929, 1932, 1948, 1955) show nearly the same values in all elevation zones resulting in bars (grey in figure 3) near by zero. In 1922 and 1946, larch trees show opposite growth in respect to the other species, just as oak in 1927. Because of the small elevational spectrum of larch (only high elevated sites) and oak (mostly in lowlands) in this dataset the individual growth reactions of this species dominate the differences between high and low elevated sites (white bars in figure 3). In 1968 beech, fir, spruce, and larch show negative growth anomalies. Oaks and the pine subspecies have no significant reactions. Therefore the highest Cropper values are located in elevations between 750 and 1500m a.s.l., the main area of fir and spruce. The resulting residual bar is dominated by the negative reactions of low elevated beechs.

For each year pointer values are found which have at least regional and/or species specific relevance. Their spatial distribution is illustrated by yearly maps created by using a GIS with an interpolation between the 8 neighbours of every site. The maps for every year of the investigation period are published on the internet (Neuwirth 2005) and exemplary in Neuwirth et al. 2003. The maps classify the years into four groups: years with (i) positive and (ii) negative growth reactions in nearly the whole investigation area; (iii) years with balanced portions of positive and negative growth anomalies; and (iv) years with growth reactions only in small regions or at several sites. In spite of the similarities in the group internal growth patterns the geographical position, the elevation and the leading species of the dendroclusters are not enough to explain the reasons for the spatial distributions of pointer values. At least we have to take into account the climatological forcings.

*Climate/growth relations*

The analysis of climate/growth relations consists of a synthesis of the climatological interpretation of pointer values and the results of correlations between climatological and tree-ring datasets, always differenciated in species specific relations. All important individual results are combined in one diagram (figure 4) showing the climatological forcings for positive and negative growth reactions for each tree species in their elevation zones. To demonstrate how to read figure 4, we present the example of fir in their upper elevation zone. Between 1250 and 1750m a.s.l. positive growth reactions result from small winter temperatures above average and strong precipitations in May above average. In contrast, negative growth reactions are caused by cold winter temperatures and/or slightly temperatures in the summer months below average. Regarding the species seperatly we can summerize the following facts:

- the sensitivity of fir against strong winterly coldness,
- the positive influence of moist summerly conditions for spruce radial growth,
- the positive correlations of beech to increasing summer temperatures, especially above 500m a.s.l.,
- the inferior sensitivity of mountain pine against climatic forcings,
- the high negative influence of temperatures in the autumn of the year before on stone pine,
- the strong sensitivity of scots pine against summerly dryness,
- the high correlation of larch tree-ring growth with summer temperature.

Regarding figure 4 the reciprocal influence of temperature and precipitation on tree-ring growth in nearly all elevations is clearly recognizable. Growth reactions are neither monocausally related to temperature in high elevations nor to precipitations in low elevations.

| Elevation | Growth anomaly | ABAL | LADE | PCAB | PICE | PISY | PIUN | FASY | QUSP |
|---|---|---|---|---|---|---|---|---|---|
|  | pos. |  | Aut$_b$ ☼(+)<br>Su ☼ + | Su ☼ +<br>Wi 💧(+) | Aut$_b$ ☼ -<br>Veg ☼ (+) |  | Sp ☼ + |  |  |
| 1750 m | neg. |  | Su 💧- | Wi ☼- | So 💧-<br>Sp NAO- |  | Sp ☼ --<br>Su ☼ + |  |  |
|  | pos. | Wi ☼ (+)<br>May 💧 + |  | Su ☼ (+)<br>Wi 💧+ |  |  | Gs ☼ (+) |  |  |
| 1250 m | neg. | Wi ☼ -<br>Su ☼ (-) |  | Wi ☼- |  |  | May 💧- |  |  |
|  | pos. | Wi ☼ +<br>Su ☼ (-) |  | Su ☼ (+) |  | Aug ☼ + |  | Su ☼ + | Su 💧+ |
| 750 m | neg. | Wi ☼ --<br>Su ☼ (+) |  | Gs 💧- |  | Sp ☼ -<br>Su 💧- |  | Su ☼ - | Su 💧- |
|  | pos. | Wi ☼ +<br>Su 💧+ |  | Su ☼ (-)<br>Gs 💧+ |  | Wi ☼ + |  | May 💧+ | May 💧+ |
| 250 m | neg. | Wi ☼ --<br>Su ☼ + |  | Gs ☼+<br>Gs 💧- |  | Gs 💧-<br>Sp ☼ - |  | Gs$_b$ ☼ -<br>Su ☼ - | Aut$_b$ ☼ + |
|  | pos. |  |  |  |  | Wi ☼ + |  | Year 💧+ | Sp 💧+<br>Su ☼ (-) |
|  | neg. |  |  |  |  | Su ☼ + |  | Gs 💧- | Gs ☼ +<br>Gs 💧- |

*Figure 4: Schematic illustration of climatic conditions as deviations in respect to the mean from 1901 to 1971 and corresponding growth anomlies of tree species in their elevation zones. Aut$_b$ = Autumn of the year before; Wi = Winter (DJF); Sp = Spring (MAM); Su = Summer (JJA); Gs = growing season; ☼ = temperatur; 💧 = precipitation; +, - = positive, negative anomalies; ( ) = weak; bold = strong; - - = extreme.*

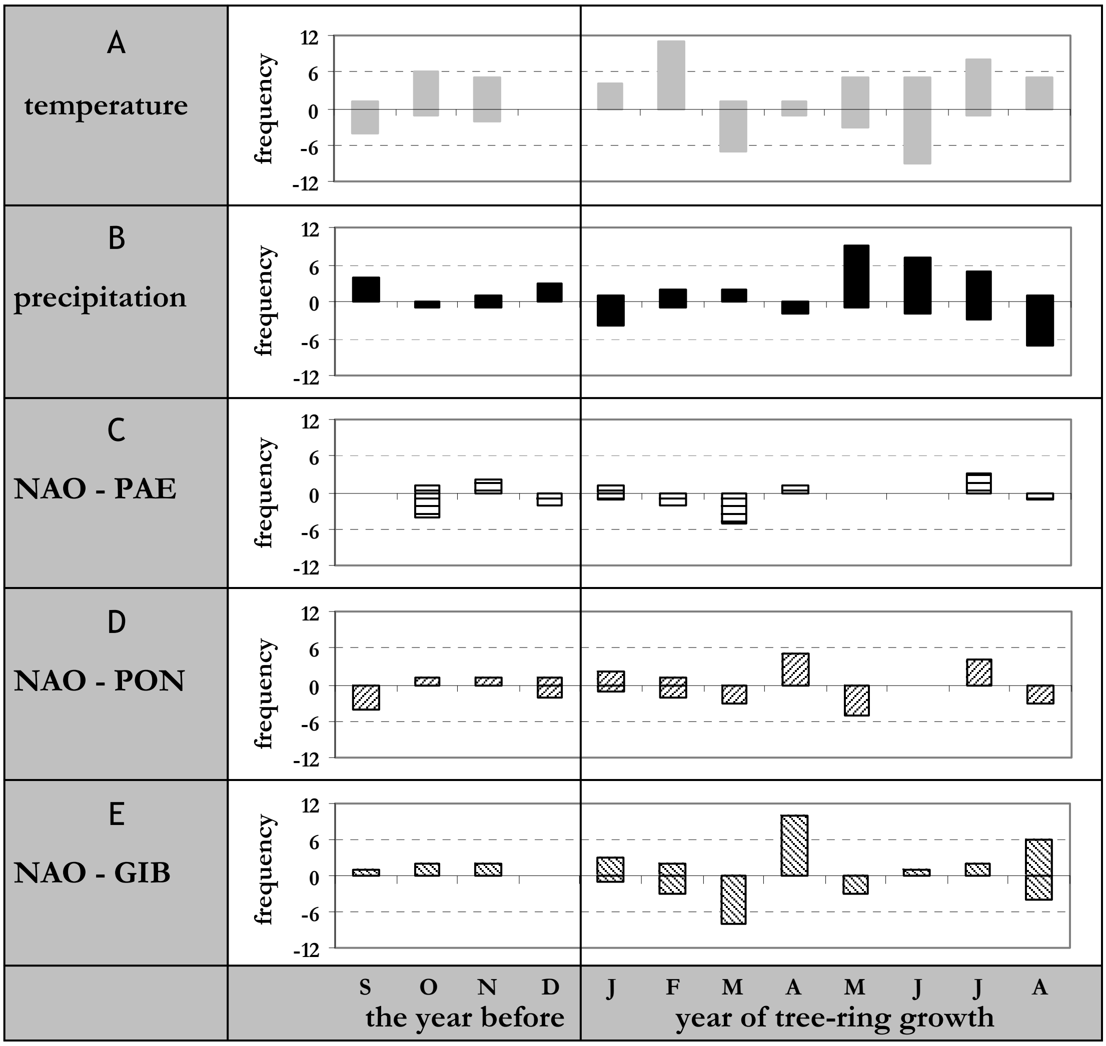

*Figure 5: Monthly frequencies of significant correlations between the five climatic indices and the 29 dendrogroups.*

Figure 5 illustrates the frequencies of the climate/growth relations in sequences from September of the year before to August in the year of tree-ring building. The frequencies are calculated for dendrogroups defined as the means of species specific means of dendroclusters in the five chosen elevation zones. Precipitation-related influences (Fig. 5B) are mainly concentrated on the months from May to August. They change from positive correlations in May to negative correlations in autumn. In contrast the temperatures correlate in winter exclusively and in summer mostly positive to radial growth. In comparison NAO indices cause less influence on interannual tree-ring growth (5A). For PAE and PON we do not find significant correlations to more than 10 dendrogroups. Only the GIB index, which is derived from the closer to Central Europe located station Gibraltar, correlates in March negative to more than a quarter of the dendrogroups and in April to more than a third of these groups. Additionally, the GIB index is significantly correlated to radial growth of 10 dendrogroups in August, six times positively and four times negatively. Combining a positive NAO index with mostly zonal atmospheric mean streams, we can conclude moist air masses over Central Europe (Hurrell et al. 2004). In April, these convective air masses are warmer, and in August colder than the surrounding ais masses.

## Conclusion

Due to the similar editing and preparation of all datasets the presented results demonstrate the suitability of tree-ring widths for comparisions of growth reactions between different tree species and different regions. The results proof that tree-ring widths in the moderate mid-latitudes are also usefull for climatological interpretation of pointer values. Growth anomalies are a suitable parameter to explain the relative yearly changing growth patterns related to the modifying influence of climatic forcings. This can be explained by the optimal adaption of trees to their specific ecological site conditions.

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