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# Growth responses to NAO along a Central European west - east transect

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Dendroclimatology investigates the relation between tree-ring growth and climate on a regional and supraregional scale. Especially temperature and precipitation are two of the dominant factors influencing tree-ring growth (Schweingruber 1996, Fritts 1976). Tree-rings are widely used proxy to reconstruct past climate elements like precipitation or temperature (Treydte et al. 2006, Esper et al. 2002). Despite the strong influence of precipitation and temperature, they do not represent the whole climate impact on tree-ring growth. Many studies have been carried out during the last decade to reconstruct large scale circulation conditions, particularly in the North Atlantic sector (Pauling et al. 2006, D'Arrigo et al. 2003, Cook et al. 2002). For instance, the typical circulation pattern over the North Atlantic sector expressed by the position and the air-pressure differences between the Islandic Low and Azores High is quite important for the weather conditions in Central Europe. These circulation modes are described as the North Atlantic Oscillation (NAO). Various indices (NAOI) have been developed to describe such variations in the air pressure fields over the North Atlantic sector (overview see Hurrell et al. 2003). For a better understanding of the influences of NAO on tree-ring growth, this study investigates growth responses to NAO along a Central European west-east transect from the Eifel (Germany) to the Ore Mountains (Czech Republic).

## Data

### *Tree-ring data*

The 430 km long transect from the Eifel (W-Germany) to the Ore Mountains (NW-Czech Republic) (area between 6-14°E and 50-51°N) consists of 37 dendrochronological sites (Fig. 1) with the following tree species*: Fagus sylvatica*, *Larix decidua*, *Picea abies*, *Pinus sylvestris, Pseudotsuga menziesii, Quercus petraea,* and *Quercus robur*.

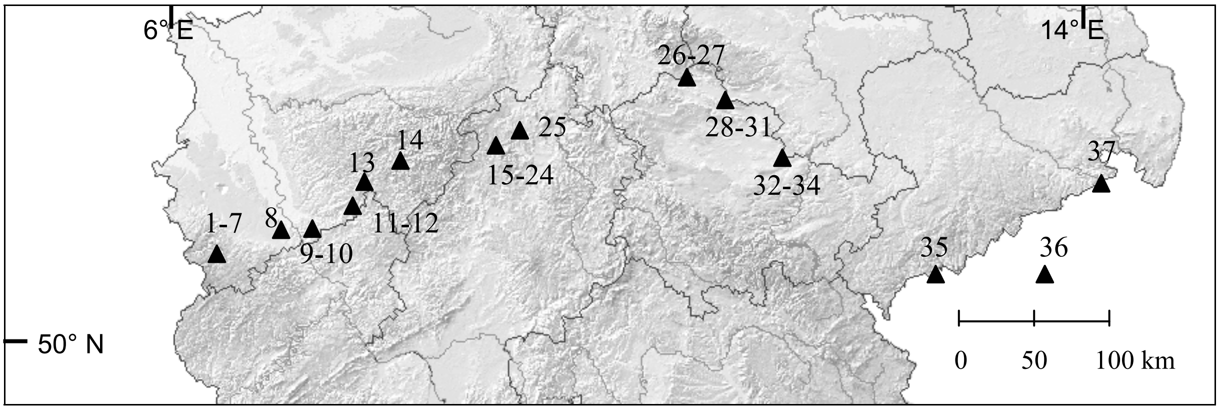

*Figure 1: Spatial distribution of the dendrochronological sites (▲).*

A dendrochronological site consists of at least 10 dominant trees for each tree species. Therefore, two or more dendrochronological sites can be found at the same spatial location.

The elevations of the sites in the transect vary from 150 m a.s.l. in the Sieg valley near Bonn to 1030 m a.s.l. in the Ore Mountains (Tab.1). The sites represent a varying ecological spectrum regarding exposition, altitude, inclination, and forest community. All selected trees are dominant trees and at least older than AD 1890.

*Table 1: Characteristics of dendrochronological* sites. *Abbreviations of the tree species see figure 2.*

| code | number | species | latitude / longitude | altitude | exposition | region |
|---|---|---|---|---|---|---|
| dre11 | 1 | QUPE | 50,5708 / 6,3603 | 500 | 150 | Rureifel |
| dre12 | 2 | FASY | 50,5717 / 6,3611 | 480 | 150 | |
| dre09 | 3 | QUPE | 50,6244 / 6,3992 | 400 | 300 | |
| dre03 | 4 | FASY | 50,6086 / 6,4569 | 530 | 315 | |
| dre04 | 5 | PSME | 50,6097 / 6,4639 | 525 | 135 | |
| dre05 | 6 | FASY | 50,6061 / 6,4900 | 470 | 60 | |
| dre13 | 7 | PCAB | 50,6056 / 6,4917 | 470 | 60 | Eifel |
| drb13 | 8 | QURO | 50,6700 / 7,0472 | 185 | 15 | Kottenforst-Ville |
| drb05 | 9 | FASY | 50,6689 / 7,2489 | 360 | 320 | Siebengebirge |
| drb06 | 10 | QUPE | 50,6694 / 7,2492 | 370 | 320 | |
| drs02 | 11 | FASY | 50,8039 / 7,5906 | 150 | 250 | Siegtal |
| drs03 | 12 | QURO | 50,8036 / 7,5908 | 165 | 245 | |
| drl02 | 13 | QUPE | 50,9825 / 7,7169 | 385 | 270 | Oberbergisches Land |
| dro01 | 14 | FASY | 51,1022 / 8,0222 | 455 | 130 | Olpe |
| dhk05 | 15 | | 51,1672 / 8,9583 | 420 | 345 | Kellerwald |
| dhk02 | 16 | | 51,1703 / 8,9669 | 310 | 150 | |
| dhk03 | 17 | QUPE | 51,1708 / 8,9681 | 290 | 135 | |
| dhk04 | 18 | FASY | 51,1936 / 9,0117 | 280 | 180 | |
| dhk11 | 19 | QUPE | 51,1561 / 9,0761 | 400 | 215 | |
| dhk12 | 20 | | 51,1556 / 9,0769 | 390 | 150 | |
| dhk07 | 21 | LADE | 51,1567 / 9,0836 | 360 | 180 | |
| dhk08 | 22 | QUPE | 51,1564 / 9,0842 | 350 | 180 | |
| dhk10 | 23 | | 51,1581 / 9,0842 | 380 | 180 | |
| dhk06 | 24 | PISY | 51,1569 / 9,0844 | 360 | 180 | |
| dhb01 | 25 | FASY | 51,3167 / 9,1833 | 300 | 270 | Hessisches Bergland |
| dtt01 | 26 | | 51,5361 / 10,5556 | 440 | 180 | Mitteldeutsches Trias Bergland |
| dtt02 | 27 | QURO | 51,5361 / 10,5556 | 440 | 180 | |
| dtk02 | 28 | FASY | 51,4125 / 11,0611 | 480 | 315 | Kyffhäuser |
| dtk03 | 29 | | 51,4083 / 11,0861 | 460 | 180 | |
| dtk01 | 30 | | 51,4194 / 11,1083 | 425 | - | |
| dtk04 | 31 | QUPE | 51,4194 / 11,1083 | 425 | - | |
| dtj02 | 32 | FASY | 51,0017 / 11,6442 | 320 | - | Jena |
| dtj01 | 33 | | 51,0014 / 11,6444 | 320 | - | |
| dtj03 | 34 | QUPE | 51,0014 / 11,6444 | 320 | - | |
| tkp01 | 35 | PCAB | 50,4000 / 12,7500 | 870 | 330 | Ore Mountains |
| tkk01 | 36 | | 50,4086 / 12,9669 | 1030 | 30 | |
| tul01 | 37 | PISY | 50,8681 / 14,3672 | 300 | 120 | |

There are 16 beech and 14 oak sites concentrated in the west and in the middle of the transect, respectively. Two spruce sites are found in the eastern part of the transect, whereas one site is located in the western area, the Eifel. The easternmost site of the transect is represented by pine. Further a pine site is located in the Kellerwald region near Kassel. There are only one larch site, which is located in the Kellerwald (site No. 21), and one site of douglas fir, which is located in the Eifel (site No. 5).

Table 1 and figure 2 illustrate that the 7 different tree species are not represented by the same number of sites. With 16 beech and 14 oak sites more than 80% of the investigated sites represent deciduous forests. This distribution does not reflect the natural distribution of tree species in the

research area. In fact, there exist clearly more spruce sites, but especially in the western part of the transect most of them are cultural forest and not old enough, to use them in this study.
Corresponding to the natural situation, the spatial distribution of the tree species is inhomogenuous; coniferous forests are concentrated to the eastern parts and deciduous forests to the middle and western parts of the transect (Tab. 1, Fig. 1).

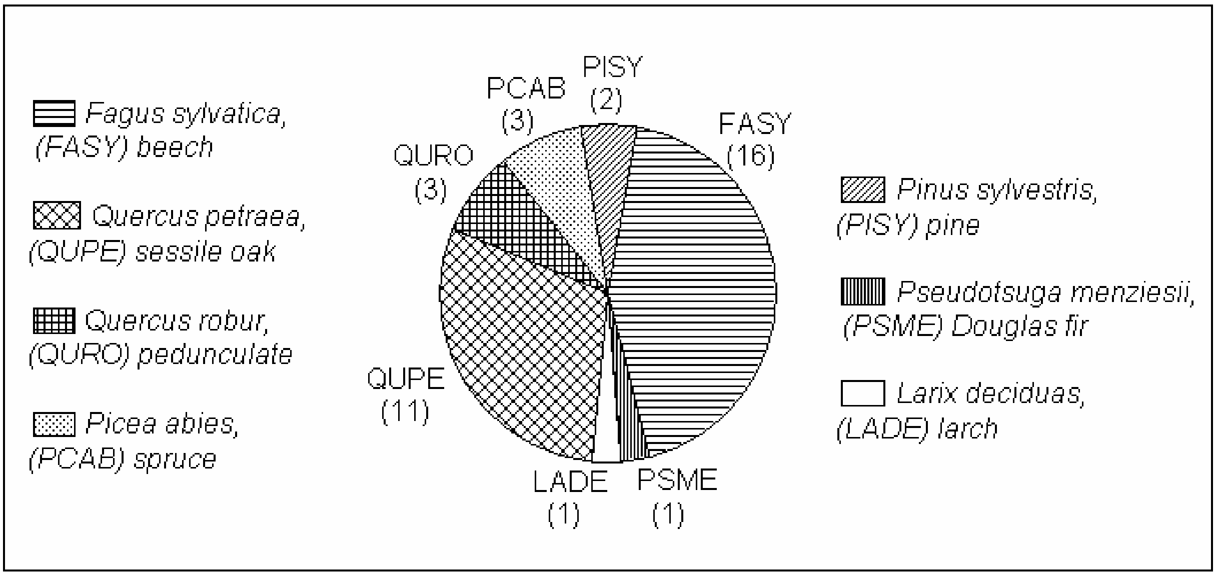

*Figure 2: Number of tree species and sites.*

*NAO data*

The NAOI is the normalised surface pressure difference between the Islandic Low and the Azores High. There are two basic ways to compute the NAOI. The first is to calculate the air pressure difference between two stationary points. The second is a zonal index, which takes into consideration that the atmospheric control centres can change their position (Glowienka-Hense 1990). In this study three different NAOI for the time period from 1901 to 1990 are used. They are derived from the climatic stations Akureyri on Iceland (65,7°N/18.1°W) and Ponta Delgada on the Azores (37.7°N/25.7°W) (Rogers 1990, van Loon and Rogers 1978) and from Stykkisholmur on Iceland (65.0°N/22.8°W) and Gibraltar (36.1°N/25.7°W) in Southern Spain (Jones et al. 1997). We abbreviate these two indices as PON and GIB, respectively. The third index is named ZON, because it is a more zonal index describing the zonal air pressure mean minima and maxima values between 20° to 70°N over the North Atlantic (Paeth 2000, Glowienka-Hense 1990).
The strongest impact of the NAO on the weather conditions in Europe and North America is observable in winter. The NAO alternates between a positive and a negative phase. A negative NAOI is associated with a weak Azores High and a weak Islandic Low. The reduced pressure differences cause fewer and weaker winter storms on a west-eastern pathway corresponding with cold and dry conditions in the North of Europe and wet conditions in the Mediterranean region. A positive NAO phase is characterised by a strong Azores High and a deep Islandic Low and yields to wet and warm winter conditions in Northern Europe (Hurrell et al. 2003).

### *Methods*

Two increment cores from opposite directions of each tree were sampled. Using Lintab V measurement tables (resolution 1/100 mm) in combination with the software package TSAPWIN-Scientific 0.53 (Rinn 2005) the tree-ring widths were measured. Synchronization and cross-dating were carried out with TSAPWin (Rinn 2005) and Cofecha (Holmes 1983). All tree ring width (TRW) series were detrended calculating ratios from a 13-year moving average. Afterwards for each site the tree series were averaged to site chronologies and shortened to the research period from AD 1901 to AD 1990.

Using Pearson's correlation coefficients r (Bahrenberg et al. 1999) and their confidence intervals expressed as 1.6-time standard deviation (white bars in Fig. 3) around the mean values, the connection between the 37 chronologies and the various NOAI series were computed. Therefore, the NAOI data were separated into 18 monthly series, from April of the previous year to September of the growth year. Further 9 averaged series for the year, two growing seasons (April to September and May to August), for the seasons winter, spring, summer, autumn and for the seasons of the prior year summer and autumn, were separated. To aggregate all histograms species specific chronologies and a mean chronology for all sites were calculated. Correlations will be classified to significant if the r-values exceed the thresholds for the 90% level. For the 90 year long investigation period (89 degrees of freedom), the critical value is r = ±0.18 (Bahrenberg et al. 2000). Significant correlations will be devided into weak and strong signals if the significance level is lower or higher than 95%, respectively. Therefore the threshold is r = ±0.22.

## Results and Discussion

In total 222 charts were analysed. Figure 3 illustrates the correlations and corresponding confidence intervals between the mean chronology derived from all sites and the three NAO indices. No bar rises up above the thresholds for the levels of significance. Thus, neither on a monthly nor on a seasonal scale a significant NAO effect to the mean growth over the whole dataset exists, regardless which NAO index is chosen. However, concerning the statistical spread of the correlations (white bars in Fig. 3) around the mean values, the values reach the level of significance and document the existence of significant correlations.

Figure 3 shows two foci of significant reactions: first a negative correlation to the beginning of the growing season, especially to March and consequently to spring, and second a positive correlation to the end of the growing season in August and/or September.

Comparing the histograms of the three NAOI some differences are obvious. While for autumn ZON and PON show positive correlations, the GIB index has a negative correlation.

In most cases however, especially regarding the strongest signals in spring/March/May and in August/September, the directions of the reaction are the same, only the values are different. Calculating the total number of all significant positive or negative correlations between the single sites and the three NAO indices, the GIB NAOI shows most significant correlations (numbers in Fig. 3). This might serve as an indicator for the fact, that for each of the three NAOI various combinations of sites and/or time periods significant correlations can be observed. This is especially amazing because of the fact, that all three indices intend to describe the same phenomena – the air pressure difference between the Azores High and the Islandic Low. Hence, the differences of the correlation values are caused by the different calculation techniques of the three NAO indices.

Therefore, in the following specifications for each case the index with the most significant correlating sites will be shown. Regarding the investigated aspects the March/spring signal will be discussed by using the GIB index and the summer/autumn signal will be discussed by using the PON index.

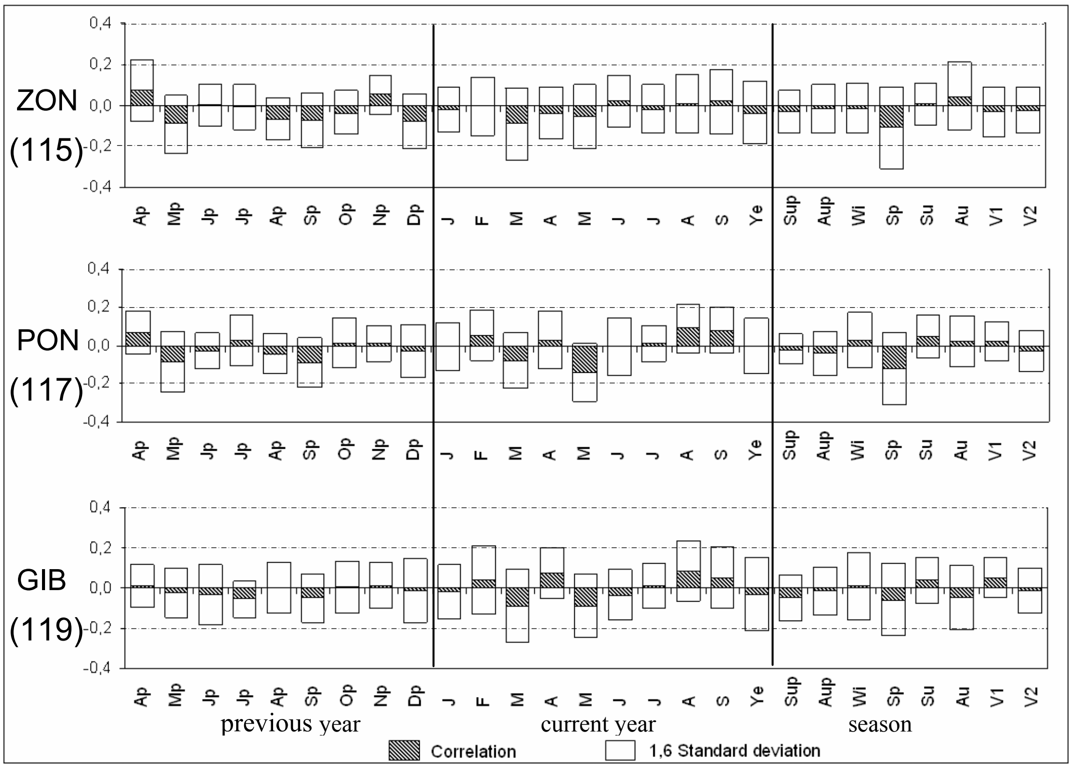

*Figure 3: Monthly and seasonal correlations between the three NAO indices ZON, PON, and GIB and the chronology averaged over all sites (grey bars) and the corresponding scatter over the single sites expressed as 1.6-time standard deviation (white bars) around the mean values. Additionally the total number of significant positive and negative correlations of all 37 sites in the 27 time windows is noted below the NAOI name. The threshold for the 90% significant level is ± 0,18 and for the 95% significant level ± 0,22. Short cuts: p =previous, Sp = Spring, Su = Summer, Au = Autumn, Wi = Winter, V1 = April-September, V2 = May-August.*

### *Specification of the spring signal*

The examination of the site specific correlations from the GIB NAOI in March (Fig. 4) involves the finding, that only the beech sites (circles) show significant correlations.

All the other species have correlations near by zero. Therefore, according to the westerly distribution of the beech sites, the apparent gradient with a decreasing March signal from West to East is explainable by the species specific reactions. Because of the fact, that the 4 non-significant beech sites are located in the western part as well as in the middle and eastern part of the beech distribution, decreasing correlations within the beech sites cannot be detected.

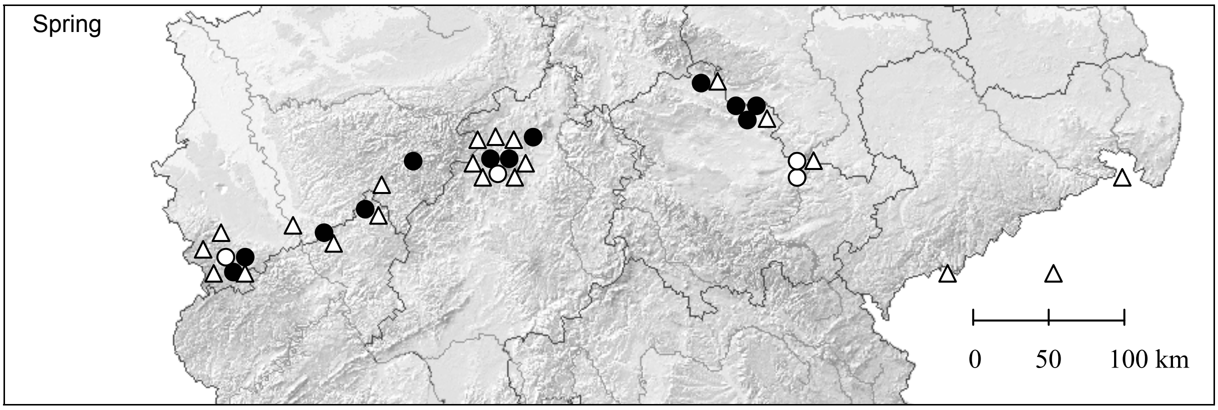

*Figure 4: Spatial distribution of beech (circles) and non beech sites (triangles) with significant negative correlations (black) and without significant correlations (white) in March against the GIB index (level of significance: 90%).*

*Specification of the summer/autumn signal*

In total, for 11 sites of the transect a positive significant correlation exists in months or seasons of the second half of the growing season, including the species oak, beech, spruce and pine (Fig. 5). The strong signals are located in the Eifel (r = 0.29 for the beech site 6 and 0.25 for the oak site 3) and in the Ore Mountains (r = 0.24 for the oak site 31). In the middle of the transect only weak correlations can be observed. Thus, from the signal strength a gradient from West to East cannot be deduced.

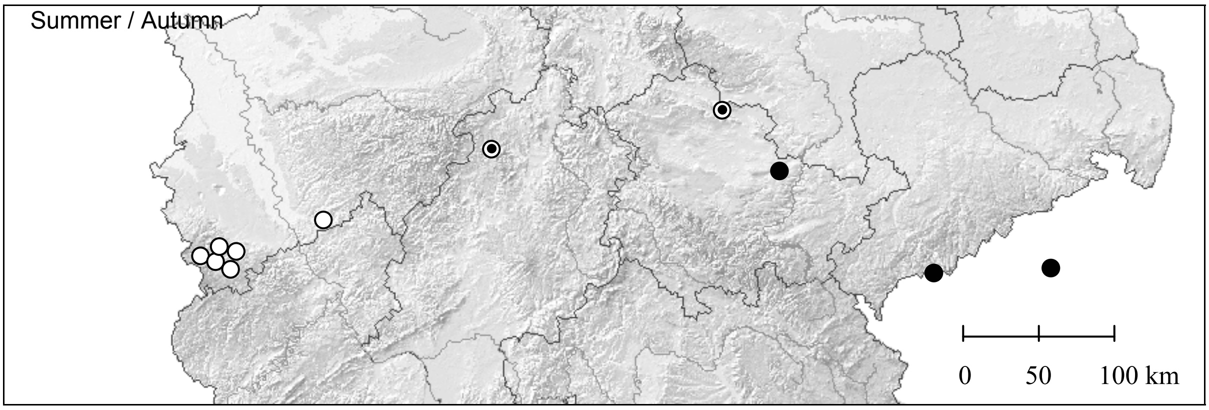

*Figure 5: Spatial distribution of sites with significant positive correlations (90% significance level) to the PON NAOI at the end of the growing season. The sites are differentiated as follows: positive significant correlations a) in June, July or summer ● ; b) in August and additionally in summer ⦿ , and c) in August, September or autumn ○.*

Focusing the view on the correlations for the investigated time periods (Fig. 3), a clear gradient from West to East is apparent. In the western part of the transect all correlations appear in the months August or September or for the autumn season (white circles in Fig 4). In contrast, in the eastern part the correlations are dated in June or July or in the summer season (black circles). In the middle of the transect two sites show significant correlations in both the summer season and additionally in august. These sites represent a transition and show the strongest reaction in late summer. In consequence, the specification of the summer/autumn signal results in a movement of the positive NAO - TRW correlation from autumn in the West to early summer in the East.

An additional investigation of the effect of the exposition of the tree sites on the NAO-signals in the TRW series did not lead to a clear result (not shown). There are no systematic differences in the results by dividing the dataset into two groups - a so called Luv-group with southern to eastern expositions and a Lee-group with western to northern expositions.

## Conclusion and Perspectives

The first results of this study concerning the effects of the NAO on tree-ring growth in a West-East transect from the Eifel (W-Germany) to the Ore Mountains (Czech Republic) can be summarized as follows:

On an interannual scale the NAO has only a small effect on tree-ring growth with highest correlations around r = 0.3. The strongest correlations appear as a negative relation at the beginning of the growing season and a positive relation at the end of the growing season. The spring signal is only caused by the beech sites and does not underline any variations within the transect. In contrast, the weaker summer/autums signal is caused by many species and describes a movement from West to East according to a decreasing length of the growing season. Both findings yield to the conclusion that especially for NAO-TRW investigations a species specific and a meridional separation of the dataset is advisable.

The next step, is to investigate the NAO signals in tree-ring chronologies on a decadal and multi-decadal scale – the scale of the strongest NAO modifications (Hurrell et al. 2003). Additionally, according to the findings of Friedrichs et al. (submitted) we have to examine the timely stability of these signals.

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