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Atmospheric Circulation indices derived from trees and GWL

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Introduction

Large-scale atmospheric circulation patterns are the dominant drivers of weather conditions, which strongly influence tree growth. Central European circulation patterns can be classified into weather regime types, known as "Großwetterlagen" (GWL) (Hess & Brezowsky 1952, Gerstengarbe 2005). The GWL data are nominally scaled and commonly used procedures for continuous time series analyses are unsuitable for investigating GWL influence on tree-ring growth. The only possibility is to work with GWL frequency distributions. Schultz et al. (2008) found no reasonable correlation, between tree-ring growth and GWL but discontinuous time series analysis showed a strong GWL influence on tree ring growth.

This paper presents a new approach for investigating the relation between tree-ring growth and GWL with continuous time series analysis using a Monte Carlo simulation. During the simulation, the GWL dataset is recoded and combined with tree-ring data. Based on this analysis, a set of new time series, called the "Atmospheric Circulation Tree-Ring Indices" (ACTI), are created. Two separate Monte Carlo simulations with different settings were applied with a test dataset consisting of 45 sites from a Central European North - South transect.

GWL Basics

The GWL dataset has a daily resolution and covers the period from 1881 to the present. Each GWL persists for at least 3 days (Gerstengarbe 2005).

The 29 GWL can be grouped into 10 synoptic types and then into three circulation types: zonal, mixed, and meridional (see Tab. 1). The GWLs are related to air masses which have their own specific combination of properties in terms of humidity and temperature, etc. Every GWL has its own weather condition pattern, which is seasonally differentiated and modified by the topography and the changing paths of anticyclones and cyclones.

Procedure for calculating ACTI

The procedure for calculating ACTI is mainly based on a Monte Carlo simulation. Therefore the results are computed by repeated random sampling in different runs. In each run a set of random numbers is used.

The procedure to calculate ACTI consists of four steps.

For each run the first step is to randomly assign weights to each GWL and then to replace all GWLs in the dataset with these randomly assigned weights for the calibration period. For each run, 29 random numbers, so-called GWL weights, which can have positive or negative values are used. From this re-coded dataset for different time periods, sums are calculated. The time periods can be defined by the user and can have for example annual, seasonal, monthly or weekly resolution. The sums are then transformed into absolute values.

The second step is to separate the re-coded GWL dataset into time series, the so-called GWL indices, which represent the different time spans. For example, when using a monthly resolution results in one time serie for each investigated month. In total there are 12 and with the previous year 24 time series and GWL indices, respectively.

	No.	GWL abbreviation	GWL		No.	GWL abbreviation	GWL
zonal	1	WA	Anticyclonic Westerly	meridional	16	НВ	High over the British Isles
	2	WZ	Cyclonic Westerly		17	TRM	Trough over Central Europe
	3	WS	South-Shifted Cyclonic Westerly		18	NEA	Anticyclonic North- Easterly
	4	WW	Maritime Westerly (Block E. Europe)		19	NEZ	Cyclonic North-Easterly
mixed	5	SWA	Anticyclonic South- Westerly		20	HFA	Scandinavian High, Ridge C. Europe
	6	SWZ	Cyclonic South- Westerly		21	HFZ	Scandinavian High, Trough C. Europe
	7	NWA	Anticyclonic North- Westerly		22	HNFA	High Norway-Iceland, Ridge C. Eur.
	8	NWZ	Cyclonic North- Westerly		23	HNFZ	High Norway-Iceland, Trough C. Eur.
	9	HM	High over Central Europe		24	SEA	Anticyclonic South- Easterly
	10	BM	Zonal Ridge across Central Europe		25	SEZ	Cyclonic South-Easterly
	11	ТМ	Low over Central Europe		26	SA	Anticyclonic Southerly
meridional	12	NA	Anticyclonic Northerly		27	SZ	Cyclonic Southerly
	13	NZ	Cyclonic Northerly		28	ТВ	Low over the British Isles
	14	HNA	Icelandic High, Ridge C. Europe		29	TRW	Trough over Western Europe
	15	HNZ	Icelandic High, Trough C. Europe		30	U	Undefined

Table 1: GWLs and associated circulation types

The third step is to calculate the Pearson's correlation coefficients r (Bahrenberg et al. 1999) between the tree ring data and the GWL indices. This procedure is repeated for all following runs. All results of the various runs are stored. The number of sites (ns), the number of runs (nr), and the number of investigated time spans (nts) define how many correlation coefficients and p-values are computed (ns*nr*nts). Due to the fact that the GWL is a large scale signal, a reasonable amount of sites are necessary to detect the signal properly. Furthermore, a large number of repetitions are necessary for a Monte Carlo Simulation. The combination of these two factors quickly leads to the situation needing greater computing capacity than is available from common software and computers.

The fourth step is to separate those runs for each site and period with the strongest correlation. So for the above described example 24 correlation coefficients would be extracted for each site. If all 24 GWL indices lead to significant correlations with respect to the multiple testing problem (see discussion) they are called ACTI.

The procedure for calculating ACTI does not depend on the number of sites, the investigated tree species, or the used tree-ring parameter like density, stable isotopes or tree-ring width. The overall procedure is always similar.

Test simulations

Two Monte Carlo simulations were carried out with R (R Development Core Team 2005) using the maximum available computer capability with different parameters (maximum 24 million correlation coefficients).

In total, 45 tree-ring sites from Germany, France, and Switzerland with a minimum of 12 dominant trees per site were used (Fig. 1). All tree-ring width series cover the time span between 1901 and 1990. The 45 sites are located along a transect from Germany's northwestern lowlands (100 m a.s.l.) to the high mountain regions of the Swiss Alps (2000 m a.s.l). The transect therefore represents a large ecological spectrum. Following tree species were investigated: *Fagus sylvatica (FASY), Quercus robur (QURO), Quercus petraea (QUPE), Pinus sylvestris (PISY), Picea abies (PCAB)*. The transect is dominated by QURO. QUPE, and FASY. The raw tree-ring width series for each site were cross-dated with TSAPWin (Rinn 2005) and Cofecha (Holms 1983) and detrended by Arstan using a 32-year spline.



Figure 1: a.) Spatial distribution of the tree-ring-sites. Not all sites are visible in the map, because of their short spatial distances to each other. One site in Rheinland-Pfalz and one site in the Lötschental is highlighted with a circle. b.) Frequency distribution of the tree species in absolute numbers

The first simulation used 45 dendro-sites with 20,000 runs and the calibration period from 1931 to 1990. The second simulation, consisting of 10 dendro-sites with 100,000 runs and 45 randomly selected years between 1901 and 1990. In total 22 monthly time spans from January of the previous year to October of the current year, and two annual, the year and the previous year were investigated.

Figure 2 shows an example for the first simulation. The grey curve is the detrended site mean curve from a site from Reinland-Pfalz (see circle Fig.1), the black curve represents the corresponding ACTI for March. The stability of the correlation over time is checked (Fig.2) and it remains significant for the whole investigation period from 1901 to 1990, even outside of the calibration period. The two curves are positively correlated and show similar behaviour. The second example (Fig. 3) shows the ACTI for May from a high mountain site from the Swiss Alps (Fig. 1 dotted circle). The two curves are generally negatively correlated.



Figure 2: Comparison between the ACTI curve (black) for March and the detrended mean curve (grey) for the oak site located in Reinland-Pfalz (see Fig 1 circle). The grey bars indicate the correlation coefficient for different time periods. The calibration period is shown in the grey rectangle. The threshold for the 95% significance level is +- 0.34 for 30 years.



Figure 3: Comparison between the ACTI curve (black) for May and the detrended mean curve (grey) for a *spruce* site located in the Swiss Alps (see Fig 1 dotted circle). The grey bars indicate the correlation coefficient for different time periods. The calibration period is shown in the grey rectangle. The threshold for the 95% significant level is +- 0.34 for 30 years.

The correlation is not stable over time because all periods show significant correlations except the period from 1961 to 1990. Due to the fact that this ACTI is derived from the second simulation, no fixed calibration period was used. GWL is a large scale circulation pattern and we observed for both simulations that many sites and even different tree species correlated significantly with the same GWL weights.

It is therefore possible to group sites, based on the GWL weightings, and this is a good indication of the quality of the weights.

Discussion and perspective

These initial results are encouraging and show that the ACTI seems to be a promising tool to examine the impact of large scale atmospheric circulation on tree ring growth. The influence of each GWL on tree-ring growth at a specific site can be estimated precisely, due to the GWL weights.

It is quite common to use a fixed calibration period, but the GWL data set is long enough to select random years for the calibration period. The advantages of randomly selected years are reduced influence of long term changes in the climate dataset, such as global warming, and reduced influence of auto- correlation. (Todman J.B., Dugard, P. 2001)

The main caveat of the ACTI method is Alpha inflation due to multiple testing. When several tests of significance are applied simultaneously, the probability of a type I error (rejecting a true null-hypothesis) becomes larger (Legendre 1998).

There are several ways to reduce this problem (Farcomeni 2008). The observed p-values in the two Monte Carlo simulations, especially in the second simulation, are mostly low enough to be considered significant after adjusting the Alpha level. Furthermore, the site grouping leads to more reliable results because the probability of type I error is reduced.

By applying this method, following questions can be addressed:

- Is the spatial pattern of tree-ring growth in Central Europe explainable by ACTI?
- How intense is the impact of GWL on tree ring growth?
- Does the sensitivity of different tree species toward GWL vary?
- Are the lowlands as sensitive as the high mountain regions with regard to the GWL influence?
- Is an altitudinal gradient, a north south, or west east gradient in the investigation area observable?

The next step consists of including more sites in the investigation and increasinge the number of repetitions. Due to limited computing capacity, the need to adjust the Alpha level and the grouping of the dendro-sites, a C program is in development. After grouping the sites and adjusting the Alpha level, a high resolution GWL reconstruction is enabled by reconstructing ACTI and comparing the groups. This method appears a promising procedure for understanding and reconstructing past weather conditions.

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