Do stable oxygen isotopes from *Pinus sylvestris* reveal different water sources in Central Germany?

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Introduction

A growing number of studies utilize tree-ring stable oxygen isotopes to address palaeoclimatic and ecological research questions. Several papers demonstrate close associations of tree-ring $\delta^{18}O$ time series with observational temperature (e.g. Anderson et al. 1998, Rebetez et al. 2003) and precipitation data (e.g. Saurer et al. 1995). $\delta^{18}O$ in tree-rings reflects the isotopic composition of the source water utilized by trees. Since this composition is similar between precipitation and soil water of the topsoil (Anderson et al. 1998, Roden et al. 2000), tree-ring $\delta^{18}O$, particularly from shallow rooted trees, offers the possibility to study past isotopic variations of precipitation and climate conditions. However, this approach is likely controlled by the trees' access to soil water, which may vary within a sampling site — due to differing microsite conditions and root depths — resulting in varying correlations between tree-ring oxygen isotope and regional climate data.

The authors address this variability by analysing oxygen isotope variations of individual trees growing within a humid sampling site in Central Germany without drought stress and limiting climate factors. $\delta^{18}O$ time series of four trees are *(a)* related to GNIP precipitation data to investigate whether the trees have utilized water from precipitation, and *(c)* calibrated against regional temperature data to evaluate potentially differing soil water access (among trees) within an otherwise homogeneous sampling site.

Isotope Theory

Water collected by the roots of a tree is the source of oxygen stable isotopes in stem xylem. Tree-ring $\delta^{18}O$ depends mainly on the isotopic composition of the meteoric source water taken up by the roots, evaporative enrichment of water in the leaf, and biochemical fractionation (Roden et al. 2000, Anderson et al. 2002). Possible water sources for a tree are precipitation, soil water and ground or retained water, which have a different isotopic composition. Shallow soil water has a similar isotopic composition as precipitation, depending on the frequency and intensity of precipitation events and hydrological soil characteristics (Tang and Feng 2001). $\delta^{18}O$ time series from deeper soil- and groundwater resources are usually more negative and contain no short-term and inter-annual variations. This is also revealed in plants rooting in different soil depths indicating access to different water stocks in their tree-ring isotopic composition (Saurer et al.1997).

Study Site

The study site is located near Altenkirchen, Germany (50°39`N, 7°38`E), near a GNIP station in Koblenz and climate station in Hilgenroth. The site receives approximately 1000 mm precipitation per year. Mean annual temperature is 9.4°C. The soil type at the sampling site is determined as a cambisol with stagnic properties. The soil texture in the horizon from 75 cm to 105 cm depth was silty clayey loam (utL). The infiltration rate of this soil texture is lower than for a well-drained soil texture like sand, therefore water needs longer time to pass the unsaturated zone (Robertson 2001). Tree composition is dominated by Scots pine (*Pinus sylvestris*), mixed with beech (*Fagus sylvatica*) and oak trees (*Quercus robur*) (FAWF 2012).

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Material and Methods

Four *Pinus sylvestris* stem disks were sampled for isotopic analysis from a permanent monitoring plot. Four to eight radii were cut out from these disks and the ring width measured using WinDendro density software (Regent Instruments). Whole tree-rings (including early- and latewood) were separated with a scalpel, ground using a mixer mill (MM200 Retsch), and treated according to the Brendel method (Evans and Schrag 2004) to gain α-cellulose. Analysis of oxygen and carbon isotopes was performed at the Department of Geobotany in the University of Trier (Germany). To investigate our hypotheses, climate data from the station Hilgenroth in approximately 15 km distance, GNIP data (oxygen isotopes in precipitation) from Koblenz in approx. 35 km distance to the sampling site were used. Additionally maximum temperature on rainy days was calculated, which is defined as maximum temperature on days with > 0mm precipitation. The forest density was 57 trees on a 0.25 ha permanent sampling site in 2009, after the forestry thinning only 37 trees remained on the plot.

Results

The individual $\delta^{18}O$ time series indicate particular high values for the year 2003 and particular low values for the years 1998 and 2002. The range of $\delta^{18}O$ values is between 32.5‰ and 35.2‰ (Fig. 1).

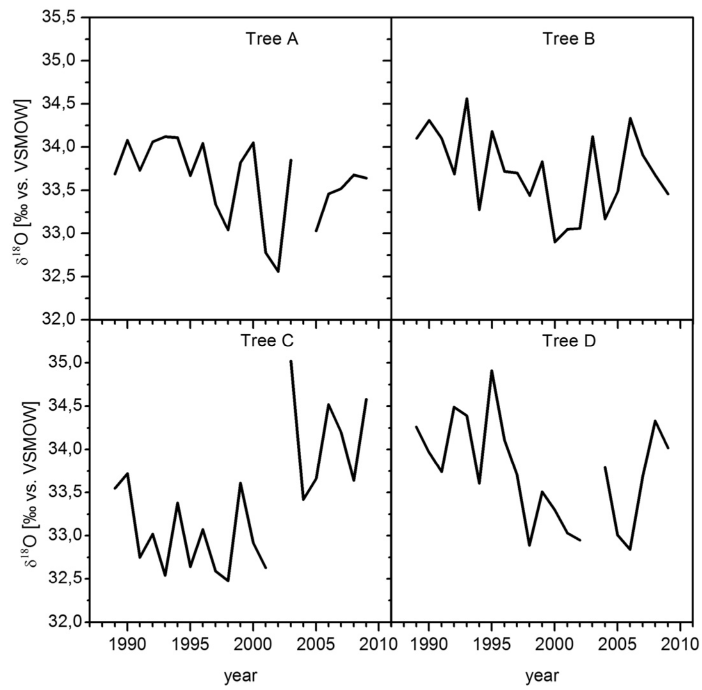

Figure 1: Oxygen stable isotope time series (1989 to 2009) of individual trees.

Inter-tree correlation at the sampling site shows low to medium correlations (Table 1). Tree C presents independent correlations compared to the other trees at sampling site. Tree A, B and D demonstrate medium correlations to each other.

Table 1: Inter-tree correlation between individual oxygen stable isotopes from tree rings.

	Tree A	**Tree B**	**Tree C**
Tree B	.44		
Tree C	.10	.19	
Tree D	.64**	.47*	-.13

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We used precipitation δ^{18}O time series from the GNIP station in Koblenz, covering the 1989 to 2007 period, for calibration of the tree-ring stable isotope measurements from Altenkirchen.
Comparison of the single-tree δ^{18}O time series with the nearby GNIP station in Koblenz reveals significant positive correlations between Tree C and July and September precipitation oxygen isotopes (Fig. 2). All other trees and all other months respectively showed insignificant correlations between tree-ring and precipitation oxygen isotopes, indicating a distinct differentiation within the Altenkirchen sampling site, likely related to differing microsite conditions. Most of the insignificant correlations of Tree A, B, and D are also of differing sign, compared to Tree C.

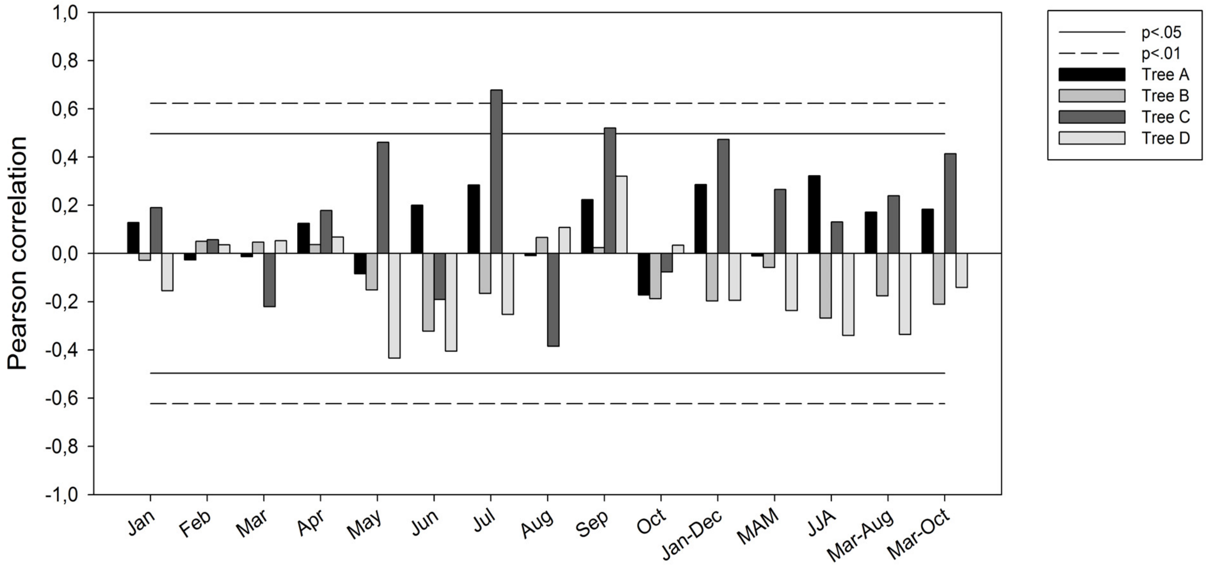

Figure 2: Pearson correlations between oxygen stable isotopes of individual trees and oxygen stable isotopes in precipitation recorded at the Koblenz GNIP station.

Correlations between tree-ring δ^{18}O and maximum temperature (Fig. 3) and maximum temperature on rainy days (Fig. 4), indicate a strong correlation of Tree C and no correlation of the other trees. Tree A, B and D presented insignificant positive correlations with Tmax and no improvement of correlations with Tmax on rainy days. Again, only Tree C showed significant correlations with Tmax and improved associations with maximum temperature on rainy days.

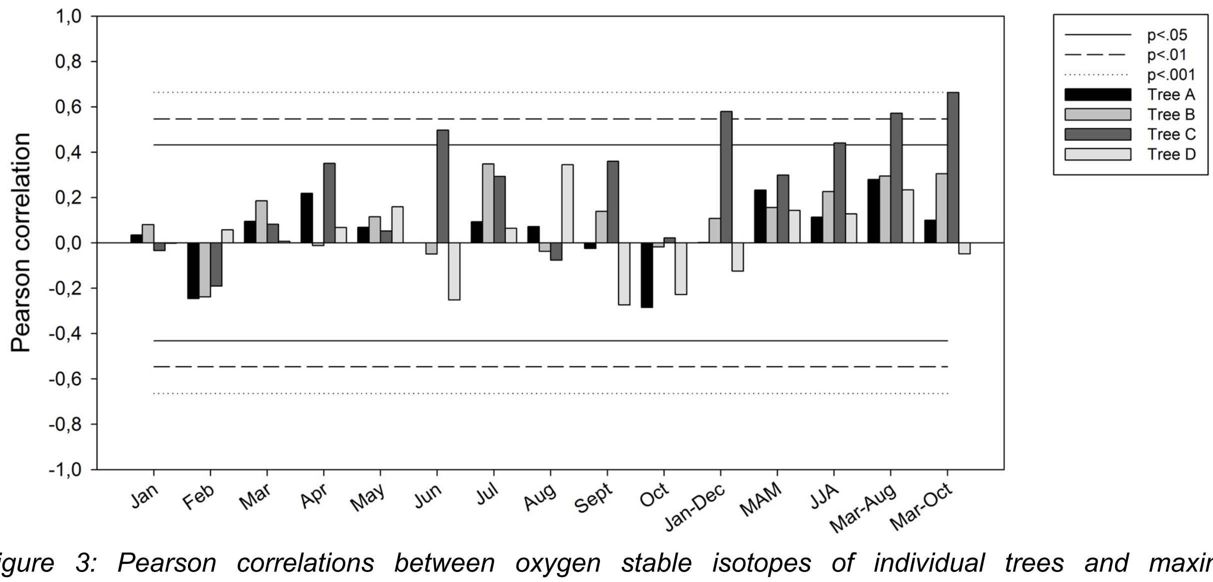

Figure 3: Pearson correlations between oxygen stable isotopes of individual trees and maximum temperature.

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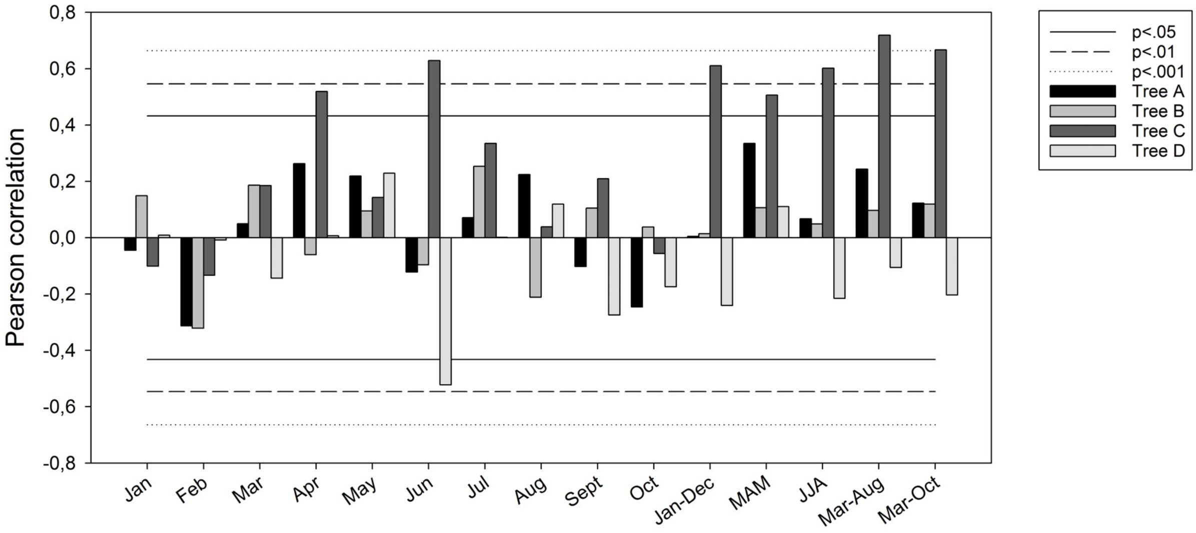

Figure 4: Pearson correlations between oxygen stable isotopes of individual trees and maximum temperature on rainy days.

Conclusions

The analysis of $\delta^{18}O$ time series from individual trees in a typical permanent monitoring plot showed varying trends over the past two decades, and associated differing correlations with the isotopic composition of precipitation and regional maximum temperature time series. The changing climate signals retained in individual tree-ring $\delta^{18}O$ time series is likely related to varying water supply of individual trees, caused by different rooting depths of single trees within the sampling site or different soil properties mentioned by differing stagnant qualities. These effects are triggered by the distinct isotope composition of precipitation, shallow soil water and stagnant or ground water. Tree C showed a good climate signal with maximum temperature and isotopic composition of precipitation. This indicates that Tree C has no access to a permanent water source like groundwater in contrast to the other trees.

These findings are in line with Saurer et al. (1995) indicating that trees growing in moist sites contain lower correlations with climatic data than trees growing on dry sites. Our analysis suggests that these between-site differences might also account for single trees within a site. Trees growing in dry microsites correlate higher with climate than trees growing in moist microsites (on this site especially stagnant soil water). Tree-ring $\delta^{18}O$ is related to the isotopic composition of the water source accessed through the root system (Roden et al. 2000). As Tree A, B and D showed no significant correlations with $\delta^{18}O$ in precipitation, this basic finding suggests that these trees use a different water source than the remaining Tree C. It is suggested that the roots of Tree A, B and D reach deeper into the stagnant or groundwater, and Tree C developed a shallower root system utilizing soil water from the unsaturated, precipitation influenced zone. As a consequence of the soil type and the infiltration rate, Tree A, B and D do not depend on precipitation water and hence the isotopic signal of $\delta^{18}O$ in precipitation is not reflected in $\delta^{18}O$ cellulose. It is likely that the climatic signal of $\delta^{18}O$ in precipitation is dampened by means of mixing with $\delta^{18}O$ in the upper soil layer. The findings suggest that the variability in correlations between $\delta^{18}O$ in trees and $\delta^{18}O$ in precipitation at the sampling site can be the result of heterogeneous isotopic composition of soil water. For our future work we recommend a detailed soil study on the permanent monitoring plot, investigating the soil texture and hydrological conditions near the trees to evaluate our findings. It is also of interest to measure $\delta^{18}O$ of water extracted from the stem (xylem) and compare it with $\delta^{18}O$ of soil water from different soil depths to estimate the level where roots mainly take up their water. Furthermore, a better replicated site with more individual trees on different environmental conditions are needed

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References

Anderson, W.T., Bernasconi, T.S.M., McKenzie, J.A., Saurer, M. (1998). Oxygen and carbon isotopic records of climatic variability in tree ring cellulose (Picea abies): An example from central Switzerland (1913-1995). *Journal of Geophysical research letters* 103 (D24): 31625-31636.

Evans, M.N., Schrag, D.P. (2004). A stable isotope-based approach to tropical dendroclimatology. *Geochimica et Cosmochimica Acta*, *68*(16): 3295-3305.

Farquhar, G.D., Leary, M.H., Berry, J.A. (1982). On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. *Australian Journal of Plant Physiology* 9: 121-137.

FAWF (2012): Permanent monitoring plot 308: Altenkirchen. <http://www.fawf.wald-rlp.de/fileadmin/website/fawfseiten/fawf/FUM/index.htm?umweltmonitoring/DBFL/forschung.html> (Date of revision: 2012) (Date of access: 02.09.2012).

Rebetez, M., Saurer, M., Cherubini, P. (2003). To what extent can oxygen isotopes in tree rings and precipitation be used to reconstruct past atmospheric temperature? A case study. *Climate change* 61: 237-248.

Robertson, I., Waterhouse, J., Barker, A., Carter, A., Switsur, V. (2001). Oxygen isotope ratios of oak in east Enngland: implications for reconstructing the isotopic composition of precipitation. *Earth and Planetary Science Letters* 191: 21-31.

Roden, J.S., Lin, G., Ehleringer, J.R. (2000): A mechanistic model for the interpretation of hydrogen and oxygen isotope ratios in tree ring cellulose. *Geochimica et Cosmochimica Acta* 64 (1): 21-35.

Saurer, M., Siegenthaler, U., Schweingruber, F. (1995): The climate-carbon isotope relationship in tree rings and the significance of site conditions. *Tellus B* 47: 320–330.

Saurer, M., Borella, S., Leuenberger, M. (1997). $\delta^{18}O$ of tree rings of beech (Fagus sylvatica) as a record of $\delta^{18}O$ of the growing season precipitation. *Tellus* 49B: 80-92.

Tang, K., Feng, X. (2001). The effect of soil hydrology on the oxygen and hydrogen isotopic composition of plant`s source water. *Earth and Planetary Science Letters* 185: 355-367.