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Winter Arctic Oscillation signal in a European tree-ring δ18O network

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Oxygen isotopes in tree rings are seen as a powerful tool for the reconstruction of past atmospheric conditions such as the isotopic composition of precipitation, air temperature, precipitation amount, relative air humidity, or atmospheric circulation patterns. Uncertainties in the climate information nevertheless arise from the complex interplay between signals carried in the source water taken up by the roots and those produced by evaporative enrichment and (post-) photosynthetic processes at the leaf level and during downstream metabolism. Besides physiological process studies, data sets of broad ecological, spatial and temporal range are requested to better estimate the environmental conditions in which climatic signals in tree-ring δ18O are maximized.

Here we present a large and well-replicated tree-ring δ18O network, developed in the EU-projects MILLENNIUM and ISONET, with 33 European sites ranging from Fennoscandia to the Mediterranean region. Tree-ring δ18O chronologies from four genera (Quercus, Abies, Cedrus, Pinus) were included in the analysis. The sampling design considered both, ecologically extreme sites at the northern and alpine tree line with temperature mainly controlling tree growth, and temperate sites where mixed climate signals are recorded in 'traditional' growth parameters (ring width and maximum late wood density). All chronologies are annually resolved and fully cover the 20th century, with at least 24 chronologies reaching 400 years back in time.

Based on PCA we could define three distinct European sub-regions: Scandinavia, central Europe and the western Mediterranean, with highest loadings of 14 central European sites dominated by Quercus species in PC1, explaining 20% of the network's variance. Spatial correlations of all PCs with air pressure fields indicate that in Scandinavia and the Mediterranean, regional mid-tropospheric air pressure systems (NCEP/NCAR reanalysis data) during summer are mirrored in tree-ring δ18O. In contrast, central European tree-ring δ18O strongly record dipole-like large-scale atmospheric circulation patterns during winter, related to the Arctic Oscillation (AO). The winter signal is supported by highly significant correlations of PC1 to January-March data of a central European precipitation δ18O record (GNIP) and relatively weak correlations to summer months. The precipitation δ18O signal itself has been shown to significantly rely on the Arctic source region during winter. Moreover, PC1 strongly corresponds to winter AO-indices (Thompson and Wallace 2000), with a robust signal throughout the whole study period (1900-2003), pointing to the potential for reconstruction of past AO-variability. This large-scale atmospheric winter signal is assumed to originate from source water uptaken from deeper soil water pools preserving winter precipitation/snow-melt water far into the growing season, particularly accessible by the deep root system of Quercus species. In Scandinavia, frozen soils and strong surface runoff before the late beginning of the vegetation period together with shallow root systems of conifers are assumed to not allow a winter signal to be preserved. Regional-scale low-pressure systems in summer are expected to provide the main water source for the trees there. This may partly also hold for shallow and dry soils in the Mediterranean, also not allowing for longer-term water storage. In addition to the source water control, however, summer signals are probably related to physiological processes at the canopy resulting in leaf water enrichment during transpiration and postphotosynthetic fractionation effects.

Additional analyses are going (1) to test the robustness of the PCs and the AO-signal over the past 400 years and (2) to disentangle the climatic and physiological drivers of tree-ring δ18O on local to regional scale by applying leaf water/wood cellulose models. The latter should allow to better estimate the role of (i) leaf water enrichment and (ii) oxygen atom exchange between sucrose and xylem water during cellulose synthesis for tree-ring δ18O (see also Ullrich et al., abstract in IG10).