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Oxygen isotope pathway from the soil to the tree-ring at alpine sites in Switzerland

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Oxygen isotopes in tree rings have become a significant tool in obtaining retrospective insight into the plant physiological response to climate and other environmental variables. The increasing number of isotope records, however, also highlights important unsolved questions and current limitations of this tree-ring parameter. Obviously, an improved understanding of the mechanisms leading to variations in the tree's internal water cycle in relation to climate, soil moisture conditions, transpiration and expansion of the root system is urgently needed. Moreover, disentangling the physiological processes and meteorological variables associated is a prerequisite for an accurate interpretation of δ18O in tree-ring ecology.

We study the intra-seasonal pathway of oxygen isotopes from precipitation and soil water to the tree-rings of Larix decidua and Picea abies (4 trees per species and site) at two sites in the Loetschental (Swiss Alps). Sites are located at the upper tree line (2100 m asl) of a south-facing slope and at the valley bottom (1300 m asl) and are characterized as cool-moist and warm-dry. The air temperature difference of approx. 3°C between the tree line and the valley bottom, which roughly coincides with the predicted deviation from current temperatures over the next 100 years makes this region an ideal place to monitor the effects of climate change on tree physiological processes.

Weekly resolved records of xylem and needle water, phloem sugars and tree-ring δ18O were and will be developed, covering three full growing seasons (2008-2010). Those data were related to external variables such as precipitation and soil water δ18O, temperature, relative air humidity and vapour pressure deficit and applied to several leaf water/wood models.

Our analyses currently suggest that tree-ring δ18O predominantly records the source water signal, including recent precipitation water and further water pools within the soil, already with the beginning of cell development in spring. Variations in needle water enrichment, which were shown to be strongly controlled by weather conditions during the whole growing season, and fractionation effects during assimilate production are found to be of lower relevance for the isotope signal in the wood. These findings are supported by modelling results, with seasonal variations captured best when applying a small 'dampening factor', which represents a strong dampening of the leaf signal in the tree ring. Moreover and most importantly, calculations of the exchange rate (pex) between oxygen atoms of the carbonyl groups and xylem water (based on measured values and different leaf water models) reveal strong seasonal variations with mean values of about 70%, being much higher than earlier published values of about 40%. High pex and its variability over the growing season might decouple the leaf water signal from the tree ring and could explain the strong correlation between tree-ring δ18O and source water δ18O.

Overall, our findings clearly suggest that the strongest climate signal should be recorded at sites, where soils are most frequently supplied with precipitation water during the growing season, namely in temperate regions under humid precipitation conditions with a precipitation maximum in summer. This would have relevant implications on future sampling strategies for climate reconstructions based on tree ring δ18O.