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Oxygen isotopes in tree rings: do they really reflect temperature?

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Introduction

Because of isotopic fractionations in the hydrological cycle, there exists a relationship between temperature and the δ^{18}O of precipitation (Dansgaard 1964). The oxygen-isotope ratio ^{18}O/^{16}O therefore is a useful proxy parameter for climate. It is applied in particular in ice-core and sea-sediment studies. Because the isotope ratio in the cellulose of tree rings reflects that of precipitation (Burk & Stuiver 1981), it should also be well suited for tree-ring studies. Modern on-line pyrolysis systems enable the processing of a large number of samples (Werner *et al.* 1996), meaning that in the future this method may be used to build long oxygen-isotope chronologies for the purpose of reconstructing climate on the continents. However, it has to be kept in mind that the isotope ratio in precipitation and tree rings is determined by a large variety of factors and that as a consequence its climatic interpretation is not straightforward.

In this context, two main questions have to be addressed:

(1) What is the exact relationship between the isotope ratios of rainwater and temperature?

(2) What are the isotope fractionations during the trees' uptake and incorporation of the water?

Regarding the first question, one has to consider that the temporal oxygen-isotope variations in meteoric water are not simply determined by temperature, but also by the evaporative conditions over the oceans where the precipitation originated, as well as by the flow path of the moisture to a particular location on the continent. Therefore, changes in the oxygen-isotope ratio of precipitation may be caused by changes in the atmospheric circulation pattern.

Regarding the second question, one has to consider the transfer function between (a) the isotope ratio in the water taken up by the roots, and (b) the isotope ratio in the cellulose of the tree rings. The isotope ratio is modified in particular in the leaf, due to transpiration, and in biochemical steps during cellulose synthesis. Only part of these processes has been quantified, rendering it difficult to use isotope ratios for quantitative climate reconstructions. In addition, isotope-fractionation processes may be dependent on species and site conditions, meaning that calibration studies cannot be generalized, but have to be verified for different ecological situations.

In this paper, we present some results from research on this subject carried out at the Paul Scherrer Institute (Villigen, CH), and discuss the potential of oxygen-isotope analysis for temperature reconstruction.

Results and Discussion

We analysed tree-ring cellulose from three beech trees (*Fagus sylvatica*) growing at a relatively dry site in Switzerland (Saurer *et al.* 1997). The measurement series show a very synchronous signal, implying a small error of the mean curve (see the width of the band in Fig. 1, upper curve). There exists a significant correlation between the isotope variations and the average temperature of the months April,

May and June (r=0.70, p<0.01), especially between the lower-frequency variations (on a decadal scale; Fig. 1). The temperature coefficient for the correlation between δ^{18}O in tree rings and temperature is 0.33‰/°C, which is clearly lower than the coefficient for the correlation between δ^{18}O in precipitation and temperature (0.6‰/°C; Dansgaard 1964).

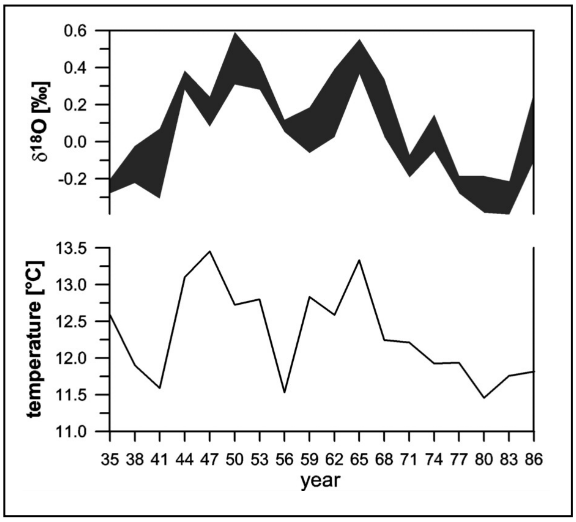

Figure 1: Upper curve: Mean δ^{18}O-curve of cellulose of beech trees from a dry site in Switzerland for the period 1935 to 1986 (anomalies with standard deviation).
Lower curve: Mean temperature of the months April/May/June at the weather station Bern.

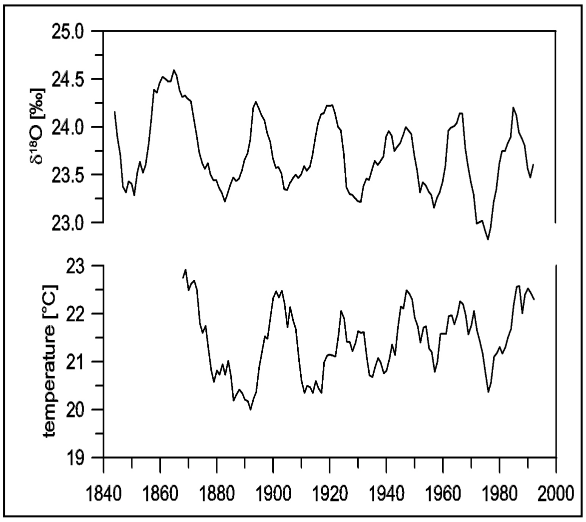

Figure 2: Upper curve: Late wood δ^{18}O-chronology for Abies alba (10-yr running mean). Lower curve: July temperature at the weather station Bern (10-yr running mean).

This indicates that some of the variability in the isotope signal of precipitation was lost while the oxygen was incorporated in the wood.

In the study presented here, we did not separate earlywood (EW) and latewood (LW), but measured entire rings. This may explain why in this case δ^{18}O correlates best with temperature during a relatively early period of the growing season (May to June).

When LW would be analysed separately, however, one would expect the summer climate to be reflected in the isotope signal. This was confirmed by a second study in Switzerland, on silver fir (*Abies alba*, Saurer *et al.* 2000). Here, isotopes were found to correlate best with July temperature, although the correlation coefficient is rather low (r=0.31). This weak correlation appears to be at odds with the strong correlation that we found between summer precipitation and δ^{18}O in the tree rings of the same trees (r=0.72). However, the latter may simply mean that the isotope signal in precipitation was well recorded in the tree rings, but cannot solely be explained by temperature.

We estimated the lower-frequency variations using a 10-year running mean. In this manner, a quasi-periodic variation became apparent, characterized by a period of ca. 24 years (Fig. 2). This signal is related to temperature and to variations in precipitation and relative humidity. Given the fact that we found a significant correlation between the yearly NAO (North Atlantic Oscillation) index and the $\delta^{18}O$ in tree-ring series, this phenomenon may be explained by fluctuations in the large-scale atmospheric circulation over Europe and the North Atlantic.

A third study also suggests that oxygen-isotope variations can be explained by changing precipitation patterns (Saurer *et al.* 2002). In this study, focussed on Northern Eurasia and including sites from Norway to Siberia, we analysed $\delta^{18}O$ for the species *Picea*, *Pinus* and *Larix*. In the interior of the continent, the period 1961-90 shows lower tree-ring isotope values than the period 1861-90. This decreasing ^{18}O content over time is in contrast with the temperature increase observed at meteorological stations. The reason might be that during the last century winter precipitation increased in this area. Winter snowfall has a strongly negative isotope signature, which would have added to a more negative average $\delta^{18}O$ of the ground water that the trees were using. Based on simple mass-balance calculations, in this case we showed that changes in the seasonality of precipitation may indeed have affected the isotope values in the studied tree rings.

In conclusion, we have found strong evidence that tree rings faithfully record the isotopic composition of precipitation, and that this holds true relatively independent of tree species and site conditions. On the other hand, it has become clear that the isotope signal is not simply a function of summer temperature, but that changes in precipitation patterns, for instance regarding the flow path of the moisture or the seasonality of the precipitation amount, may be responsible for the observed isotope variations.

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