

## The climatic signal in oxygen isotopes of junipers at the lower timberline in the Karakorum, Pakistan

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### Introduction

Ice-core and sea-sediment studies have shown that oxygen isotopes are a suitable tool for temperature reconstruction (Johnsen *et al.* 2001, Jouzel *et al.* 1997). However, the question remains, whether this parameter measured in tree-rings can also be used as a “paleothermometer”. The analysis of oxygen isotopes in wood cellulose requires great technical and time expenditures, and only since the late 1990’s have modern on-line measurement systems enabled the processing of large numbers of samples. Consequently, only a few publications currently exist that show annually resolved oxygen measurements from multi-decadal tree-ring series (Lipp *et al.* 1996; Anderson *et al.* 1998; Saurer *et al.* 2000; Robertson *et al.* 2001). Most of these studies describe highest correlations between the isotope values of tree-rings and the water uptake that originates from precipitation and/or ground or soil water sources. The relationship between tree-ring oxygen isotopes and climate variations mostly results from the climatic dependence of the source-water isotope values (Craig 1961; Dansgaard 1964; Siegenthaler and Oeschger 1980; Gray 1981; Rozanski *et al.* 1992; Cole *et al.* 1999; Jouzel *et al.* 2000; Gonfiantini *et al.* 2001). Consequently, the atmospheric forcing of  $\delta^{18}\text{O}$  in tree-rings is maximized by choosing dry and thus precipitation controlled sites.

Here we present five, 100-year oxygen records, from living juniper trees (*Juniperus excelsa*), growing at a warm and dry site (3000 m asl) near the lower timberline in the Bagrot Valley (Karakorum Mountains / Pakistan) (Fig. 1). The aim of the study was to investigate:

1. the suitability of this tree species for oxygen isotope analyses, and
2. the tree-ring / climate relationships and their potential for climate reconstruction

## Methods

We sampled juniper trees (*Juniperus turcestanica* and *J. excelsa*) at 4 sites in 3 valleys situated both south and north of the main Karakorum ranges in Northern Pakistan. Site selection strategy sought to cover the whole range of ecological conditions typical for this subtropical high mountain system. Figure 1b shows the locations of the sampling plots. They are situated along a S-N precipitation gradient, resulting from decreasing monsoonal influences from the SW. Three sites are situated near the upper timberline (3900 m asl) and one site near the lower timberline (3000 m asl, BAG low). The latter site is relevant for this study.

12 to 20 trees per site were sampled and 5 to 7 cores per tree were taken from opposing radial directions. After cross dating and measuring the ring widths, 5 to 7 trees per site and 2 cores per tree (similar radii for all individuals) were chosen for isotope analysis displaying few missing rings and straight ring boundaries. Individual tree-rings were separated with a scalpel, wood was milled with an ultra-centrifugal mill and then the cellulose was extracted (Treydte *et al.* 2001). This procedure was done for every single tree-ring. The cellulose samples were pyrolyzed to CO in an elemental analyzer (Carlo Erba) interfaced to an isotope-ratio mass spectrometer (Micromass-Optima), and the measured oxygen isotope values scaled to the Vienna standard of mean ocean water (VSMOW). Additionally, a record of annually pooled samples (using all five trees) was derived at BAG low, with the aim to test this method of combining samples for oxygen isotope measurements. The value of this approach is already established for carbon isotope investigations (Leavitt and Long 1984; Borella *et al.* 1998; Treydte *et al.* 2001).

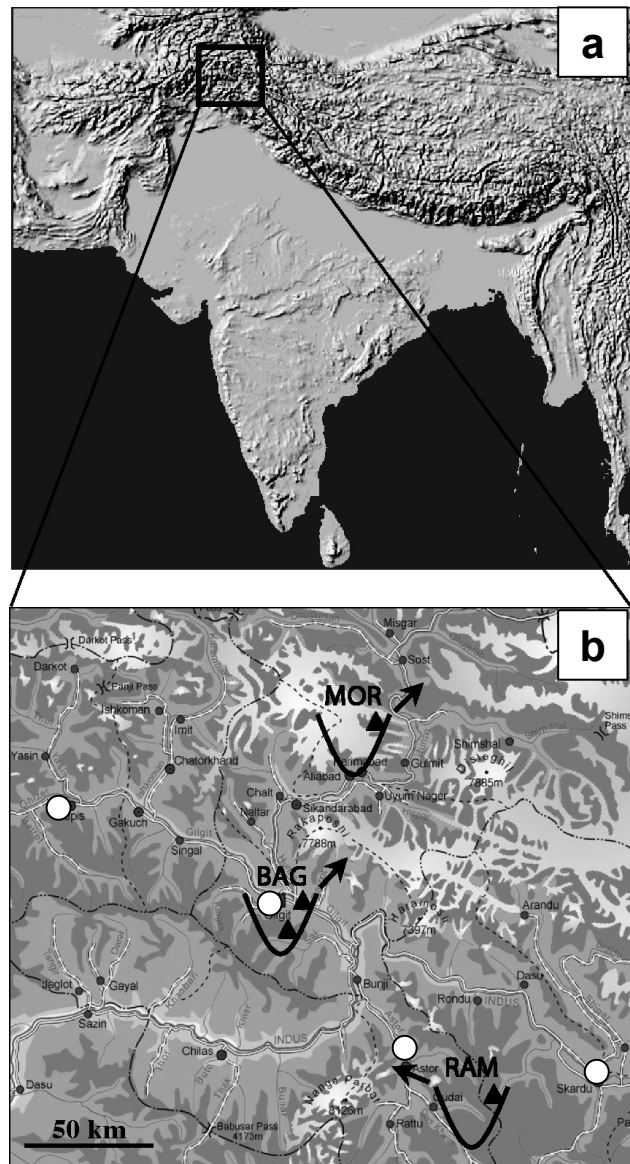


Figure 1: High Asia (a) and location of the sampling sites in northern Pakistan (b); the lower site in BAG is focused in this paper [dots = climatic stations]

Map sources:

(a): <http://edcdaac.usgs.gov/gtopo30/e060n40.html>

(b): Spohner & Winiger (2001), Institute of Geography, University of Bonn, Germany

## Results

Figure 2 shows the raw ring width (TRW) and  $\delta^{18}\text{O}$  series of the five isotope trees at BAG low. The mean inter-series correlation (MISC) between the TRW records is 0.74 for the period of maximum overlap (1866-1998 AD) and 0.77 for the 20<sup>th</sup> century. The common percentage of year-to-year intervals with similar trends (termed “Gleichläufigkeit” GLK or “coefficient of parallel variation”) for this 100-year period is 73%. In comparison, MISC of the  $\delta^{18}\text{O}$  records (0.69) is lower while GLK has nearly the same value (75%). The higher correlation value of the TRW series results from a common decreasing long-term trend due to aging processes of these approximately 150 year old trees. At the other three sites with older trees such a trend in the 20<sup>th</sup> century is not seen in the TRWs (Treydte 2003). In contrast, the  $\delta^{18}\text{O}$  series remain on a similar level over the whole investigation period. Consequently, the calculation of a mean site record from raw measurements seems to be appropriate for the isotope series. In contrast, the age trend from the TRW records need to be removed prior to climate analyses (Cook and Kairiukstis 1990; Briffa 1995; Briffa *et al.* 1996; Cook *et al.* 1997; Esper *et al.* 2002; Esper *et al.* 2003).

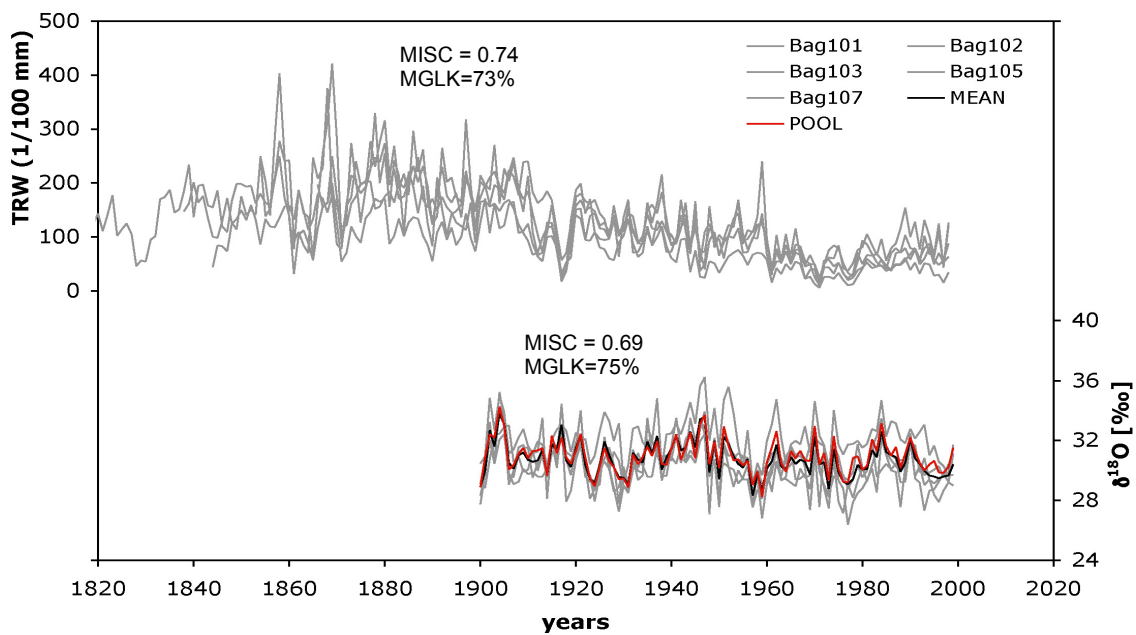


Figure 2: Raw ring widths (upper part) and  $\delta^{18}\text{O}$  values (lower part) of the 5 isotope trees at BAG low (MISC = mean inter series correlation, MGLK = mean Gleichläufigkeit)

The pooled record of tree-rings mirrors the mean calculated from all separately measured samples, with a correlation of 0.9 (Fig. 2, lower part). This result proves the suitability of this time and cost saving method for oxygen investigations when addressing site comparisons.

The climate response of the tree-ring parameters was studied using monthly records of temperature and precipitation from 4 climatic stations within the high mountain area (Fig.1). It has to be taken into account that all stations are situated at valley bottoms, limiting their representativeness of conditions at the tree sites. Even the nearest station (Gilgit, 1460 m asl) has a difference in elevation of 1500 meters to BAG low. The approximately 50-year long records from the single stations were averaged to form a regional record. This leads to

higher correlations with the tree-ring data. We calculated the correlation coefficients with standardized TRW series, using ratios of 51-year Kernel filters, and with the raw  $\delta^{18}\text{O}$  data. Tests with standardized isotope records showed similar results (Treydte 2003).

The moisture dependency of this warm/dry lower timberline site is obvious in the formation of tree-ring widths. Warm and therefore dry conditions during the vegetation period result in narrow rings, whereas wet and cool conditions result in wide rings. The precipitation conditions of the whole year influence tree growth, in the sense that melt water from winter precipitation plays a role when growth starts in spring. Most clearly, the winter season is pronounced in the highly significant negative relationship between oxygen isotopes and November to February precipitation.

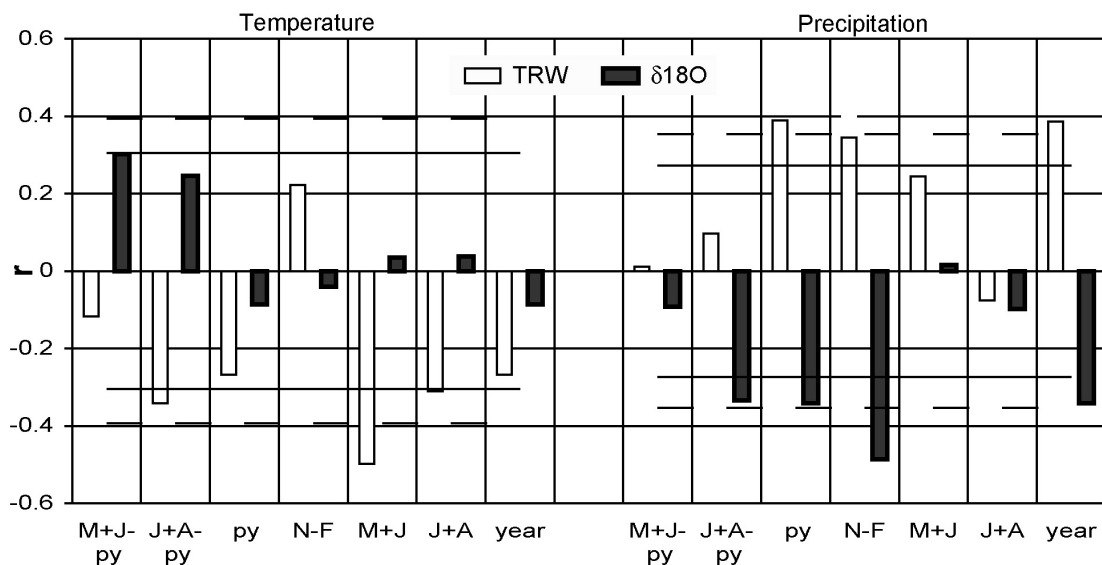


Figure 3: Correlation coefficients (Pearson) between the mean records of the two tree-ring parameters and the regional temperature and precipitation records; TRW were standardized using a 51-year Kernel filter; solid and dashed lines = 99% and 95% significance levels; M+J, J+A, N-F = mean temperatures and precipitation sums of May+June, July+August and November-February, py = previous year

In contrast, the relationship to temperature is less distinct. For  $\delta^{18}\text{O}$ , these correlations with temperature and precipitation are homogenous at all sites (Treydte 2003).

## Discussion

But how does the amount of winter precipitation influence the oxygen isotopes of tree-rings and why is this relationship negative? As mentioned above, the  $\delta^{18}\text{O}$  values in tree-rings to a certain extent reflect the isotope values of the water uptake. Comparisons with data from the Global Network of Isotopes in Precipitation (GNIP), established by the International Atomic Energy Agency (IAEA), are problematic as the GNIP network is patchy for Central Asia. Closest stations to the research region are Kabul, Tashkent, Karachi, Lhasa or New Delhi. However, synoptic weather conditions at these sites are not representative of those in Northern Pakistan, which is situated at the fringes of the westerlies and the SW monsoon.

Secondly, the records are short and/or incomplete with missing values in nearly every month. Therefore, it is not possible to calculate robust correlations with these data. However, from the GNIP-Network (Rozanski *et al.* 1992) and from our own measurements of precipitation samples in the Karakorum (Treydte 2003), we know that the isotope values of frozen precipitation are strongly depleted in comparison to those of rain (ca. 30‰ lower).

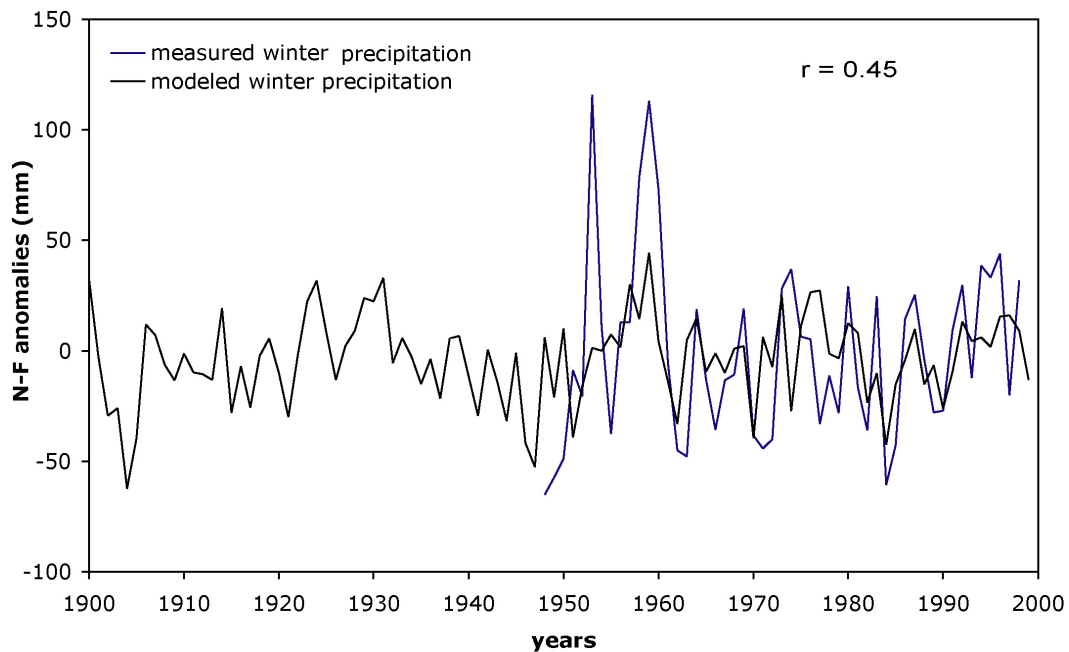


Figure 4: Winter (Nov.- Feb.) precipitation anomalies (residuals from the mean) - direct measurements versus modeled values from  $\delta^{18}\text{O}$  at BAG low

Considering that the tree-rings of *Juniperus* species contain about 90% early wood vessels, built in spring and early summer, a large fraction of the incorporated water should originate from the snowmelt. Larger amounts of frozen winter precipitation will result in more depleted oxygen values in the tree-rings. On the other hand, a low or even absent melt water supply leads to higher tree-ring isotope values. This explains the negative relationship between precipitation sums and tree-ring isotopes. However, temperature and hence evaporation and transpiration effects at the beginning of the vegetation period modify the isotope values of both the melt water and the organic material.

Figure 4 shows a comparison between the regional winter precipitation record (November to February), calculated from single stations, and the modeled precipitation derived from the oxygen isotopes in the tree-rings at BAG low. Both records show strong similarities in the high and lower frequency variations. This is somewhat surprising considering the limited representativeness, particularly for precipitation, of the climate station data for the tree site. Moreover, statistical inhomogeneities of the precipitation measurements result in additional uncertainties. These facts probably are the reason for the differences between both records in several years, especially in the early 1950s. Despite these limitations, this example proves the suitability of oxygen isotopes in tree-rings for precipitation reconstruction in the Karakorum Mountains. Following publications will demonstrate, that this result is true for

ecologically different sites, with a particular focus on one site, where millennia length tree-ring chronologies can be established.

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