The European Isotope Network ISONET: First Results

K. Treydte[1], G.H. Schleser[2], J. Esper[1], L. Andreu[3], T. Bednarz[4], J. Berninger[5], T. Böttger[6], C.D. D‘Allessandro[7], N. Ethien[8], M. Filot[9], D. Frank[1], M. Grabner[10], E. Gutierrez[3], M. Haupt[6], G. Helle[2], H. Jungner[11], M. Kalela-Brundin[11], M. Leuenberger[9], N. Loader[12], V. Masson-Delmotte[7], A. Pazdur[13], O. Planells[3], R. Pukiene[14], C. Reynolds[15], K. Rinne[16], M. Saurer[15], E. Soninen[11], M. Stievenard[7], R. Switsur[16], M. Szczepanek[13], L. Todaro[7], J. Waterhouse[16], M. Weigl[10], R. Wimmer[10]

[1]Federal Research Institute WSL, Zürcher Str. 11, CH-8903 Birmensdorf, Switzerland
[2]Forschungszentrum Jülich GmbH, Leo-Brandt-Str., D-52425 Jülich, Germany
[3]Universitat de Barcelona, Av. Diagonal, 645, 08028 Barcelona, Spain
[4] Agricultural University, 29 Listopada 46 PL-31425 Krakow, Poland
[5]University of Quebec, Montreal,
[6]Umweltforschungszentrum Leipzig-Halle GmbH, Theodor-Lieser-Strasse 4, D-06120 Halle/Saale, Germany
[7]Università della Basilicata, v.le Ateneo Lucano, 10, 85100 Potenza, Italy
[8]Laboratoire des Sciences du Climat et de l'Environnement; L'Orme des Merisiers CEA Saclay; LSCE UMR CEA/CNRS 1572 Bat 709; 91 191 Gif sur Yvette cedex, France
[9]University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland
[10]Universität für Bodenkultur, Gregor-Mendel-Strasse 33, A-1180 Wien, Austria
[11]University of Helsinki, POB11, FIN-00014 Helsinki, Finland
[12]University of Wales, Singleton Park, Swansea, SA2 8PP, United Kingdom
[13]Silesian University of Technology, Boleslawa Krzywoustego 2, 44 –100 Gliwice, Poland
[14]Vytautas Magnus University, Kaunas Botanical Gardens, lab, Kaunas, Lithuania
[15]Paul Scherrer Institut, 5232 Villigen, Switzerland
[16]Anglia Polytechnic University, East Road, Cambridge, CB1 1PT, United Kingdom

Introduction

Within the EU-Project ISONET (co-ordinator: G. Schleser, *http//www.isonet-online.de*), 13 partner institutions collaborate to develop the first large-scale network of stable isotopes (C, O and H), integrating 25 European tree sites reaching from the Iberian Peninsula to Fennoscandia. Key species are oak and pine. The sampling design considers not only ecologically “extreme” sites, with mostly a single climate factor dominating tree growth, as supportive for ring width and wood density analyses (Bräuning & Mantwill 2005; Briffa et al. 2001, 2002; Frank & Esper 2005a, b), but also temperate regions with diffuse climate signals recorded in the ‘traditional’ tree ring parameters.

Within the project we aim to estimate temperature, humidity and precipitation variations with annual resolution, to reconstruct local to European scale climate variability over the last 400 years. Climate variability is addressed on three timescales, namely decade-century, inter-annual and intra-annual. This strategy allows understanding of both, high frequency (high resolution exploration of seasonality signals, and extreme events) and longer-term trends (source water/air mass dominance, baseline variability) in site specific and synoptic climate across Europe. Here we present results from initial network analyses considering first data of carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopes, to evaluate (a) common patterns in these networks and (b) their potential for detailed climate reconstruction beyond the information commonly achieved from ring width and density analyses.

Material and Methods

Oxygen isotopes were measured at 18 sites, and carbon isotope analyses at 21 sites (several data sets provided independent from ISONET), ranging from the Iberian Peninsula to Fennoscandia, as shown in Fig. 1.

Ring widths were measured using a semi-automated RinnTech system with a resolution of 0.01 mm, cross dated, following standard procedures (Fritts 1976). About 4 trees per site (2 cores per tree) were selected for isotope analysis. Criteria for sample selection were low numbers of missing rings and regular ring boundaries. Tree rings were then separated year-by-year using sharp knifes or scalpels. For the majority of sites tree-rings grown in the same year were pooled prior to cellulose extraction to facilitate the development of this large network (Borella et al. 1998; Leavitt & Long 1984; Treydte et al. 2001). Cellulose was extracted following standard procedures (overview in McCarroll & Loader 2004) and burned to CO_2 or pyrolised to CO, respectively, before mass spectrometer analysis (McCarroll & Loader 2004). $\delta^{18}O$ values are expressed as deviations from the VSMOW and $\delta^{13}C$ values to the VPDB standard (Craig 1957).

Carbon isotope records were corrected for the decrease of atmospheric $\delta^{13}C$ values due to fossil fuel burning since the beginning of industrialisation AD 1850 (Friedli et al. 1986; Francey et al. 1999).

Results and Discussion

In a first step, individual site chronologies of all records were calculated over the common period of AD 1913-1994. $\delta^{18}O$ means mirror the patterns of $\delta^{18}O$ values in precipitation, recorded by European GNIP-stations (“Global Network of Isotopes in Precipitation”, IAEA), with distinct gradients from lower to higher latitudes, oceanic to continental regions, and low to high elevation. These patterns are related to evaporation and condensation effects taking place as air masses move from oceanic source regions to higher latitudes, over continental land or from low lands to mountainous regions (Cole et al. 1999; Jouzel et al. 2000; Siegenthaler & Oeschger 1980; Rozanski et al. 1993). Corresponding mean values of the $\delta^{13}C$ chronologies reflect local water supply, which is related to the regional atmospheric moisture distribution (Saurer et al. 1997b; Treydte et al. 2001) (Fig. 1).

Cluster and Principal Component Analyses (PCA) suggest that both $\delta^{18}O$ and $\delta^{13}C$ site chronologies show systematic spatial relationships independent of species, although the inter-site correlations are higher for $\delta^{18}O$ than for $\delta^{13}C$. Clusters are identified in western central, eastern, and southern Europe. The “network extremes“, namely both Mediterranean sites in southern Spain and Italy and the Finnish site do not fit in any clusters, pointing to specific climate and/or site conditions.

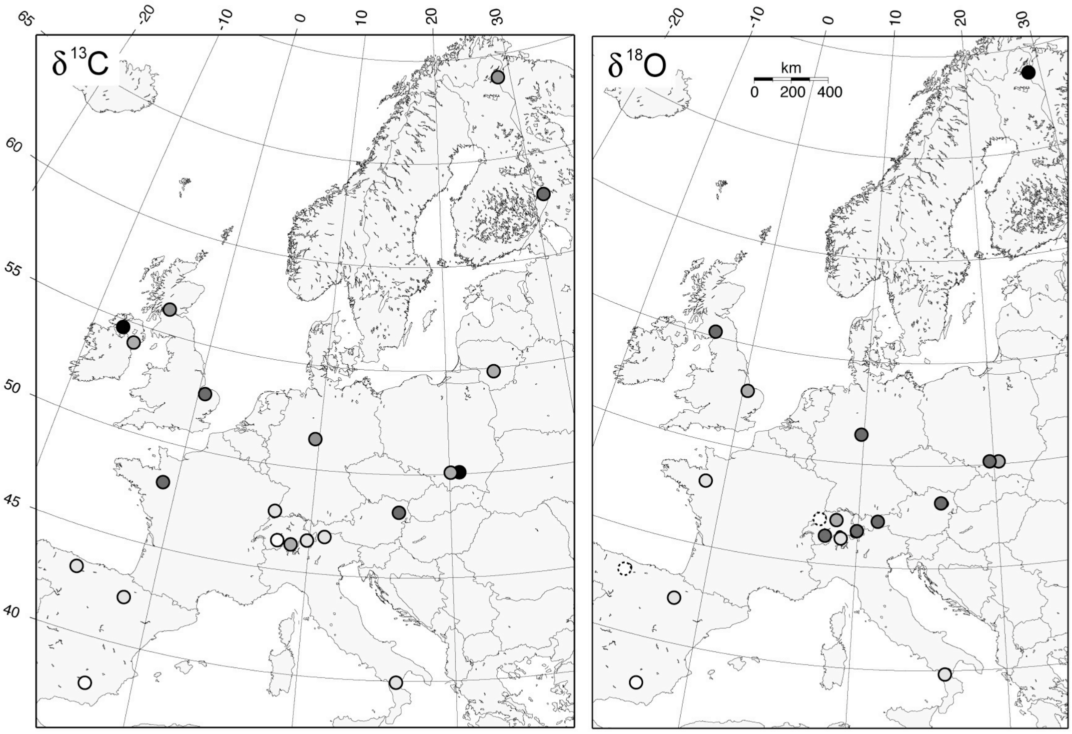
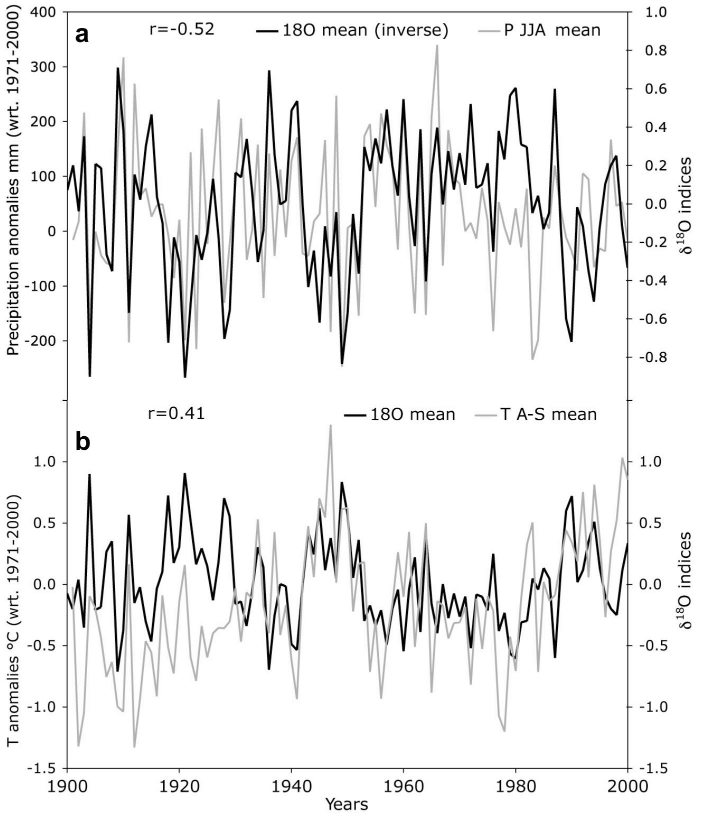


Fig. 1:

Sites used for preliminary network analysis (left: δ^{13}C, right: δ^{18}O). Light colours: high mean isotope values, dark colours: low mean isotope values, dotted signature: no cellulose values over the common period available yet, therefore excluded for comparison of mean values, but used for time series analysis.

Most of the δ^{18}O sites show positive loading on PC1 (again except for the above mentioned sites), pointing to a common signal over the network. In comparison, coherence within the δ^{13}C network is lower, likely resulting from differences in local ecological conditions, which have a greater influence on δ^{13}C than on δ^{18}O patterns (Saurer et al. 1997a; Treydte 2003). Both, PCA and cluster analysis prove the quality particularly of the δ^{18}O network through clear common signals, but also point to potential regionalisation of European climate reconstruction.

Parameter-specific analysis of low-frequency trends, using 200-year splines, suggests heterogeneous long-term behaviour in the oxygen records. In contrast, δ^{13}C long-term trends are rather common over the network pointing to the dominant impact of decreasing atmospheric δ^{13}C values induced by fossil fuel burning since industrialisation (Friedli et al.1986; Francey et al. 1999). Correcting the records for this effect leads to heterogeneous long-term behaviour similar to the oxygen measurements. Differences could either be due to regionally differing low-frequency climatic trends over the study region, from individual age-related long-term biases in the records, local factors or currently unexplainable noise (Treydte 2003; Treydte et al. 2005). However, this finding has to be tested in the future using all records covering the full time span of 200-400 years.



After high-pass filtering from 200-year-splines, the oxygen records in particular reveal significant variance in the inter-decadal frequency domain. This signal seems to be common over the whole network.

The oxygen isotope network was used for initial climate calibration. Based on calculations with a 100-year (1901-2000) monthly European temperature and precipitation 0.5° gridded data set (New et al. 2002), months of significant correlation could be identified.

Fig. 2:
Comparisons between precipitation (a), temperatures (b) and a mean (European) δ^{18}O chronology for the 20th century; The isotope chronology was developed by averaging δ^{18}O measurements from all available sites, the climate records by averaging all corresponding grid point data. P JJA mean is the mean summer precipitation from June to August; T A-S are the mean temperatures from April to September.

At the majority of sites, δ^{18}O correlates positively with temperature and negatively with precipitation variations during the summer months. Averaging the δ^{18}O records of all sites and correlating them with similarly averaged meteorological data, leads to highly significant relationships for June to August precipitation (-0.52) and April to September temperature (0.41). It should be noted, that in some cases the meteorological grid points do not ideally represent local site conditions. This holds particularly for precipitation conditions at high elevation sites, e.g. in Italy. Hence, using local meteorological station instead of grid point data could likely enhance the precipitation signal.

The rather coarse data treatment of averaging all sites and hence ignoring spatial details within the network provides already surprisingly good results. Obviously precipitation variability is mirrored particularly in the short-term (year-to-year) domain (Fig. 2a), whereas temperature variability is fingerprinted particularly in the decadal scale domain (Fig. 2b). Differing temperature and isotope records in the early period (Fig. 2b) could be explained on the one hand through a too stiff de-trending of the isotope records, on the other hand through decreasing data replication in the instrumental records (Büntgen et al. 2005, this volume).

Initial comparisons of the mean carbon and oxygen isotope chronologies averaged over the whole network (Fig. 3a) indicate significant correlation between these parameters (0.53 for the 20th century). This relationship seems to appear mainly between high-frequency variations, whereas on decadal scales some differences exist. Correlations between the first principal components of the carbon and oxygen data improve this relationship to 0.58.

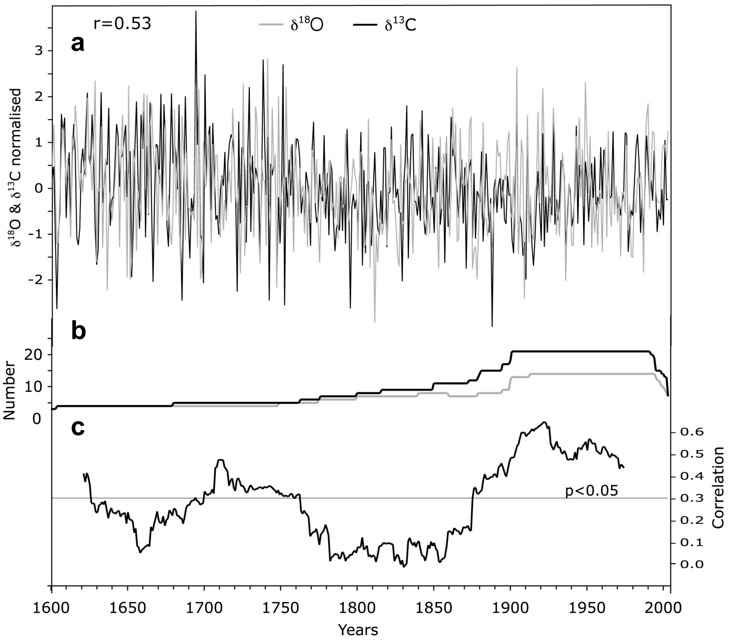


Fig. 3:
Relationship between the "European" δ^{18}O and δ^{13}C chronologies; Site data are de-trended using 200-year splines (a). The records correlate at 0.53. (b) Replication of the chronologies, and (c) moving correlation using 30-year time windows.

Moving correlations over a 30-year time window (Fig. 3c) indicate strongest relationships in the 20th century, being the period with highest replication (Fig. 3b).

High-frequency similarity between carbon and oxygen data is explained through variations in stomatal conductance, influencing the behaviour of both isotopes, due to the combined effect of varying temperature and precipitation conditions, which themselves are inter-correlated. Low stomatal conductance during dry/warm weather conditions causes high δ^{13}C values through weak discrimination against ^{13}C. Nevertheless transpiration increases compared to cool/wet conditions, resulting in higher leaf water enrichment and thus in higher δ^{18}O values (Anderson et al. 1998, 2002; Farquhar & Lloyd 1993; Leuenberger et al. 1998; Masson-Delmotte et al. 2005; Rafalli-Delerce et al. 2004; Roden et al. 2000; Treydte 2003; Treydte et al. 2004). Hence, both parameters should be mainly driven by summer moisture conditions.

Conclusion and Outlook

Preliminary tree ring δ^{13}C and δ^{18}O network analyses integrating data from about 20 European sites clearly demonstrate the potential for detailed European climate reconstructions over the last 400 years. Isotope datasets from temperate sites in Central Europe contain species-independent common signals, which enable to spatially extend climate reconstruction from tree rings which at present are mainly limited to "extreme" sites. Common signal strength on annual to multi-decadal timescales is higher in the oxygen isotope than in the carbon isotope network, pointing to a stronger external forcing. Nevertheless, the comparison of "European" δ^{13}C and δ^{18}O chronologies after averaging all sites indicates significant similarities on annual to decadal scales. We hypothesise that both parameters are mainly driven through summer moisture availability.

Centennial scale variation is, however, not yet understood in δ^{13}C and δ^{18}O data. Besides the incompleteness of the current data, sets regionally differing synoptic conditions, age-related biases, and varying plant physiological reactions on changing atmospheric CO_2 concentrations could account for heterogeneities in the long-term behaviour between sites.

Further investigations will be based on the use of complete and extended isotope datasets from all sites, covering the full period of 400 years where possible. Detailed wavelength analyses by separating the datasets into different timescales (high frequency, decadal, secular) will be employed to analyse the climate signal in tree ring data and to differentiate potential age- and site-related and anthropogenic noise from climate signals.

Consideration of additional meteorological data such as vapour pressure, sunny hours, cloudiness, and particularly drought indices will be utilized to test the environmental information in the isotope records. Together with large-scale surface pressure data sets, such as NAO, and comparisons with new European temperature reconstructions (e.g. Luterbacher et al. 2004), detailed knowledge about European climate variation over the past few centuries will be derived.

Acknowledgements

Supported by the European Union, EVK2-CT-2002-00147 (ISONET).

References

Anderson, W.T., Bernasconi, S.M., McKenzie, J.A. (1998): Oxygen and carbon isotopic record of climate variability in tree-ring cellulose (*Picea abies*): an example from central Switzerland. *Journal of Geophysical Research 103*: 31625-31636.

Anderson, W.T., Bernasconi, S.M., McKenzie, J.A., Saurer, M. & Schweingruber, F.H. (2002): Model evaluation for reconstructing the oxygen isotopic composition in precipitation from tree ring cellulose over the last century. *Chemical Geology 182*: 121-137.

Borella, S., Leuenberger, M., Saurer, M., Siegwolf, R. (1998): Reducing uncertainties in $\delta^{13}C$ analysis of tree rings – pooling, milling and cellulose extraction. *Journal of Geophysical Research 103*: 19519-19526.

Bräuning, A., Mantwill, B. (2005): Summer temperature and summer monsoon history on the Tibetan Plateau during the last 400 years recorded by tree-rings. *Geophysical Research Letters 32*, doi:10.1029/2004GL020793.

Briffa, K.R., Osborn, T.J., Schweingruber, F.H., Harris, I.C,. Jones, P.D., Shiyatov, S.G., Vaganov, E.A. (2001): Low-frequency temperature variations from a northern tree ring density network. *Journal of Geophysical Research 106*: 2929-2941.

Briffa, K.R., Osborn, T.J., Schweingruber, F.H., Jones, P.D., Shiyatov, S.G., Vaganov, E.A. (2002): Tree-ring width and density data around the Northern Hemisphere – part 2, spatio-temporal variability and associated climate patterns. *The Holocene 12*: 759-789.

Büntgen, U., Esper, J., Frank, D. C., Böhm, R. (2005): Influence of instrumental data on reconstructed Alpine temperature amplitudes. *TRACE, this volume*.

Cole, J.E., Rind, D., Webb, R.S., Jouzel, J. & Healy, R. (1999): Climatic controls on interannual variability of precipitation $\delta^{18}O$: Simulated influence of temperature, precipitation amount, and water source region. *Journal of Geophysical Research 104*: 14223-14235.

Craig, H. (1957): Isotopic standards for carbon and oxygen and correction factors for mass-spectrometric analysis of carbon dioxide. Geochimica et Cosmochimica Acta 12:133-149.

Farquhar, G.D. & Lloyd, J. (1993): Carbon and oxygen isotope effects in the exchange of carbon dioxide between terrestrial plants and the atmosphere. In: Ehleringer, J.R., Hall, A.E. & Farquhar, G.D. (Eds.): Stable Isotopes and Plant Carbon Water Relations. Academic, San Diego, California: 47-70.

Francey, R.J., Allison, C.E., Etheridge, D.M., Trudinger, C.M., Enting, I.G., Leuenberger, M.C., Langenfelds, R.L., Michel, E., Steele, L.P. (1999): A 100-year high precision record of $\delta^{13}C$ in atmospheric CO_2. *Tellus 51B*: 170-193.

Friedli, H., Lötscher, H., Siegenthaler, U., Stauffer, B. (1986): Ice core record of the $^{13}C/^{12}C$ ratio of atmospheric CO_2 in the past two centuries. *Nature 324*: 237-238.

Frank, D., Esper, J. (2005a): Characterization and climate response patterns of a high-elevation, multi-species tree-ring network in the European Alps. *Dendrochronologia 22:* 107-121.

Frank, D., Esper, J. (2005b): Temperature reconstructions and comparisons with instrumental data from a tree-ring network for the European Alps. *International Journal of Climatology*, in press.

Fritts, H.C. (1976): Tree rings and climate. New York: Academic Press, 567 S.

IAEA/WMO (2004). Global Network of Isotopes in Precipitation. The GNIP Database. Accessible at: http://isohis.iaea.org.

Jouzel, J., Hoffmann, G., Koster, R.D., Masson, V. (2000): Water isotopes in precipitation: data/model comparison for present-day and past climates. *Quaternary Science Reviews 19*: 363-379.

Leavitt, S.W., Long, A. (1984): Sampling strategy for stable carbon isotope analysis of tree rings in pine. *Nature 311*: 145-147.

Leuenberger, M, Borella, S., Stocker, T., Saurer, M., Siegwolf, R., Schweingruber, F.H., Matyssek, R. (1998): Stable isotopes in tree rings as stress indicators. vdf Hochschulverlag Zürich. 200 S.

Luterbacher, J., Dietrich, D., Xoplaki, E., Grosjean, M., Wanner, H. (2004): European seasonal and annual temperature variability, trends, and extremes since 1500. *Science 303*: 1499-1503.

Masson-Delmotte, V., Raffalli-Delerce, G., Danis, P. A., Yiou, P., Stievenard, M., Guibal, F., Mestre, O., Bernard, V., Goose, H., Hoffmann, G., Jouzel, J. (2005): Changes in European precipitation seasonality and in drought frequencies revealed by a four-century-long tree-ring isotopic record from Brittany, France. *Climate Dynamics 24*: 57-69.

McCarroll, D., Loader, N.J. (2004): Stable isotopes in tree rings. *Quaternary Science Reviews 23*: 771-801.

New, M., Lister, D., Hulme, M. and Makin, I. (2002): A high-resolution data set of surface climate over global land areas. *Climate Research 21*: 1-25.

Rafalli-Delerce, G., Masson-Delmotte, V., Dupouey, J. L., Stievenard, M., Breda, M., Moisselin, M. (2004): Reconstruction of summer droughts using tree-ring cellulose isotopes: a calibration study with living oaks from Brittany (western France). *Tellus 56B*: 160-174.

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

Rozanski, K., Araguas-Araguas, L. & Gonfiantini, R. (1993): Isotopic patterns in modern global precipitation. In: Swart KLLPK, McKenzie, J., Savin, S. (eds.): Climate change in continental isotopic records. AGU *Geophysical Monograph*: 1-37.

Saurer, M., Aellen, K. & Siegwolf, R. (1997a): Correlating $\delta^{13}C$ and $\delta^{18}O$ in cellulose of trees. *Plant, Cell and Environment 20*: 1543-1550.

Saurer, M., Borella, S., Schweingruber, F.H., Siegwolf, R. (1997b): Stable carbon isotopes in tree rings of beech: climatic versus site-related influences. *Trees 11*: 291-297.

Siegenthaler, U. & Oeschger, H. (1980): Correlation of ^{18}O in precipitation with temperature and altitude. *Nature 285*: 314-317.

Treydte, K., Schleser, G.H., Helle, G., Winiger, M., Frank, D., Haug, G., Esper, J. (2005): 20th-century precipitation maximum in western High Asia from 1000 years of tree-ring $\delta^{18}O$. *Nature,* in review.

Treydte, K. (2003): Dendro-Isotope und Jahrringbreiten als Klimaproxis der letzten 1200 Jahre im Karakorumgebirge/Pakistan. Schriften des Forschungszentrums Jülich, Reihe Umwelt/Environment 38, 190 S.

Treydte, K., Schleser, G.H., Schweingruber, F.H., Winiger, M. (2001): The climatic significance of $\delta^{13}C$ in subalpine spruce (Lötschental, Swiss Alps) – a case study with respect to altitude, exposure and soil moisture. *Tellus 53*: 593-611.

Treydte, K., Welscher, C., Schleser, G.H., Helle, G., Esper, J., Frank, D., Büntgen, U. (2004): The climatic signal in oxygen isotopes of junipers at the lower timberline in the Karakorum, Pakistan. *TRACE 2*: 100-106.