Climate signals in the European isotope network ISONET

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Introduction

Over the last three years, 16 European isotope labs collaborated in the EU project ISONET (co-ordinator: G. Schleser, http//www.isonet-online.de) on developing the first large-scale network of $\delta^{13}C$, $\delta^{18}O$ and $\delta^{2}H$ in from oak, pine and cedar tree-rings, covering sites from Fennoscandia to the Mediterranean region. The sampling design considered not only ecologically "extreme" sites, with a single climate factor predominantly determining tree growth, as required 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. This strategy, however, may enable expanding climatic reconstructions into regions not yet well covered. As reported earlier (Treydte et al. 2005), the aim is 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 intra-annual to century timescales. This strategy should allow understanding both, high frequency variations including the exploration of seasonality signals and extreme events, and longer-term trends including source water/air mass changes and baseline variability across Europe.

Here we present first climate calibration results for the 20th century, using $\delta^{13}C$ and $\delta^{18}O$ data from up to 25 sites currently available in the network. We discuss (i) relationships of each parameter to summer conditions expressed by maximum temperatures, precipitation and drought, (ii) strength of the climate signal within the networks and (iii) similarities/differences of climate response between the networks. Finally we provide some ideas for further investigations of this unique dataset to fully exploit its potential for detailed European climate reconstruction beyond the information commonly achieved from ring width and density analyses.

Material and Methods

At every site ring widths were measured using a semi-automated RinnTech system with 0.01 mm resolution and cross dated following standard procedures (Fritts 1976). Four trees per site (two 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 oak only late-wood was considered). 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 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 as deviations from the VPDB standard (Craig 1957). For determination of deuterium/hydrogen (D/H) ratios of nonexchangeable hydrogen in cellulose an improved on-line method has been developed (Filot et al. 2006) based on the equilibration reaction of hydroxyl hydrogen of cellulose and water vapour of known isotopic composition (Feng et al. 1993, Schimmelmann 1991, Wassenaar et al. 2000). The equilibrated cellulose is pyrolysed and the total D/H ratio determined by subsequent online IRMS. With a mass balance system the D/H ratio of nonexchangeable hydrogen is recalculated and expressed as deviation from the VSMOW standard after an empirical calibration has been performed (Filot et al. 2006). Climate calibration of the $\delta^{2}H$ network will be published separately.

25 sites of the network - ranging from northern Sweden to Marocco (Fig. 1) - have been considered in this study, with 24 containing C and O isotope data, and two sites only either C or O isotope data respectively (Tab. 1).

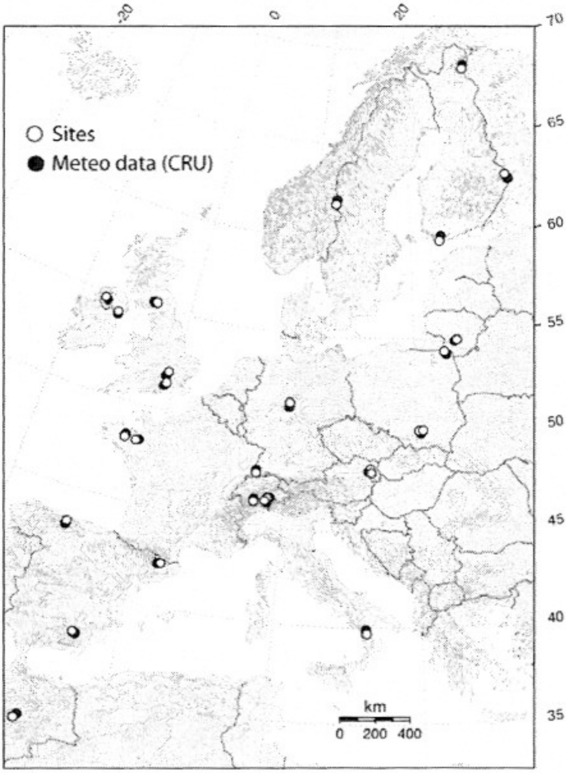


Figure 1: Tree sites and corresponding grid cells with meteorological data (0.5° x 0.5° CRU grids; Mitchell and Jones 2005; van der Schrier et al. 2006) considered in this study

Table 1: Sites, species and isotope data used in this study

Country	Site	Code	Coordinates	Altitude (m asl)	Species	$\delta^{13}C$	$\delta^{18}O$
Austria	Lainzer Tiergarten	**Lai**	16.20, 48.18	300	*Quercus petrea*	x	x
Austria	Poellau	**Poe**	16.06, 47.95	500	*Pinus nigra*	x	x
Finland	Bromarv	**Bro**	23.08, 60.00	5	*Quercus robur*	x	x
Finland	Sivakkovaara, Ilomantsi	**Ilo**	30.98, 62.98	200	*Pinus sylvestris*	x	x
Finland	Kessi, Inari	**Ina**	28.42, 68.93	150	*Pinus sylvestris*	x	x
France	Fontainebleau	**Fon**	-2.67, 48.38	100	*Quercus petrea*	x	x
France	Rennes	**Ren**	-1.70, 48.25	100	*Quercus robur*	x	x
Germany	Dransfeld	**Dra**	9.78, 51.50	320	*Quercus petrea*	x	x
Germany	Hardwald	**Har**	7.33, 47.78	240	*Quercus petrea*	x	
Italy	Monte Polino	**Mon**	16.20, 39.93	1900	*Pinus leucodermis*	x	x
Lithuiana	Panemunes Silas	**Pan**	23.97, 54.88	45	*Pinus sylvestris*	x	x
Marocco	Col Du Zad	**Col**	-5.07, 32.97	2200	*Cedrus atlantica*	x	x
Norway	Gutuli	**Gut**	12.18, 62.00	800	*Pinus sylvestris*	x	x
Poland	Niepolomice, Gibiel	**Nie1**	20.38, 50.12	190	*Quercus robur*	x	x
Poland	Niepolomice, Gibiel	**Nie2**	20.38, 50.12	190	*Pinus sylvestris*	x	x
Poland	Suwalki	**Suw**	22.93, 54.10	160	*Pinus sylvestris*	x	x
Scotland	Lochwood	**Lch**	-3.43, 55.27	175	*Quercus robur*		x
Spain	Sierra de Cazorla	**Caz**	-2.96, 37.81	1820	*Pinus nigra*	x	x
Spain	Pinar de Lillo	**Lil**	-5.25, 43.07	1600	*Pinus sylvestris*	x	x
Spain	Massis del Pedraforca	**Ped**	1.70, 42.24	2120	*Pinus uncinata*	x	x
Switzerland	Cavergno	**Cav**	8.60, 46.35	900	*Quercus petrea*	x	x
Switzerland	Lötschental	**Löt**	7.78, 46.40	1900	*Pinus sylvestris*	x	x
Switzerland	Vigera	**Vig**	8.77, 46.50	1400	*Pinus sylvestris*	x	x
United Kingdom	Windsor	**Win**	-0.59, 51.41	10	*Pinus sylvestris*	x	x
United Kingdom	Woburn	**Wob**	-0.59, 51.98	50	*Quercus robur*	x	x

Common period of overlap is a 98-year time window ranging from 1901 to 1998, except the Lötschental site (Swiss Alps) covering only 50 years (AD 1946-1995). Nevertheless we included it in the analyses, since it is one of only few sites that represents alpine tree line conditions (Treydte et al. 2001, Neuwirth et al. 2004).

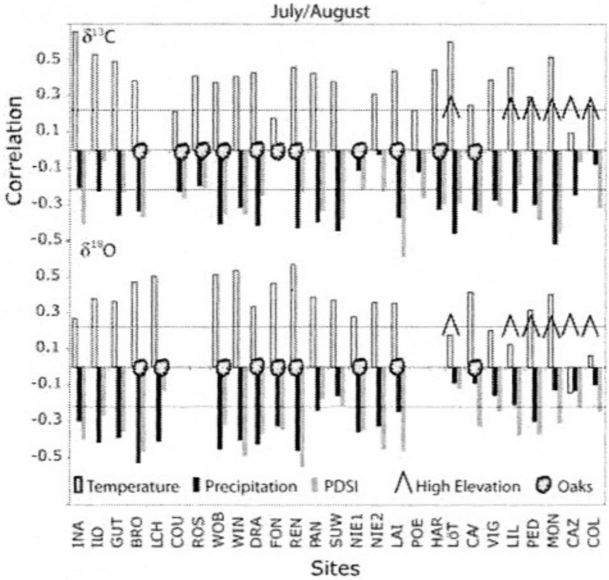
Pearson's correlation coefficients between isotope ratios and climate variables were calculated using an updated version of the 0.5° x 0.5° gridded meteorological data set TS 2.1 of the *C*limate *R*esearch *U*nit (CRU, Norwich/UK), providing homogenized monthly data for the full 20th century (1901-2002) (Mitchell & Jones 2005). For this study we considered mean, minimum and maximum temperatures, precipitation, wet day frequencies and vapour pressure, but present only results from the two variables leading to highest correlations, namely maximum temperatures and precipitation. Moreover we used a newly developed European 0.5° x 0.5° grid of monthly resolved Palmer Drought Severity Index data (PDSI) which is available for the same period (van der Schrier et al. 2006, Wells et al. 2004). At every site, the closest grid cell was chosen and in cases of similar distance to the site, all relevant grid cells were tested and finally the one providing best results was used. It should be noted that in some cases correlations using single meteo station records reveal higher correlation values, as it is for example the case at the Spanish site Pedraforca (Planells et al. 2005), since artificial grid cells might sometimes not ideally represent local site conditions. To achieve, however, best homogeneity in terms of data use and treatment when running analyses over the whole network, we accept single cases of lower correlation as long as they do not contradict site internal results.

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). Assuming that similar, non-climatic biases are absent in oxygen and hydrogen isotope records at least during the 20th century calibration period, we here present correlation results based on raw data only, without any correction or detrending.

Results

Correlation calculations based on monthly data from March of the previous to October of the current year revealed no systematic and significant impact of previous year climate conditions on the fixation of either carbon or oxygen isotopes in tree-rings (without figure). This finding was somewhat expected for oak species, where isotope ratios were measured from late wood cellulose only. However, the observation also holds for pine species and therefore contradicts hypotheses on memory effects in conifers, where cellulose of whole tree rings was measured, with the early wood potentially containing remobilized reserves built up under previous year late summer conditions (Helle et al. 2004).

Generally, strongest response of all isotope parameters was found to current year summer conditions, with highest correlations from June or July to August. Figure 2 shows the strength of the relationships on a site basis for combined July/August mean maximum temperatures, precipitation sums and PDSI indices. Despite the broad range of ecological conditions in the network, nearly all sites respond in a similar way, with positive relationships to temperature and negative relationships to precipitation and PDSI, respectively. Signals are not only robust between sites (although in some cases not reaching significance) but also between isotope parameters, with only one exception: δ^{18}O-temperature Caz. Both networks show strong similarities in their correlation coefficients' signs as well as in the strength of the relationships, suggesting common forcing of isotope fixation. This is confirmed through mean and maximum correlation values given in the table of figure 2.



	Tmax	P	PDSI
13C-mean	0.36	-0.29	-0.29
13C-max	0.66	-0.52	-0.59
18O-mean	0.32	-0.28	-0.33
18O-max	0.57	-0.53	-0.55

Figure 2: Correlation between carbon and oxygen isotope ratios and climate variables, using CRU 0.5° x 0.5° gridded data, namely mean maximum temperatures, precipitation sums and PDSI indices for combined July/August conditions, with lines representing 99% signifcance levels. Mean (averaged over all sites) and highest (max) correlation values per network are given in the table.

Overall correlation to temperatures is slightly higher for δ^{13}C than for δ^{18}O (0.36 versus 0.32), whereas the latter shows slightly higher absolute values concerning drought (-0.29 versus -0.33). Correlations with precipitation sums are a similar (-0.29 versus -0.28). Although these averaged correlation values are not extraordinarily high (but nevertheless strongly significant), they highlight the potential of increasing the strength of the climatic signals when averaging several site datasets to regional records. This was demonstrated earlier with a rather coarse data treatment for the oxygen isotope network: Averaging all site records and correlating them with similarly averaged meteorological data, increased strength of the correlations for June-August precipitation to -0.52 and April-September temperature to 0.41, indicating the potential for regionalized European climate reconstructions (Treydte et al. 2005).

More detailed site-by-site analyses did not reveal systematic differences between signal strength of C and O iosotope ratios, neither on latitudinal nor on altitudinal or species-specific scales. Therefore, closer correlations of one or another isotope parameter seem to largely depend on local site ecological conditions.

Discussion

Despite the fact of different fractionation processes driving the fixation of C and O isotopes in tree rings, since carbon and water uptake rely on independent sources (atmospheric CO_2 versus soil water), strong similarities in the response of $\delta^{13}C$ and $\delta^{18}O$ networks to summer climate conditions are found. Carbon isotope ratios depend on diffusion and biochemical processes during photosynthetic CO_2 assimilation, with fractionation effects occurring on the way of carbon dioxide diffusion into the stomata and during carbon fixation processes at the enzyme Rubisco. High $\delta^{13}C$ values therefore reflect low CO_2 concentration in the leaf intercellulars (depending on low stomatal conductance e.g. related to drought stress) and/or high photosynthetic rates (related to temperature and photon flux), or some combination of both (McCarroll & Pawellek 2001).

In contrast, $\delta^{18}O$ (and also $\delta^{2}H$) values largely depend on the isotope ratio of soil water, which itself is related to the isotope composition of rain water, residence time in the soil, evaporation effects and of leaf water enrichment due to evapo-transpiration through the stomata (Yakir & Sternberg 2000), strongly biasing the original source water signal. On the way down from the leaves, 40-50% of sugar bound oxygen atoms transported in the phloem undergo isotope exchange with xylem water ascending from the roots, which carries the original source water signal (Hill et al. 1995).

Earlier network analyses based on a rather coarse data treatment by averaging site C and O isotope chronologies over the whole network already indicated significant correlation between both parameters of 0.53 for the 20th century (Treydte et al. 2005). Correlations between the first principal components of both data sets even increased this relationship to 0.58, confirming single site investigations, which report significant d13C-d18O relationships as well (Planells et al. 2005; 2006, Rafalli-Delerce et al. 2004, Saurer et al. 1997). Results presented here allow a view beyond these relationships, by shedding light on the common site response to climate. Processes described above allow for the statement, that both isotope parameters are linked through the explained effects on the leaf level, namely variation in stomatal conductance 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 $\delta^{13}C$ 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 $\delta^{18}O$ 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, particularly under temperate conditions both parameters are mainly driven by summer moisture conditions, in this study expressed through strong positive correlations to temperature and negative correlations to precipitation, which in most cases are in a similar range. Although not at all sites leading to the highest absolute correlation values, we believe the ecologically integrating PDSI expressing drought to represent best the general climatic-ecological control on the networks – at least in the higher frequencies. It has to be noted that calculations of this study were based on raw values only. Taking into account the possibility of long-term effects of an atmospheric CO_2 increase as well as biological trends (Treydte et al. 2001, 2006), these results could still change if potential age-related biases, variable physiological response (e.g. reduction of stomatal conductance) to increasing CO_2 depending on differing site conditions, or currently unexplainable noise are removed from the records (Treydte 2003, Treydte et al. 2005). Therefore further tests on the networks' climate sensitivity need to be based on high and low pass filtered data respectively, which also should enable a regionalization of climate response patterns.

Conclusion and Outlook

First climate correlation results of the European isotope network ISONET, calculated on a site-by-site basis, indicate that trees not growing at their ecological distribution boundaries, record significant climate information and hence enable to spatially extend climate reconstruction from tree rings in temperate regions. These findings confirm an earlier hypothesis that isotope parameters of the European network ISONET are mainly driven through summer moisture availability. This is crucial for future reconstruction efforts, since currently detailed tree-ring reconstructions of precipitation or drought are lacking for temperate regions. Moreover, there is still no clear evidence for species-specific climate response in the network, what proves the potential of combining all species for a well-replicated and robust regional to European scale climate reconstruction. Further calibration tests will include combined $\delta^{13}C$ and $\delta^{18}O$ series with the aim to reduce the non-climatic noise contained in these records, possibly favouring the common climatic variability. This was recently shown by Planells et al. (2006), who found that a combination of both reveals the best proxy record to reconstruct summer climate, namely aridity, at an alpine *Pinus uncinata* site in the Spanish Pyrenees. Band-pass filtering based on complete and extended isotope datasets from all sites, covering the full period of 400 years where possible will be employed by separating the datasets into different timescales (high frequency, decadal, secular). This will enable better understanding particularly of centennial scale variations, which currently seem to be heterogenous over the networks. Possible reasons include the incompleteness of the current datasets, regionally differing synoptic conditions, age-related biases, and varying plant physiological reactions on changing atmospheric CO_2 concentrations.

Comparisons with European datasets of the IAEA Global Network of Isotopes in Precipitation (GNIP) (Jouzel et al. 2000, Rozanski et al. 1993), large-scale surface pressure data sets such as NAO, and with new European temperature reconstructions (e.g., Luterbacher et al. 2004) should provide detailed knowledge about European climate variation over the past few centuries.

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