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Reaction of siberian subarctic larch trees to abrupt climatic changes derived from tree-ring and isotope data

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Introduction

The Siberian Subarctic region is highly interesting for the investigation of climatic and environmental changes because of its sensitivity to climate change [Vaganov and Shiyatov 1999; Körner 2000; IPCC 2007]. The application of long-term tree-ring chronologies (a natural archive for studies of climatic changes) can help us to evaluate climatic and environmental changes in the past and to understand the mechanisms of these changes. Stable isotopes in tree rings provide an additional proxy for paleoclimate with a defined annual resolution [Leng 2006].

It is well known that volcanic eruptions play an important role in climatic changes. Major volcanic eruptions eject particles and aerosols into the stratosphere leading to global cooling for up to several years due to a decrease in incoming solar radiation [Robock 2000; Zielinski 2000]. Recently, many reports about the influence of volcanic eruptions on tree ring width have been published [Baillie 1994; Briffa et al. 1998; Zielinski 2000; D'Arrigo 2001; Krakauer and Randerson 2003]. Only few studies were carried out to analyze the isotopic composition in trees in response to volcanic eruptions [Battipaglia et al. 2007] but none for the high latitudes of Eurasia.

A prominent example is the "dust-veil" event (AD 536) [Baillie, 1994], which had a catastrophic effect on the environment and civilization. Many scientists tried to explain this event [Baillie 1994; Zielinski et al. 1994; Briffa et al. 1998; Stothers 1999]. One hypothesis is that dry fogs spawned by large volcanic eruptions cooled the climate during that time by partially blocking incident sunlight and perturbed the atmospheric circulation patterns. The climatic and epidemiological consequences of seven intense volcanic dry fogs of the past 21 centuries, detected in Europe and the Middle East, were investigated using historical reports, supplemented by tree-ring data and polar-ice acidity measurements. An alternative hypothesis suggests that cosmic phenomena (asteroid or comet) could have caused the strong climatic changes during this time [Rigby et al. 2004]. European chronologies showed a decreasing radial growth during 10 years after the AD 536 event [Baillie 1994; Stothers, 1999].

The goal of this paper is to reveal the reaction of larch trees from the Siberian Subarctic (Eastern Taimyr) after the abrupt climatic change in AD 536, an event, which was characterized by cooling throughout the vast territory of Subarctic Eurasia. Tree rings and isotopic data ($\delta^{13}C$, $\delta^{18}O$) were examined for a better understanding of physiological responses of trees to climatic and environmental changes.

Material and Methods

The investigation was carried out in the Siberian Subarctic - in Eastern Taimyr (72N-102E). This region is characterized by an extra continental climate, short vegetation periods (32-65 days), a growth limiting temperature regime, low amount of precipitation (300 mm) and permafrost. A well-replicated chronology based on ring-width measurements is available for the period BC 431 - AD 2006 [Naurzbaev et al., 2002, Sidorova et al., 2003, 2007 in preparation]. The June-July air temperature reconstruction was available from AD 1-1996 [Naurzbaev et al., 2002; Sidorova, 2003].

For the isotope analyses we chose four stem discs from dead larch trees (*Larix gmelinii* Rupr.) for the period AD 516-560 (20 years before and 24 years after the event of AD 536). Resins were extracted from wood samples in ethanol for 36 hours in a Soxhlet apparatus and then the samples were washed in distilled water and dried [Cook et al., 1990]. All samples were first measured and cross-dated according to standard dendrochronological procedures [Cook et al. 1990]. The age of these trees was 350 years excluding the influence of the "juvenile effect" [Cook et al. 1990; McCarrol and Loader 2004]. The samples were split into individual years for all analyzed trees. Sample preparations for the isotope analysis and cellulose extraction were carried out according to standard procedures described by Loader et al. [1997].
The measurement of the stable isotope ratios of $\delta^{13}C$ and $\delta^{18}O$ of cellulose was carried out by a mass-spectrometer Delta Plus XL (Thermo Quest Finnigan, Germany) at the Helmholz Centre for Environmental Research - UFZ, laboratory of Isotope Hydrology and at the Paul Scherrer Institute (PSI), Laboratory of Atmospheric Chemistry, Stable Isotope and Ecosystem Fluxes.
The $\delta^{13}C$ and $\delta^{18}O$ of wood and cellulose were expressed in the delta notation:

$$\delta_{sample} = (R_{sample}/R_{standard}-1) \times 1000$$

where R is the $^{13}C/^{12}C$, or the $^{18}O/^{16}O$ ratio of the sample and standard (VPDB for carbon, VSMOW for oxygen), respectively.

Results and Discussion

The dendrochronological analyses revealed decreased tree radial growth (Fig. 1) and decreased June-July air temperature of up to 3.2°C for 23 years after AD 536, which testifies to exceptional conditions. Continuous cooling over a 23 year period could result in very negative or even catastrophic effects on the environment and civilization).
As mentioned before, this signal in European chronologies was observed for a shorter period emphasizing the climatic sensitivity of the study area.

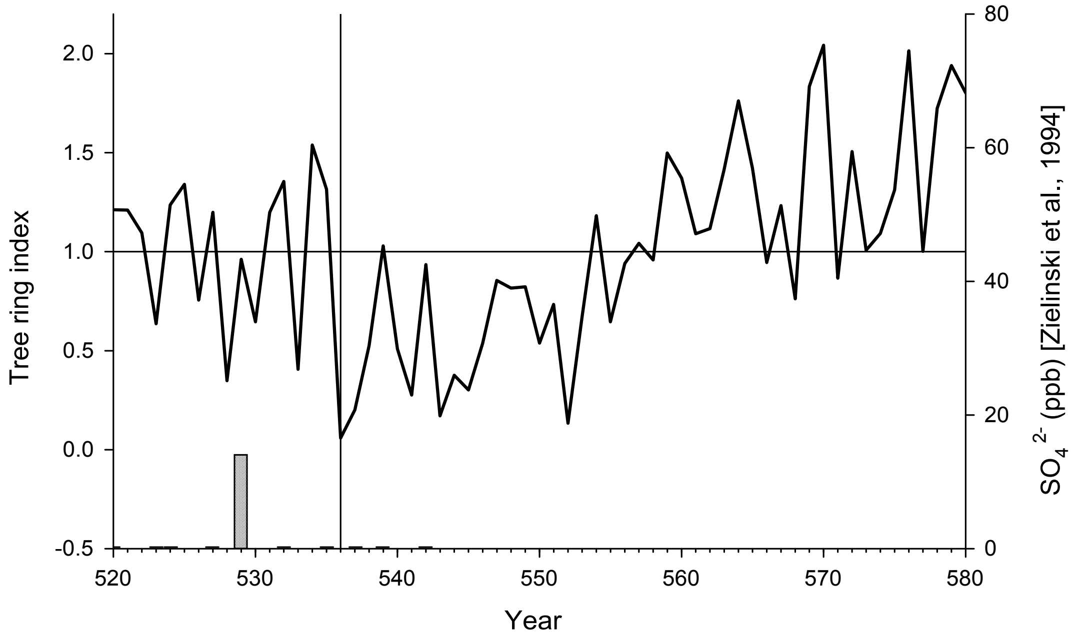

Figure 1: Reaction of larch trees from eastern Taimyr to the event AD 536 reflected in tree ring growth.

We established an isotope chronology for $\delta^{13}C$ and $\delta^{18}O$ in cellulose of four individual trees for the period AD 516-560. The correlation coefficients between the four different trees were very high for carbon ($r=0.8$; $p<0.05$) and somewhat lower for oxygen ($r=0.6$; $p<0.05$).

The δ^{13}C and δ^{18}O-data of cellulose confirmed the occurrence of a stress factor during the period from AD 535-560, similar to tree-ring width, showing decreasing isotope values (Fig. 2 a b).

We observed the highest correlation coefficient (r=0.62; p<0.05) for the relationship between δ^{13}C of cellulose and the reconstructed June-July air temperature. This relationship was not as strong for δ^{18}O of cellulose (r=0.42; p<0.05). The isotope values reflect not only temperature changes like tree ring width, but also reflect the influence of relative humidity during this time.

Regression analysis between carbon and oxygen isotope ratios for the Eastern Taimyr shows a significant relationship (r=0.70; p<0.05) that indicates a combined effect of temperature and relative humidity after such a strong event.

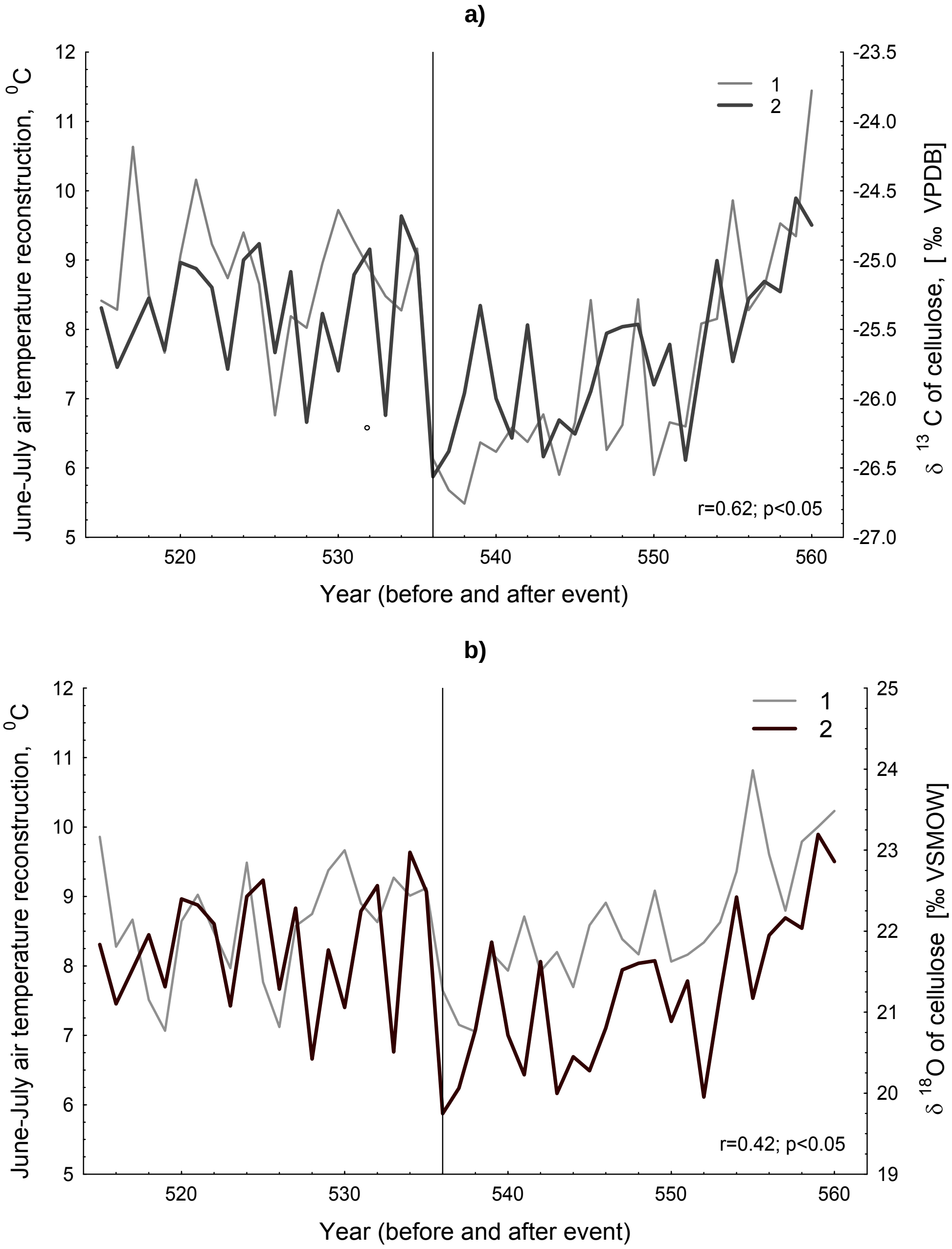

Figure 2: The δ^{13}C (a), δ^{18}O (b) of cellulose (1) and June-July air temperature reconstruction (2) *in comparison.*

Conclusions

The isotope values $\delta^{13}C$, $\delta^{18}O$ of cellulose confirm the information stored in tree-ring width and show decreasing isotope values during the same period when growth was reduced after the major event of AD 536 (we assume major volcanic eruption). These results indicate an increase of relative humidity, which could have led to higher stomatal conductance and lower photosynthetic capacity due to a reduction of solar radiation and subsequent temperature decrease. The combination of isotope and ring-width data provide strong data base from which we can learn more about the effect of the drastic AD 536 event on the Boreal forest ecosystems.

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