Short communication

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Diatom oxygen isotope records of Northern Eurasia as indicators of environmental, hydrological and climate changes in the regions

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ABSTRACT. The environmental, hydrological and climate dynamics were assessed in Northern Eurasia during the Holocene. The reconstructions are based on oxygen isotope composition of lacustrine diatom silica ($\delta^{18}O_{diatom}$) preserved in sediment cores from Ladoga, Bolshoye Shchuchye and Emanda lakes. Interpretation of the $\delta^{18}O_{diatom}$ data is supported by a comprehensive study of modern isotope hydrology and analysis of local and regional proxies. The Northern Eurasia $\delta^{18}O_{diatom}$ records are characterized by pronounced short term variations (1.5–5‰), pointing to the unstable climatic and hydrological conditions in the study regions. All records have clearly demonstrated a gradual depletion over the Holocene in their $\delta^{18}O_{diatom}$ values by ~3–4‰, which follows the trend of decreasing summer insolation, as well as the temperature history of the Northern Hemisphere (NH), indicating a positive response of diatom oxygen isotope signal to large-scale climate changes.

Keywords: stable oxygen isotopes, hydrological fluctuations, diatoms, climate change, lake sediments

1. Introduction

Lacustrine sediments are reliable archives, providing fundamental information on environmental and climate changes since the formation of a lake system (e.g. Subetto et al., 2017). In the last decades, diatom oxygen isotope analysis has become a dependable tool to trace hydrological and climate dynamics in individual lake catchments. Generally related to lake temperature (T_{lake}) and water isotope variations ($\delta^{18}O_{lake}$), $\delta^{18}O_{diatom}$ perfectly reflects these changes and is commonly applied in palaeoenvironmental and/or climatic reconstructions especially for northern regions where ice archives are unavailable and/or biogenic carbonates limited (e.g. Swann and Leng, 2009).

In the current study, the environmental, hydrological and climatic variability was reconstructed from sediment cores of lakes located along a ~6000 km transect across Northern Eurasia, using diatom oxygen isotopes in the context of modern hydrology and other relevant local (diatom taxonomy, chironomid and biogeochemical analyses, isotope mass balance model) and regional parameters (modern moisture origin and digital elevation models). Combining the newly obtained $\delta^{18}O_{diatom}$ records with other regional and hemispheric reconstructions provides a complementary assessment of environmental conditions in normally intact, remote lake systems.

2. Materials and methods

The sediment cores Co1309, Co1321, Co1412 were respectively recovered from lakes Ladoga (60°59' N, 30°41' E; water depth: 111 m); Bolshoye Shchuchye

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(67°53' N, 66°19' E; water depth: 136 m); Emanda (65°18' N, 135°46' E; water depth: 14.6 m) during the drilling campaign within the German-Russian Paleolimnological Transect (PLOT) project (Fedorov et al., 2020), using gravity and percussion piston-corers operated from a floating platform (UWITEC Ltd., Austria).

Separation and cleaning of diatoms from the sediment matrix was carried out using a multistep process of wet chemistry, sieving, and heavy liquid separation described in detail in Kostrova et al. (2019; 2021). The oxygen isotope composition of purified diatom samples was measured at the ISOLAB Facility at AWI Potsdam with a PDZ Europa 2020 mass spectrometer using the laser fluorination method (Chapligin et al., 2010). A geochemical mass-balance approach (Chapligin et al., 2012) was applied for contamination correction of the measured $\delta^{18}O$ values.

3. Results and discussion

The $\delta^{18}O_{diatom}$ values from Lake Ladoga range from +29.8 to +35.0‰. The relatively high values between ~7.1 and 5.7 cal. ka BP are interpreted to indicate the Holocene Thermal Maximum (HTM). A continuous depletion in $\delta^{18}O_{diatom}$ after 6.1 cal. ka BP is related to Middle to Late Holocene cooling, which culminated in the interval 0.8–0.2 cal. ka BP corresponding to the Little Ice Age (LIA). Elevations/declines of the lake water level are accompanied by fluctuations in $\delta^{18}O_{diatom}$ towards lower/higher values, respectively. Thus, relatively low $\delta^{18}O_{diatom}$ values at ~10.7 cal. ka BP indicate that the lake existed as an eastern deep bay of the Ancylus Lake. The regression of the Baltic Sea and the formation of Lake Ladoga as an independent reservoir were accompanied by a decrease of the lake level and characterized by relatively higher $\delta^{18}O_{diatom}$. Between ~5.7 and 4.4 cal. ka BP, a decline in $\delta^{18}O_{diatom}$ values could reflect a lake level rise caused by the formation of a new inflow to the lake via River Vuoksi. The subsequent increase of $\delta^{18}O_{diatom}$ at 4.4–4.0 cal. ka BP gives an indication for a rather early opening of the Neva River outflow. An accelerated decrease in $\delta^{18}O_{diatom}$ after 4.0 cal. ka BP probably reflects an overall cooling with more persistent lake ice cover and reduced evaporation.

The Lake Bolshoye Shchuchye $\delta^{18}O_{diatom}$ record exhibits variations between +23.4 and +31.8‰. The short term (centennial-scale) variations often exceeding 5‰, especially in Middle and Late Holocene, are superimposed on the general decreasing trend. These fluctuations occur contemporaneously with and similarly to Holocene NH glacier advances. However, large Holocene glacier advances in the Lake Bolshoye Shchuchye catchment are unknown and have not left any significant imprint on the lake sediment record. Consequently, to explain the observed shifts for the deep and voluminous lake, about 30 – 50% of its volume should be replaced by isotopically different water within decades. Snow, which is known to be transported in surplus by redistribution from the windward to the leeward side of the Polar Urals, is considered a likely source of water with a light isotope composition. Snow melt and influx changes are assumed to be the dominant mechanism responsible for the short term changes in the $\delta^{18}O_{diatom}$ record.

The $\delta^{18}O_{diatom}$ values from Lake Emanda vary from +22.5‰ to +27.8‰. An obvious shift in $\delta^{18}O_{diatom}$ at 11.7–11.5 cal. ka BP reflects the onset of the Holocene. Relatively high $\delta^{18}O_{diatom}$ during the Early Holocene suggests relatively warm and/or dry climate with associated evaporation effects. The absolute maximum in the record at ~7.9 – 7.0 cal. ka BP is supposed to be a Middle HTM. A continuous depletion in $\delta^{18}O_{diatom}$ values since ~5.0 cal. ka BP reaching the absolute minimum at 0.4 cal. ka BP is interpreted as Middle to Late Holocene cooling culminated at the LIA and associated with colder T_{air}, a more persistent lake ice cover and reduced evaporation. The pattern of the Lake Emanda $\delta^{18}O_{diatom}$ record is close to that obtained from Lake El'gygytgyn (Swann et al., 2010).

All $\delta^{18}O_{diatom}$ records follow a decrease in summer insolation and are in line with the regional and the NH temperature history, demonstrating a good response of the isotope signal to insolation-driven temperature changes. A consistent decrease in $\delta^{18}O_{diatom}$ is observed in the records from ~6.5–5.2 cal. ka BP, indicating Middle to Late Holocene cooling.

4. Conclusions

The Holocene oxygen isotope records on fossil diatoms extracted from sediment cores of lakes Ladoga, Bolshoye Shchuchye and Emanda are combined with the recent isotope hydrology and local proxy's data, and used to characterize the environmental, hydrological and climate variability in Northern Eurasia. The data revealed that all lakes existed during the Holocene as well-mixed freshwater bodies without any evidence of a brackish or marine environment. The variability of $\delta^{18}O_{diatom}$ is mainly controlled by changes in $\delta^{18}O_{lake}$ rather than changes in T_{lake}. However, in Ladoga and Emanda lakes it is also associated with enhanced evaporation effects, whereas evaporative effects are negligible in Lake Bolshoye Shchuchye. Here, local snowmelt may change the local $\delta^{18}O_{lake}$.

The Lake Ladoga region has undergone significant hydrological changes throughout the Holocene. The isolation of the lake basin in the Early Holocene, the subsequent opening of the Vuoksi River inflow at ~5.7 cal. ka BP and the formation of the Neva River outflow at ~ 4.4–4.0 cal. ka BP are accompanied by lake level changes and notable as respective maxima and minima in the $\delta^{18}O_{diatom}$ record.

The Lake Bolshoye Shchuchye $\delta^{18}O_{diatom}$ record displays short term, centennial-scale changes attributed to snow transport to the catchment and switch on/off of meltwater supply to the lake. The $\delta^{18}O_{diatom}$ signal is interpreted as indicator for palaeoprecipitation, whereas the decreasing long-term trend in the record follows summer temperature changes.

The Lake Emanda $\delta^{18}O_{diatom}$ record demonstrates striking similarity to that obtained from Lake El'gygytgyn (Swann et al., 2010) despite obvious hydrological differences, suggesting a common "eastern" regional signal in both records.

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Conflict of interest

The authors declare no conflict of interest.

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