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Lake baikal isotope records of holocene Central Asian precipitation

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ABSTRACT

Climate models currently provide conflicting predictions of future climate change across Central Asia. With concern over the potential for a change in water availability to impact communities and ecosystems across the region, an understanding of historical trends in precipitation is required to aid model development and assess the vulnerability of the region to future changes in the hydroclimate. Here we present a record from Lake Baikal, located in the southern Siberian region of central Asia close to the Mongolian border, which demonstrates a relationship between the oxygen isotope composition of diatom silica ($\delta^{18}O_{diatom}$) and precipitation to the region over the 20th and 21st Century. From this, we suggest that annual rates of precipitation in recent times are at their lowest for the past 10,000 years and identify significant long-term variations in precipitation throughout the early to late Holocene interval. Based on comparisons to other regional records, these trends are suggested to reflect conditions across the wider Central Asian region around Lake Baikal and highlight the potential for further changes in precipitation with future climate change.

1. Introduction

The forest-steppe ecotone of Central Asia is dominated by grassland and taiga ecosystems that are vulnerable to both changes in the climate and other anthropogenic activities (Craine et al., 2012; Hijioka et al., 2014; Settele et al., 2014; Tautenhahn et al., 2016). Declines in precipitation over the past three decades have led to marked reductions in grassland biomass across the Mongolian steppes and wider region (Endo et al., 2006; Liu et al., 2013; Li et al., 2015), whilst global reductions in boreal forest due to fire and forestry are second only to losses in tropical forests (Hansen et al., 2013). Ongoing work points to the continuing fragility of these ecosystems. For example, 21st Century climate change across Central Asia is likely to lead to a northward migration of the forest–steppe ecotone with remaining forest stand height highly dependent on rates of precipitation (Tchebakova et al., 2009, 2016). At the same time reductions in soil moisture associated with climate change are expected to accelerated grassland degradation, negatively impacting nomadic pastoralism (Liu et al., 2013; Sugita et al., 2015), whilst issues of water security are likely to be exacerbated by plans for increased groundwater extraction and dam construction (Karthe et al., 2015). Growth of hemi-boreal forests in the forest - steppe ecotone has already slowed, linked to decline soil water content due to regional warming (Wu et al., 2012).

Changes in the central Asian hydrological cycle will also alter regional carbon cycling. The increased risk of fires across grasslands and boreal forest will impact vegetation regeneration (Tchebakova et al., 2009; IPCC, 2012; Tautenhahn et al., 2016) and lead to an immediate increase in atmospheric CO_2 (Randerson et al., 2006). Reductions in soil moisture availability and rising temperatures will further reduce carbon terrestrial storage by increasing the decomposition of organic matter in soils and lowering net carbon uptake by plants (Lu et al., 2009; Crowther et al., 2016). However, more significant are the threats posed by permafrost degradation,

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particular in southern Siberia and northern Mongolia where permafrost is vulnerable to degradation through warming, human impacts and increased wildfires (Sharkuu, 1998; Romanovsky et al., 2010; Zhao et al., 2010; Törnqvist et al., 2014). Combined, these processes will release carbon to the atmosphere (Schuur et al., 2015) and increase organic carbon export to water bodies (Selvam et al., 2017).

In order to improve future predictions of the Central Asian hydrological cycle there is an urgent need to understand long-term changes in the climate system beyond the instrumental record. Here we use the oxygen isotope composition of diatom silica ($\delta^{18}O_{diatom}$) from Lake Baikal (Russia) to constrain historical changes in Central Asian precipitation over the last 10,000 years, within the context of the modern day. Situated at the edge of the forest-steppe ecotone, the lake's catchment extends into northern Mongolia (Fig. 1) and is highly sensitive to changes in the hydrological cycle. Future changes in the region have the potential to reduce river flow around Lake Baikal, impacting the provision of water to one of the world's greatest lakes (Törnqvist et al., 2014) as well as decreasing soil moisture content and so increasing the risk of forest fires and associated carbon release (Forkel et al., 2012). Concurrently, climate change is likely to lead to further loss of permafrost across the region (Sharkuu, 1998; Törnqvist et al., 2014), potentially increasing the flow of dissolved organic carbon into Lake Baikal (Mackay et al., 2017) and altering the microbial food web, nutrient recycling and carbon processing within this ecological sensitive lake (Moore et al., 2009).

1.1. Lake Baikal reconstructions of the hydrological cycle

Lake Baikal is the world's oldest, deepest and most voluminous lake and, located in southern Siberia, contains c. 20% of the world's surface freshwater not stored within ice. The lake is divided into three basins (south, central and north) separated by the Buguldeika Saddle and the Academician Ridge, respectively (Fig. 1). Inputs of water to the lake are primarily derived from direct precipitation (c. 16%) and riverine inputs (c. 80%) (Seal and Shanks, 1998). Groundwater inputs are minor, believed to provide <4% of annual inflow (Seal and Shanks, 1998), although no systematic study has been carried out on groundwater, its residence time or isotope composition. Whilst over 350 rivers drain an area of c. 540,000 km^2 into Lake Baikal, inputs are dominated by the Selenga River, extending south into Mongolia, and the Upper Angara and Barguzin Rivers, draining the north of the catchment, which contribute c.

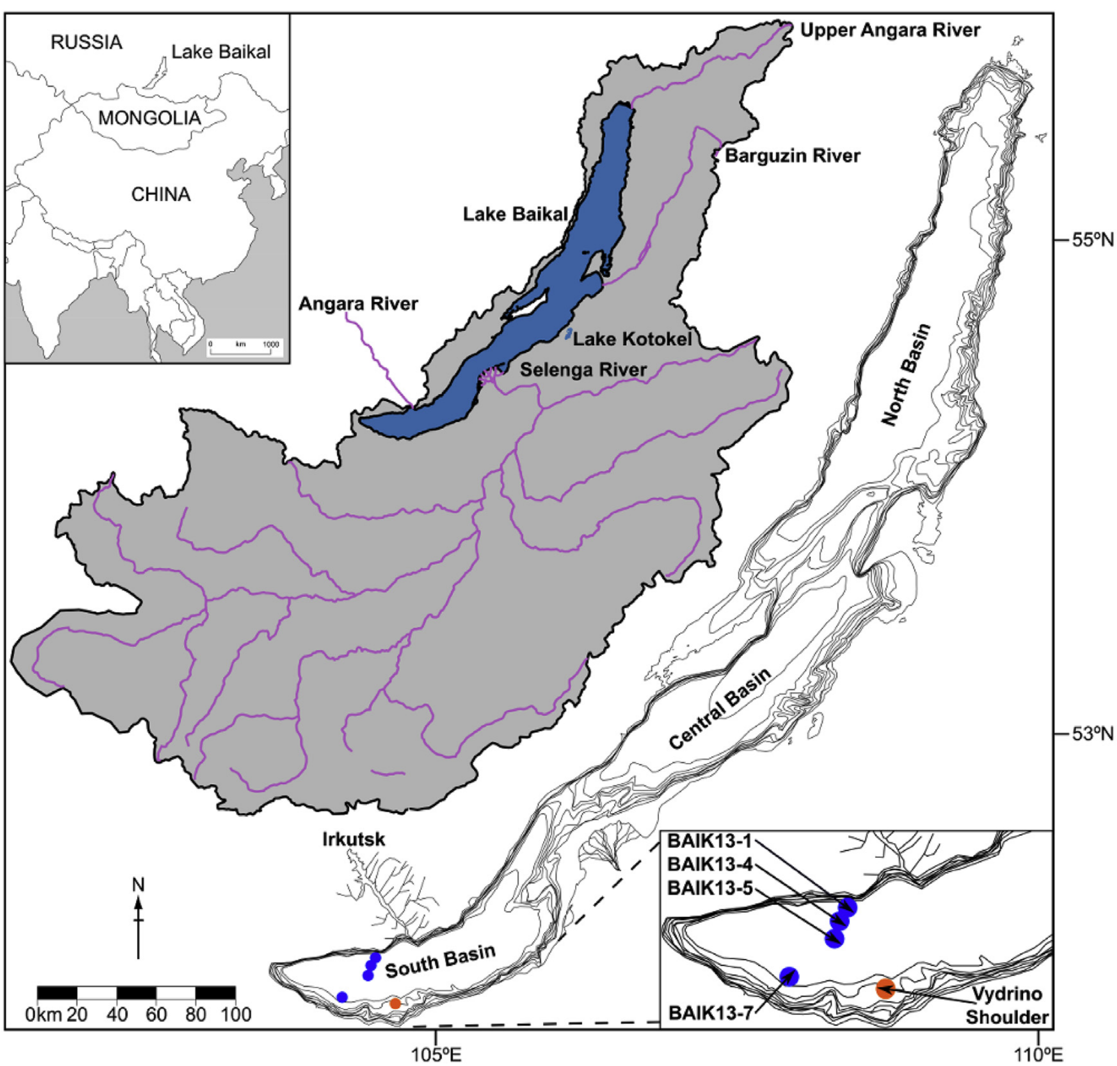

Fig. 1. Location of Lake Baikal and its catchment (grey region) together with Lake Kotokel, the city of Irkutsk, major rivers, coring sites BAIK13-1, BAIK13-4, BAIK13-5, BAIK13-7 (blue circles) and Vydrino Shoulder (orange circle). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)