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Climate variability and lake ecosystem responses in western Scandinavia (Norway) during the last Millennium

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ABSTRACT

This paper provides a high-resolution temperature reconstruction for the last Millennium from Lake Atnsjøen, SE Norway (61°52′31″N, 10°10′37″E). The sedimentary record reveals strong influence of the large-scale global climate patterns on the local climate in southern part of Eastern Norway. We reconstructed mean July air temperature using Chironomidae-based transfer function and fossil Chironomidae assemblages. The reconstruction was supported by a selection of climate-sensitive geochemical and paleoecological sedimentary proxies of terrestrial and aquatic origin, including Cladocera, pollen and macrofossils. Presented results revealed that summer temperatures were 1–2 °C warmer than the mean Millennial temperatures during the 11th, 13th, 15th and 20th centuries and 1–2 °C lower during the 12th, 14th, 17th–18th centuries. A persistent cold period, the Little Ice Age (LIA), occurred between 1550 and 1800 CE, was interrupted by a short warming at 1650 CE. The recognized regional climate fluctuations during the last Millennium affected the lake and its catchment, of which the strongest impact was caused by the LIA cooling. During the LIA the catchment vegetation was impacted by climate deterioration and the lake productivity reached its lowest level during the last Millennium. The current temperature reconstruction is in agreement with a previous continental scale temperature reconstruction for Europe. From obtained results it emerges that during the LIA the climate of western Scandinavia has been dictated by the atmospheric patterns originating from the North Atlantic.

1. Introduction

Climate variability and its impacts on the ecosystems can be reconstructed using natural archives, e.g. lake sediments that date back several millennia and provide multi-proxy long-term records (Battarbee et al., 2004; Elias and Mock, 2013). This is essential because a long temporal perspective on the magnitude and speed of environmental change is inevitable to discern between natural and anthropogenic forcing on the climate changes during the last centuries. A number of studies have been conducted to improve the knowledge of climate variability (Battarbee et al., 2004; Luterbacher et al., 2004; Mann, 2007; Nesje et al., 2000; Osborn and Briffa, 2006; Xoplaki et al., 2005) and several major global or hemispheric climatic episodes have been recognized during the last 1000 years (Mann et al., 2009; Osborn and Briffa, 2006; PAGES 2k Consortium, 2013; Wanner et al., 2008), among which the Medieval Climate Anomaly (MCA), the Little Ice Age (LIA), and the ongoing climate warming act as the most important.

Western Scandinavia is a key region to study paleoclimate due to its sensitivity to climate-forming processes in the North Atlantic shaping the climate of Europe (Helle, 2003). Of the large scale climate processes the North Atlantic Oscillation (NAO) is one of the main drivers of climate changes in Europe (Trouet et al., 2009; Wanner et al., 2008). It is speculated that the NAO is driven, at least partly, by solar forcing (Engels and van Geel, 2012; Shindell et al., 2001; van Geel et al., 1999). It has also been recognized that the external forcing related to atmospheric circulation patterns and solar activity cause long-term changes in aquatic ecosystem (Adrian et al., 2009; Dokulil et al., 2006; Luoto and Nevalainen, 2016; Ottersen et al., 2001). Though the global and regional climate trends are relatively well established, there is still a need for more detailed knowledge of the influence of large-scale atmospheric forcing on local climate dynamics at long temporal scales.

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The main aim of this research was to disentangle temperature variability and its impact on the functioning of a pristine lake in SE Norway with emphasis on climatic events related to changes in solar radiation and the NAO. The sediment core from Lake Atnsjøen located in the area with relatively low anthropogenic activity was analyzed. The reconstruction of climate changes and their impact on the lake environment during the last Millennium was performed using paleoecological and geochemical methods at ~30 yr resolution from a sediment core. The mean July air temperature was reconstructed using a Chironomidae-based calibration model and fossil Chironomidae assemblages, the lake and catchment responses were traced with indices based on subfossil Cladocera, pollen and macrofossils as well as total organic carbon (TOC).

The results were compared with a regional temperature reconstruction for the last two millennia (PAGES 2k Consortium, 2013), indices of solar activity (Reimer et al., 2013) and the NAO (Trouet et al., 2009) in order to examine the influence of large-scale external climate forcing on the local processes. The presented study aims at improving the understanding on local decadal climate dynamics and impacts during the last 1000 yr, their relationship with regional climate patterns, large-scale atmospheric and solar forcing.

1.1. Regional setting

Lake Atnsjøen is located in the eastern part of southern Norway, in the Atna Valley, to the east of the Rondane mountain chain (61°52′ 51 N, 10°09′55 E), 701 m a.s.l (Fig. 1). It is the largest lake in the River Atna watershed (area 4.8 km^2). The lake is deep and oligotrophic with a maximum depth of 80 m and a mean depth of 35.4 m. The river Atna drains into the lake in the western end, and leaves in the eastern. The retention time of the lake is about 6 months. The catchment of the lake Atnsjøen is 457 km^2 and the major part (85%) is located above the tree line (approximately 1000 m a.s.l.). The bedrock consists mainly of feldspar quartzite with locally large deposits of quaternary and fluvial materials (Halvorsen, 2004). The area has a continental, subarctic climate with average annual temperature and precipitation of 0.7 °C and 555 mm, respectively (Nordli and Grimenes, 2004). The mean July temperature is 13.4 °C (Fig. 2) based on the raw data provided by the Norwegian Meteorological Institute. A large part of the catchment lies within the Rondane National Park. Due to the remote location of the catchment, the Atna watershed and Lake Atnsjøen remain relatively unaffected by human activities.

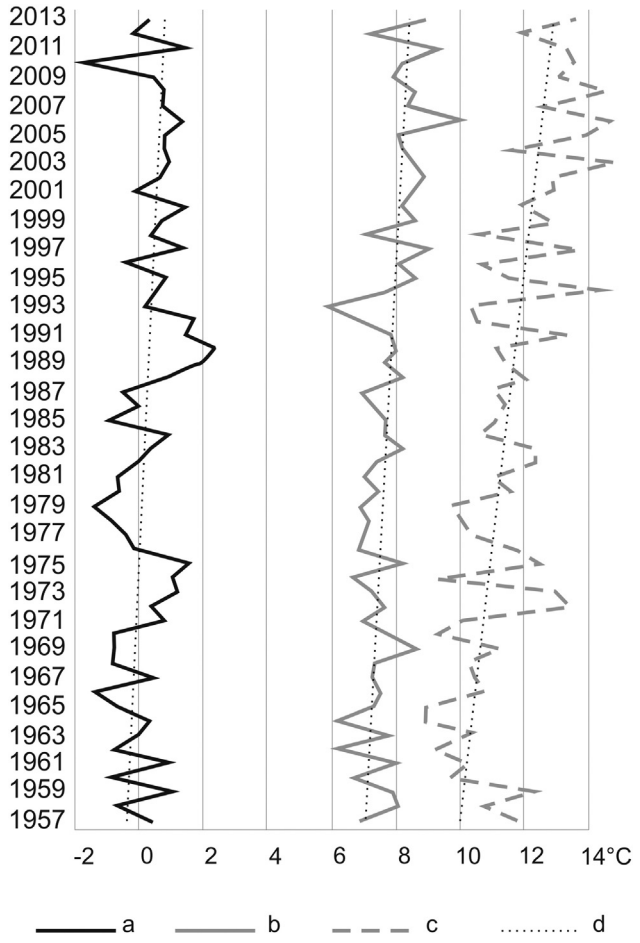

Fig. 2. Temperature data from Lake Atnsjøen for the period 1957–2012: a) annual, b) June–October period, c) mean July, d) mean value. The data are provided by the Norwegian Meteorological Institute and based on gridded temperature data (1 km^2) interpolated from surrounding weather stations. See Mohr (2008, 2009) for methods and more information.

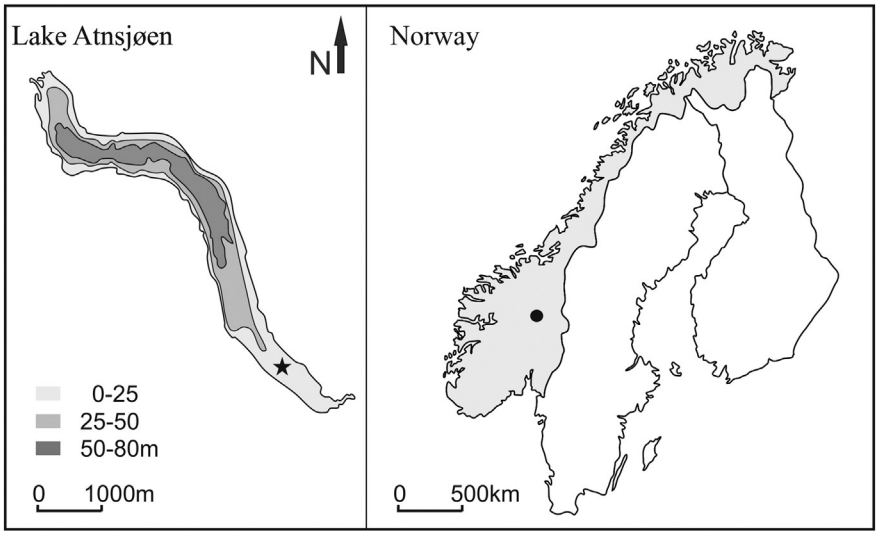

Fig. 1. Bathymetry of Lake Atnsjøen and its location in northern Europe, (a black dot). The bathymetric depth contours are grey shaded. The sediment core was taken in southern part of the Lake Atnsjøen and sampling location is indicated on the map with a black star.