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Evidence for higher-than-average air temperatures after the 8.2 ka event provided by a Central European $\delta^{18}O$ record

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A B S T R A C T

The so-called 8.2 ka event represents one of the most prominent cold climate anomalies during the Holocene warm period. Accordingly, several studies have addressed its trigger mechanisms, absolute dating and regional characteristics so far. However, knowledge about subsequent climate recovery is still limited although this might be essential for the understanding of rapid climatic changes. Here we present a new sub-decadally resolved and precisely dated oxygen isotope ($\delta^{18}O$) record for the interval between 7.7 and 8.7 ka BP (10^3 calendar years before AD 1950), derived from the calcareous valves of benthic ostracods preserved in the varved lake sediments of pre-Alpine Mondsee (Austria). Besides a clear reflection of the 8.2 ka event, showing a good agreement in timing, duration and magnitude with other regional stable isotope records, the high-resolution Mondsee lake sediment record provides evidence for a 75-year-long interval of higher-than-average $\delta^{18}O$ values directly after the 8.2 ka event, possibly reflecting increased air temperatures in Central Europe. This observation is consistent with evidence from other proxy records in the North Atlantic realm, thus most probably reflecting a hemispheric-scale climate signal rather than a local phenomenon. As a possible trigger we suggest an enhanced resumption of the Atlantic meridional overturning circulation (AMOC), supporting assumptions from climate model simulations.

1. Introduction

The Holocene warm period has been punctuated by several short-term climate perturbations (Mayewski et al., 2004) with that around 8.2 ka BP (10^3 calendar years before AD 1950) being a particularly prominent one (Alley and Ágústsdóttir, 2005; Alley et al., 1997; Rohling and Pälike, 2005). This cold episode, commonly termed 8.2 ka event, is generally considered as having been triggered by the catastrophic drainage of the Laurentide proglacial lakes Agassiz and Ojibway after the collapse of the Hudson Bay ice dome (Barber et al., 1999; Teller et al., 2002; von Grafenstein et al., 1998). The associated sudden input of a large amount of freshwater into the North Atlantic caused a salinity/density reduction of the ocean surface waters and consequently a transient slowdown of the Atlantic meridional overturning circulation (AMOC; Ellison et al., 2006; Kleiven et al., 2008). This

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resulted in reduced northward heat transport, leading to a pronounced cooling in the North Atlantic realm (Alley and Ágústsdóttir, 2005; Morrill and Jacobsen, 2005; Rohling and Pälike, 2005), which is also evident in climate model simulations (Bauer et al., 2004; Morrill et al., 2013b; Wiersma and Renssen, 2006). Several proxy-based studies have therefore focused on investigating the causal mechanisms, absolute dating, duration, amplitude, spatio-temporal characteristics and environmental consequences of the 8.2 ka event (e.g. Alley and Ágústsdóttir, 2005; Alley et al., 1997; Barber et al., 1999; Boch et al., 2009; Daley et al., 2011; Ellison et al., 2006; Kleiven et al., 2008; Kobashi et al., 2007; Marshall et al., 2007; Morrill and Jacobsen, 2005; Nicolussi and Schlüchter, 2012; Rasmussen et al., 2007; Rohling and Pälike, 2005; Teller et al., 2002; Thomas et al., 2007; Veski et al., 2004; von Grafenstein et al., 1998). However, these studies have so far given only little attention to climate recovery at the demise of the cold event though this could provide important insights into the dynamics and regional peculiarities of rapid climate warming. Likewise, also only very few modelling studies have addressed the resumption of the AMOC and related climatic changes after a freshwater perturbation under Holocene climate boundary conditions in particular (e.g. Renold et al., 2010; Stouffer et al., 2006). Furthermore, the results of climate model simulations for the 8.2 ka event are still ambiguous with respect to the strength and duration of the AMOC slowdown and the following temperature decrease, mostly not matching the proxy evidence (Morrill et al., 2013b). The limitations of climate models in correctly reproducing the full spatio-temporal pattern of climatic changes around 8.2 ka BP are supposedly related to a suite of different factors, involving the complexity and resolution of the models, the probably non-linear response of the AMOC to freshwater forcing (LeGrande and Schmidt, 2008) and a number of not yet well-constrained in-/external forcings (Morrill et al., 2013b), including the volume and rate of freshwater discharge and its exact routing in the North Atlantic (Li et al., 2009; Morrill et al., 2014; Wiersma et al., 2006), the possible role of freshwater background forcing from the melting Laurentide Ice Sheet (Matero et al., 2017; Wagner et al., 2013), the ocean circulation mode around 8.2 ka BP (Born and Levermann, 2010; Morrill et al., 2013b) and the early Holocene climate background state (LeGrande et al., 2006). Hence, there still remain many uncertainties regarding the amplitude and pattern of the AMOC slowdown during the 8.2 ka event and its subsequent recovery as well as regarding the associated climatic changes.

Using analyses of the oxygen isotope ($\delta^{18}O$) composition of benthic ostracod valves ($\delta^{18}O_{ostracods}$) preserved in the varved lake sediments of pre-Alpine Mondsee (Austria), the current study presents a new sub-decadally resolved and precisely dated $\delta^{18}O$ record from Central Europe for the interval between 7.7 and 8.7 ka BP, providing new information about climate development around 8.2 ka BP. Besides using the detailed characterization of the well-reflected 8.2 ka event in the Mondsee $\delta^{18}O_{ostracods}$ record to discuss the suitability of the archive for reconstructing past changes in the oxygen isotope composition of precipitation ($\delta^{18}O_{precip}$) and mean annual air temperature (MAAT), we especially focus on climate development at the end of the 8.2 ka event and during the first decades thereafter, an issue so far not sufficiently addressed by proxy-based palaeoclimate studies. In particular, we discuss a previously not described short-term $\delta^{18}O$ overshoot immediately after the 8.2 ka event, which might reflect a pronounced warming above the pre-8.2 ka event level in Central Europe. Although so far not explicitly interpreted in terms of higher-than-average air temperatures, a similar pattern is also observed in other stable isotope records from the North Atlantic realm, suggesting a signal of hemispheric-scale relevance. By discussing the potential trigger of this episode of possibly higher-than-average air temperatures, we contribute to a more comprehensive view on climate recovery at the end of the 8.2 ka event. This helps to improve our understanding of the dynamics and mechanisms of rapid climate warming but also challenges climate model simulations.

2. Study site

Mondsee (47°48′N, 13°24′E, 481 m a.s.l.) is a relatively large and deep hardwater lake (lake surface area ~13.8 km^2, maximum water depth 68 m, lake volume ~0.5 km^3, catchment area ~247 km^2; Beiwl and Mühlmann, 2008), located ~30 km east of Salzburg (Austria) at the foothills of the Northern Calcareous Alps (Fig. 1). The present-day lake basin established at the end of the last glaciation after the retreat of the Traun Glacier from the area, which most likely occurred already prior to ca. 18,000–19,000 cal years BP (Reitner, 2007; van Husen, 1977, 1997). The lake is at present mainly monomictic with a long stratification period between late April and December and mixing during winter/early spring; dimictic conditions with a short winter stagnation of a few weeks occur only sporadically during the rare years with ice cover (Dokulil and Skolaut, 1986; Ficker et al., 2017; Kämpf et al., 2015). Mondsee is fed by three major tributaries (Fuschler Ache, Zeller Ache, Wangauer Ache), which account for ~70% of the total inflow, as well as several minor creeks. In addition, rainfall on the lake surface and possibly also groundwater flow contribute to the water budget. Lake drainage takes place through a single outlet (Seeache), which has an average discharge of 9.2 m^3 s^{-1}, resulting in a theoretical lake water renewal time of ~1.7 years (Jagsch and Megay, 1982; Klee and Schmidt, 1987). The present-day local climate is temperate with a MAAT of 8.5 °C and January and July air temperature means of −1.3 °C and 18.3 °C, respectively. The average annual precipitation sum is 1566 mm with about 50% falling as rain between May and September (all climate data for the period 1981–2010; Central Institute for Meteorology and Geodynamics (ZAMG), Vienna, Austria). Precipitation mainly originates from North Atlantic and Central European sources whereas the Mediterranean contribution north of the Alpine main ridge is at present only minor (~10–17%) (Kaiser et al., 2002; Sodemann and Zubler, 2010). This is corroborated by present-day (1981–2010) wind field data, revealing a dominance of westerly and northwesterly directions with an only minor and seasonally stable contribution from southerly directions (Central Institute for Meteorology and Geodynamics (ZAMG), Vienna, Austria).

3. Material and methods

3.1. Previous work

3.1.1. Lake sediment coring

Two parallel sediment cores (Mo_05_01 and Mo_05_02), each consisting of consecutive 2-m-long core segments, were recovered from a coring site at ~62 m water depth in the southern part of the Mondsee lake basin (47°48′25″N, 13°24′05″E) in June 2005 by using a 90 mm diameter UWITEC piston corer (Lauterbach et al., 2011). Additionally, several short surface sediment cores were recovered with a UWITEC gravity corer from the same location to obtain the undisturbed sediment-water interface. All core segments were subsequently opened, lithostratigraphically described, photographed and subsampled. The overlapping segments of the two piston cores Mo_05_01 and Mo_05_02 and gravity core Mo_05_P3 were visually correlated via distinct macroscopic lithological marker layers, resulting in a continuous composite sediment core of 1493 cm length, which covers more than the last 15 ka, i.e. the complete Holocene and Lateglacial (Lauterbach et al., 2011).