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Short communication

Major cooling intersecting peak Eemian Interglacial warmth in northern Europe

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ABSTRACT

The degree of climate instability on the continent during the warmer-than-present Eemian Interglacial (around ca. 123 kyr ago) remains unsolved. Recently published high-resolution proxy data from the North Atlantic Ocean suggest that the Eemian was punctuated by abrupt events with reductions in North Atlantic Deep Water formation accompanied by sea-surface temperature cooling. Here we present multi-proxy data at an unprecedented resolution that reveals a major cooling event intersecting peak Eemian warmth on the North European continent. Two independent temperature reconstructions based on terrestrial plants and chironomids indicate a summer cooling of the order of 2–4 °C. The cooling event started abruptly, had a step-wise recovery, and lasted 500–1000 yr. Our results demonstrate that the common view of relatively stable interglacial climate conditions on the continent should be revised, and that perturbations in the North Atlantic oceanic circulation under warmer-than-present interglacial conditions may also lead to abrupt and dramatic changes on the adjacent continent.

1. Introduction

The stability of future climate in the North Atlantic region is highly debated as potential tipping points in the North Atlantic oceanic circulatory system may, if crossed, affect the climate on adjacent continents (Vellinga and Wood, 2002; Hofmann and Rahmstorf, 2009). Model projections vary widely and include a large spread (0–50%) in reduction in strength of the Atlantic Meridional Overturning Circulation (AMOC) (IPCC, 2013). The effects of changes in ocean circulation on climate, environment, and human society around the North Atlantic are even more uncertain (Seager et al., 2002). The failure of models to provide consistent answers about the fate of the AMOC in a warming climate and its effects in the North Atlantic and surrounding land areas underlines the need for detailed paleo-climate records from warmer-than-present interglacials to constrain future climate-change scenarios.

Large parts of the globe experienced a warmer-than-present climate during the Eemian Interglacial, roughly corresponding to Marine Isotope Stage (MIS) 5e, dated to between ca. 130–115 kyr ago. This makes the Eemian a suitable analogue to test hypotheses about projected future global warming. Numerous studies on deposits of Eemian age in central Europe suggest that the interglacial was characterized by a rather stable climate evolution with only minor short-term climate variability (Cheddadi et al., 1998; Rioual et al., 2001, 2007; Kühl et al., 2007). The apparent stability of climate in Europe is in sharp contrast, however, to recent data from high sediment-accumulation rate sites in the North Atlantic Ocean that reveal abrupt changes in North Atlantic Deep Water (NADW) formation (Galaasen et al., 2014) and major sea-surface temperature (SST) cooling intersecting Eemian Interglacial warmth (Bauch et al., 2011; Irvalı et al., 2012). The effects of such changes on climate and ecosystems of the adjacent continents, however, are still unresolved (Galaasen et al., 2014).

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The Sokli basin in north-east Finland (67°48′N, 29°18′E, 220 m a.s.l.; Fig. 1) is one of the few terrestrial sites in northern Europe where Eemian Interglacial sediments have been found preserved in a stratigraphic sequence with overlying glacial till beds and non-glacial sediments of Weichselian age (ca. 115–15 kyr ago). The Eemian Interglacial (locally named Nuortti Interglacial) (Helmens, 2014) bed at Sokli is furthermore one of the few deposits from this area with an unequivocally Eemian age (Helmens et al., 2000, 2007). The Sokli sedimentary sequence has escaped major glacial erosion in part due to non-typical bedrock conditions. Here we present the first results of a high-resolution study on a recently recovered, unusually thick (9-m) Eemian diatom gyttja deposit from the Sokli basin. The focus of our study is on a major cooling event detected in the middle part of the diatom gyttja bed and provides a detailed correlation with North Atlantic marine data.

The Eemian diatom gyttja deposit at Sokli stretches as a marker horizon near the base of the unconsolidated sediment infill. Its interglacial pollen content was first noted by Ilvonen (1973) and was correlated with the Eemian. Detailed stratigraphic studies on the overlying Weichselian sediment sequence, combined with absolute dating control, have supported the Eemian age assignment (Helmens et al., 2000, 2007). The diatom gyttja bed has been bracketed by TL and IRSL dating to > ca. 110 and < ca. 150–180 kyr (Helmens et al., 2000), and OSL dating on quartz (using SAR dose protocol) to > ca. 95 kyr (Helmens et al., 2007; Alexanderson et al., 2008). Furthermore, multi-proxy analysis on the fossil-rich lacustrine and fluvial sediments of Weichselian and Holocene age have earlier shown the potential of the Sokli record in providing detailed paleo-environmental and -climatic data for northern Europe (Helmens, 2014). Here, we apply geochemical and multiple paleoecological proxies (pollen, conifer stomata, plant macrofossils, diatoms and chironomids) for paleo-environmental reconstruction and use quantitative proxy–climate transfer functions to reconstruct July mean temperatures (T_{jul}).

2. Methods

The present study was conducted on a new borehole Sokli 2010/4 that was cored at a site located between boreholes Sokli B-series/901 and 902 from the central and marginal (respectively) parts of the Sokli basin (Helmens et al., 2000, 2007). Additionally, several

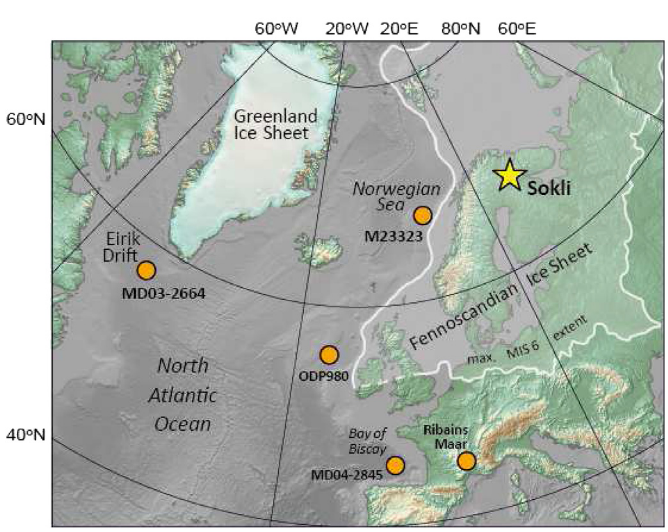

Fig. 1. Location map of the Sokli study site and other referenced sites in the North Atlantic region, with maximum Saalian (MIS 6) glaciation over northern Europe (Svendsen et al., 2004).

samples from core 901 were re-analysed for pollen (Helmens et al., 2000). The latter core records the final birch phase that is missing (truncated) at the site of borehole Sokli 2010/4.

2.1. Proxy analyses

2.1.1. Pollen and stomata

Pollen samples were prepared from 1 cm^3 subsamples at mainly 2–10 cm intervals, using KOH, sieving (212 μm mesh), Na-pyrophosphate, acetolysis, and finally a bromoform heavy-liquid treatment to remove silicate. The preparations were mounted in glycerol and counted using a light microscope. Pollen percentages were calculated from the sum of all terrestrial pollen and spore taxa. A mean of 392 (min = 220, max = 513) terrestrial pollen and spore grains were counted from each sample. Conifer stomata were also counted from the pollen slides.

2.1.2. Macrofossils

Macrofossil samples were prepared at 4–20 cm intervals from subsamples of mainly ca. 5 cm^3. The sediment was sieved using a 100 μm mesh under running water and the residue examined using stereo and high-magnification light microscopes.

2.1.3. Chironomids

Seventeen samples were prepared covering the 2211–2405 cm sediment depth interval. Weighted (wet) sediment samples (0.55–1.91 g) were treated with warm 5% KOH and rinsed through a sieve with a 95-μm mesh. Chironomid remains, as well as remains of other organisms such as Chaoboridae and Ephemeroptera, were hand-picked from the residue using a Bogorov sorting tray. The remains were air-dried and subsequently mounted on permanent slides using Euparal mounting medium. Chironomid percentages were calculated using the total sum of chironomid remains. Remains from e.g. Chaoboridae were excluded from the chironomid sum. A mean of 83 head capsules (min = 39.5, max = 123.5) were counted from each sample.

2.1.4. Diatoms

Diatom samples were taken at 2–10 cm interval, processed with H_2O_2 (30%) and decanted after sedimentation overnight. The residue was mounted in Naphrax and analyzed using a light microscope, with a minimum of 400 diatom valves counted per slide.

2.1.5. XRF core scanning

The Eemian diatom gyttja bed was scanned using an ITRAX XRF Core Scanner from Cox Analytical Systems (Gothenburg, Sweden). The XRF analyses were made using a Mo tube set at 30 kV and 45 mA with a step size of 2 mm and a dwell time of 60 s. All data were normalized to the (incoherent + coherent) scattering and smoothed using a 5-point running mean. A Principal Component Analysis (PCA) was made using JMP 9.0.0 software in correlation mode using a varimax rotation. Before analysis all data were converted to Z-scores. The PCA was run using all measured elements between the depths of 16 and 25 m. Five main principal components explain 95% of the variance in the data. The first component (PC1), explaining 36% of the data, is associated with Zr, Ti, K, Rb and, to a lesser (although still significant) extent, Ca and Si. These elements have in common the fact that these can be transported detritally into the lake. Based on previous studies of the Sokli complex these elements are likely hosted in zircon, titanium oxides, feldspars, micas, calcite, apatite and various silicates (Lee et al., 2005, 2006). PC1 is thus interpreted to represent minerogenic input to the lake. Changes in the importance of this process over time are revealed by the plot of component scores with depth, where a value of 0 represents the “average” behaviour of that process. The most