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Inter-annual climate variability in Europe during the Oligocene icehouse

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ABSTRACT

New sclerochronological data suggest that a variability comparable to the North Atlantic Oscillation (NAO) was already present during the middle Oligocene, about 20 Myr earlier than formerly assumed. Annual increment width data of long-lived marine bivalves of Oligocene (30–25 Ma) strata from Central Europe revealed a distinct quasi-decadal climate variability modulated on 2–12 (mainly 3–7) year cycles. As in many other modern bivalves, these periodic changes in shell growth were most likely related to changes in primary productivity, which in turn, were coupled to atmospheric circulation patterns. Stable carbon isotope values of the shells ($\delta^{13}C_{shell}$) further corroborated the link between shell growth and food availability. Sub-decal oscillations in the 3–7 year band in other annually resolved fossil archives were often interpreted as El Niño-Southern Oscillation (ENSO) cycles. This possibility is discussed in the present study. However, combined shell-derived proxy and numerical climate model data lend support to the interpretation of a NAO-like variability. According to numerical climate models, winter sea-level pressure (wSLP) and precipitation rate (wPR) across Central Europe during the Oligocene exhibited a pattern similar to the modern NAO. The simulated NAO index for the Oligocene shows periodicities coherent with those revealed by the proxy data (2.5–6 years), yet, on shorter wavelengths than the modern NAO (biennial and 6–10 year cycles). Likely, the different paleogeography and elevated atmospheric CO_2 concentrations not only influenced the sea-level pressure pattern, but also the temporal variability of the NAO precursor. The present study represents the first attempt to characterize the inter-annual climate variability in Central Europe during the Oligocene and sets the basis for future studies on the early phase of the Cenozoic icehouse climate state.

1. Introduction

The Eocene/Oligocene boundary marks the shift of global climate from the early Paleogene Greenhouse to the modern icehouse state (Miller et al., 1991; Zachos et al., 2008). The resulting pervasive climate deterioration particularly affected the Northern Hemisphere, leading to the largest marine and terrestrial faunal turnover of the Cenozoic era in Europe (Prothero, 1994; Prothero et al., 2003), also known as the *Grande Coupure* (Stehlin, 1909). Previous studies suggested that climatic changes across the North Atlantic sector and Central Europe significantly contributed to this event (e.g., Ivany et al., 2000; Eldrett et al., 2009; Mosbrugger et al., 2005; Kocsis et al., 2014). For example, according to palynological data, mean annual and winter temperatures dropped by ca. 3 to 10 °C (Mosbrugger et al., 2005; Erdei et al., 2012) between the late Eocene and the early Oligocene (Rupelian). A similar trend was reconstructed from the oxygen isotope composition of terrestrial rodent teeth phosphate (Héran et al., 2010). Likely, climate cooling in Central Europe was related to a change of the source of atmospheric masses across the continent. Numerical model simulation and proxy data suggest that until the Eocene, central European atmospheric masses originated from the Tethys and the Pacific Ocean (e.g., Bice et al., 2000; Kocsis et al., 2014). As indicated by varved sediments, atmospheric circulation was controlled by the ENSO during this time interval (Mingram, 1998; Lenz et al., 2010). However, $\delta^{18}O$ data from terrestrial mammals from Europe show a trend toward negative values from the Eocene to the Oligocene (Héran et al., 2010; Kocsis et al., 2014) suggesting a shift of the source of the atmospheric moisture toward the North Atlantic during the Late Paleogene. This time interval coincides with the major uplift phase of the Alps (Kuhlemann, 2007), which likely acted as an atmospheric barrier to the Tethyan realm and the Pacific climate (Kocsis et al., 2014). This configuration resembles the modern situation with the westerlies being the major trajectory of Central European atmospheric masses (Hurrell and Deser, 2009). Today, the interannual climate variability of Europe is largely influenced by sea-level pressure (SLP) dynamics across the North Atlantic, i.e., the North Atlantic Oscillation. As indicated by annually resolved $\delta^{18}O$ data from corals (Brachert et al., 2006; Mertz-Kraus et al., 2009), speleothems (e.g., Scholz et al., 2012) and laminated lacustrine sediments (Muñoz et al., 2002; Kloosterboer-Van Hoeve et al., 2006), the NAO existed already

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