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ORIGINAL PAPER

Seasonality in the North Sea during the Allerød and Late Medieval Climate Optimum using bivalve sclerochronology

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Abstract Seasonal temperature patterns may have changed through time in response to current global warming. However, the temporal resolution of available proxy records is not sufficient to quantify paleotemperature seasonality prior to anthropogenic forcing of the climate. In the present study, we reconstructed seasonal and inter-annual temperature patterns of the North Sea during the last 140 years, the Allerød Interglacial and the Late Medieval Climate Optimum using sclerochronological and $\delta^{18}O_{aragonite}$ data from bivalve shells, *Arctica islandica*. On average, the climate during 1278–1353 AD was ca. 1.1°C colder and seasonality was ca. 60% less than today. During the Allerød, long-term temperatures remained about 3.2°C below present values, and absolute summer and winter anomalies were ca. −4 and −2.7°C, respectively. However, seasonality was statistically indistinguishable from today. Long-term average temperatures compare well with existing data for the Late Medieval and Allerød, but detailed information on seasonality during the studied time intervals has never been presented before. Our data also demonstrated that annual instrumental and $\delta^{18}O_{aragonite}$-derived temperatures did not always match. This difference is explained by (1) NAO-driven salinity changes, which influence the temperature estimation from $\delta^{18}O_{aragonite}$ and (2) food-driven changes in growth rates; portions of the shell that formed more rapidly are overrepresented in carbonate samples. Our study indicated that individual bivalve shells can open discrete, near-century long, ultra-high-resolution windows into the climate past. Such information can be vital for testing and verifying numerical climate models.

Keywords Paleoseasonality · Paleoclimate oscillations · *Arctica islandica* · Growth rates · Oxygen isotopes

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Introduction

A thorough characterization of how current global warming deviates from that of ancient times requires information on past climate variability at different time scales and from different localities. Currently, sustained efforts are focused primarily on studying annual- to millennial-scale climate oscillations during the Holocene and Pleistocene epochs (Storch et al. 2004; Mann 2007). Of particular interest are time intervals of rapid temperature shifts and temperature extremes such as the Medieval Climate Optimum (900–1300 AD; Lamb 1965; Mann 2002) and the Allerød Interstadial (Hartz and Milthers 1901; ca. 14100–12900 BP) during the Last Glacial Termination. Detailed description of the paleoclimate changes at these times helps place current global warming in its longer-term context, and enables the effects of short-term anthropogenic climate perturbation to be quantified and isolated from longer-term natural forcings.

Although borehole data (e.g., Birch 1948; Anderssen and Saull 1973; Pollack and Smerdon 2004) are useful indicators of climate fluctuations at the century-scale, other proxy archives must be used to achieve annual and sub-annual resolution. The most reliable records currently used are obtained from tree rings, coral skeletons, stalagmites,