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Marine climatic seasonality during medieval times (10th to 12th centuries) based on isotopic records in Viking Age shells from Orkney, Scotland

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Abstract

Seasonal sea-surface temperature (SST) variability during the Medieval Climate Anomaly (MCA), which corresponds to the height of Viking exploration (800–1200 AD), was estimated using oxygen isotope ratios ($\delta^{18}O$) obtained from high-resolution samples micromilled from archaeological shells of the European limpet, *Patella vulgata*. Our findings illustrate the advantage of targeting SST archives from fast-growing, short-lived molluscs that capture summer and winter seasons simultaneously. Shells from the 10th to 12th centuries (early MCA) were collected from well-stratified horizons, which accumulated in Viking shell and fish middens at Quoygrew on Westray in the archipelago of Orkney, Scotland. Their ages were constrained based on artifacts and radiocarbon dating of bone, charred cereal grain, and the shells used in this study. We used measured $\delta^{18}O_{WATER}$ values taken from nearby Rack Wick Bay (average 0.31 ± 0.17‰ VSMOW, n = 11) to estimate SST from $\delta^{18}O_{SHELL}$ values. The standard deviation of $\delta^{18}O_{WATER}$ values resulted in an error in SST estimates of ±0.7 °C. The coldest winter months recorded in the shells averaged 6.0 ± 0.6 °C and the warmest summer months averaged 14.1 ± 0.7 °C. Winter and summer SST during the late 20th century (1961–1990) was 7.77 ± 0.40 °C and 12.42 ± 0.41 °C, respectively. Thus, during the 10th to 12th centuries winters were colder and summers were warmer by ~2 °C and seasonality was higher relative to the late 20th century. Without the benefit of seasonal resolution, SST averaged from shell time series would be weighted toward the fast-growing summer season, resulting in the conclusion that the early MCA was warmer than the late 20th century by ~1 °C. This conclusion is broadly true for the summer season, but not true for the winter season. Higher seasonality and cooler winters during early medieval times may result from a weakened North Atlantic Oscillation index.

Highlights

► We investigated oxygen isotope ratios of Viking Age limpet shells. ► Seasonal SST was reconstructed for the early MCA (10th–12th centuries). ► Early MCA winters were cooler and summers were warmer than late 20th century. ► MCA seasonality was higher than the late 20th century.

Introduction

Late Holocene climate episodes provide critical information about pre-industrial climate change relevant to understanding natural variation in the climate system. Recent attention has focused on temporal and spatial variability during the Medieval Climate Anomaly (MCA) and Little Ice Age (LIA) (Jansen et al., 2007, Mann et al., 2009, Trouet et al., 2009, Diaz et al., 2011, Graham et al., 2011). Graham et al. (2011) and Diaz et al. (2011) provide an excellent historical background and synthesis of proxy records, regional climate reconstructions, and results from climate model experiments supporting global climate reorganization during the MCA and LIA. This interval of time is significant culturally because it spans the height of Viking (Scandinavian) exploration and economic intensification during the MCA (800–1200 AD), and subsequent retrenchment in the early LIA (1200–1550 AD). Paleoclimate reconstructions that use archaeological sources contribute to our understanding of human–climate interactions (Surge and Walker, 2005, Walker and Surge, 2006, Hallmann et al., 2009, Hufthammer et al., 2010, Jones et al., 2010, Andrus, 2011, Helama and Hood, 2011, Wang et al., 2011, Wang et al., 2012), especially in regions that are sensitive to climate change.

Proxy records reconstructing climatic conditions during the MCA are strongly biased towards decadal to annual resolution and summer/growing seasons (e.g., Table 6.1 in Jansen et al., 2007 and Table 1 in Christiansen and Ljungqvist, 2011). Few studies resolve the winter season. Those that do focus on winter precipitation and even fewer report on winter air temperatures, which are reconstructed based on documentary evidence (Ogilvie and Farmer, 1997, Pfister et al., 1998). Studies of pre-industrial climate change that resolve summer and winter variability in sea surface temperature (SST) are scarce (Patterson et al., 2010, Wanamaker et al., 2011). Regional climate models illustrate the need for such high-resolution studies at seasonal time scales. Numerical (idealized multi-level primitive equation) and sensitivity (ECBilt-Clio) model experiments demonstrate that small changes in the coupled atmospheric-oceanographic climate system influence regional mid-latitude seasonality (Lee and Kim, 2003, van der Schrier et al., 2007). These model simulations for the North Atlantic sector show that minute changes in the position and intensity of the subtropical jet stream at low latitudes restrict the polar front jet stream to high latitudes. As with a positive North Atlantic Oscillation (NAO) index (a stronger than usual subtropical high pressure center and a deeper than usual Icelandic low), restriction of the polar front jet stream to high latitudes (i.e., a decrease in atmospheric meridional heat transport) and an intensified Gulf Stream (i.e., an increase in oceanic meridional heat transport) transfers a broad band of moisture and latent heat farther northeast. Simulations of the enhanced meridional heat transport as a result of these complementary atmospheric–oceanic processes generate equable climate at mid latitudes and demonstrate the potential sensitivity of mid-latitude regions to seasonal-scale changes.

Archives from fast-growing shells can potentially capture summer and winter seasons and, thus, approach the full seasonal range of sea surface temperature (SST). Often, fast-growing shells are short-lived and, thus, provide “snapshots” of multi-year seasonal cycles. Archaeological limpet shells of the genus, *Patella*, collected by the local human inhabitants are potentially valuable archives of variability in seasonal SST from coastal marine environments (Shackleton, 1973, Cohen and Branch, 1992, Fenger et al., 2007, Ferguson et al., 2011, Wang et al., 2012). This study presents reconstructed mid-latitude SST at seasonal time scales using oxygen isotope ($\delta^{18}O$) proxy data from shells of the European limpet, *P. vulgata*, harvested by the inhabitants of the Quoygrew archaeological site on Westray in the archipelago of Orkney (a Scandinavian colony of the Viking Age that came under Scottish rule in 1468 AD) (Fig. 1). We tested the hypothesis that seasonal variability in coastal SST during the 10th to 12th centuries was similar to that of the late 20th century (1960–1991).

Section snippets

Archaeological context

The Quoygrew archaeological site (59.34°N, 2.98°W) is located at the head of Rack Wick Bay on the island of Westray in the archipelago of Orkney, north of mainland Scotland (Fig.1). It was a rural farming and fishing settlement occupied between the 10th century AD and 1937. Excavation focused on houses and associated middens (refuse dumps) dating from the earliest seven centuries of this millennium-long sequence. Midden deposits from the 10th to 15th centuries (MCA-LIA) were particularly well…

Water sampling and oxygen isotope analysis

Monthly water samples for $\delta^{18}O$ analysis were collected from the large northwest-facing bay, Rack Wick, on Westray, Orkney (Fig.1). Fifteen milliliters of water were collected once a month from August 2005 to 2006 (missing months December 2005 and June 2006, n=11). Salinity was measured using a refractometer with an accuracy of 0.5 psu. Water samples were analyzed on a Finnigan Delta-S dual inlet mass spectrometer using an automated CO_2–H_2O equilibration unit. Standardization is based on…

Salinity and oxygen isotope ratios of water

Salinity of monthly water samples taken at Rack Wick Bay collected from August 1, 2005 to August 24, 2006 is relatively stable, averaging 34.8±0.5 psu (n=11) and ranging from 34.0 to 35.5 psu (Table2). Oxygen isotope ratios also have minimal variability (Table2). Measured values average 0.31±0.17‰ (VSMOW; n=11) and range from −0.12‰ to 0.45‰. Samples taken during year 2006 are especially invariant, averaging +0.40±0.04‰ (n=7). Estimated values based on mixing Eq.(1) are consistent with…

Estimated SST and comparison to the late 20th century

The quasi-sinusoidal $\delta^{18}O$ time series of MCA shells from the 10th to 12th centuries all reflect seasonal temperature fluctuation. Like other *Patella* shells from the cold-temperate biogeographic province, prominent growth lines form in the winter (Fenger et al., 2007 and references therein; Wang et al., 2012) (Fig.3, Fig.4). A single exception, specimen QG2-7180-2, also formed growth lines during spring (located at 1.3, 2.9 and 10.5 mm from the growth margin) and summer (located at 8.9 mm from…

Conclusions

Our study provides reconstructed SST variability at seasonal time scales in the North Atlantic along northern coastal Scotland during the early MCA (10th to 12th centuries). We illustrate the value of using climate archives from fast-growing, short-lived mollusc shells. Such high-resolution archives simultaneously record winter and summer seasons and, unlike more traditional proxy records, approach the full seasonal range of temperature. Because the shells in our study grow fastest during the…

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> …Current knowledge of the MCA indicates that this was a period of global climate reorganization, with pronounced warming in the high-latitude North Atlantic (Lamb, 1965; Mann et al., 2009), increased cool-season precipitation in the British Isles (Lamb, 1965), warming and drying in California (LaMarche, 1974), cooling and reduced winter precipitation in Central Asia (Graham et al., 2011; Mann et al., 2009), and cooler SSTs in the central and Eastern Equatorial Pacific (Cobb et al., 2003; Rein et al., 2004). This global-scale climate reorganization has been connected to circulation pattern

changes in the Indo-Pacific warm pool, strengthening of the El Nino/Southern Oscillation phenomenon, variation in the NAO, and strengthening of the North Atlantic meridional overturning circulation (Cronin et al., 2010; Graham et al., 2011; Surge and Barrett, 2012; Wanamaker et al., 2012). Multiproxy approaches for assessing decadal-to centennial-scale variations in temperature during the MCA were compiled by Mann et al. (2009), and were subsequently used to model spatially resolved large-scale relative changes in temperature.…

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