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Holocene sea subsurface and surface water masses in the Fram Strait – Comparisons of temperature and sea-ice reconstructions

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ABSTRACT

Two high-resolution sediment cores from eastern Fram Strait have been investigated for sea subsurface and surface temperature variability during the Holocene (the past ca 12,000 years). The transfer function developed by Husum and Hald (2012) has been applied to sediment cores in order to reconstruct fluctuations of sea subsurface temperatures throughout the period. Additional biomarker and foraminiferal proxy data are used to elucidate variability between surface and subsurface water mass conditions, and to conclude on the Holocene climate and oceanographic variability on the West Spitsbergen continental margin. Results consistently reveal warm sea surface to subsurface temperatures of up to 6 °C until ca 5 cal ka BP, with maximum seawater temperatures around 10 cal ka BP, likely related to maximum July insolation occurring at that time. Maximum Atlantic Water (AW) advection occurred at surface and subsurface between 10.6 and 8.5 cal ka BP based on both foraminiferal and dinocyst temperature reconstructions. Probably, a less-stratified, ice-free, nutrient-rich surface ocean with strong AW advection prevailed in the eastern Fram Strait between 10 and 9 cal ka BP. Weakened AW contribution is found after ca 5 cal ka BP when subsurface temperatures strongly decrease with minimum values between ca 4 and 3 cal ka BP. Cold late Holocene conditions are furthermore supported by high planktic foraminifer shell fragmentation and high δ^{18}O values of the subpolar planktic foraminifer species *Turborotalita quinqueloba*. While IP$_{25}$-associated indices as well as dinocyst data suggest a sustained cooling due to a decrease in early summer insolation and consequently sea-ice increase since about 7 cal ka BP in surface waters, planktic foraminiferal data including stable isotopes indicate a slight return of stronger subsurface AW influx since ca 3 cal ka BP. The observed decoupling of surface and subsurface waters during the later Holocene is most likely attributed to a strong pycnocline layer separating cold sea-ice fed surface waters from enhanced subsurface AW advection. This may be related to changes in North Atlantic subpolar versus subtropical gyre activity.

1. Introduction

In the Arctic, effects of global climate change occur more rapidly and severe than in other regions on Earth due to the polar amplification (Manabe and Stouffer, 1980). Over the past few decades, the Arctic sea-ice cover has been shrinking continuously while more heat is delivered to the high north through different atmospheric and oceanic mechanisms. Climate model projections not only predict a change from perennial to more seasonal sea-ice cover in the Arctic but also globally rising sea level with significant feedbacks to global climate (e.g., Bengtsson et al., 2006).

The Fram Strait between Greenland and Svalbard is the only deepwater connection where warm and cold surface to deep water masses exchange between the Arctic and the world's oceans. Northward flowing warm and saline Atlantic Water (AW) via the eastern Fram Strait strongly contributes to the Arctic Ocean's heat budget.

Reconstructions of past climate and oceanographic conditions

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are essential for understanding and modelling of the current and future climate. Extending the record of ocean temperatures beyond the era of instrumental measurements facilitates improved knowledge about the long-term mechanisms of heat advection into the Arctic Ocean and water mass stratification. This also includes their forcing factors such as insolation, sea-ice extent, ocean current strength, and sea-level changes. During recent decades, the eastern Fram Strait as the major gateway between the northern North Atlantic and the Arctic Ocean has been studied extensively to better understand Holocene environmental changes (Hald et al., 2004; 2007; Ślubowska et al., 2005; Rasmussen et al., 2007, 2013; Ślubowska-Woldengen et al., 2008; Müller et al., 2009; 2011; 2012; Werner et al., 2011; 2013; 2014; Aagaard-Sørensen et al., 2014a,b) However, complex water mass interactions complicate straightforward reconstructions of past water mass temperatures in the area. In this paper, Holocene planktic foraminifera from the eastern Fram Strait have been used to reconstruct past sea subsurface water temperatures using transfer functions (Husum and Hald, 2012). Modern planktic foraminifer assemblages are dominated by two main species *Neogloboquadrina pachyderma* and *Turborotalita quinqueloba*. *N. pachyderma* is associated with cold polar waters (e.g., Bé and Tolderlund, 1971; Volkmann, 2000) while *T. quinqueloba* is commonly linked to warm and saline Atlantic Water advection in the Fram Strait area (Volkmann, 2000), in addition to the Arctic Front where Atlantic and Arctic water masses encounter (Johannessen et al., 1994; Matthiessen et al., 2001). *T. quinqueloba* is a symbiont-bearing foraminifer that is therefore bound to the uppermost photic zone due to required light conditions for photosynthetic activity (Bé, 1977). Different from studies in the central Irminger Sea where both species record temperatures around the same depth but during different periods of the spring/summer season (Jonkers et al., 2010), recent studies of living planktic foraminifera from the Fram Strait show no clear differences in seasonal flux patterns between *N. pachyderma* and *T. quinqueloba.* Depending on water mass and sea-ice conditions, both species inhabit rather similar summer depth habitats within the uppermost ca 200 m of the water column (Manno and Pavlov, 2014; Pados and Spielhagen, 2014). Previous studies from the Fram Strait and western Svalbard have shown heat advection to the Arctic Ocean was enhanced during the Early Holocene, driven by maximum summer insolation and wind force and/or thermohaline circulation (e.g., Koç et al., 1993; Hald et al., 2007; Rasmussen et al., 2007; 2013; Ślubowska-Woldengen et al., 2008). Most studies indicate a cooling trend after ca 8 cal ka BP (Hald et al., 2004; Ślubowska-Woldengen et al., 2007; Müller et al., 2012). A significantly warmer Mid-Holocene and probably increased heat flux to the Arctic Ocean was found by some studies in the Barents Sea/Svalbard area with ocean temperatures likely higher than for the remainder of the Holocene (e.g., Sarnthein et al., 2003; Hald et al., 2007; Rasmussen et al., 2007). Consistent with a decreasing summer insolation during the late Holocene, compared to the preceding early and mid-Holocene intervals, reconstructed seawater temperatures were lower; and more stable conditions with extended sea-ice conditions prevailed in the area (Sarnthein et al., 2003; Müller et al., 2012; Werner et al., 2013). However, many of the reconstructions using planktic foraminifera and transfer functions were based on transfer functions with only few polar and subpolar modern analogues (e.g., Kucera et al., 2005; Husum and Hald, 2012).

Two high-resolution sediment cores comprising the last ca 12,000 years have been studied for planktic foraminiferal content in order to reconstruct sea subsurface temperatures at 100 m water depth (SST100; cf. Husum and Hald, 2012). Proxy data such as the ice-rafted debris and biomarkers complement SST100 reconstructions for a comprehensive reconstruction of Holocene variability in this crucial area with regards to the changing modern Arctic system. The spring sea ice proxy IP_{25} (Belt et al., 2007; Brown et al., 2014), the ratio of IP_{25} to its structurally related C_{25} highly branched isoprenoid (C_{25}-HBI)diene (DIP_{25} index; Fahl and Stein, 2012; Cabedo-Sanz et al., 2013), and biomarkers indicative of phytoplankton productivity allow estimates of sea-ice and primary-productivity changes associated with temperature variations at the core site. Previously, it has been assumed that the DIP_{25} index could refer to relative sea surface temperature (at ca 10 m water depth; SST10) changes (Xiao et al., 2013; Müller and Stein, 2014). Here, for the first time, DIP_{25} values are directly compared to reconstructed ocean temperature trends, which may give insight into the suitability of the DIP_{25} index as a potential SST10 proxy.

2. Hydrography

Northward flowing warm and saline Atlantic Water enters the Arctic Ocean as the West Spitsbergen Current (WSC) via the eastern Fram Strait (Fig. 1). The WSC delivers warm and saline (T up to 6 °C, S > 35, Figs. 1 and 2) AW at surface to subsurface water depths to the Arctic Ocean where its upper part becomes transformed into a less saline surface layer by ice melt and mixing with low-saline waters of mainly riverine origin.

The strength of northward flowing AW is affected by the variability of both the cyclonic subpolar gyre (SPG) and the anticyclonic subtropical gyre (STG) in the North Atlantic Ocean (Hátún et al., 2005). In particular, increasing salinities in the northeastern part of the North Atlantic have been found to correspond to decreasing circulation of the SPG (Häkkinen and Rhines, 2004) as well as to the shape of the gyre (Hátún et al., 2005).

In response to Arctic Ocean surface current patterns (Transpolar Drift and Beaufort gyre), sea ice as well as cold, fresh water masses exit along western Fram Strait as part of the East Greenland Current (EGC), which carries cold and fresh polar waters (T < 0 °C, S < 34.4; e.g., Rabe et al., 2009) towards the Greenland Sea. Accordingly, sea-ice extent in the Fram Strait is controlled by two opposite current systems keeping eastern Fram Strait at present ice-free year-round while western Fram Strait stays perennially sea-ice covered.

3. Material and methods

The 9.54 m long Kastenlot core MSM5/5-723-2 from the eastern Fram Strait (79°9′N, 5°20′E, 1350 m water depth) was retrieved in summer 2007 during cruise leg MSM5/5 with RV Maria S. Merian. The uppermost section of the sediment core (4.75 m) was investigated at high resolution for proxy climate indicators such as biomarkers, foraminiferal assemblages and stable isotopes, and contents of ice-rafted debris. The studied section consists of dark olive to brownish black silty clays where from visual core inspection no evidence for abrupt changes in sedimentation rates such as hiatuses etc. could be indicated. Age control of the sediment core is based on six accelerator mass spectrometry (AMS) radiocarbon dates which had been published previously by Müller et al. (2012). To the existing age-depth-model we add two more dates (Table 1; Fig. 3). Analyses were conducted at the Leibniz Laboratory of Kiel University using ca 10 mg of $CaCO_3$. All measurements were carried out on a single species *N. pachyderma*. Radiocarbon dates were converted to calendar years BP (present = 1950 AD) applying the calibration software Calib version 7.1 (Stuiver and Reimer, 1993) with the Marine13 calibration data set (Reimer et al., 2009), including a reservoir correction of ~400 years. Chronology is established using the calibrated calendar ages and assuming uniform sedimentation rates between them by linear interpolation.

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