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Evaluation of the sea ice proxy IP_{25} against observational and diatom proxy data in the SW Labrador Sea

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ABSTRACT

The recent rapid decline in Arctic sea ice cover has increased the need to improve the accuracy of the sea ice component in climate models and to provide detailed long-term sea ice concentration records, which are only available via proxy data. Recently, the highly branched isoprenoid IP_{25}, identified in marine sediments underlying seasonal sea ice, has emerged as a potential sea ice specific proxy for past sea ice cover. We tested the reliability of this biomarker as a sea ice proxy against observational sea ice data (sea ice concentrations from the global HadISST1 database) and against a more established sea ice proxy (sea ice diatom abundance in sediments) in the South-West (SW) Labrador Sea. Furthermore, our study location at the southern margin of Arctic sea ice drift provided a new environmental setting in which to further test the novel PIP_{25} index. Our two study sites are located North-East (NE) and South-East (SE) of Newfoundland where box cores covering the last ca 100–150 years were collected. IP_{25} concentrations are nearly an order of magnitude higher and sea ice diatoms more abundant in sediments from NE of Newfoundland, where sea ice prevails 2–4 months per year compared to the sediments SE of Newfoundland, where conditions are generally ice-free year round. The IP_{25} fluxes NE of Newfoundland agree well with multi-decadal North Atlantic Oscillation (NAO) trends in the study area, which in previous studies have been shown to affect the climatic and sea ice conditions in the region. When assessed against observational sea ice data, IP_{25} appears to be a more sensitive indicator of sea ice variability in this setting compared to sea ice diatoms and proved to be a robust and reliable proxy for reconstructing low-frequency variability in past sea ice concentrations. The PIP_{25} index results clearly differ from the observed sea ice data underlining that caution needs to be exercised when using the index in different environmental settings.

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1. Introduction

Arctic sea ice plays an important role in Northern Hemisphere climate and ocean circulation, modulating surface albedo, air-sea heat and gas exchange and surface water stratification (de Vernal et al., 2008 and references therein). A number of studies have revealed a significant reduction in Arctic sea ice cover over the past three decades (e.g. Cavalieri et al., 1997; Johannessen et al., 2004; Stroeve et al., 2007; Comiso et al., 2008) and it is proposed that this melt is in part associated with the recent rise in global temperatures, which is further amplified at high latitudes (IPCC, 2007). As snow and ice are replaced with darker ocean and land surfaces, the surface albedo decreases, which, in turn, results in an even more pronounced warming trend over the Arctic. A recent study by Screen and Simmonds (2010) further suggests that diminishing sea

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ice has played a leading role in the amplification of Arctic near-surface air temperature. If the current trends continue, Arctic winter sea ice cover will be much thinner in the future and the Arctic ocean may become largely ice free during the summer as soon as the middle of this century (Holland et al., 2006; Wang and Overland, 2009). These drastic changes are expected to affect sea ice and fresh water export from the Arctic Ocean into the North Atlantic (Lique et al., 2009), and will likely impact both atmospheric and oceanic circulation thus influencing the global climate system (Serreze et al., 2007). However, although we can predict that changes will occur in the future, their magnitude remains poorly constrained (Nghiem et al., 2007), with future changes in Arctic sea ice cover representing one of the largest uncertainties in the prediction of future climate (Hewitt et al., 2001; Renssen et al., 2005; Stroeve et al., 2007). Hence knowledge of the natural and long-term (>30 years) variability of Arctic sea ice cover is critical due to its importance in the global climate system and thus global climate models (see references in Wang and Overland, 2009). However, at present very few, pre-instrumental era documentary records of Arctic sea ice exist, and these often include less accurate or low-resolution data (e.g. Bergthórsson, 1969; Grumet et al., 2001; Ogilvie and Jónsson, 2001).

In the absence of reliable long-term instrumental and other historical data, proxy records contained in terrestrial ice and in marine sediments underlying sea ice covered regions can offer a valuable alternative. A variety of sedimentary and ice core proxies have been used to trace the past extent of sea ice, including lithogenic tracers entrained in and dispersed by sea ice (ice-rafted debris; IRD), sedimentary facies (the position of opal belt), microfossils (dinoflagellates cysts, diatoms, foraminifera and ostracods), (bio)chemical proxies (methanesulfonic acid (MSA), sea salt (ssNa)) and stable isotopes (foraminiferal $\delta^{18}O$) (for a detailed treatise, see elsewhere in this issue). Unfortunately, most proxy records have their limitations and this also holds true for sea ice related proxies. These limitations include dissolution (calcareous and siliceous microfossils), the confounding effect of other environmental factors on the reconstructed sea ice signal ($\delta^{18}O$) and bias introduced by meteorological and oceanographic conditions (e.g. prevailing wind directions and the presence of permanent sea ice; ssNa). Even the calibration of sea ice proxies in surface sediments (assumed to represent modern sedimentation) against sea ice concentrations from satellite observations suffers from poorly constrained sedimentation rates, which can potentially lead to a significant mismatch between the time periods compared for calibration.

Another important aspect to consider is that all currently used Arctic sea ice proxies are not sea ice specific, even if found in the sea ice matrix like fine-grained sediment and some microalgal species: Ice-inhabiting dinoflagellate taxa do not produce fossilisable cysts (that could be identified in the underlying sediments) and cryophilic diatom taxa also thrive in cold waters beyond the sea ice edge (von Quillfeldt et al., 2003; von Quillfeldt, 2004; de Vernal and Marret, 2007; Lundholm and Hasle, 2010). Given these disadvantages it can be argued that additional, complementary sea ice proxies are needed to improve our understanding of Arctic sea ice variability.

Recently, a class of unsaturated hydrocarbon compounds (highly branched isoprenoids; HBIs) has drawn attention as a potential new sea ice proxy. These HBIs have been identified both in polar sea ice and in underlying sediments back to 60 000 yr BP (Collins et al., 2013 and references therein (this issue)). They are produced by diatoms living in the brine channels of sea ice, released during melt and subsequently archived in the underlying marine sediments providing a proxy for seasonal sea ice presence (Belt et al., 2007, 2010; Brown et al., 2011). Studies on sea ice, sediment traps and sediment samples from the Canadian High Arctic have shown that a C_{25} mono-unsaturated HBI isomer (IP_{25}) may be used as a proxy for past sea ice presence in the Arctic (Belt et al., 2007). Importantly, unlike the previously discussed sea ice proxies, IP_{25} is specific to sea ice, which is confirmed by its unique isometric nature, presence within the sea ice (combined with its absence from the open water phytoplankton assemblage), and its enriched stable carbon isotope ($\delta^{13}C$) values (Belt et al., 2008).

Since the emergence of IP_{25} as a sea ice proxy, records have been compiled for several marine sediment cores from the Arctic (Massé et al., 2008; Andrews et al., 2009; Müller et al., 2009; Vare et al., 2009, 2010; Belt et al., 2010; Müller et al., 2011; Fahl and Stein, 2012; Xiao et al., 2013), with the longest record reaching back ca 30 000 years (Müller et al., 2009). Most of these studies compare IP_{25} with a range of sea ice and climate-related proxies, while Müller et al., 2011 also compare surface sediment IP_{25} abundances with satellite sea ice data. However, as the proxy is still novel (its potential applicability as a sea ice proxy was first suggested by Belt et al., 2007), the reliability of IP_{25} needs to be further tested in a variety of environments and geographical locations, especially for past sea ice conditions.

To date no comparison of down-core IP_{25} reconstructions with detailed observational sea ice and other instrumental data from the 20th century exists. Hence the aim of the present study is to test IP_{25} data from box core sediments against observational data in order to study the reliability of IP_{25} as a proxy of past sea ice conditions. This test is based on IP_{25} data from box cores off Newfoundland (Fig. 1), which are compared with instrumental data from nearby stations (Fig. 1) and with a more well-established Arctic sea ice proxy (the percentage abundance of sea ice diatoms in sediments) (e.g. Moros et al., 2006; Ran et al., 2006; Justwan and Koc, 2008; Ren et al., 2009). No previous study has attempted the comparison of these two sea ice proxies. We further aim to assess the applicability of the recently introduced PIP_{25} sea ice index based on IP_{25} and an open-water phytoplankton marker (Müller et al., 2011, 2012). The resulting reconstructions are the first of their kind in the Labrador Sea and the most southern IP_{25} records to date.

2. Regional setting

Our two study sites are located NE (Bonavista Bay) and SE (Placentia Bay) of Newfoundland (Fig. 1). The area is directly influenced by the southward flowing polar Labrador Current (LC), which is a major source of fresh water, sea ice and icebergs to mid-latitudes. The LC is fed by the West Greenland Current (WGC), the Baffin Current and the Hudson Current (Fig. 1). The northward-flowing WGC, which is a mix of the polar East Greenland Current and the warmer Irminger Current carrying Atlantic water, splits into two branches before reaching Davis Strait. The main branch crosses the Labrador Sea, mixing with water from Baffin Bay, and forms the outer LC carrying ca 80% of the southward-flowing waters (Drinkwater, 1996; Cuny et al., 2002). The other branch of the WGC continues along the West Greenland coast into Baffin Bay to eventually join the southward-flowing Baffin Current, which entrains low-salinity Arctic surface waters from the Canadian Archipelago and Nares Strait (Drinkwater, 1996; Tang et al., 2004). The outflow from Hudson Strait is another important fresh water supply (Mertz et al., 1993), mixing with waters from Baffin Bay it forms the inner LC, carrying the remaining 20% of the southward flow (Drinkwater, 1996). The southern coast of Newfoundland is mostly influenced by Gulf Stream-derived waters (Catto et al., 1999, 2003), with only a moderate influence of the LC.

The dominant atmospheric pressure system over the North Atlantic (the North Atlantic Oscillation; NAO, Hurrell et al., 2003) exerts a strong influence over the area extending from Baffin Bay to the Labrador Sea; when the NAO index (defined as the difference in

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