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Sea-ice distribution in the modern Arctic Ocean: Biomarker records from trans-Arctic Ocean surface sediments

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Abstract

Records of the spatial and temporal variability of Arctic Ocean sea ice are of significance for understanding the causes of the dramatic decrease in Arctic sea-ice cover of recent years. In this context, the newly developed sea-ice proxy IP_{25}, a mono-unsaturated highly branched isoprenoid alkene with 25 carbon atoms biosynthesized specifically by sea-ice associated diatoms and only found in Arctic and sub-Arctic marine sediments, has been used to reconstruct the recent spatial sea-ice distribution. The phytoplankton biomarkers 24S-brassicasterol and dinosterol were determined alongside IP_{25} to distinguish ice-free or permanent ice conditions, and to estimate the sea-ice conditions semi-quantitatively by means of the phytoplankton-IP_{25} index (PIP_{25}). Within our study, for the first time a comprehensive data set of these biomarkers was produced using fresh and deep-frozen surface sediment samples from the Central Arctic Ocean proper (>80°N latitude) characterised by a permanent ice cover today and recently obtained surface sediment samples from the Chukchi Plateau/Basin partly covered by perennial sea ice. In addition, published and new data from other Arctic and sub-Arctic regions were added to generate overview distribution maps of IP_{25} and phytoplankton biomarkers across major parts of the modern Arctic Ocean. These comprehensive biomarker data indicate perennial sea-ice cover in the Central Arctic, ice-free conditions in the Barents Sea and variable sea-ice situations in other marginal seas. The low but more than zero values of biomarkers in the Central Arctic supported the low in-situ productivity there. The PIP_{25} index values reflect modern sea-ice conditions better than IP_{25} alone and show a positive correlation with spring/summer sea ice.

When calculating and interpreting PIP_{25} index as a (semi-quantitative) proxy for reconstructions of present and past Arctic sea-ice conditions from different Arctic/sub-Arctic areas, information of the source of phytoplankton biomarkers and the possible presence of allochthonous biomarkers is needed, and the records of the individual biomarkers always should be considered as well.

1. INTRODUCTION

Sea ice, prevailing in the polar region and characterised by distinct seasonal and interannual variability, plays a pivotal role in the climate system. For instance, the variability of sea ice affects the interplay between the atmosphere and the ocean by means of changing the heat flow (albedo) and gas exchange (Haas, 2010), as well as the deep-water formation related to the salinity variation caused by brine rejection/absorption during sea-ice formation/retreat (Petrich and Eicken, 2010). Furthermore, with an area covering 7% of the earth's surface (at least during winter; Comiso, 2010 and references therein) sea ice is also one of the largest biomes on earth. Changes in Arctic sea ice cover directly affect the ecological system including microbiological and macrobiological communities, and even the top predators (e.g., polar marine mammals and birds) of the food web (Legendre et al., 1992; Thomas and Dieckmann, 2010).

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By the end of the melt season in September, there remains only multi-year ice in the Arctic basin, parts of the Canadian Archipelago and parts of around Greenland (Comiso, 2010). In the marginal seas, large zones of fast ice (ice fastened to the coastline) occur on the shallow shelf during wintertime. Along the boundary of the fast ice, there are polynyas and leads (areas of open water surrounded by sea ice). Both fast ice and polynyas influence the dynamics and thermodynamics of the ocean circulation as well as the climate system (Polyakov et al., 2003; Ólason and Harms, 2010). Additionally, the occurrence of fast ice and polynyas plays an important role in the ecological system. The presence of fast ice in spring limits the light penetration, and thus the primary production. The polynyas, on the other hand, provide favourable living conditions for phytoplankton, resulting in significantly increased productivity (Pesant et al., 1996).

One of the characteristics of the Arctic Ocean is that it is a landlocked sea, comprising shallow shelf seas with one deep gateway, the Fram Strait, connecting the Arctic with the Atlantic Ocean (Fig. 1). Therefore, the sea ice in the Arctic is strongly influenced by freshwater discharge from the Eurasian and North American rivers, e.g., Yenisei, Ob, Lena and Mackenzie (Fig. 1; Peterson et al., 2002; Stein and Macdonald, 2004). The supply of riverine freshwater is essential to the process of formation, transport and decay of sea ice; conversely, changes in sea-ice cover may affect the freshwater export from the Arctic Ocean, and even impact global ocean circulation patterns (Aagaard and Carmack, 1989; Holland et al., 2006, 2009).

Satellite observations of seasonal and interannual sea-ice variability document the rapid decline of sea-ice cover at the end of the melt season during the last decades (Johannessen et al., 1995; Serreze et al., 2003, 2007; Comiso and Parkinson, 2004; Stroeve et al., 2005, 2007; Perovich et al., 2008). Following the extreme sea-ice reduction in summer of 2007 (Kerr, 2007; Perovich et al., 2008; Wang and Overland, 2009), the Arctic sea ice reached a minimum with an extent of 3.29 million square kilometres in September 2012 that is 18% less than in 2007 and 49% less than in 1979, respectively (Boetius et al., 2013).

In order to understand the causes of sea-ice loss, i.e., whether anthropogenic influence and/or natural variability are major controlling processes, it is essential to reconstruct

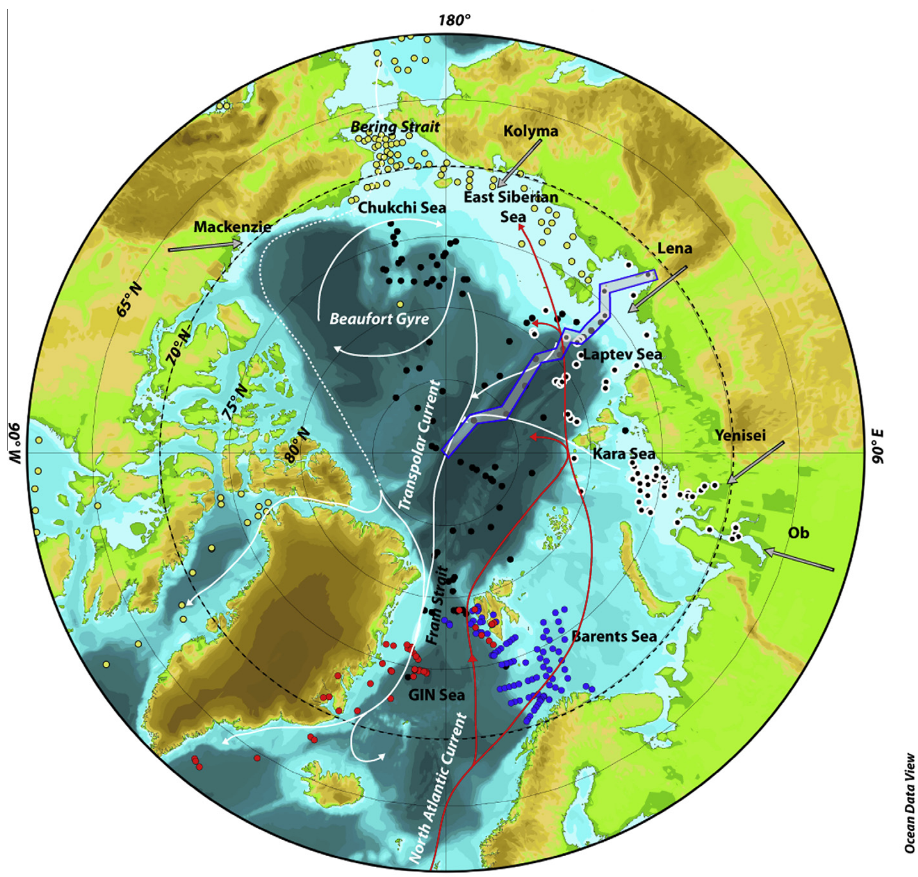

Fig. 1. Locations of surface sediments used for IP_{25} study in the Arctic Ocean. Dots in different colours reflect the samples from different studies: black dots (this study); red dots (Müller et al., 2011); blue dots (Navarro-Rodriguez et al., 2013); yellow dots (Stoynova et al., 2013); black dots with white circle (Xiao et al., 2013). A transect from North Pole to Laptev Sea along Lomonosov Ridge with sea-ice and biomarker distributions discussed in more detailed and illustrated in Fig. 5, is indicated by semi-transparent grey bars. Red arrows show the warm and salty surface water from the Atlantic enters the Arctic Ocean, while white arrows show the process of the cold and less salty water (Jones, 2001). Straight arrows indicate rivers draining into the Arctic Ocean. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)