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Shelf basin exchange along the Siberian continental margin: Modification of Atlantic Water and Lower Halocline Water

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ABSTRACT

Salinity and stable oxygen isotope ($\delta^{18}O$) evidence shows a modification of Atlantic Water in the Arctic Ocean by a mixture of sea-ice meltwater and meteoric waters along the Barents Sea continental margin. On average no further influence of meteoric waters is detectable within the core of the Atlantic Water east of the Kara Sea as indicated by constant $\delta^{18}O$, while salinity further decreases along the Siberian continental slope.

Lower Halocline Waters (LHW) may be divided into different types by Principal Component Analysis. All LHW types show the addition of river water and an influence of sea-ice formation to a varying extent. The geographical distribution of LHW types suggest that the high salinity type of LHW forms in the Barents and Kara seas, while other LHW types are formed either in the northwestern Laptev Sea or from southeastern Kara Sea waters that enter the northwestern Laptev Sea through Vilkitsky Strait. No further modification of LHW is seen in the eastern Laptev Sea but the distribution of LHW-types suggest a bifurcation of LHW at this location, possibly with one branch continuing along the continental margin and a second branch along the Lomonosov Ridge. We see no pronounced distinction between onshore and offshore LHW types, as the LHW components that are found within the halocline over the basin also show a narrow bottom-bound distribution at the continental slope that is consistent with a shelf boundary current as well as a jet of water entering the western Laptev Sea from the Kara Sea through Vilkitsky Strait.

1. Introduction

Due to strong stratification the Arctic Ocean halocline insulates the sea-ice cover from the underlying Atlantic Water (AW) heat and thus plays a fundamental climatological role (e.g. Rudels et al., 1996). With the ongoing climate change in the Arctic Ocean involving alterations in sea-ice patterns (e.g. Overland and Wang, 2013; Timokhov et al., 2012) and increasing meteoric freshwater input (Zhang et al., 2013) significant changes are to be expected for the upper Arctic Ocean and halocline (e.g. Itkin et al., 2015 Bauch et al., 2010; Holland and Bitz, 2003; Bekryaev et al., 2010). Hence, further knowledge is needed on the current structure, formation processes and regions of the Arctic Ocean halocline.

In the Eurasian part of the Arctic Ocean the Lower Halocline is formed by modification of AW over the Barents and Kara seas (Rudels, 2004; Steele and Boyd, 1998; Aagaard et al., 1981); it has salinities of about ~33 to 34.5 and temperatures close to the freezing point of sea-water. However, temperatures may be slightly higher at the continental margin of the Laptev Sea (LS). This could be attributed to an enhanced vertical exchange above the continental shelf slope (Dmitrenko et al., 2011), although the underlying mechanism is under debate (Timokhov et al., 2015).

Here we study the shelf-basin exchange along the Siberian continental margin. The influx of large quantities of river water and low salinity shelf waters occurs at the eastern LS continental margin and has been investigated before (Bauch et al., 2014). In this study we will focus on the layers below about 50 m water depth down to the depth of the Atlantic core and specifically ask: are Lower Halocline Water (LHW) and AW modified by shelf waters along the continental slope of the Kara and Laptev shelves? As sea-ice processes are a dominant feature on the shelves, an application of $\delta^{18}O$ analysis and salinity/$\delta^{18}O$ mass balances are highly appropriate tools that enable us to identify and quantify the signal of sea-ice modification (melting and sea-ice formation) within the water column (e.g. Östlund and Hut, 1984; Bauch et al., 1995). Such shelf-basin interactions may have strong interannual and regional variability and are expected to be relatively small

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Nomenclature

Water masses

LHW Lower Halocline Water
AW Atlantic Water
modAW modified Atlantic Water
BSBW Barents Sea Branch Water
FSBW Fram Strait Branch Water

Currents

WSC West Spitzbergen Current
EGC East Greenland Current
ASBB Arctic Shelf Break Branch
VSC Vilkitsky Strait Current

Geographical names

SZ Severnaya Zemlya
VS Vilkitsky Strait
BS Barents Sea
KS Kara Sea
LS Laptev Sea
ESS East Siberian Sea

Others

AO Arctic Ocean oscillation
PCA Principal Component Analysis
EOF Empirical Orthogonal Functions

within the subsurface water masses such as the LHW and AW. First, we evaluate the properties of the core of AW in the Eurasian Basin of the Arctic Ocean in respect to geographical and inter annual variability. As the contributions of shelf components are expected to be small, this requires a high measurement precision of the $\delta^{18}O$ data. Therefore average $\delta^{18}O$ values are considered for the evaluation of the AW where variations are in the same range as the measurement precision. Then, we use a Principal Component Analysis (PCA) of the upper 50–250 m of the water column including $\delta^{18}O$ derived parameters and also hydrochemical data to investigate the influence of shelf waters in LHW and the modification of LHW along the Siberian continental margin. The approach of a PCA is chosen to decrease the degrees of freedom within this diverse multi-parameter oceanographic data set that includes strong gradients combined with strong inter annual variations.

2. Methods

Samples for $\delta^{18}O$ analyses at the Eurasian continental margin were collected in summer from 2005 to 2009 within the framework of the Nansen and Amundsen Basins Observational System (NABOS) program (expedition technical reports are available at http://nabos.iarc.uaf.edu/cruise/reports.php) and Polarstern expedition ARKXXII/2 in summer 2007 (see expedition reports in Schauer, 2008) (Fig. 1). Also shown are $\delta^{18}O$ data from Polarstern expeditions in 1993 and 1995 (Frank, 1996). In all cases water samples were taken with a conductivity-temperature-depth (CTD)-rosette with an accuracy of at least ±0.002 S/m in conductivity and ±0.005 °C in temperature.

Accuracy for all presented $\delta^{18}O$ is at least ±0.04‰ (Bauch et al., 2010, 2011a, 2011b, 2013). All $H_2{}^{18}O/H_2{}^{16}O$ ratios were calibrated with Vienna Standard Mean Ocean Water (VSMOW) and reported in the usual δ-notation (Craig, 1961). A subset of the NABOS stable isotope data from the LS continental margin were published before (Bauch et al., 2011a, 2011b). Data taken in 2007 were published without special attention on LHW (Bauch et al., 2011b).

Based on S/$\delta^{18}O$ mass balance calculations fractions of AW, meteoric water and sea-ice meltwater are derived following Bauch et al. (1995, 2011a). It is assumed that each sample is a mixture between fractions of Atlantic derived water (f_{mar}), river runoff (f_r), and sea-ice meltwater (f_{SIM}). As only stations west of 150°E are discussed, no additional analysis for the influence of Pacific derived waters is necessary (Abrahamsen et al., 2009; Bauch et al., 2011b). The mass balance is governed by the following equations:

$f_{mar}+f_r+f_{SIM}=1,$
$f_{mar}{}^*S_{mar}+f_r{}^*S_r+f_{SIM}{}^*S_{SIM}=S_{meas},$
$f_{mar}{}^*O_{mar}+f_r{}^*O_r+f_{SIM}{}^*O_{SIM}=O_{meas},$

where f_{mar}, f_r, and f_{SIM} are the fractions of marine water, river runoff, and sea-ice meltwater (SIM) in a water parcel, and S_{mar}, S_r, S_{SIM}, O_{mar}, O_r and O_{SIM} are the corresponding salinities and $\delta^{18}O$ values of the endmembers (Table 1). S_{meas} and O_{meas} are the measured salinity and $\delta^{18}O$ of the water samples. Technically f_r refers to meteoric water, which includes local precipitation, but as

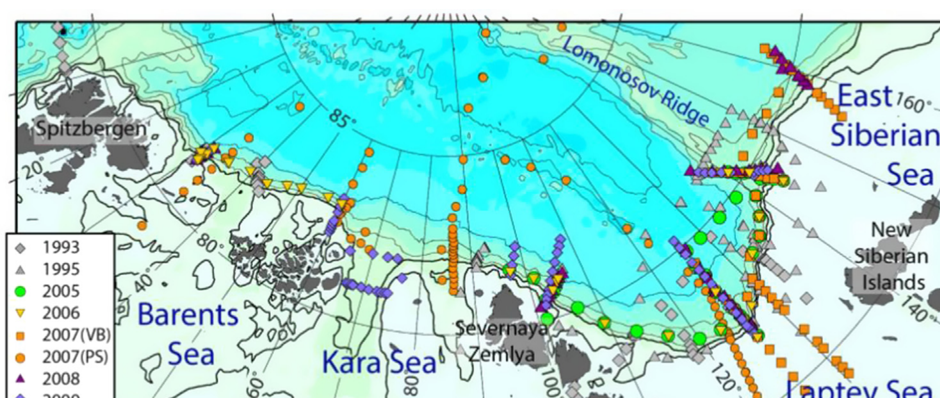

Fig. 1. Station distribution of NABOS data 2005–2009 and Polarstern data 1993, 1995 and 2007.