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Eurasian Arctic shelf hydrography: Exchange and residence time of southern Laptev Sea waters

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ABSTRACT

The hydrography of the Laptev Sea is significantly influenced by river water and sea-ice processes, which are highly variable over the annual cycle. Despite of an estuarine structure the inner and outer shelf regions are decoupled at times as documented by the stability of a warm intermediate layer formed during summer below the Lena River plume. We demonstrate that a remnant of this warm layer is preserved below the fast ice until the end of winter, while only slightly farther to the north, offshore of the landfast ice in the polynya region, the pycnocline is eroded and no signature of this layer is found. The warm intermediate layer (WIL) formed during summer can be used as tracer for Laptev Sea shelf waters throughout the winter. Thereby, residence times of southern Laptev Sea waters can be estimated to be at least from summer to the end of winter/spring of the following year.

1. Introduction

Variations and residence times of Laptev Sea waters may significantly influence the structure of the Arctic Ocean halocline (Johnson and Polyakov, 2001), which normally acts to isolate the sea-ice cover from the warm Atlantic-derived layer below. Although an average mean residence time for all Siberian shelves was derived as 3.5 ± 2 years (Schlosser et al., 1994), there is a clear lack of any detailed and more specific temporal information. A better knowledge of the residence time of waters on the shelf in causal linkage to the prevailing processes is of urgent importance in order to understand and predict both regional shelf dynamics and global environmental changes.

The vast Arctic shelves comprise about $\frac{1}{3}$ of the total Arctic Ocean area. While sea-ice and brine waters are produced during winter, the shelves are free of sea-ice during summer and sea-ice melt water is released together with fresh water from huge rivers. The Laptev Sea is one of the main production regions for Arctic sea-ice during winter (e.g. Zakharov, 1966) and large amounts of fresh water are received from the Lena River during summer. The seasonal hydrologic cycle explains about 25–75% of the entire salinity variability spectrum of the Siberian shelf hydrography (Dmitrenko et al., 2008a). Inter-annual and decadal fresh water anomalies on the Laptev and East Siberian shelves are of the same order of magnitude as the annual fresh water export rate to the Arctic Ocean (Dmitrenko et al., 2008b).

In this study, the distribution and transformation of water masses in the Laptev Sea are evaluated on a seasonal basis using data collected between 1993 and 2003. It is shown that the feature of a warm intermediate layer (WIL) formed during summer season beneath the river plume can be used as a tracer for shelf waters throughout the winter. While we cannot quantitatively evaluate the various processes eroding the WIL, from the fact that the WIL is still preserved at some positions at the end of winter a lower estimate for the residence time is derived for the subsurface layer in the southern Laptev Sea.

2. Material and methods

Ship-based expeditions were carried out in early summer 1998 (Fig. 1a), in 1993, 1994, 1999, 2000 and 2003 during main summer (Fig. 1b) and during autumn 1995 (Fig. 1c). Data from winter/spring expeditions were gained from the fast ice in the southern Laptev Sea and from the pack ice in the coastal polynya region in 1996 and 1999 (Fig. 1d). All CTD data have an accuracy of at least 0.02 °C in temperature and 0.02 mS/cm in conductivity. Salinity is reported on PSU scale without units according to SI convention.

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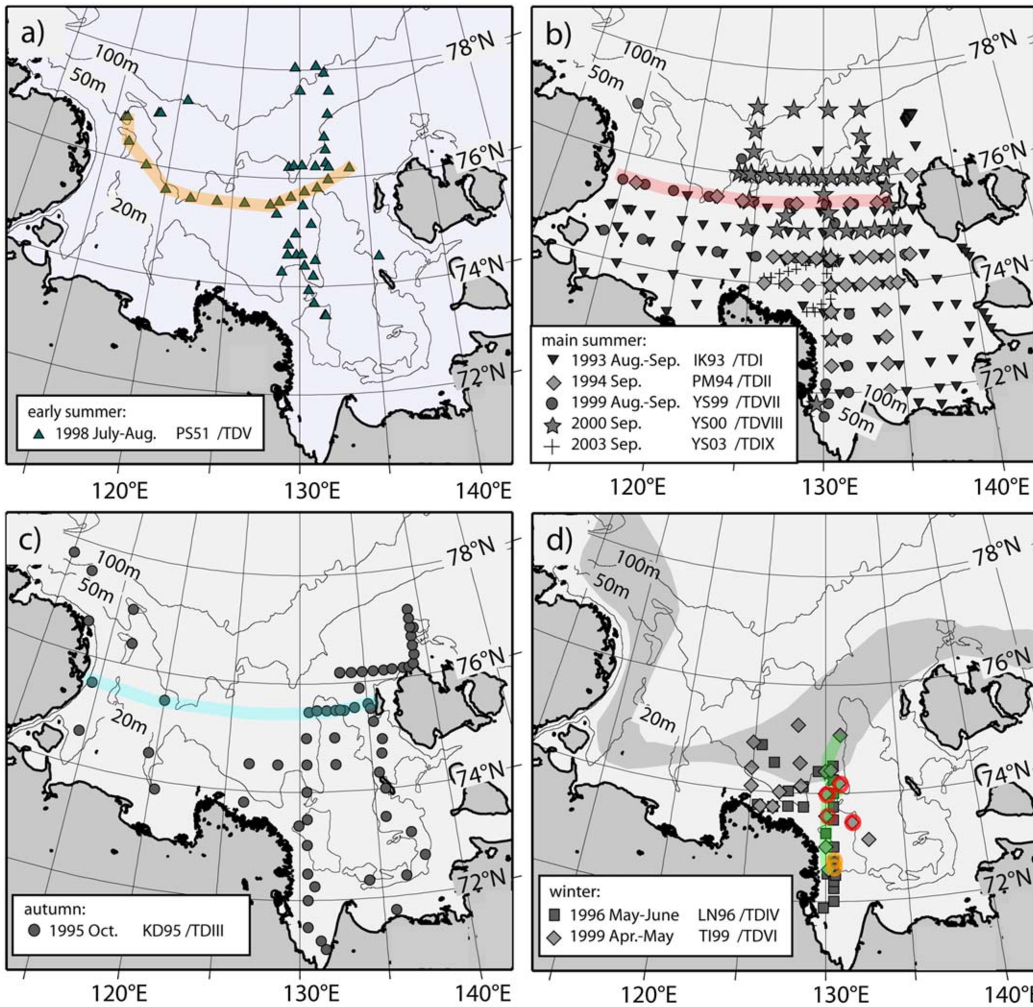

Fig. 1. Geographical distribution of stations (a) during early summer 1998, (b) main summer seasons, (c) autumn 1995 and (d) winter/spring season in 1996 and 1999. Stations with intermediate temperature maxima during winter/spring 1999 (red circles) and 1996 (orange circles) are highlighted. The shaded gray area represents the position of the coastal polynya in the Laptev Sea during winter sea-ice coverage according to Zakharov (1997). Shaded lines in 1a–d are along the sections presented in Fig. 2a–d for July/August 1998 (blue), September 1999 (red), October 1995 (orange) and April/May 1999 (green), respectively. The main outflows of the Lena River are between 72–73°N and 128°E. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Further details on expeditions are given within Kassens et al. (1994, 1997), Kassens and Dmitrenko (1995), Dmitrenko et al. (1999, 2005b), Pivovarov et al. (1999).

3. Hydrographic results

The fast ice in the Laptev Sea generally breaks up in June at the time of the main river discharge, which is about 4–5 times higher than the annual mean discharge (e.g. Létolle et al., 1993). Sea-ice cover retreats mainly during July and August before it recurs in October (Bareiss and Görgen, 2005). Therefore, in early summer the surface waters are generally cold and within about 1 °C above the freezing point (Fig. 2a). In July–August 1998 sampling occurred directly after the peak in main river discharge and fast ice break-up, and at a time when sea-ice cover was regressing, but still covering 30–40% of the eastern Laptev Sea shelf area (Bareiss and Görgen, 2005). At this stage, only the low-salinity river plume showed a warm surface signal of up to 5 °C (Fig. 2a), since solar radiation had not yet warmed the surface layer of the investigated shelf area (Fig. 1a). A slight intermediate temperature maximum is, nevertheless, already visible at two stations below the river plume (compare Fig. 2a at about 120°E and 124°E and about 15 m water depth).

The main summer season is during September and due to extensive exposure to solar radiation there is an overall warm surface layer (Fig. 2b). The main outflow and dispersion of river runoff extends east of about 125–130°E with inter-annual differences mainly in geographical extension to the north (Dmitrenko et al., 2005a; Bauch et al., 2009). A WIL with temperatures of up to 5 °C is observed beneath the river plume (see Fig. 2b). This warm intermediate temperature layer at relatively high salinities (above 23) is seen in all our summer datasets (Fig. 1b) below the river plume and is generally found in the entire eastern Laptev Sea (Dmitrenko et al., 1999).

In autumn, surface waters are cooled again (Fig. 2c) and the shelf starts to freeze-up. A WIL of up to 3 °C was preserved in autumn 1995 at depths between 15 and 20 m (Fig. 2c) at all stations east of about 127°E throughout the study area from 71 to 77°N (see Fig. 1c), while the surface layer was close to the freezing point.

In late winter, a remnant of this WIL is still preserved as documented in a local temperature maximum of up to about −0.5 °C and about 0.2–0.5° higher than surrounding temperatures observed at about 10–13 m water depth and at a salinity of about