Distribution of Sea Ice Derived Brine Signals from the Siberian Shelf Area Based on Stable Oxygen Isotope and Salinity Data

Irina Semeryuk[1] and Dorothea Bauch[2]

With 2 Figures

The Arctic Ocean is stratified by low-salinity surface and halocline waters, Atlantic water, and intermediate and deep waters (Aagaard et al. 1985). The water masses in the upper ocean between the surface and ~ 150 m in depth are subdivided into the cold polar mixed layer, which reaches depths of 30–50 m, and the underlying (50–150 m) cold halocline, characterized by near freezing temperature and increasing salinity with depth (Rudels et al. 1985). The water masses of the Arctic Ocean shelf regions are significantly influenced by river water runoff and processes of sea-ice melting and formation.

The distribution of the oxygen stable isotopes in the hydrological cycle is controlled by processes connected with phase transition. Due to isotope equilibrium in ice – water and water – vapour system, the less mobile phase has a higher concentration of the 18-oxygen than has the more mobile phase. The linear relationship between delta oxygen isotope content and S values can be accepted only as a first-order approximation (see Fig. 1). Any deviations from this direct mixing between river water and marine water can be attributed to sea ice processes.

Since river water is highly depleted in $\delta^{18}O$ relative to marine waters as well as to sea-ice, the $\delta^{18}O$ composition and salinity of a water sample can be used to separate the different water sources (Bauch et al. 1995, Östlund and Hut 1984).

The $H_2^{18}O/H_2^{16}O$ ratio is expressed as the fractional difference between the ratio in the sample to the ratio in standard mean ocean water (SMOW). According to the following notation:

$$\delta^{18}O(\text{‰}) = ({}^{18}O/{}^{16}O_{sample} - {}^{18}O/{}^{16}O_{SMOW})/{}^{18}O/{}^{16}O_{SMOW} \times 1000 \text{ (Craig 1961).}$$

1   Arctic and Antarctic Research Institute, Saint Petersburg, Russia, E-Mail: Irinasemeryuk@aari.ru.
2   GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany, E-Mail: dbauch@geomar.de.
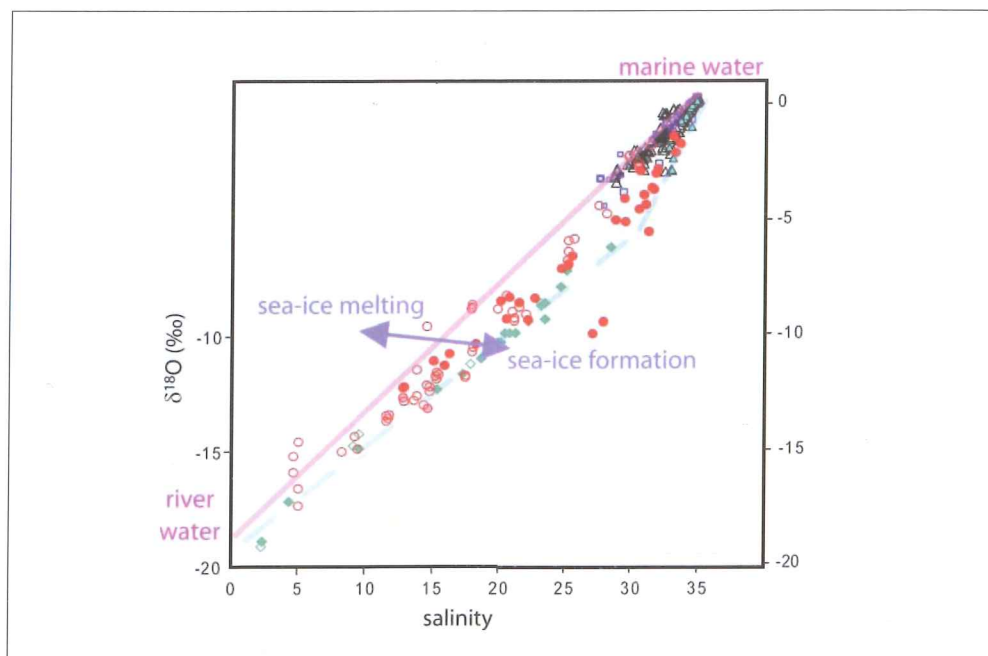
Fig. 1 Property plot of $\delta^{18}O$ *versus* salinity and shows data from the Laptev Sea continental margin (BAUCH et al. 2009). A mixing line between river water and Atlantic-derived waters (solid line) is indicated along with mixing lines including a brine-enriched water mass (dashed lines). The schematic arrow indicates the effects of sea ice melting and sea ice formation (BAUCH et al. 2009). Figure modified from BAUCH et al. 2009.

It is assumed that each sample is a mixture between marine water (*fmar*), river runoff (*fr*), and sea ice meltwater (*fi*). The balance is governed by following equations:

$$fmar + fr + fi = 1 \qquad\qquad [1]$$

$$fmar \times Smar + fr \times Sr + fi \times Si = S_{sample} \qquad\qquad [2]$$

$$fmar \times Omar + fr \times Or + fi \times Oi = O_{sample} \qquad\qquad [3]$$

where *fmar*, *fr*, *fi* are the fractions of Atlantic water, river runoff, and sea ice meltwater in water samples (subscript m) and Sx, $\delta^{18}Ox$, are the corresponding salinity and $\delta^{18}O$ (BAUCH et al. 1995).

The data used in this Masters thesis were collected during the icebreaker expeditions Nansen and Amundsen Basin Observation System (NABOS) in the Eurasian Basin (August–September 2005–2009) (BAUCH et al. 2014). Water samples were taken at the standard levels collected in glass bottles in order to prevent evaporation. Samples for $\delta^{18}O$ were analyzed at the Stable Isotope Laboratory of the Alfred Wegener Institute, Germany, Geoscience Isotope Laboratory of the British Geological Survey, UK, and the Leibniz Laboratory. Kiel, Germany. The precision of analytical measurements for all laboratories is ± 0.03 (BAUCH et al. 2011, 2014).

The data from NABOS 2005–2009 expeditions were used to analyze thermohaline structure in the upper part of the Arctic Ocean.

The water masses classification (see Fig. 2) was done on the basis of following parameters (T, S):

– Mixed layer: S ≤ 31.5;
– Shallow halocline water: t < 0.0 °C, 31.5 < S < 33.0;
– Deep halocline water: t < 0.0 °C, 33.0 ≤ S;
– Atlantic layer: t ≥ 0.0 °C, 33.0 ≤ S.

The Mixed layer is characterized by the vertically uniform low-salinity value. A strong salinity gradient is typical for the Shallow and Deep halocline water. The maximum temperature and salinity corresponds to the depth of the Atlantic water core.
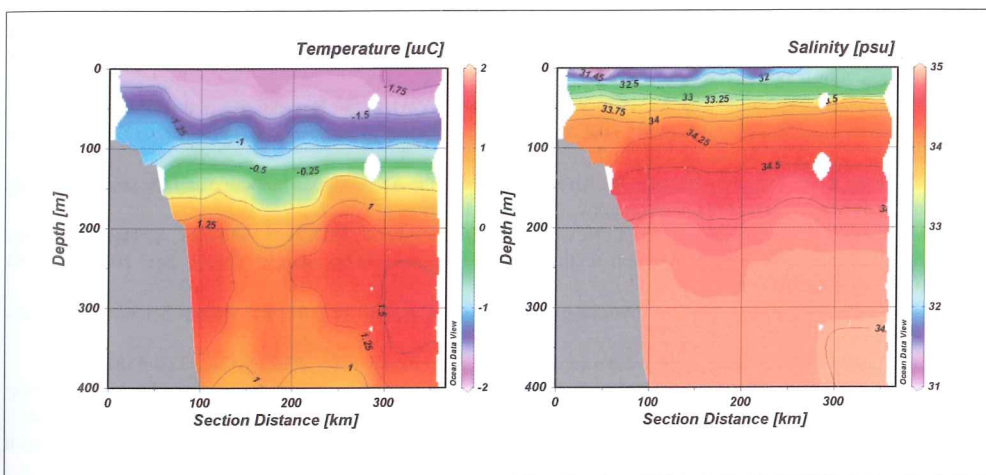

Fig. 2 Section of temperature and salinity distribution used for the water mass classification.

In the course of study, $\delta^{18}O/S$ mass balance was used to estimate the content of sea ice melt water and river water in the sea column and to describe temperature-salinity characteristics of the shelf waters.

It was observed that:

– Mean temperature and salinity of surface mixed layer have decreasing behaviour along the continental slope around the Eurasian basin. The most negative value of fi is in the mixed layer of the western Laptev Sea.
– Freshening and accumulation of brine-enriched water occur at the shelf areas of the Kara and Laptev Seas in an eastern direction. The modification of the halocline water along the continental slope occurs without significant changes in temperature. The largest signal of sea-ice melt water fraction was found in the Shallow halocline water in the western part of the Laptev Sea in 2007.
– There are cooling and freshening in the warm core of the Atlantic layer within the Arctic Ocean.
– Our study confirmed that the isotope-tracer method can be used successfully in oceano-

graphic observations to clearly separate between different shelf water masses depending on the content of sea ice melt water and river runoff.

– Stable oxygen isotopic composition of seawater in combination with salinity and temperature data allows to identify the source and conditions of formation of local water types and to assess quantitatively the extent of mixing between these waters.

References

AAGAARD, K., SWIFT, J. H., and CARMACK, E. C.: Thermohaline circulation in the Arctic Mediterranean Seas. J. Geophys. Res. *90*/C3, 4833–4846 (5C0002) (1985)

BAUCH, D., ERLENKEUSER, H., and ANDERSEN, N.: Water mass processes on Arctic shelves as revealed from δ^{18}O H_2O. Global and Planetary Change *48*, 165–174 (doi:10.1016/j.gloplacha.2004.12.011) (2005)

BAUCH, D., DMITRENKO, I., WEGNER, C., HOELEMANN, J., KIRILLOV, S., TIMOKHOV, L., and KASSENS, H.: Exchange of Laptev Sea and Arctic Ocean halocline waters in response to atmospheric forcing. J. Geophys. Res. *114*, C005008 (doi:10.1029/2008JC005062) (2009)

BAUCH, D., RUTGERS VAN DER LOEFF, M., ANDERSEN, N., TORRES-VALDES, S., BAKKER, K., and ABRAHAMSEN, E. P.: Origin of freshwater and polynya water in the Arctic Ocean halocline in summer 2007. Progress in Oceanography *91*, 482–495 (doi:10.1016/j.pocean.2011.07.017) (2011)

BAUCH, D., SCHLOSSER, P., and FAIRBANKS, R.: An H_2^{18}O study of the Arctic Ocean halocline and the sources of deep and bottom waters. Progress in Oceanography *35*, 53–80 (1995)

BAUCH, D., TORRES-VALDES, S., POLYAKOV, I., NOVIKHIN, A., DMITRENKO, I., McKAY, J., and MIX, A.: Halocline water modification and along-slope advection at the Laptev Sea continental margin. Ocean Sci. *10*/1, 141–154 (doi:10.5194/os-10-141-2014) (2014)

CRAIG, H.: Standard for reporting concentrations of deuterium and oxygen-18 in natural waters. Science *133*, 1833–1834 (1961)

ÖSTLUND, H., and HUT, G.: Arctic Ocean water mass balance from isotope data. JGR *89*/C4, 6373–6381 (1984)

RUDELS, B., LARSSON, A.-M., and SEHLSTEDT, P.-I.: Stratification and water mass formation in the Arctoc Ocean: some implications for the nutrient distribution. In: SAKSHAUG, E., HOPKINS, C. C. E., and ØRITSLAND, N. A. (Eds.): Proceedings of the Pro Mare Symposium on Polar Marine Ecology. Trondheim, 12–16 May 1990. Polar Research *10*/1, 19–31 (1991)

Irina SEMERYUK
Arctic and Antarctic Research Institute
Second line 23
199053 Saint Petersburg
Russia
E-Mail: Irinasemeryuk@aari.ru

Dorothea Bauch
GEOMAR Helmholtz Centre for Ocean Research
Wischhofstraße 1–3
24148 Kiel
Germany
E-Mail: dbauch@geomar.de