RUSSIAN JOURNAL OF EARTH SCIENCES
vol. 17, 3, 2017, doi: 10.2205/2017ES000602

Seafloor relief inhomogeneities and the tectonics of the Greenland-Lofoten Basin in the North Atlantic

D. I. Frey, A. N. Novigatsky,
M. D. Kravchishina, E. G. Morozov

Shirshov Institute of Oceanology, Russian Academy of Sciences, Moscow, Russia

Abstract. We analyzed CTD and ADCP measurements in the western Barents Sea carried out onboard the Russian R/V *Akademik Mstislav Keldysh* (cruise 68) in July–August 2017. We studied the water structure over a meridional section between Norway and Svalbard. The velocities of the bottom flow were measured on a mooring deployed in the deepest part of the trough. We compared direct velocity measurements with the tidal velocities calculated from satellite altimetry data. Despite strong barotropic tides in the region, the mean bottom flow was permanently directed from the Barents to the Norwegian Sea, which corresponds to the measured thermohaline structure of the deep waters.

This is the e-book version of the article, published in Russian Journal of Earth Sciences (doi:10.2205/2017ES000602). It is generated from the original source file using LaTeX's **ebook.cls** class.

Introduction

The Norwegian Current transports relatively warm, saline waters into the Arctic Ocean. This current has an offshore and coastal (North Cape Current) branches [*Bjerke and Torsethaugen*, 1989]. The former branch warms the west coast of Svalbard, while the latter transports warm water to the Barents Sea.

The interaction between cold and low-saline Arctic waters and relatively warmer and more saline Atlantic waters is a key feature of the entire North Atlantic region. Strong interaction between these waters occurs in the Barents Sea. Together with the Fram Strait it contributes to the water masses exchange between the Arctic and Atlantic oceans [*Giraudeau et al.*, 2016]. The shelf slopes define the western and northern margins of the Barents Sea (Figure 1). The western boundary is called the Barents Sea Opening (BSO) [*Smedsrud et al.*, 2013]; the northern boundary is the Northern Barents Sea Opening (NBSO) [*Lind and Invaldsen*, 2012]. The eastern strait between Franz Josef Land and Novaya Zemlya is called the Barents Sea Exit (BSX) [*Gammelsrød et al.*, 2009]. The outflow of cold deep waters from the Barents Sea occurs through all three boundaries [*Årthun*, 2011]. The first hydro-

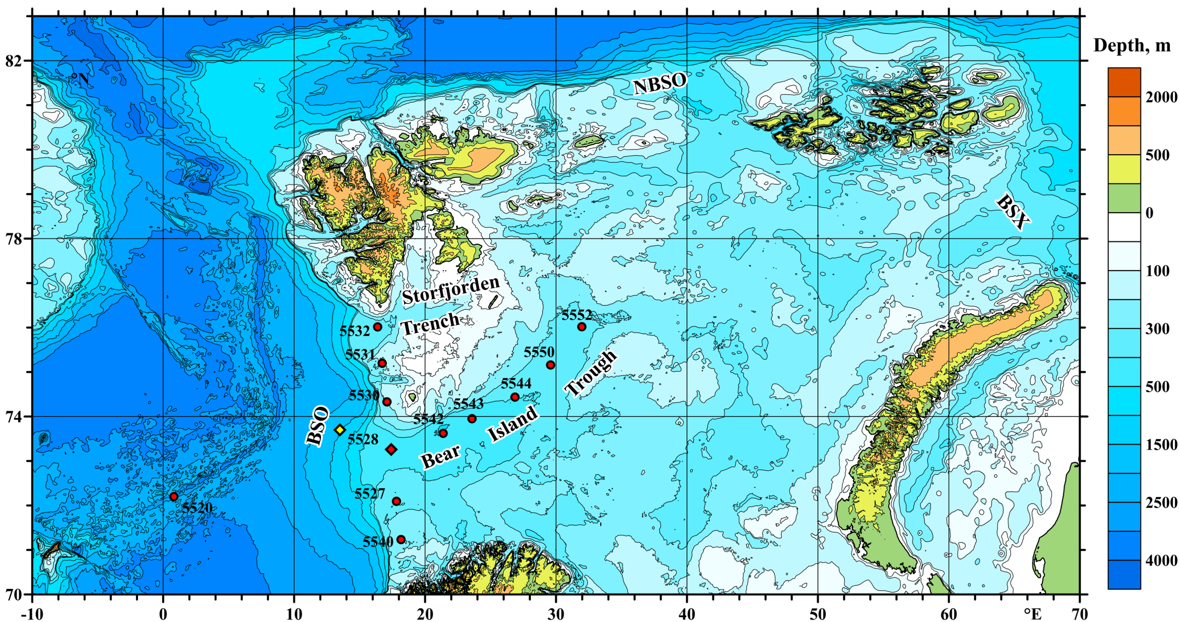

Figure 1. Locations of the measurements in the western Barents Sea in July–August 2017. Red circles show our CTD stations; red diamond is the site of mooring deployment in the Bear Island Trough; yellow diamond is the mooring location in 1995. Bathymetry is based on GEBCO 2014 data. Abbreviations: Northern Barents Sea Opening (NBSO); Barents Sea Opening (BSO); Barents Sea Exit (BSX).

graphic measurements in this region were performed in the beginning of previous century by *F. Nansen* [1906].

The deepest pathway for the water exchange between the Norwegian and Barents seas is the Bear Island Trough. It is located in the southwestern part of the Barents Sea; the characteristic depths of the trough are up to 500 meters; the background depths are 100–200 meters shallower. The length of the trough is more than 500 km and the width is approximately 100 km. The bottom current in the Bear Island Trough is directed to the Norwegian Sea [*Lukashin and Shcherbinin*, 2007].

The goal of this paper was to analyze the hydrographic conditions in the region of the Bear Island Trough in July–August 2017. We analyzed our direct velocity measurements in the deepest part of the trough and thermohaline structure of the bottom waters in the western Barents Sea.

Experimental Results and Discussion

On July 23–August 3, 2017, we occupied two CTD (Conductivity-Temperature-Depth) sections across and along the Bear Island Trough in the western Barents Sea. Each section includes 6 stations. We deployed a mooring with Acoustic Current Doppler Profiler (ADCP) close to the bottom at the point of intersection (station 5528) between these two sections in the deepest part of the Bear Island Trough. The bottom topography along the sections was measured by the Kongsberg EA600 12 kHz single beam echo sounder. The locations of CTD stations and moorings are shown in Figure 1.

The CTD profiles were measured from the surface to the bottom (3–4 meters above the seafloor) using Sea-Bird SBE-911plus profiler. This CTD system was equipped with two parallel temperature and conductivity sensors; the mean temperature difference between them did not exceed 0.001°C, while that of salinity was not greater than 0.001 PSU. The raw CTD data were processed by SBE Data Processing software version 7.23.2 with standard parameters described in Sea-Bird Electronics Inc., 2014, Seasoft V2: SBE Data Processing (URL http://www.seabird.com/software/SBEData ProcforWindows.htm).

Observed potential temperature and salinity over both sections are shown in Figure 2 and Figure 3. The surface temperature was approximately 7–8°C along the entire quasi-meridional section from Norway to 76°N near Svalbard slowly decreasing to the north. Unlike

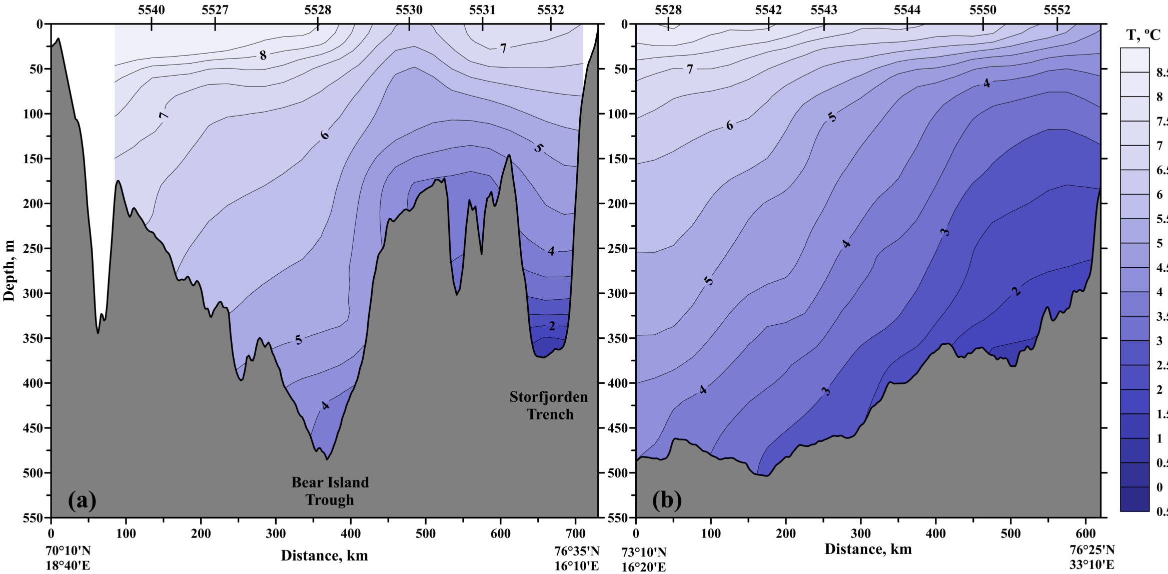

Figure 2. Potential temperature sections across (a) and along (b) the Bear Island Trough measured on July 23–August 3, 2017. The mooring was deployed at station 5528 in the deepest part of the quasi-meridional section. The vertical scale and temperature levels are the same in both figures. The grey color shows the ocean bottom.

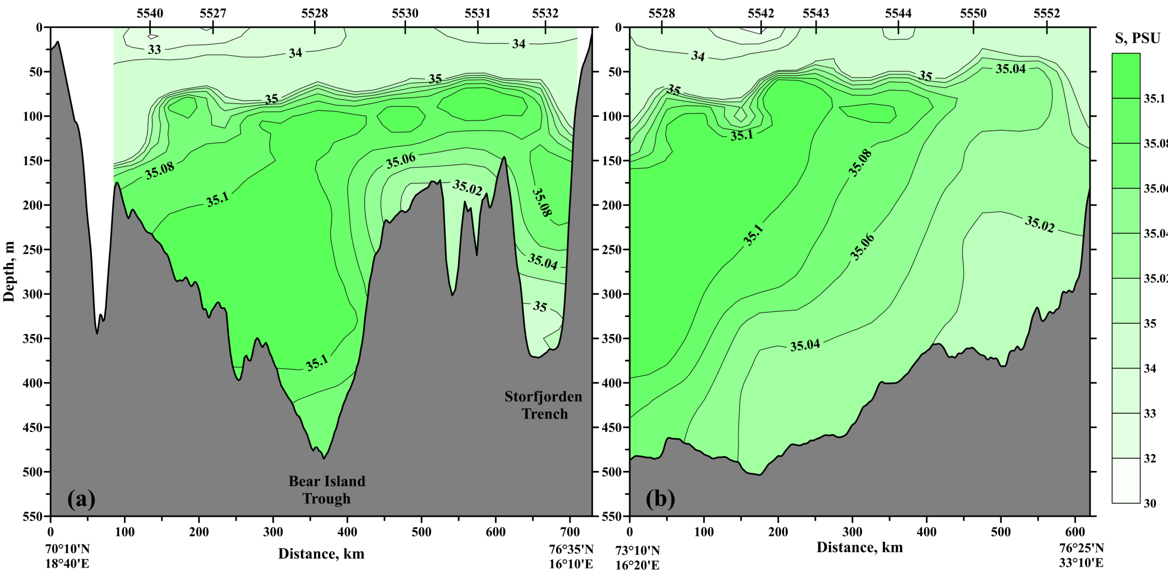

Figure 3. Salinity sections across (a) and along (b) the Bear Island Trough measured on July 23–August 3, 2017. The vertical scale and salinity levels are the same in both figures. The grey color shows the ocean bottom.

the surface temperatures, the bottom temperatures decreased significantly to the north forming a strong density gradient that drives the geostrophic currents. Despite the fact that the bottom water temperature in the deepest part of the Bear Island Trough was quite low (3.52°C), it was not the coldest water over this section. The Storfjorden Trench located immediately south of Svalbard to the north of Bear Island is 150 meters shallower but the bottom temperature there was much lower (1.05°C), which is approximately 2.5°C lower than in the Bear Island Trough. The second section along the trough (Figure 2b) shows significant increase of bottom temperature in the southwestern direction along this trough. The minimum temperature here was 1.53°C at a depth of 400 m in the northeastern part; the temperature near the exit from the Bear Island Trough (station 5528) was 3.52°C at a depth of 500 m. The temperature increase can be caused by the influence of warm Atlantic waters in the western part of the Barents Sea and by mixing of cold bottom water with warmer waters above the bottom layer during its southwestward propagation.

Temperature and salinity profiles at station 5528 are shown in Figure 4. Salinity decreases significantly (from 35.11 to 35.03 PSU) from 200 meters to the bot-

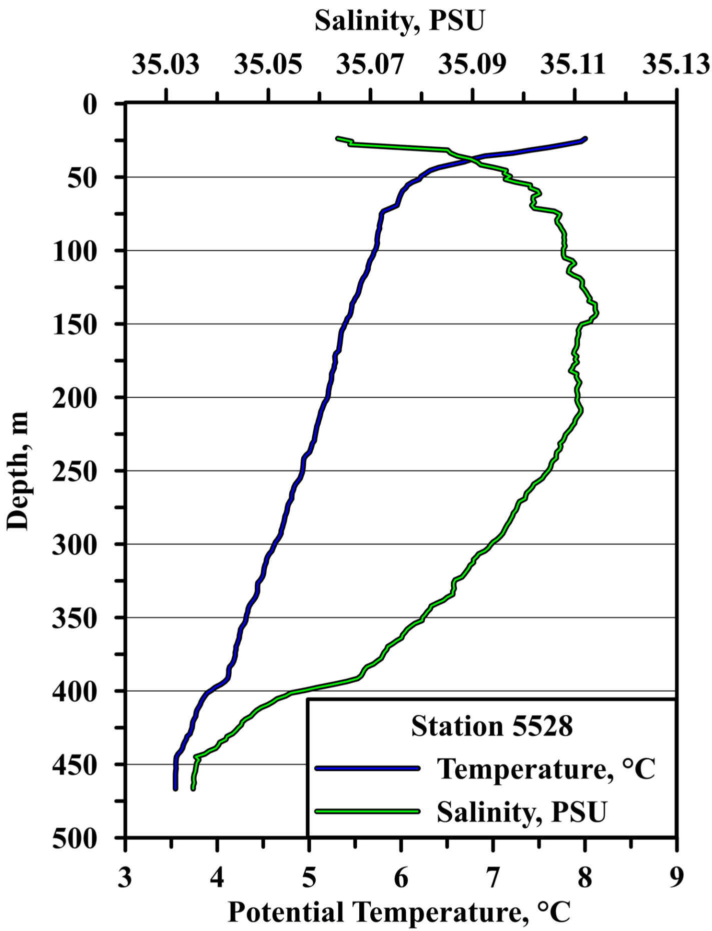

Figure 4. Vertical profiles of potential temperature and salinity at the location of mooring in the Bear Island Trough (station 5528).

tom. The bottom layer about 30 meters thick between depths of 450 and 480 meters is well mixed. The bottom potential temperature at the westernmost station in the trough was 3.52°C, and salinity was 35.04 PSU. The ADCP velocity measurements were carried out near the upper boundary of this layer. The $\theta - S$ diagrams for four stations along the Bear Island Trough are shown in Figure 5.

The salinity section along the trough reveals a tongue of low saline waters descending down the slope from northeast to southwest (Figure 3). Salinity increases in the course of the propagation of this water downslope the Bear Island Trough. The $\theta - S$ diagrams at stations along the trough, shows that the coldest water was found at the bottom of the shallowest station in the northeastern part of the trough. As the water descends down the trough it becomes warmer and the cold "tails" on the $\theta - S$ diagram are sequentially truncated (stations 5552, 5544, 5528) (Figure 4). The curves differ only above the density level 27.85, which corresponds to 200 m. The $\theta - S$ diagram for station 5516 in the western part of the Norwegian Sea is absolutely different from the diagrams in the Bear Island Trough, which indicates that the water structure in the ocean and in the trough are different. The bottom wa-

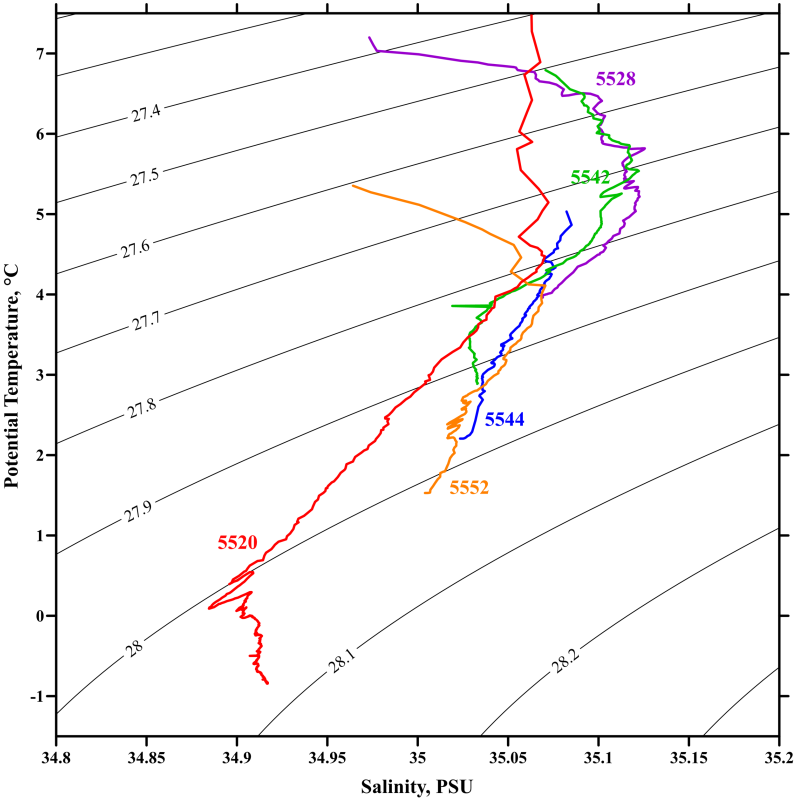

Figure 5. The $\theta - S$ diagrams for four stations along the trough. Stations 5528, 5544, 5542, and 5552 are in the Bear Island Trough, station 5520 is southwest of the trough near Jan Mayen Island.

ter in the Bear Island Trough is formed predominantly by descending of cold low saline water from the slopes that becomes warmer and more saline as it flows. The bottom water in the region west of the trough is generally of the oceanic origin. The difference between them drives the geostrophic current to the north.

Mooring observations of the velocity time series were carried out at $73^{\circ}15.6'$ N, $17^{\circ}24.6'$ E in 25 meters above the seafloor using downward looking Teledyne RD Instruments Doppler Volume Sampler (DVS) 2400 kHz ADCP. It was deployed for 4 days (July 24–28, 2017) with a 10 minutes sampling interval. Each velocity measurement consisted of 120 pings. The range of measurements was 1 meter from the ADCP with a blank distance of 30 cm. The data were processed [*Frey*, 2017] by standard DVS software (Teledyne RD Instruments, 2012, Doppler Volume Sampler (DVS) Operation Manual).

The velocity measurements reveal a westward bottom flow in the Bear Island Trough (Figure 6). Strong tides in this region are responsible for the variations in the bottom currents. We calculated tidal velocities by TPXO7.1 model using satellite altimetry data [*Egbert and Erofeeva*, 2002]. A comparison of measured and calculated tidal velocities shows that the observed

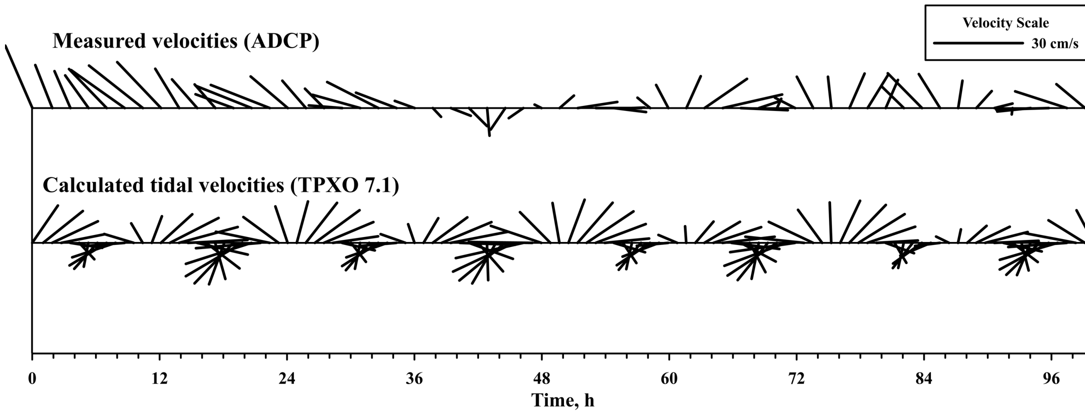

Figure 6. Velocity vectors based on four-day mooring measurements (station 5528) of bottom flow in the Bear Island Trough on July 24–28, 2017 at 73°15.6′ N, 17°24.6′ E; and calculated tidal velocities for the same period.

change of the bottom flow direction is caused by the semidiurnal tides. Nevertheless, the mean current is directed from the Barents to the Norwegian Sea. The four-day mean westward component was 4.1 cm/s; the northward component was 6.6 cm/s.

We compared our recent velocity data with the mooring bottom current measurements in July 1995 [*Aleynik et al.*, 2002]. Velocities near the bottom were measured in summer of 1995 in the cruise of the R/V *Akademik Mstislav Keldysh*. The mooring was deployed at 73°42′ N, 13°06′ E. The instrument was located at a depth of 1674 m over the ocean depth at 1687 m. The sampling interval was 1 hour. The bottom flow was generally directed to the north (Figure 7). In the period of measurements from July 28–August 7, the mean northward velocity was 13.2 cm/s, the mean eastward component was 5.2 cm/s. The influence of the semidiurnal tides is also observed over this time series.

Conclusions

We analyzed two CTD sections and moored ADCP measurements at the boundary between the Barents and Norwegian seas carried out in July–August, 2017. Thermohaline structure and velocity data in the Bear Is-

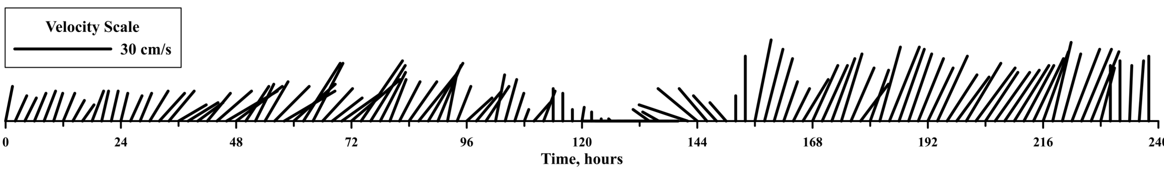

Figure 7. Vectors of bottom currents measured at 73°42′ N, 13°06′ E in July–August 1995.

land Trough showed the bottom water spreading along the trough from the Barents to the Norwegian Sea. The four-day mean velocity at the exit from the trough was 7.8 cm/s directed to the northwest. This flow of warm Norwegian Atlantic Current waters transported heat to the northwest and western part of the Svalbard Archipelago, which does not freeze in winter. The bottom temperature in the Bear Island Trough was 3.52°C, while it was lower (1.05°C) in the Storfjorden Trench, which is 150 meters shallower. The bottom temperatures along the trough increased from 1.53°C in its eastern part to 3.52°C in the western boundary of the Barents Sea. Strong semidiurnal tides in this region influence bottom currents significantly, but the mean flow is directed from the Barents Sea to the Norwegian Sea.

Acknowledgments. This work was supported by Russian Science Foundation project No 14-27-00114-P and by the I3П Program of the Presidium of the Russian Academy of Sciences (project 0149-2015-0050). The authors thank A. A. Agarkov, A. V. Tolstikov, and V. M. Pyatakov and the crew of the R/V *Akademik Mstislav Keldysh* for their assistance in the fieldworks.

References

Aleynik, D. L., V. I. Byshev, A. D. Shcherbinin (2002), Water dynamics in the Norwegian Sea at the site of the accident of the Komsomolets nuclear submarine, *Oceanology, 42*, No. 1, 7.16.

Årthun, M., R. B. Ingvaldsen, L. H. Smedsrud, C. Schrum (2011), Dense water formation and circulation in the Barents Sea, *Deep-Sea Res., I, 58*, 801.817, doi:10.1016/j.dsr.2011.06.001

Bjerke, P. L., K. Torsethaugen (1989), *Environmental conditions on the Norwegian Continental Shelf, Barents Sea*, Report no STF60 A89052, Norwegian Hydrotechnical Laboratory, SINTEF, Trondheim.

Egbert, G. D., S. Erofeeva (2002), Efficient inverse modeling of barotropic ocean tides, *J. Atmos. Ocean Tech., 19*, 183.204, doi:10.1175/1520-0426(2002)019<0183:EIMOBO>2.0.CO;2

Frey, D. I. (2017), Data processing of deep-sea measurements applied to currents in abyssal channels, *Fundamentalnaya i Prikladnaya Gidrofizika, 10*, No. 2, 25.33.

Gammelsrød, T., Ø. Leikvin, V. Lien, W. P. Budgell, H. Loeng, W. Maslowski (2009), Mass and heat transports in the NE Barents Sea: observations and models, *J. Mar. Syst., 75*, No. 1, 56.69, doi:10.1016/j.jmarsys.2008.07.010

Giraudeau, J., V. Hulot, V. Hanquiez, L. Devaux, H. Howa, T. Garlan (2016), A survey of the summer coccolithophore community in the western Barents Sea, *J. Mar. Syst., 158*, 93.105, doi:10.1016/j.jmarsys.2016.02.012

Lind, S., R. B. Ingvaldsen (2012), Variability and impacts of Atlantic Water entering the Barents Sea from the north, *Deep-Sea Res.* Part I, 62, 70.88, doi:10.1016/j.dsr.2011.12.007

Lukashin, V. N., A. D. Shcherbinin (2007), Nepheloid layer and horizontal flux of the sedimentary material in the Norwegian Sea, *Oceanology, 47*, No. 6, 894.908.

Nansen, F. (1906), Northernwaters: Captain Roald Amundsens oceanographic observations in the Arctic Seas in 1901. *Vidensk. Selsk. Skr. I. Mathematisk-Natur. Klasse*, 145 pp., Jacob Dybwad, Christiania.

Smedsrud, L. H., I. Esau, R. B. Ingvaldsen, T. Eldevik, P. M. Haugan, C. Li, V. S. Lien, A. Olsen, A. M. Omar, O. H. Otteraa (2013), The role of the Barents Sea in the Arctic climate system, *Rev. Geophys., 51*, No. 3, 415.449, doi:10.1002/rog.20017