Deep-Sea Research I 111 (2016) 79–90

Contents lists available at ScienceDirect

Deep-Sea Research I

journal homepage: www.elsevier.com/locate/dsri

Bottom temperature and salinity distribution and its variability around Iceland

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A R T I C L E I N F O

Article history:
Received 30 June 2015
Received in revised form
12 February 2016
Accepted 16 February 2016
Available online 24 February 2016

Keywords:
Average hydrographic conditions near Iceland
Hydrographic variability
Seasonal cycle
Species distribution modelling

A B S T R A C T

The barrier formed by the Greenland–Scotland-Ridge (GSR) shapes the oceanic conditions in the region around Iceland. Deep water cannot be exchanged across the ridge, and only limited water mass exchange in intermediate layers is possible through deep channels, where the flow is directed southwestward (the Nordic Overflows). As a result, the near-bottom water masses in the deep basins of the northern North Atlantic and the Nordic Seas hold major temperature differences.

Here, we use near-bottom measurements of about 88,000 CTD (conductivity–temperature–depth) and bottle profiles, collected in the period 1900–2008, to investigate the distribution of near-bottom properties. Data are gridded into regular boxes of about 11 km size and interpolated following isobaths. We derive average spatial temperature and salinity distributions in the region around Iceland, showing the influence of the GSR on the near-bottom hydrography. The spatial distribution of standard deviation is used to identify local variability, which is enhanced near water mass fronts.

Finally, property changes within the period 1975–2008 are presented using time series analysis techniques for a collection of grid boxes with sufficient data resolution. Seasonal variability, as well as long term trends are discussed for different bottom depth classes, representing varying water masses. The seasonal cycle is most pronounced in temperature and decreases with depth (mean amplitudes of 2.2 °C in the near surface layers vs. 0.2 °C at depths >500 m), while linear trends are evident in both temperature and salinity (maxima in shallow waters of +0.33 °C/decade for temperature and +0.03/decade for salinity).

1. Introduction

The near-bottom water masses in the deep basins of the northern North Atlantic and the Nordic Seas hold major temperature differences due to the barrier formed by the Greenland–Scotland-Ridge (GSR). A direct exchange of deep water across the ridge is not possible, and only limited water mass exchange in intermediate layers takes place through several channels, where the flow is southward (the Nordic Overflows; Hansen and Østerhus, 2000). The influence of this topographic barrier can be connected to species distributional patterns and to the species composition of specific benthic organisms (e.g. Weisshappel, 2001; Dijkstra et al., 2009; Brix and Svavarsson, 2010), as the exchange between benthic organisms for bottom depths exceeding about 500 m is also restricted.

Surface-intensified, northward flow across most of the GSR brings warm and saline waters into the Nordic Seas, which are carried within the three current branches of the North Atlantic Current: The Iceland branch, the Faroe branch and the Shetland branch (Østerhus et al., 2005). At the western GSR (along the east Greenlandic coast) cold and fresh water is transported southwestward within the East Greenland Current. Interchanges of some benthic species are thus possible along the shelf regions within these currents, which also provide a possible pathway for the spreading of invading species. As recent studies already found evidence for increasing temperatures in Arctic and Subarctic waters as well as in the shallower regions around Iceland within the last 10 years (Astthorsson et al., 2007; Larsen et al., 2012; Yashayaev and Seidov, 2015), it seems likely that climate alterations will also have an effect on organisms living within the affected region.

Several abiotic factors such as sediment type (Stransky and Svavarsson, 2010), temperature and salinity (Mayer and Piepenburg, 1996), as well as bathymetry (Schnurr et al., 2014; Dauvin et al., 2012), are known to shape and influence community composition and species distributions in Arctic and Subarctic regions.

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http://dx.doi.org/10.1016/j.dsr.2016.02.009
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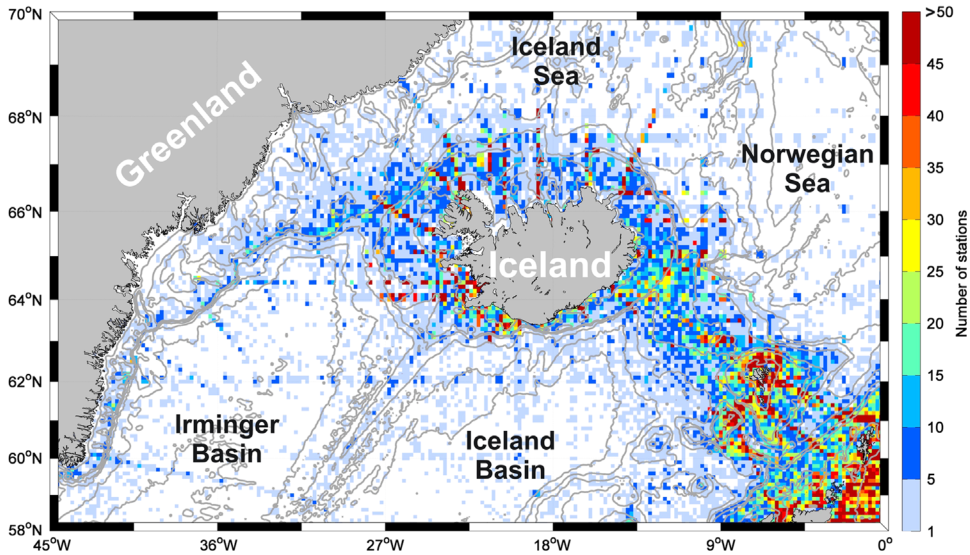

Fig. 1. Gridded data distribution of near-bottom temperature measurements in the area of investigation. The overall maximum number of measurements for a few grid cells is exceeding 300 and is thus out of scale, which was adjusted to the range of the most common numbers of measurements in the cells. The bottom depth is taken from ETOPO2 bathymetry and contours illustrate the [5000 4000 3000 2000 1500 1000 500 300 100] m depth levels.

Information on these spatially changing environmental variables in combination with species distribution data can be used for species distribution modeling (SDM), which is a tool for a better understanding of species distributions within the marine environment (Elith and Graham, 2009). These models can provide an estimate of the response of the marine ecosystem and species distributions to climate change.

In this work we use near-bottom temperature and salinity measurements to obtain spatial property distributions north and south of the GSR (Fig. 1), which have already been used to create realistic SDMs (Meißner et al., 2014). Local variability is discussed according to the standard deviations within the region, which reflects the uncertainty of the distributions, as well as highlights ocean variability (e.g. oceanic fronts or migrating currents). Additionally, we analyse the hydrographic changes on seasonal and longer time scales within the last 30 years.

2. Data selection and quality control

The hydrographic data used in this study were extracted from the NISE data base (Norwegian Iceland Seas Experiment, http://monarch-a.nersc.no/node/45 and Nilsen et al., 2008), which is composed of 509,625 hydrographic stations. The NISE project is a joint venture of research institutions in Iceland (MRI, Marine Research Institute), the Faroe Islands (HAVSTOVAN, Faroe Marine Research Institute), and Norway (IMR, Institute of Marine Research; GFI, Geophysical Institute). NISE contains hydrographic data records of over 100 years and is based on the ICES data set (International Council for the Exploration of the Sea, www.ices.dk), which is the most comprehensive in the region of interest and has undergone established quality control. The ICES data have been complemented with data from the contributing research institutions, as well as other online sources such as WOCE (Word Ocean Circulation Experiment, www.woce.organd Argo (www.usgodae.org). An additional general outlier removal has been performed in the creation of the NISE database (see Nilsen et al., 2008 for more details). Compared with more recent climatological collections such as the NOAA Atlas of the Nordic Seas (Korablev et al., 2014) NISE has a similar data resolution in the early years. Nevertheless, the NOAA Atlas covers a larger area and will be maintained in the future; therefore it is recommended for follow-up studies. The geographical region that encompasses the NISE project spans from the Subpolar North Atlantic Ocean (east of 55°W and north of 50°N) to the GSR and the Iceland and Norwegian Seas. The original NISE data set ended in 2006, but the data base is updated infrequently by J.E.Ø. Nilsen, who provided the NISE data, including the years 2007 and 2008 for this study. In total, 103,378 stations were found within the area of investigation (70°N–58°N, 45°W–0°W).

Historical measurements of temperature and salinity were achieved by collecting water samples in Nansen and Niskin bottles, and since the 1980s electronically by using CTD (Conductivity Temperature Depth) profilers. The data coverage is increasing from sparse in the first half on the last century to more than 1500 measurements per year in recent years (see Fig. A1 in the Appendix). The majority of the profiles was collected between April and September, while sampling effort was least in wintertime. Data coverage is best in the shelf regions around Iceland and the Faroe Islands, as well as along the GSR, whereas only a few stations are available from the deep Irminger and Iceland Basins and the deeper areas of the Iceland and Norwegian Seas.

Since the focus of this study is on the bottom distribution of temperature and salinity, only the deepest measurements of each profile were considered. In order to guarantee that these really provide near-bottom information, the data set was quality-controlled regarding the depth information. A probable bottom depth was allocated to all stations with missing bottom depth information, which was extracted from ETOPO2 (provided by NOAA, see Acknowledgments). The ETOPO2 data base for the region south of 64°N consists of the Smith and Sandwell bathymetry (Smith and Sandwell, 1997) and north of 64°N of the International Bathymetric Chart of the Arctic Ocean (Jakobsson et al., 2000). Closest ETOPO2 latitude and longitude positions were used to assign bottom depths to stations (which lacked bottom depth in the data set) in order to allocate a bottom depth to the given station. Additionally all bottom depths provided in the NISE data set were compared with ETOPO2. All stations with a difference in bottom depth between NISE and ETOPO2 of more than 200 m were excluded from further analysis, as for these stations the real bottom depth is either unknown or the profile did not reach the near-bottom layer. Only stations with a maximum distance of up to 80 m between the last measurement within the profile and the bottom were used in this study.