OBSERVING DEEP-WATER CHANGES IN THE NORTHERN NORTH ATLANTIC

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In 1997–2009, full-depth transatlantic hydrographic section along 60°N between Cape Farewell (Greenland) and the Scottish shelf was repeatedly occupied on board the Russian research vessels. Since 2002 onwards, the section has been repeated annually. The comprehensive dataset thus collected has contributed to the research of the recent and long-term deep-water changes in the region. Our presentation summarizes the main published and work-in-progress results of this research including analyses of decadal hydrographic variability, local water mass formation and regional circulation changes.

1. INTRODUCTION

As discussed by [7,6] in the current issue, repeated full-depth transoceanic observations are an indispensable effective tool for assessing the large-scale circulation and thermohaline changes in the deep ocean and investigating mechanisms governing these changes. Below we summarize the recent achievements in the study of the northern North Atlantic (NA) deep-water changes obtained using the data collected in the zonal transatlantic section along 60°N. Besides reporting on the results, the aim of the review is to highlight the range of issues, which cannot be addressed without sustained shipboard measurements in the deep ocean obscured to satellites and floats.

The 60°N transatlantic section (Fig. 1) was designed for monitoring the large-scale circulation and thermohaline/ chemical properties of oceanic waters at the northern periphery of the NA – the region where the warm upper-ocean Atlantic waters carried northward by the North Atlantic Current, are transformed by deep convection and mixing into the colder intermediate and deep waters – the Labrador Sea Water (LSW), Iceland Scotland Overflow Water (ISOW) and Denmark Strait Overflow Water (DSOW) – transported southward in the lower limb of the Atlantic meridional overturning circulation (e.g., [17]).

The data collected at 60°N since 1997 together with those obtained within the framework of the kindred projects, primarily the French OVIDE (see http://www.ifremer.fr/lpo/ovide), hydrographic datasets and earlier published time series have been used for the study of the deep water renewal [5], decadal changes in temperature and salinity in the intermediate–deep water column [12, 13], causes of these changes [14, 16], and the long-term circulation variability in the region [15].

2. DEEP CONVECTION IN THE IRMINGER SEA

The oxygen data collected in 1997 at several sections ending nearby the southern tip of Greenland provided the observation-based argument supporting the hypothesis [11] that winter convection in the Irminger Sea may penetrate deep into the LSW layer thus causing local renewal of this water mass. A separate lateral maximum of oxygen concentrations in the deep LSW layer has been detected east of Cape Farewell (59–60°N, 36–40°W): the concentrations increased (by ~0.1 ml/l) from the Labrador Sea eastern edge toward the Irminger Sea rather than the reverse, as would be expected if LSW observed in the Irminger Sea interior were solely of advective origin [5].

3. REVERSAL OF DEEP-WATER FRESHENING

The LSW and Nordic Seas overflow-derived deep waters, ISOW and DSOW, freshened in the northern NA during the last three–four decades of the 20th century [2]. Between the 1960s and 1990s, the water column in the region freshened on average by ~0.03 [4].

The long-term freshening reversed in the mid-1990s [12]. The subsequent nearly decade-long warming and salinification of the intermediate and deep waters (see Fig. 3 by [7], this issue) resulted in temperature/salinity increase in the intermediate–deep water column ($\sigma_0 \geq$ 27.45, depths > 500–1000 m) by ~0.3°C / 0.03–0.04 as observed at 60°N in 1997–2006 [13].

In the Irminger Sea, the long-term freshening in the deep water column (σ_0>27.82, depths > ~2000 m) reversed in the early 2000s. The observed freshening reversal was a lagged consequence of the persistent ISOW salinification that occurred upstream, in the Iceland Basin, after 1996 due to salinification of the northeast Atlantic waters entrained into the overflow [16]. The entrainment salinity increase was associated with the North Atlantic Oscillation (NAO)-induced weakening and contraction of the Subpolar Gyre and corresponding northwestward advance of subtropical waters that followed the NAO decline in the mid-1990s and continued through the mid-2000s. Remarkably, the ISOW freshening reversal was not related to changes in the overflow water salinity. Analysis of the DSOW salinity time series (1960s–1990s) [2] updated with the new data obtained at 59–60°N (1990s–2000s) showed the absence of any net trend in the DSOW salinity over the past two and a half decades (1980s–2000s). After 2004, salinity of DSOW has rapidly increased, and in 2008, the highest salinity of this water for the last 30 years (1978–2008) was observed.

The study was conducted in cooperation with the Laboratoire de Physique des Océans, Ifremer, France.

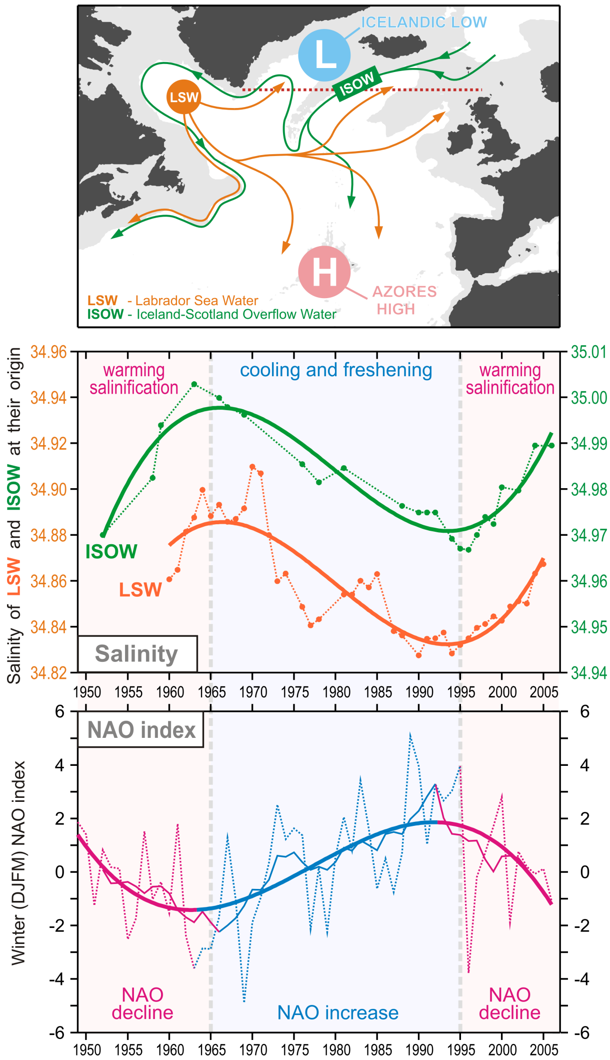

Figure 1. Coherence of decadal changes in the LSW and ISOW salinities and the NAO. Upper: Schematic representation of the LSW and ISOW pathways in the northern NA and locations of the Icelandic Low (L) and Azores High (H) centers constituting the NAO dipole pattern. The red dotted line indicates the 60°N transatlantic section. Middle: Salinity time series for LSW in the Labrador Sea [18] and ISOW in the Iceland basin [3, 12] overlaid by the third order polynomial fits. Lower: Time series of the winter NAO index, after [9], overlaid by 7-year running mean and third order polynomial.

4. DEEP-WATER THERMOHALINE CHANGES AND THE NAO

Close relationship between the thermohaline properties of the northern NA intermediate and deep waters and the winter NAO index ($r^2 \approx 0.65$, 1950s–2000s, Fig. 1) has been revealed [14] from the observation-based salinity time series for LSW in the Labrador Sea [18] and ISOW in the Iceland basin [3, 12]. Persistent NAO decline (amplification) leads to warming and salinification (cooling and freshening) in the intermediate–deep water column.

An explanation for the close link between the NAO and decadal changes in the intermediate and deep water properties in the region (Fig. 1) has been proposed [14]. The two factors dominate this link (Fig. 2): (i) intensity of convection in the Labrador Sea controlling injection of relatively cold fresh waters into the intermediate layer and (ii) zonal extension of the Subpolar Gyre that regulates the relative contributions of cold fresh subpolar waters and warm saline subtropical waters to the entrainment into the Norwegian Sea overflow south of the Iceland–Scotland Ridge and to the Atlantic inflow to the Nordic Seas. These factors act in phase leading to the coherent thermohaline changes in the intermediate–deep water column.

5. DEEP-WATER SALINITY CHANGES AND CLIMATE CHANGE

There are increasing concerns that in the warmer climate, the thermohaline circulation (THC) of the world ocean may substantially decline due to decrease in the convective activity in the northern NA and Nordic Seas [10]. The long-term freshening in the Nordic Seas and freshening of the northern NA deep waters in the 1960s–1990s have been cautiously considered as a likely indicator or precursor of the dramatic change in THC (e.g., [8]). The freshening has been attributed to a combination of factors potentially associated with the global warming: the increasing ice melt and net precipitation at high latitudes of the northern hemisphere (e.g., [4]). A probable causality between the climate change and the decreasing NA Deep Water salinity has supported the concerns and unfavorable predictions thus 'warming up' the reasonable scientific debate on climate change and overblown speculations in media.

However, despite the long-term increase in freshwater input to the Arctic, freshening in the Nordic Seas and the northern NA deep-water freshening had reversed in the mid-1990s. This reversal forces us to revise the hypotheses on the mechanisms behind the deep-water thermohaline anomalies, as it seems doubtful that the persistent global temperature growth may lead to the opposite decadal trends (positive-then-negative-then-positive, Fig. 1) in the deep water salinity.

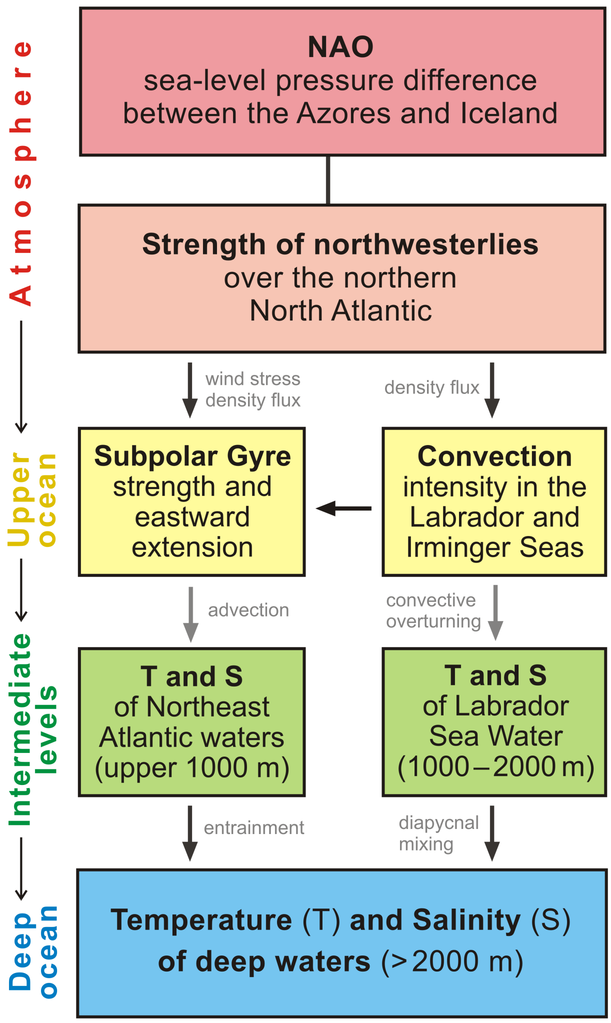

Figure 2. The main links between the NAO and decadal changes in temperature (T) and salinity (S) of the northern NA intermediate and deep waters inferred from the documented changes in the deep convection activity, regional circulation and water mass distribution and properties; after (Sarafanov, 2009). Positive / negative links shown with the dark / light grey arrows mean that changes in 'causative' and 'consequential' characteristics have the same / opposite sign(s). The overall effect of the NAO on T and S of the in the water column is negative: persistent NAO decline leads to warming and salinification of the water masses and vice versa, see Fig. 1.

The results of the recent observation-based studies [14, 16] summarized herein suggest that natural atmospheric variability over the NA plays the major role in the formation of the deep-water thermohaline anomalies in northern NA on a decadal time scale. There are no strong reasons to associate the deep-water freshening in the 1960s–1990s with climate change, unless the 3-decade-long surface forcing amplification is evidently shown to be a consequence of the latter. At the same time, the net 1950s–2000s trends in the water mass salinities are still negative implying that the global factors (e.g., probable intensification of hydrological cycle) may act but on time scales longer than decadal.

6. DECADAL VARIABILITY OF THE DEEP WESTERN BOUNDARY CURRENT AT CAPE FAREWELL

A set of hydrographic sections in vicinity of Cape Farewell (1991–2007), including the 6 repeats of the 60°N section (1997–2007), was used by [15] to assess the recent decadal changes in the baroclinic transport of the Deep Western Boundary Current (DWBC) carrying the Greenland–Scotland overflow-derived waters along the East Greenland slope.

Since the mid-1990s, the DWBC baroclinic transport has increased by ~2 Sv, which constitute ~20% of the mean absolute transport (9.0 Sv) as obtained from three OVIDE cruises in 2002–2006. Transport increased in both the ISOW and DSOW layers accounting for 60% and 40% of the DWBC transport increase respectively.

The long-term record of the DWBC baroclinic transport updated after [1] (1955–2007) is characterized by clear decadal variability (±2–2.5 Sv) with the transport minima in the 1950s and mid-1990s, maximum in the early 1980s and moderate-to-high transport in the 2000s. The overall trend in the DWBC baroclinic transport is nearly zero ($+0.02 \pm 0.3$ Sv / decade) providing no evidence of the DWBC slowdown or acceleration over the past five decades.

The DWBC baroclinic transport anomalies in the Irminger Sea are shown to be negatively correlated ($R = -0.80$) with thickness anomalies of the Labrador Sea Water (LSW) at its origin. This implies a close association between the DWBC transport east of Greenland and the LSW production. At the same time, the earlier suggested relationship between the DWBC transport in the Irminger Sea and the Jan Mayen winter air temperatures used as a proxy of the atmospheric forcing of deep convection in the Nordic Seas [1] is not supported by the updated time series.

The study was conducted in cooperation with the Laboratoire de Physique des Océans, Ifremer, France.

7. PERSPECTIVES

Annually repeated observations at 60°N are planned to be continued by Shirshov Institute of Oceanology. These observations, being complemented with the quasi-continuous float and satellite measurements, provide a great opportunity for the long-term full-depth shore-to-shore monitoring in the northern NA – the key region for THC. Cooperation proposals are welcome.

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