Thermohaline changes in the Irminger Sea

by

John Mortensen and Héðinn Valdimarsson
Marine Research Institute (MRI), Reykjavik

121 Reykjavik
Skúlagata 4
Fax: +354 5623790
e-mail: johnm@hafro.is
e-mail: hv@hafro.is

Abstract

The Irminger Sea is part of the Subpolar Gyre in the northwestern North Atlantic and plays a central role in the large-scale thermohaline overturning of Atlantic Water which is believed to influence the long-term changes of the climate system. In this area thermohaline changes are observed at almost all depth levels in the nineties. The most pronounced change is connected to the Modified North Atlantic Water (MNAW) where an overall increase of temperature and salinity were observed during the nineties. Time series from the Icelandic continental slope reveal that the recent onset of increasing temperatures took place in the winter 1995/1996 and was accompanied by a more pronounced salinity increase in late summer 1997.

A historical comparison with nearby sections occupied in the early eighties and late nineties reveals that changes in the distribution of water masses have taken place recently. The reason is likely to be connected to the densification of the Labrador Sea Water (LSW) since the late eighties. The change is seen as a downward movement of the LSW core now occupying in the Irminger Sea the depth range of 1500 to 2100 m instead of 500 to 1200 m in e.g. 1981. The changes are observed as a freshening and cooling of the LSW.

Keywords: Irminger Sea, thermohaline changes, Labrador Sea Water and Modified North Atlantic Water.
Introduction

Since the first recorded oceanographic work in the Irminger Sea was published by Irninger (1853), the area has attracted periodic interests. By the turn of the century the main hydrographic structure was known. The cold, deep water overflow across the Greenland-Iceland and Iceland-Faroe Ridges was first observed by Knudsen (1898, 1899) and later discussed by Nansen (1912) who also presented a surface current map of the area. A summary of all investigations in the area for the period 1853 to 1957 is given by Dietrich (1957). A similar summary doesn't exist for the period 1958 until today (1999). Some larger international programmes since 1957 in the area can be mentioned such as the International Geophysical Year (1958-59) (Dietrich, 1969), NORWESTLANT 1-3, 1963 (Lee, 1968), Irminger Sea Project 1963 and 1965 (Stefánsson, 1968), ICES Overflow 1973 (Anon., 1976), WOCE 1990-1997, Nordic WOCE 1992-1997 and VEINS 1997-1999. Beside these a number of special cruises have been conducted in the area with an increasing frequency in the nineties. During the sixties the water mass definitions and their approximate origin became well established and one of the first papers regarding this area and its annual variations was published by Blindheim (1968). The last water mass to be recognised in the Irminger Sea was the LSW (Lee and Ellett, 1965, 1967). In the seventies and early eighties the overflow was the main research subject in the area (Anon., 1976). The general tendency in the eighties was a northward movement of the international research programs leaving the Irminger Sea less observed. However, the overflow was still monitored (Dickson and Brown, 1994) and satellite tracked drifters were released for the first time in the area (Krauss, 1995). The nineties were an introduction to a new era for the Irminger Sea, from being a low research activity area to becoming a higher one. Large international programs such as WOCE (including Nordic WOCE) and VEINS contributed to an increased focus on the climatic aspect of the area.

In this paper thermohaline changes of the LSW and MNAW in the Irminger Sea (Figure 1) in the nineties are described by analysis of hydrographic data obtained by Icelandic and international research programs.

Results

LSW changes

The spreading of the LSW from its formation in the Labrador Sea has been described by Talley and McCartney (1982). They followed the water mass from its origin into the North Atlantic by its low potential vorticity, utilizing the fact that convectively-formed water is
characterized by a vorticity minimum.

Hydrographic observations in the Labrador Sea of the LSW over the last decades show that the LSW has undergone significant changes (Talley and McCartney, 1982; Dickson et al., 1996). Of special interest are the late property changes of the LSW which started in 1988 (e.g. Sy et al., 1997) where different LSW vintages produced up to 1994 were distinguishable by their temperatures. From 1988 to 1994 the LSW water mass was observed with decreased temperature and salinity of the order of 0.4°C and 0.02 psu respectively. Utilizing temperature, salinity and chlorofluorocarbon concentration data Sy et al. (1997) found surprisingly rapid spreading rates of newly formed LSW. They estimated that it reached the southern parts of the Irminger Sea in about 6 months. Yielding a mean spreading speed of 4.5 cm/s. It is therefore of interest to see if these velocities are maintained in the rest of the Irminger Sea and how the density increase of the LSW influences the water mass distribution.

Figure 2 shows the temporal changes of the thermohaline characteristics of the LSW in the northern part of the Irminger Sea as potential temperature versus potential density relative to 1500 dbar for the LSW salinity minimum or core. The temporal development of the LSW core reveals a cooling in the northern part of the Irminger Sea of the order of 0.45°C during the period 1988 to 1996 and then a slight increase during 1997 to 1998. The salinity changes were of the order of -0.03 psu and +0.01 psu during the same periods. The depth of the LSW core was continuously increasing during the entire period, being ca. 1300 m in 1988 increasing to 1600 m during the years 1992 to 1994 ending up at approximately 1850 m in the period 1996 to 1998. It is important to note that the density increase observed during 1997 and 1998 is linked to the salinity increase mentioned above, suggesting a mixing between the LSW and Iceland-Scotland Overflow Water (ISOW).

With support in results reported by Sy et al. (1997) the present data suggests that the transit time of the LSW from the WOCE A1E section situated at 60°N to the northern part of the Irminger Sea is in the range of 6 to 12 months. With an assumed length of the pathway of 444 km, this is equivalent to a mean speed of about 1.4 – 2.9 cm/s.

A historical comparison of two nearby sections occupied in the early eighties (1981) and late nineties (1998), reveals changes in the distribution of water masses (Figure 3) that have taken place recently in this period. The changes are seen as a downward movement of the LSW core in the late nineties occupying the depth range 1500 to 2100 m instead of 500 to 1200 m in 1981.
MNAW changes

During its northward path from the North Atlantic Current the MNAW experiences a gradual cooling and freshening due to atmospheric interaction and mixing with the Subpolar Gyre and East Greenland Current. After passing the Reykjanes Ridge from the Iceland Basin it is generally accepted that the MNAW participates in the cyclonic circulation of the Irminger Sea as the Irminger Current. After branching in the Denmark Strait the western branch of the MNAW finally joins the East Greenland Current on its southward path as a band of variable width. The onshore side is characterised by cold and fresh waters of polar origin, whereas the central Irminger Sea is occupied by relatively cold and fresh Irminger Sea Water (IW), also referred to as Subarctic Water (SAW) (Dickson et al., 1998).

A station from the MRI Faxaflói section, Faxaflói 9 (fx9), is used to describe the thermohaline variability in the northern part of the Irminger Sea through the nineties. This station (Figure 1) is located near the 1000 m isobath on the Icelandic continental slope in the outer core of the MNAW water mass. Therefore this station can be considered as a good proxy for the MNAW in the area.

Isopleths of potential temperature, salinity and potential density for fx9 (Figure 4) all reveal both interannual and seasonal variations in the entire water column. The most pronounced seasonal signal is found in the surface layer mainly connected to air-sea exchange. During early summer a seasonal thermocline develops in the surface layer which is followed by a freshening due to increased stability and precipitation. During winter the surface layer is broken down by winter mixing which can reach depths greater than 500 to 600 m. This cycle can to some degree be disturbed by advection. An example of this is seen in the isopleth of salinity after 1996 as a less distinguished fresh water layer than before. Below the surface layer the seasonal signal is mainly connected to the winter mixing and the advection cycle of the MNAW.

The isopleths (Figure 4) indicate warming during the winter 95/96 of the upper layers, followed by increasing salinities especially since late 1997. During 1998 temperatures and salinities reached levels (T>7.5°C; S>35.15) which are comparable to those observed during the warm and saline period before the "Great Salinity Anomaly" in the late sixties (Lee, 1968). Heat and salt content of the water column between 5 and 950 m for fx9 (Figure 5) support these tendencies and give a clearer picture of the development. The salt content reveals a clear seasonal signal but this is less distinguishable in the heat content. Beside the seasonal signal, four pronounced non-seasonal signals are evident. The first change was observed during the winter 92/93 as a cooling and freshening of the water column. The second change was observed during the period November 1995 to August 1996 where the temperature increased by ~0.7°C (2.8 GJ/m²) and the salinity by 0.01 psu. Since August 1996 the heat content has stayed at nearly the same level and has only been interrupted by a
cooling and freshening event (third change) in spring 1997. This change was followed by increasing heat and salinity (fourth change) which peaked in May 1998 raising the salinity of the water column by about 0.095 psu.

Discussion and conclusions

During the nineties the Irminger Sea was subjected to pronounced thermohaline changes. At intermediate depth the water mass distribution underwent pronounced changes due to the arrival of the so called "1988 LSW cascade" (Sy et al., 1997) of newly formed, cold and dense LSW. The arrival of the cascade was seen as a pronounced downward movement of the LSW. Changes in the MNAW layer show a complex nature and observations from Fæfjøl 9 station suggest that at least four larger changes have taken place during the period 1992 to 1999. Together they resulted in an overall increase in temperature and salinity of the MNAW water column of the order of 0.5°C and 0.03 psu during this period. The reason for the seasonal signal (observed particularly in the salt content) has not yet been established but is likely linked to the advection cycle of MNAW in the Irminger Sea.

With respect to the 1988 LSW cascade, it can be added, that there is evidence of transit times of the LSW in the Irminger Sea in the range of 6 to 12 months which are equivalent to mean speed of about 1.4-2.9 cm/s. It is important also to note that the LSW density increase observed during 1997 and 1998 is linked to the salinity increase, suggesting a mixing between the LSW and ISOW.

The question is now, are the changes observed in the MNAW at Fæfjøl 9 caused by local or (large-scale) advective processes. Among local processes can for example be mentioned ocean-to-atmosphere heat fluxes, wind stress curl influencing the doming of the Subpolar Gyre, frontal movements, eddies and changed mixing conditions between the MNAW and the interior of the Subpolar Gyre.

Answering this question is not straight forward from the data available. The question is therefore turned around to become: Which signals or causes mentioned above can be seen in the Fæfjøl 9 time series?

Estimates of heat fluxes produced by the National Centers for Environmental Prediction (NCEP) reanalyses and by the European Centre for Medium Range Weather Forecasts (ECMWF) analyses in the study area has been reported by Reverdin et al. (1999). They arrive at results, which suggest positive heat flux anomalies larger than 100 W/m² during the winter 1995/1996. Further they report strong negative heat fluxes during the winter 1992/1993 and a negative anomaly of short duration in late winter 1996/1997. It is interesting to notice that all three anomalies are well described by the heat content time series observed at Fæfjøl 9 (Figure 5).
Not explained by heat fluxes given by Reverdin et al. (1999) is the heat and salt content increase observed during the period June 1997 to May 1998. During this period Icelandic MRI hydrographic cruises observed increasing salinities both south and west of Iceland. For the first time since the early sixties (e.g. Lee, 1968) salinities above 35.20 were observed at the Reykjanes Ridge. These observations suggest that advection plays a significant role in the observed change of the MNAW characteristics between 1997 and 1998.

References

Anon., 1976, Overflow '73 inventory, ICES oceanographic data lists and inventories, no. 29, 203 pp.


Irminger, C. 1853. Om Havets Strømninger m. m., Nyt Archiv for Søvæsnet, Anden Række, 8 bd., 115-137, København.


Figure 1. Location of the Faxaflói section and station Faxaflói 9 (fx9). In addition are shown the location of repeated VEINS CTD sections and moorings deployed by Icelandic research vessels.

Figure 2. Potential temperature versus potential density relative to 1500 dbar for the LSW salinity minimum.
Figure 3. The distribution of water masses in the Irminger Sea, illustrated by the Transient Tracers in the Ocean (TTO) in August 1981 (top) and VEINS (Faxafloi) in May 1998 (bottom) salinity sections. Shading indicates different water masses: Labrador Sea Water (LSW), Denmark Strait Overflow Water (DSOW) and Iceland-Scotland Overflow Water (ISOW) respectively (the TTO section is adapted from Dickson and Brown, 1994).
Figure 4. Isopleths of (top) potential temperature, (middle) salinity, and (bottom) potential density for Faxaflói 9 in the period 1992 to 1999.
Figure 5. Temporal variability of heat and salt content of the 5-950 m depth range for Faxaflói 9 in the period 1992 to 1999.