ICES Journal of
Marine Science

ICES Journal of Marine Science (2012), 69(5), 809–815. doi:10.1093/icesjms/fss024

Water mass transport variability to the North Icelandic shelf, 1994–2010

Steingrímur Jónsson[1]* and Héðinn Valdimarsson[2]

[1]Marine Research Institute and University of Akureyri, Borgir v/Norðurslóð, 600 Akureyri, Iceland
[2]Marine Research Institute, PO Box 1390, 121 Reykjavík, Iceland

*Corresponding author: tel: +354 4608972; fax: +354 4608998; e-mail: steing@unak.is.

Jónsson, S., and Valdimarsson, H. 2012. Water mass transport variability to the North Icelandic shelf, 1994–2010. – ICES Journal of Marine Science, 69: 809–815.

Received 19 May 2011; accepted 8 January 2012; advance access publication 26 February 2012.

In the Denmark Strait between Greenland and Iceland, the north-flowing warm, saline Atlantic Water (AW) of the Irminger Current meets the south-flowing cold, relatively fresh Polar Water (PW) of the East Greenland Current. A mixture of these two surface water masses then flows along the shelf north of Iceland. The mixture can vary from being almost pure AW to consisting, to a large extent, of PW. The relative quantities of each water mass to some extent determine the productivity and the living conditions on the shelf north of Iceland. The flow has been monitored with current meters on a section north of Iceland since 1994, and these measurements, together with hydrographic data, are used to study its structure and variability. The amount of AW carried by the flow is calculated along with the associated heat transport. In the period 1994–2010, the flow consisted on average of 68% of AW with a transport of 0.88 Sv and an associated heat transport of 24 TW. There is notable seasonal variation in the flow and strong interannual variability.

Keywords: Atlantic water, circulation, heat transport, Iceland, transport, variability, water masses.

Introduction

Northwest of Iceland in the Denmark Strait, the warm, saline Atlantic Water (AW) of the Irminger Current meets the cold, low-salinity Polar Water (PW) of the East Greenland Current, and a mixture of these water masses then flows east over the continental shelf and at least sometimes partly over the slope north of Iceland. The flow of AW through Denmark Strait and its subsequent presence over the shelf north of Iceland are important for the ecosystem and climate in the area. AW has a higher nutrient content than PW (Stefánsson and Ólafsson, 1991).

Primary production is significantly greater in years when AW dominates over the shelf than in years when AW is mixed with more PW, which contains less nutrients and increases stratification (Thordardottir, 1984). Moreover, the timing of the spring bloom seems to depend on the quantity of AW flow onto the shelf, occurring earlier when there is more cold, fresher PW in the area, increasing stratification relative to years when the less-stratified AW is dominating (Thordardottir, 1984). When there is more AW, primary production during summer is greater owing to the occasional breakdown of the pycnocline, providing nutrient input to surface layers (Thordardottir, 1984).

Hence, inflow of AW not only provides high concentrations of nutrients but also brings about favourable conditions for continued growth during summer. Furthermore, increased AW over the shelf leads to increased zooplankton biomass in the area (Astthorsson and Gislason, 1998), then to increased weight of individual capelin (*Mallotus villosus*) and a rise in capelin biomass (Vilhjálmsson, 2002). This chain of events based on varying amounts of AW over the shelf area was described in a conceptual model by Astthorsson and Vilhjálmsson (2002).

Another role played by the inflow of AW to the North Icelandic shelf is in the transport of eggs and larvae of some of the main fish stocks around Iceland, e.g. cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), and capelin. The main spawning grounds of these stocks are off the southwest coast, and the eggs and larvae drift with currents towards the feeding grounds over the North Icelandic shelf. The success of spawning therefore relies, along with many other factors, on the flow of AW, with the Irminger Current and its continuation north of Iceland (the North Icelandic Irminger Current, NIIC) to the North Icelandic shelf, along with the conditions there.

A third reason for studying the flow of AW to the North Icelandic shelf is that it affects the climate on land, as seen through history (Hamilton *et al.*, 2004). During the so-called "ice years" in Iceland (1965–1970), the northern and even the eastern shelves off Iceland were covered with PW and sea ice, with severe consequences for the ecosystem there, and also for climate on land (Malmberg and Jónsson, 1997). Recently, it has been suggested that the process forming the deep water carried by the North Icelandic Jet (NIJ) depends on AW inflow with the NIIC, in conjunction with transformation in the interior of the Iceland Sea (Våge *et al.*, 2011). If that is true, the flow is truly a part of the meridional overturning circulation and as such affects the thermohaline circulation in the global ocean.

The flow of AW is highly variable, as observed in the hydrography, which shows changes from virtually no presence of AW over the shelf (e.g. in spring 1995) to the shelf being entirely covered with AW, even extending beyond the shelf break (Malmberg and Jónsson, 1997). The established importance of the flow led to an interest in measuring it directly, and for the purpose, a mooring was deployed by the Marine Research Institute in Iceland in 1985 at 67°10′N 22°53′W, ~60 km west of the Hornbanki section (Figure 1). Kristmannsson (1998) reported on its measurements from 1985 to 1990. In 1994, the measurements were moved to the Hornbanki section, and since then, current meter records have been obtained continuously in the NIIC along that section.

Jónsson and Valdimarsson (2005) studied the data from 1994 to 2000 and Østerhus *et al.* (2005) from 1999 to 2001 in the context of the flow of AW over the Greenland–Scotland Ridge. Here, the data from 1994 to 2010 are discussed. During this time, several improvements to the measurements and the methods have been made, and they are described. This is the first time that the interannual variability approaching the decadal time-scale has been investigated in detail.

Methods

Data

Current meter moorings have been maintained on the Hornbanki section north of Iceland since 1994 (Figure 1). The moorings are generally deployed in late summer and turned around annually. Until 1999, only one mooring was deployed (HBII), but since then, three moorings (HBI, HBII, and HBIII) have been deployed most of the time. However, the moorings have not always been recovered, probably because of heavy fisheries activity in the area, and some gaps in the dataset have also been caused by battery failure or other technical problems.

The current meters were positioned at 80 and 150 m depth at HBII and HBIII and at 80 m depth at HBI, as shown in Figure 2. Also shown are the temperature and salinity distributions on the Hornbanki section in May 2000, and at that time, the moorings were clearly situated in the core of the AW. This, however, is not always the case, and the hydrography on the Hornbanki section is highly variable, as shown by Jónsson and Valdimarsson (2005). The current meters used until 2009 were of the Aanderaa RCM7 type, and they measured speed and direction and usually also temperature. In 2009, the meters were replaced by 150 kHz RDI acoustic Doppler current profilers (ADCPs) at HBII and HBIII and a 300 kHz RDI at HBI, and thermistors were placed at 150 and 80 m depth. Unfortunately, the ADCP at HBI did not work and the thermistors at 80 m were lost on moorings HBII and HBIII. The timelines of measurements

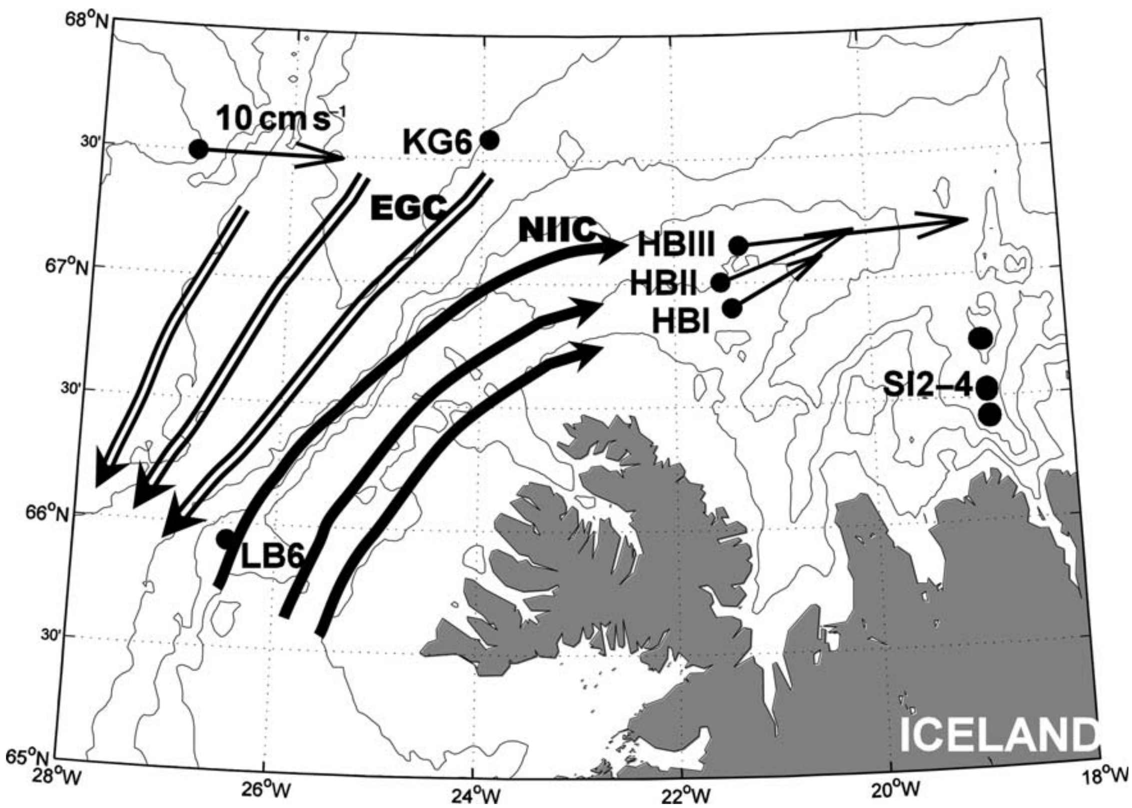

Figure 1. Map showing the positions of current meter moorings (HBI–III) on the Hornbanki section north of Iceland. The arrows show the average current at 80 m depth for the period November 2001—August 2003. The standard hydrographic stations LB6 and KG6 are shown. Stations SI2, SI3, and SI4 on the standard hydrographic section Siglunes are shown. Also shown schematically are the two surface currents in Denmark Strait, i.e. the East Greenland Current (EGC; open arrows) and the NIIC (solid arrows). The depth contours are 100, 200, 300, 500, and 1000 m.

at the different positions are shown in Figure 3. There are three periods for which data from all current meters are available, 1999/2000, 2001–2003, and 2006/2007. All data are low-pass filtered to remove the tides, then resampled daily at noon to represent daily averages. Therefore, there are daily values of all parameters, and this leads to daily averages of all derived variables such as the transport of AW and heat transport.

Conductivity, temperature, depth (CTD) data have usually been obtained four times annually from the hydrographic standard sections Látrabjarg, Kögur, and Hornbanki (Figure 1).

Vessel-mounted ADCP data were obtained from the Hornbanki section in November of 2001–2004 and in August 2005. The section was traversed four times on each occasion, making a total of 20 sections, and the average of the east–west component of the current over all sections is shown in Figure 4.

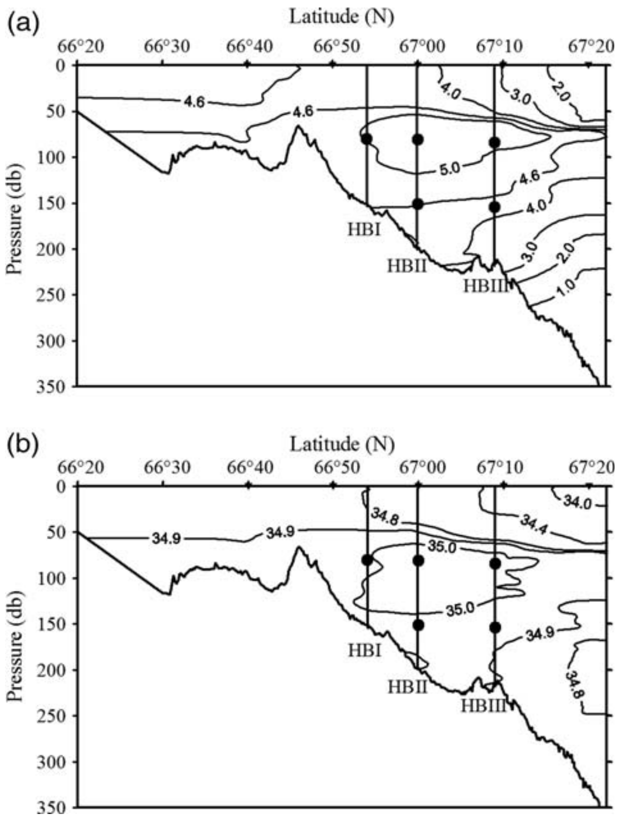

Figure 2. (a) Temperature (°C) and (b) salinity on the Hornbanki section north of Iceland in May 2000. The three moorings on the section are shown, and the current meters as dots. The CTD stations are shown as solid triangles along the upper axis.

Although each section is only a snapshot of the conditions and together they only cover 5 d in total, the spatial structure of the flow is similar on all occasions.

Calculating volume and heat transport

The method for calculating the transport of AW through the Hornbanki section was described in Jónsson and Valdimarsson (2005), but in view of the larger dataset and different new types of data used here, some improvements have been made that need to be described. The cross section used is the same as before and delimited to the north by 67°20′N. The results from the vessel-mounted ADCP data shown in Figure 4 indicate that the speed decreases horizontally from HBIII towards 67°20′N, and that beyond that it decreases rapidly towards the NIJ, that is seen as a west-flowing current over the slope carrying Denmark Strait Overflow Water towards the sill (Jónsson and Valdimarsson, 2004; Våge *et al.*, 2011). The transport calculations are limited to the uppermost 200 m because water deeper than that is usually cold deep water flowing onto the shelf from the north (Jónsson and Valdimarsson, 2005).

More detailed information about the vertical structure of the current was obtained from the moored ADCPs deployed in 2009 and recovered in 2010 at all moorings (although the HBI ADCP failed). The 150 kHz ADCPs at HBII and HBIII measured at 8 m intervals from ~12 m above the seabed to ~30 m depth, and Figure 5 shows the mean of the east–west component of the velocity at all depths at HBII and HBIII.

The current showed very high coherence through the whole water column. The mean current at HBIII was depth-independent or barotropic, whereas at HBII, it increased slightly with depth in a linear fashion (Figure 5). This is in agreement with previous discrete measurements available only from 80 and 150 m depth. The moored ADCP data show that these assumed profiles are valid over the water column up to ~30 m depth, so reducing the uncertainty of the behaviour of the flow close to the surface. Jónsson and Valdimarsson (2005) assumed that the current at 80 m was representative of the current between 0 and 115 m depth and that the current at 150 m was representative of the current from 115 to 200 m depth. The results from the ADCPs indicate that this is a reasonable assumption and add confidence to the method used previously by Jónsson and Valdimarsson (2005).

One way to estimate the water mass composition on the Hornbanki section would be to use the CTD sections taken there, but as shown by Jónsson and Valdimarsson (2005), there is not much continuity in time between the CTD data from one section to the next. There is considerable short-term variability in the temperature measured by the current meters that is not picked up by the CTD sections. For example, the temperature at all current

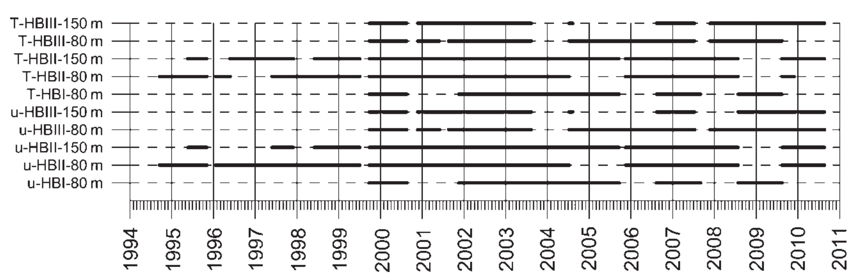

Figure 3. Timeline of the observed parameters from each instrument, showing when the various parameters are available.

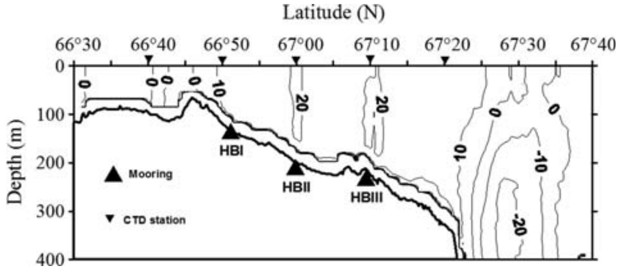

Figure 4. The average of the E–W component (positive towards the east) of the current measured with a vessel-mounted ADCP at the Hornbanki section for a total of 20 sections in November of 2001–2004 and in August 2005. Units of contoured speeds are 10^{-2} m s^{-1}.

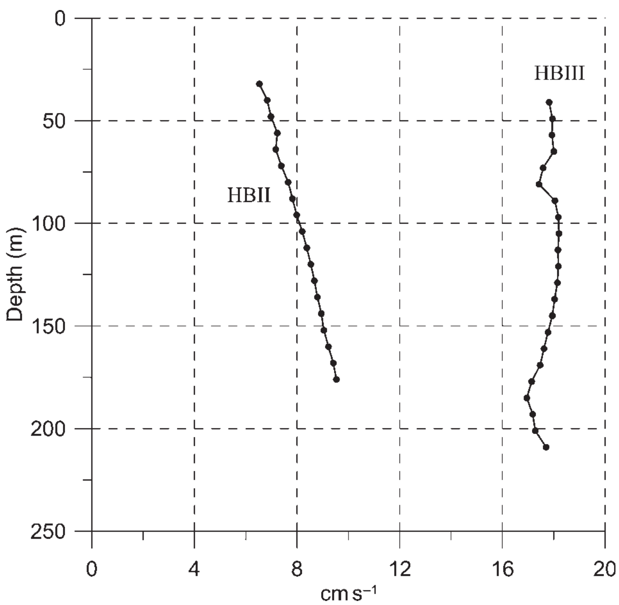

Figure 5. The time-averaged vertical profiles of the east–west component of current speed for all depth bins for HBII and HBIII from the ADCPs during 2009 and 2010.

meters fell by almost 3°C from the time the CTD section was taken in mid-November 1999 up to the end of that month. This can only be explained by a change in water mass composition on the section towards one with more influence of the colder PW. There are many such cases of sudden cooling and warming taking place over the measurement period considered here. Because of the temporal variability in the water masses on the section, the CTD data from the Hornbanki section are not directly useful for determining the proportion of AW present on the section.

Alternatively, the proportion of AW at each current meter was determined assuming that the temperature measured there was a result of a mixture of water coming from the north with the East Greenland Current and of the AW coming from the south. For this purpose, two standard stations where CTD measurements were taken four times annually were used. These are stations LB6 on the Látrabjarg section, which is always embedded in the core of the AW, and KG6, which usually is within the PW of the East Greenland Current or at least contains cold water masses from the north (Figure 1). The KG6 station on the Kögur section is not always accessible because it is sometimes covered with sea ice.

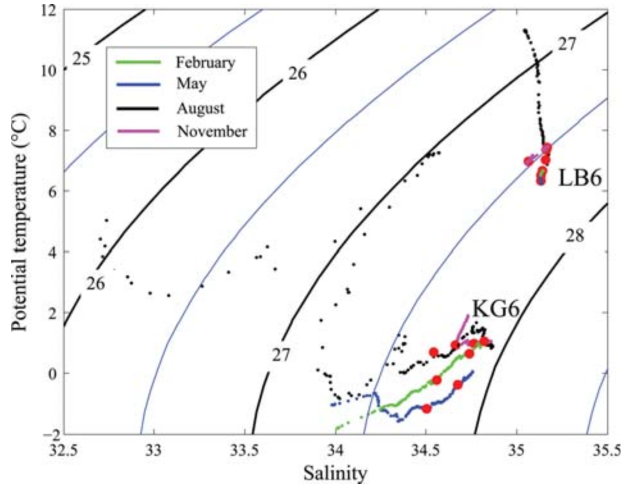

Figure 6. A θ–S diagram for stations KG6 and LB6 from 0 to 200 m depth for four occupations from August 2008 to May 2009. The data from 80 and 150 m are marked as red dots. Also shown are the density contours.

Occasionally, however, AW does flow to the station, so data from KG6 were only used when there was no AW present there. Other stations in the area were used if they did not include any AW, and for that purpose, the NISE database was used (Nilsen *et al.*, 2008).

A θ–S diagram for stations KG6 and LB6 from the surface to 200 m depth for the four occupations from August 2008 to May 2009 are depicted in Figure 6. The data from 80 and 150 m are marked by red dots. Salinity at the LB6 station was always >35, indicating the presence of AW there. There is very little spread in the data at LB6 except for the warming during summer seen in the upper 50 m in August 2008. The amplitude of the seasonal variations at LB6 was 0.57 and 0.54°C at 80 and 150 m, respectively. There is considerably more spread in the data in the surface layers from KG6, and the amplitude of the seasonal variation there was 0.98 and 0.48°C at 80 and 150 m, respectively. The two stations are clearly separated in the θ–S space and, as discussed below and also shown by Jónsson and Valdimarsson (2005), the temperatures obtained from the current meters on the Hornbanki section almost always lie between the temperatures at the two stations.

The total freshwater run-off from Iceland has been estimated by Jónsdóttir (2008) to be 0.0048 Sv, and a very small part of this comes from the area around Hornbanki. The run-off from land is therefore extremely small compared with the oceanic transports considered here, and it does not measurably influence the temperatures used here. It could, however, have some effect on the salinity, though this does not affect the mixing model used because it merely uses the temperature. It is therefore reasonable to assume that the water at the Hornbanki section consists of a mixture of the waters at LB6 and the colder waters at KG6.

The available data from LB6 and KG6 were fitted with a sinusoid, simulating the seasonal cycle. This series was then subtracted from the original series that was subsequently linearly interpolated, and the seasonal variation added back in again. This is slightly different from the method applied in Jónsson and Valdimarsson (2005), where a linear trend was assumed to exist in the temperature at stations KG6 and LB6. For the period for which the transport was calculated in Jónsson and Valdimarsson

(2005), the change had only minimal effect on the transport. In this way, daily values of the temperature were obtained at 80 and 150 m at stations KG6 and LB6, and these values were then used to calculate the proportion of AW at 80 and 150 m at the current meters. The temperature at the current meters was almost always (i.e. more than 98% of the time) between that of the AW and the water at KG6. If it was above or below those values, then the proportion of AW was set to 100 or 0%, respectively. Always, where this happened, the temperature was only slightly outside the range between the AW and the water at KG6, so there is no reason to invoke further water masses into the mixing scheme used here.

By multiplying the proportion of AW with the velocity and a representative area for each current meter, the total transport of AW to the North Icelandic shelf area was estimated. Heat transport was calculated relative to 0°C, and only the AW portion of the flow was included and multiplied by the temperature of the pure AW as well as by the heat capacity and the density. The reason for using 0°C is that most of the water flowing out of the Arctic Mediterranean has a temperature close to 0°C (Hansen *et al.*, 2003). Considering that the average temperature calculated from the heat transport and the AW transport is 6.6°C, much higher than 0°C, the choice of a reference temperature for the outflowing water that is definitely close to 0°C is not going to induce large errors in the calculated heat transport. The procedure described previously was used for estimating the transport of AW and heat for the period when five current meters were available, giving daily values for all parameters.

Error estimates

When one of the parameters was missing from an instrument, it was obtained using linear regression from the nearest available instrument for the measurement period 1999–2000. The validity of this approach can be checked by using data when data from all the instruments are available, then removing data from one of the moorings, using the regressions, and looking at the effect on the transport calculations. There are three such periods that are a total of ~4 years long (Figure 3). The first is from 1999 to 2000, the second from 2001 to 2003, and the last from 2006 to 2007. The error made in only considering HBII, which was the only mooring present from 1994 to 1999, and omitting data from the other two moorings results in 13% lower mean transport for the three periods than when all data were included. In 1999/2000, there was only 1% difference, whereas in 2001–2003, the difference was 18%. During this period and especially for 2002/2003, velocities were high particularly at HBIII. Most of this underestimate stems from omitting the data from HBIII, and omitting data from HBI only contributes ~2% for the whole period. Omitting data from HBII had very little (<1%) effect. The effect of omitting an instrument's data was always to reduce the transport of AW and its variability.

A lack of data from a mooring or an instrument therefore probably induces <15% error in the estimation of the flux of AW to the North Icelandic shelf. This is mainly a problem for the earlier period from 1994 to 1999, when only one mooring was present. After that there are only few gaps in the data from HBIII, which is the most important mooring for the estimation. Hence, there is good reason to believe that the method we used is robust and truly represents the flow of AW to the North Icelandic shelf. The main source of error is probably the open boundary to the north. Changing the outer boundary by 3′ or ~5.5 km, which seems a lot when looking at Figure 4, the area is changed by ~9%. Considering the greater velocity at HBIII than at the other moorings, the error might be of the order of 10%. Considering the error induced when moorings are missing, a reasonable error estimate for the transports reported here would probably be <15%.

Results

Interannual variability

The means of the transport of AW and the associated heat transport for the whole period are 0.88 Sv (1 Sv = 10^6 m^3 s^{-1}) and 24 TW (1 TW = 10^{12} W), respectively. These are somewhat larger than the numbers given in Jónsson and Valdimarsson (2005) of 0.75 Sv and 19 TW, but since 1999, the flow and temperature of AW has been increasing. The proportion of AW in the flow is 68%, slightly higher than the 66% found by Jónsson and Valdimarsson (2005).

Monthly averages of AW and heat transport have been calculated and are shown in Figure 7. The transport of AW varies from almost 0 to ~1.6 Sv, and the heat transport from almost 0 to 50 TW. The variability of the AW and heat transport is similar, and the reason for this is of course that the temperature of the inflowing AW does not vary much, so changes in the heat transport are very much in accord with changes in AW transport.

A 13-month running mean is shown in Figure 7. This better illustrates interannual variability. One event clearly stands out,

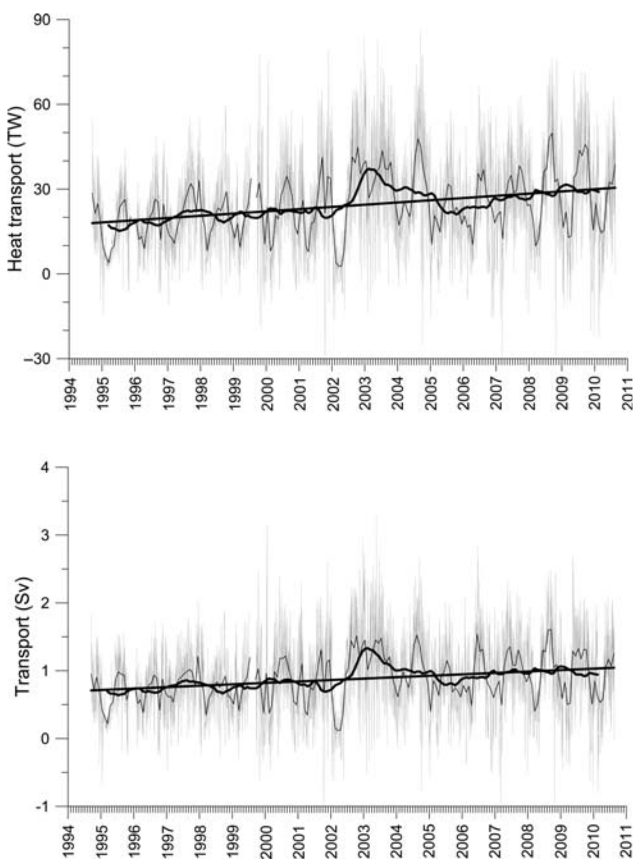

Figure 7. Monthly mean of the AW transport (Sv) in the lower panel and heat transport (TW) in the upper panel (thin black line). A 13-month running mean is shown as well as a linear trend (thick lines). The grey line shows the daily transport.

the very strong inflow of AW in 2003, when winter values were extremely high relative to other years. There seems to be a trend towards more AW and heat being transported from the start of the time-series to the end, and a linear trend for the whole period is shown in Figure 7. Looking at the biological parameters associated with the anomalous inflow of AW water in 2003, a record amount of juvenile haddock was observed in 2003 north of Iceland (Anon., 2004), and the distribution and abundance of juvenile cod were also broad/high. During winters of 1995 and 2002, very low values of both AW and heat transport were recorded.

The variability can be compared with the hydrography collected four times annually at standard sections over the North Icelandic shelf, and the temperature and salinity there should reflect the amount of AW flowing into the area with the NIIC. The temperature from the Siglunes section, eight stations extending from the central north coast to the continental slope at 68°N, is shown in Figure 8 together with the heat transport. The temperature shown is the average from stations SI2, SI3, and SI4 (Figure 1) over the depth interval from 50 to 150 m, which usually includes the core of the AW on that section. The temperature at the Siglunes section should be close to the temperature of the inflowing AW; the more PW mixed with it, the lower should be the temperature. Therefore, the temperature at the Siglunes section should show behaviour similar to the heat transport, although it should not be expected always to be the same because the flow or velocity is not measured there.

The Siglunes temperature clearly shows the same trend as the heat transport, with rising temperature over the whole period. In 2003, there was a record temperature that corresponded to the high heat transport and also with the fact that during the first 5 months of 2003, the proportion of AW in the inflow was very high, at 76%. In spring 1995, when heat transport was small for several months, the proportion of AW in the flow was very low, just 36%. This is in agreement with the temperature at Siglunes, which showed the lowest temperature during the whole period in spring 1995. In spring 2002, there was a drop in temperature at Siglunes, and this also is in agreement with the heat transport; for the first 5 months of that year, the proportion of AW in the inflow was 36%. In all other years, the proportion of AW in the inflow for the first 5 months of the year was between 53 and 67%, so the 3 years discussed earlier are the years that really stand out in the series. The fact that the transport of AW is consistent with the temperature measured at Siglunes is an indication that the method for calculating the inflow is robust.

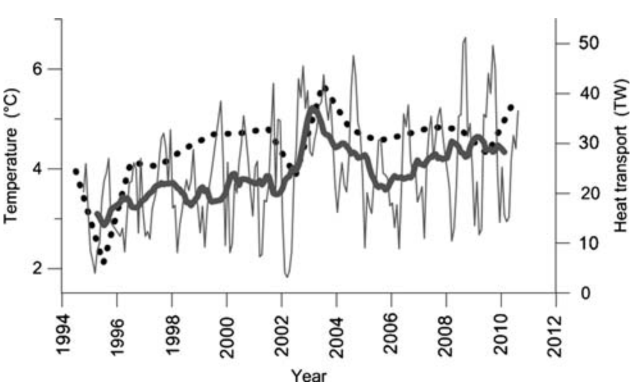

Figure 8. Annual average of temperature at three stations on the Siglunes section over the depth interval between 50 and 150 m, shown as a dotted line. The stations are SI2, SI3, and SI4 (Figure 1). The thin line shows the monthly heat transport on the Hornbanki section and the thick line the 13-month running mean.

During the period considered here, changes have taken place in the relevant water masses. The AW on the Látrabjarg section has been warming, and its salinity has increased. The PW, on the other hand, has not shown any trend in temperature. The temperature from the moorings show a trend similar to that observed at Látrabjarg, which is not surprising because the water there on average consists of 68% AW. This warming of the AW has been observed over most of the northern North Atlantic (Holliday *et al.*, 2008), who attributed the warming to a shift in the Subpolar Front that moved west during the warming period because of a weakening of the Subpolar Gyre, as suggested by Hátún *et al.* (2005). This would allow an increase in the flow of warmer, more saline water from the subtropical gyre to the northern North Atlantic.

Seasonal variation

Seasonal variations have been calculated and show that both AW and heat transport show a strong seasonal signal, with a minimum in March and a maximum in August (Figure 9). The amplitude of the seasonal variation for the AW transport is ~0.26 Sv, ~30% of the mean. The corresponding numbers for the heat transport are ~10 TW, ~40% of the mean. As the AW transport is calculated from the velocity and the proportion of AW, and the heat transport also depends on the temperature of the inflowing AW, it is of interest to know which of these factors contributes to the seasonal signal. There is a seasonal signal in the velocity at both HBII and HBIII, whereas it is very weak at HBI. Relative to the mean velocity at HBII and HBIII, the amplitude of the seasonal signal is similar, but at HBIII it is ± 3 cm s^{-1} and at HBII it is ± 2 cm s^{-1}, and the velocity is at a minimum in March and a maximum in August, the same as the transports. Therefore, velocity changes do contribute to the seasonal cycle of the transports, and the contribution is mostly from the outer two moorings.

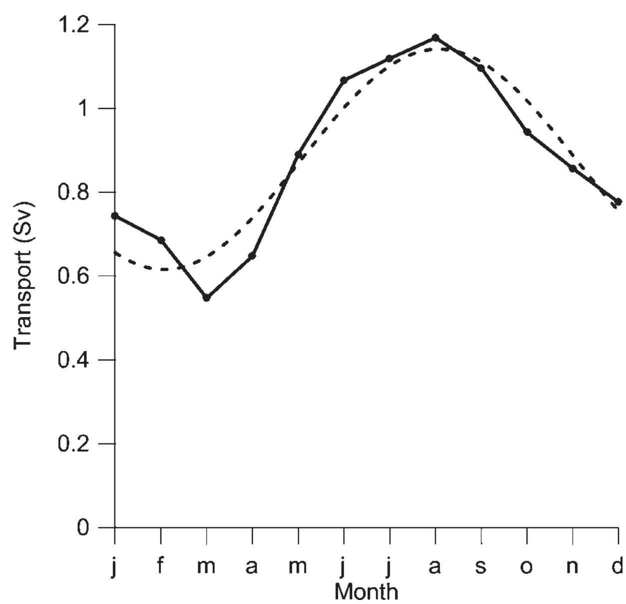

Figure 9. Seasonal variations in the calculated AW transport (Sv, solid line) along with a sinusoidal fit (dashed line).

Water mass composition, or the proportion of AW on the section, also varies seasonally, with a minimum in March and a maximum now in July. The data show that the proportion of the AW has a greater effect on the seasonal variation in the flow than the variation in the velocity. The proportion of AW is similar at all instruments, with a minimum of ~0.5 in March and a maximum of ~0.85 in July. The only exception is the slightly lower values at HBIII at 150 m, probably the result of an influence of deep water from the north.

The temperature of the inflowing AW also varies seasonally, adding further to the seasonal variation in heat transport. The greatest contribution to the seasonal variability in AW and heat transport stems from variations in the proportion of the AW flowing across the section and, to a lesser extent, by variations in the velocity.

Discussion and conclusions

Deriving a meaningful estimate of the transport of AW to the North Icelandic shelf area is not trivial. The Denmark Strait is wide and there are flows in both directions and probably also recirculation of some of the flow. The NIIC therefore has an open boundary to the north that may be variable. However, the NIJ that flows to the west over the slope on the Hornbanki section on its way towards the Denmark Strait sill probably limits the extent of AW inflow to the north, helping to constrain the inflow. The behaviour of the flow close to the northern boundary is probably the weakest link in the transport estimate, and an improvement would be to deploy a mooring farther north to get a better idea of the northern limit of the inflowing AW. However, there are many fisheries in the area, so the risk of losing moorings there is high.

The AW flow and heat transport values reported here (0.88 Sv and 24 TW) are somewhat larger than those reported in Jónsson and Valdimarsson (2005; 0.75 Sv and 19 TW). Part of the difference may derive from underestimation by the earlier study, because that work was mainly based on data from the HBII mooring alone, but this is not the only reason. The higher values in the current study are also due to higher velocities and, for heat transport, a rise in the temperature of the inflowing AW.

Although the flow of AW to the North Icelandic shelf is important locally, it is not a great part of the flow of AW into the Arctic Mediterranean over the Greenland–Scotland Ridge. The flow in the two branches on both sides of the Faroes was estimated by Østerhus *et al.* (2005) to be 7.6 Sv and 290 TW for the heat transport. This means that the NIIC only provides some 10% of the AW transport and 8% of the heat to the Arctic Mediterranean. However, it has been suggested by Våge *et al.* (2011) that the NIIC may be an important part of the formation of the water in the NIJ and may therefore contribute to the thermohaline circulation.

The measurements on the Hornbanki section provide a robust and cost-effective estimate of the flow of AW and the associated heat transport to the North Icelandic shelf. It has often been suggested that the flow of AW is important for the biology in this area, so this work provides crucial parameters that can be related to biological parameters for better understanding the consequences of variable inflow of AW. It is also a challenge for future numerical models of the area to try to simulate the AW transport provided.

Acknowledgements

The research leading to these results received funding from the European Community's 7th framework programme (FP7/2007–2013) under grant agreement GA212643 (THOR: "Thermohaline Overturning—at Risk", 2008–2012).

References

Anon. 2004. Environmental conditions in Icelandic waters 2003. Marine Research Institute, Reykjavík. 44 pp.

Astthorsson, O. S., and Gislason, A. 1998. Environmental conditions, zooplankton and capelin in the waters north of Iceland. ICES Journal of Marine Science, 55: 808–810.

Astthorsson, O. S., and Vilhjálmsson, H. 2002. Iceland Shelf LME: decadal assessment and resource sustainability. *In* Large marine Ecosystems of the North Atlantic. Changing States and Sustainability, pp. 219–243. Ed. by K. Sherman, and H. R. Skjoldal. Elsevier Science, Amsterdam. 449 pp.

Hamilton, L. C., Jónsson, S., Ögmundardóttir, H., and Belkin, I. 2004. Sea changes ashore: the ocean and Iceland's herring capital. Arctic: Journal of the Arctic Institute of North America, 57: 325–335.

Hansen, B., Østerhus, S., Hátún, H., Kristiansen, R., and Larsen, K. M. H. 2003. The Iceland–Faroe inflow of Atlantic water to the Nordic Seas. Progress in Oceanography, 59: 443–474.

Hátún, H., Sandø, A. B., Drange, H., Hansen, B., and Valdimarsson, H. 2005. Influence of Atlantic Subpolar Gyre on the thermohaline circulation. Science, 309: 1841–1844.

Holliday, N. P., Hughes, S. L., Bacon, S., Beszczynska-Möller, A., Hansen, B., Lavin, A., Loeng, H., *et al.* 2008. Reversal of the 1960s to 1990s freshening trend in the northeast North Atlantic and Nordic Seas. Geophysical Research Letters, 35: L03614.

Jónsdóttir, J. F. 2008. A runoff map based on numerically simulated precipitation and a projection of future runoff in Iceland. Hydrological Sciences Journal, 53: 100–111.

Jónsson, S., and Valdimarsson, H. 2004. A new path for the Denmark Strait Overflow Water from the Iceland Sea to Denmark Strait. Geophysical Research Letters, 31: L03305.

Jónsson, S., and Valdimarsson, H. 2005. The flow of Atlantic water to the North Icelandic Shelf and its relation to the drift of cod larvae. ICES Journal of Marine Science, 62: 1350–1359.

Kristmannsson, S. S. 1998. Flow of Atlantic water into the northern Icelandic shelf area, 1985–1989. ICES Cooperative Research Report, 225: 124–135.

Malmberg, S. A., and Jónsson, S. 1997. Timing of deep convection in the Greenland and Iceland Seas. ICES Journal of Marine Science, 54: 300–309.

Nilsen, J. E. Ø., Hátún, H., Mork, K. A., and Valdimarsson, H. 2008. The NISE dataset. Faroese Fisheries Laboratory Technical Report, 07–01. 177 pp.

Østerhus, S., Turrell, W. R., Jónsson, S., and Hansen, B. 2005. Measured volume, heat, and salt fluxes from the Atlantic to the Arctic Mediterranean. Geophysical Research Letters, 32: L07603.

Stefánsson, U., and Ólafsson, J. 1991. Nutrients and fertility of Icelandic waters. Rit Fiskideildar, 12: 1–56.

Thordardottir, Th. 1984. Primary production north of Iceland in relation to water masses in May–June 1970–1980. ICES Document CM 1984/L: 20. 17 pp.

Våge, K., Pickart, R. S., Spall, M. A., Valdimarsson, H., Jónsson, S., Torres, D. J., Østerhus, S., *et al.* 2011. Significant role of the North Icelandic Jet in the formation of Denmark Strait overflow water. Nature Geoscience, 4: 723–727.

Vilhjálmsson, H. 2002. Capelin (*Mallotus villosus*) in the Iceland–East Greenland–Jan Mayen ecosystem. ICES Journal of Marine Science, 59: 870–883.

Handling editor: Bill Turrell