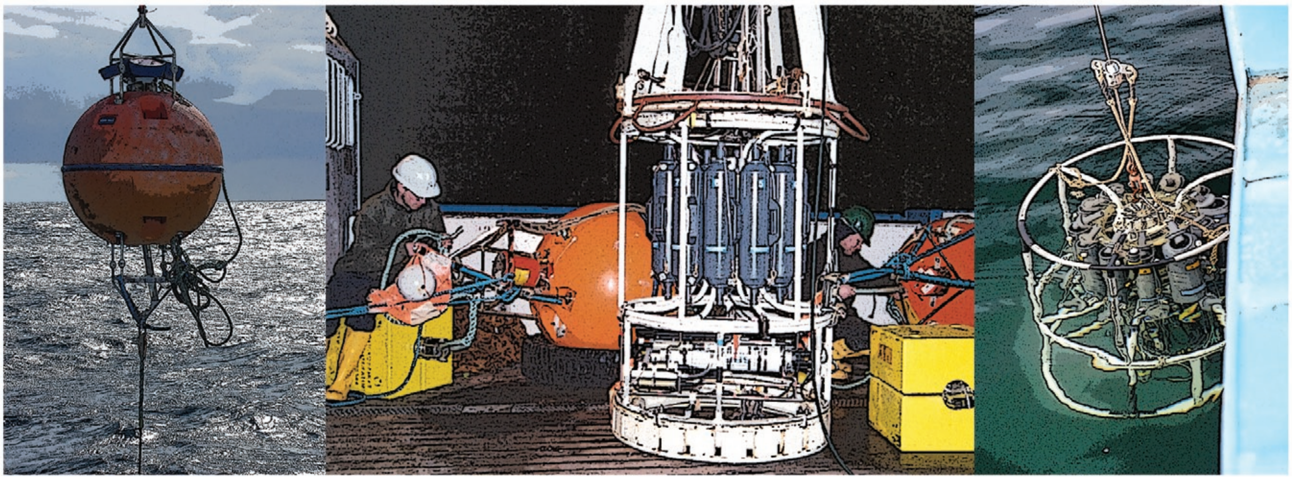
The hydrography and circulation of the Faroe–Shetland Channel



A century of research

Bee Berx

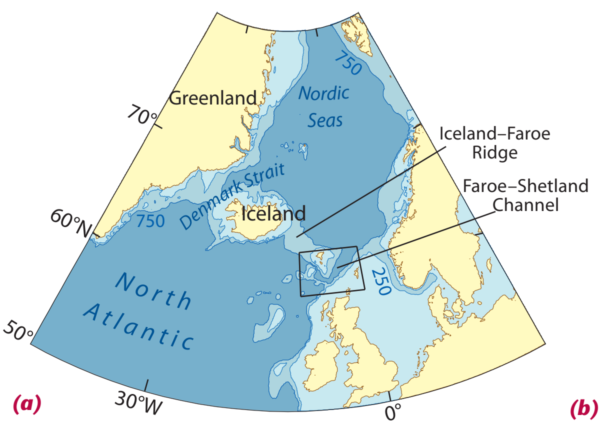
The Faroe–Shetland Channel has been a region of scientific interest since the late 19th century, and research there continues to date. What is the oceanographic significance of this area? And what have we discovered so far? The following article provides a short overview of the oceanographic importance of the Faroe–Shetland Channel, and of the general circulation within it, as currently understood. This is followed by a summary of results so far, and an outline of work to come.

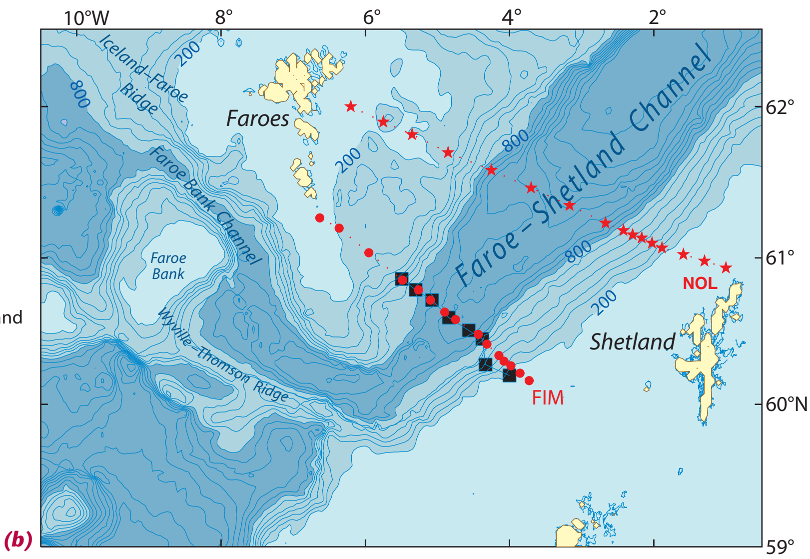
The northward flow of warm Atlantic water helps maintain the mild climate experienced by the British Isles and north-west Europe, in comparison with equivalent latitudes on the eastern coast of North America. But Atlantic water flowing into the Nordic Seas between Greenland and Scotland (Figures 1 and 2) is not only of significance for our pleasant weather, it is also an important component of the global ocean circulation.

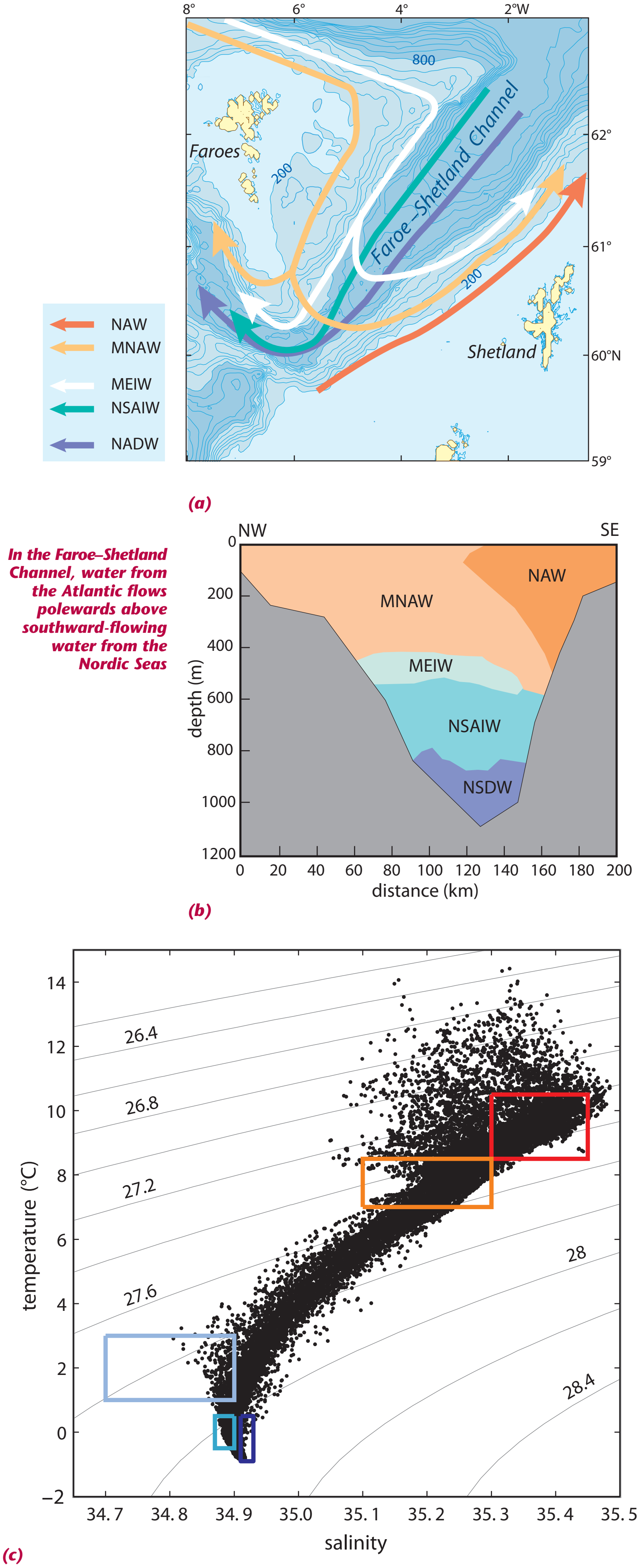
There are three main ways in which water from the North Atlantic enters the Nordic Seas (i.e. the Norwegian and Greenland Seas): there is an inflow of Atlantic water through the Faroe–Shetland Channel, discussed in this article; the Faroe Current crosses the Iceland–Faroe Ridge; and the North Iceland Irminger Current flows polewards in the eastern Denmark Strait. Within the Greenland Sea cooling of these relatively high-salinity Atlantic waters causes them to become sufficiently dense to sink, filling the deepest parts of the Greenland and Norwegian Seas.

The Faroe–Shetland Channel is a critical link between the North Atlantic and the Nordic Seas

Figure 1 ***(a)*** *The setting of the Faroe–Shetland Channel, between the North Atlantic and the Nordic Seas. (Area in box enlarged in (b)).* ***(b)*** *Bathymetry of the Faroe–Shetland Channel, showing the positions of the Fair Isle–Munken Line (FIM) (red dots), the Nolso–Flugga Line (NOL) (red stars) and the ADCP monitoring locations (black squares). Contour values are in metres.*







In the Faroe–Shetland Channel, water from the Atlantic flows polewards above southward-flowing water from the Nordic Seas

Figure 2 (a) Schematic representation of the paths of the main water masses flowing through the Faroe–Shetland Channel: NAW: North Atlantic Water; MNAW: Modified North Atlantic Water; MEIW: Modified East Icelandic Water; NSAIW: Norwegian Sea Intermediate Water; NADW, North Atlantic Deep Water. (b) Highly schematic section across the Faroe–Shetland Channel showing the generalised distribution of water masses. (a) and (b) are based on CTD data collected between 1994 and 2005. (c) Temperature–salinity diagram for water in the Faroe–Shetland Channel, indicating the T–S ranges of the main water masses and mixtures between them, based on observations collected between 1994 and 2008.

((a) and (b) by courtesy of Sarah Hughes)

Formation of deep water in turn draws more Atlantic water northwards into the Nordic Seas across the Greenland–Scotland Ridge. This thermohaline circulation, combined with wind and mixing, drives the Meridional Overturning Circulation or 'great ocean conveyor belt', which is of global significance in the Earth's climate system. Between Greenland and Scotland, these deep cold water masses flow southwards, channelled through the three gaps mentioned above: the Denmark Strait, the Iceland-Faroe Ridge, and the Faroe-Shetland Channel (Figure 1).

As climate change has increasingly gained our attention, so scientific interest in ocean circulation has grown, particularly in regions where key processes affecting the conveyor occur. Nevertheless, whilst scenarios of the impact of global circulation changes have received much publicity, relatively little attention is paid to the continuous monitoring 'behind the scenes'. This effort not only contributes to our present knowledge on the drivers and variability of ocean circulation, but also provides early warnings of changes in the ocean's circulation.

Research in the 19th and 20th century

As mentioned earlier, scientific interest in the oceanography between Greenland and Scotland, and particularly in the Faroe–Shetland Channel, is not new. In the late 19th century scientists from around Europe were organising expeditions to the Faroe–Shetland Channel; not only for purely oceanographic reasons, but also to study the organisms of this biologically productive region, from its plankton, to fish and large mammals.

Monitoring of the properties of oceanic water masses began in the early 20th century, with Dr H.N. Dickson of the then Scottish Fisheries Board undertaking the first regular surveys in the region. Since then, many more researchers from a truly international field (including Scottish, Faroese, Norwegians and Russians) have come to the Faroe–Shetland Channel to make observations of temperature, salinity and transport. From the early days, efforts have been focussed on two hydrographic sections across the Channel: one from South Faroe to South Shetland (the Fair Isle–Munken Line, FIM), and one from North Faroe to North Shetland (the Nolso–Flugga Line, NOL) (see Figure 1). Observations in the Faroe–Shetland Channel have been made on an almost annual basis since 1903, with the exception of the war years and several years in the early 1980s, making this one of the longest oceanographic time-series worldwide.

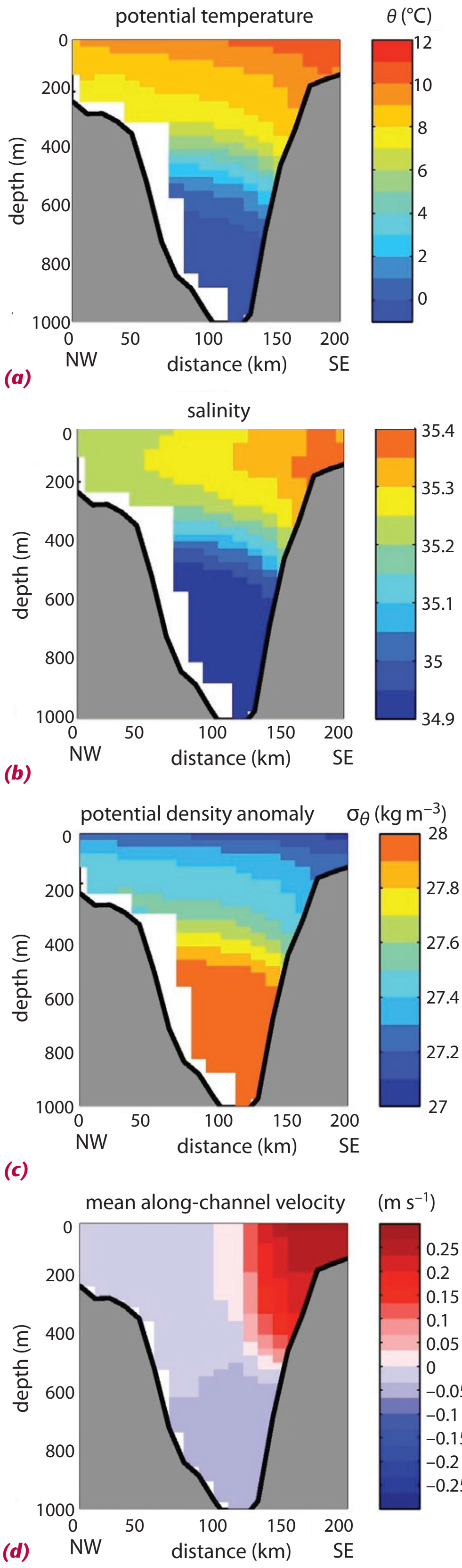
Water masses and circulation

Water column structure across the channel (Figure 2(b)) reveals the presence of five main water masses. Each of these water masses can generally be identified using temperature-salinity diagrams (Figure 2(c)) and is characterised by a specific range of chemical/biological properties. In the Faroe–Shetland Channel, the water above ~400 m is made up of either North Atlantic Water (NAW) or Modified North Atlantic Water (MNAW). NAW flows as a slope current along the Shetland Shelf Edge, whilst MNAW flows into the Channel from the north of the Faroe Islands and recirculates in the Channel (Figure 2(a)). These two surface water masses are the saltiest and warmest (Figure 2(c); Figure 3(a),(b)), and together they are responsible for the northward transfer of heat and salt from the Atlantic to the Nordic Seas through the Faroe–Shetland Channel.

At intermediate depths (typically around 400–800 m depth), Modified East Icelandic Water (MEIW) and Norwegian Sea Arctic Intermediate Water (NSAIW) can be found. The deepest water mass is Norwegian Sea Deep Water (NSDW) which makes up most of the southward overflow, directed through the Faroe Bank Channel and across the Wyville Thomson Ridge. This overflow, together with overflows in the Denmark Strait, will become part of North Atlantic Deep Water (NADW).

From 1994 to the present, a collaborative effort between Faroese, Scottish and Norwegian scientists has led to the establishment of an array of acoustic Doppler current profilers (ADCPs) to monitor the strength of the inflow of Atlantic Water into the Nordic Seas (Figure 1(b)). The mean along-channel current velocities are summarised in Figure 3(d). The strongest currents are those associated with the highly saline, warm-water core of the northward flowing slope current, transporting NAW. On the Faroese (north-west) side, southerly currents (blue in Figure 3) transport MNAW, while on the other side of the Channel, MNAW flows northwards again (pink and paler red in FIgure 3(d)). As indicated above, these Atlantic waters have flowed northwards over the Iceland–Faroe Ridge and then around the north of the Faroe Islands, before recirculating in the Faroe–Shetland Channel (Figure 2(a)). In the deeper layers, dense overflow water can also be observed travelling south; these waters will contribute to the Faroe Bank Channel and Wyville Thomson Ridge overflows with transports of 1.9 Sv and 0.9 Sv, respectively (1 sverdup (Sv) = $10^6\,m^3s^{-1}$).

Figure 3 *Distributions of **(a)** mean potential temperature (θ, °C), **(b)** mean salinity, **(c)** mean potential density anomaly (σ_θ, kg m^{-3}), all from ship-based CTD surveys made between 1994 and 2008. **(d)** Mean along-channel velocity (m s^{-1}) from five ADCP moorings on the Fair Isle–Munken line (see Figure 1) in the Faroe–Shetland Channel between 1994 and 2008.*



Deployment of modern instrumentation meant that details of the hydrography in the Faroe–Shetland Channel became clearer between 1994 and 2008

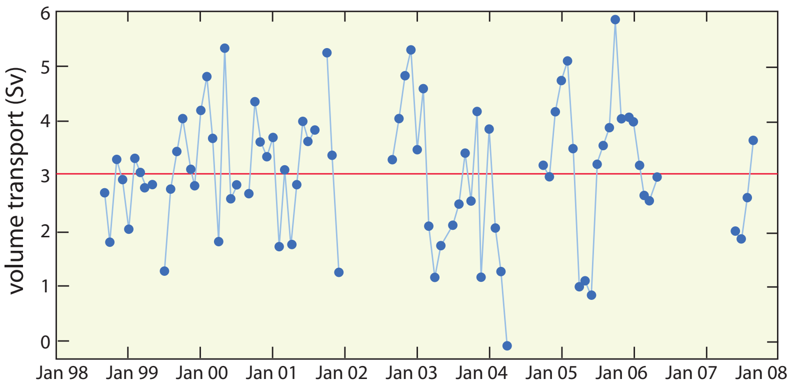
Variability in the Faroe–Shetland Channel

Research based on the above-mentioned long-term observations (1994–present day) has highlighted the region as a highly variable, energetic environment. A time-series of the volume flux of Atlantic water through the Faroe–Shetland Channel (Figure 4) shows the seasonal and interannual variability to be high. Sherwin and colleagues found wind stress to be an important influence on the seasonal patterns of the Atlantic inflow, and eddy kinetic energy levels in the Channel to be relatively high because of the passage of mesoscale eddies. In addition, Hatun and colleagues have had some success with simulating the observed seasonal and longer-term variability in the Faroe–Shetland Channel using a numerical model. They found good correlation for the prediction of raw and annual mean temperatures, but were less successful in simulating the salinities. Predicting the volume transport through the Faroe–Shetland Channel remains difficult, and the observational time-series is being compared to various numerical ocean models to verify their predictions.

Analysis of the water-mass properties in the Faroe–Shetland Channel has also revealed important changes. In the surface layers, both North Atlantic Water and Modified North Atlantic Water have increased in temperature and become more saline over the past two decades. Temperatures have been increasing by approximately 0.5 °C per decade, and salinities by approximately 0.07 per decade. It is thought that this is in part due to the weakening and westwards retraction of the subpolar gyre in the Irminger and Labrador Seas, opening a pathway for an increased contribution of subtropical waters to the water masses in the Faroe–Shetland Channel. Analysis of the characteristics of the deeper layers, by Turrell and colleagues, has shown that bottom waters in the Faroe–Shetland Channel have been freshening by about 0.01 per decade, due to both an influx of fresh Arctic waters into the Nordic Seas (i.e. changes in the properties of water masses), and a decrease in the formation of deep water in the Greenland and Iceland Seas (i.e. changes in the ratios of different source water masses). Within the deepest parts of the Nordic Seas, bottom waters have been getting warmer. Furthermore, the variability of water mass properties in the Faroe–Shetland Channel is not limited to the extremities of the water column, as changes of the order of 0.02 per decade have been found in the salinity of the intermediate water masses too.

The volume of Atlantic Water flowing through the Channel is highly variable on both seasonal and interannual time-scales

Figure 4 *Monthly averaged volume flux of Atlantic Water through the Faroe–Shetland Channel (in sverdrups), as determined at the FIM monitoring site by integrating the velocity observations over the surface 500 m. (1 sverdrup = $10^6\, m^3\, s^{-1}$)*



Project THOR

Observations of volume, heat and salt transport in the Faroe–Shetland Channel were first made within numerous international projects, and have continued to be part of such projects. Currently, the research effort is part-funded under the EU Framework 7 Project THOR (ThermoHaline Overturning – at Risk?) which started in December 2008.

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This European project is focussing on monitoring and forecasting the North Atlantic thermohaline circulation on decadal time-scales, and on assessing its stability and the risk of a breakdown in a changing climate. The project involves the collaboration of more than 20 institutes from across nine countries, and will conclude in 2013. The research activities are centred on five core themes: quantifying and modelling variability of the thermohaline circulation using palaeoclimate observations and simulations; an assessment of uncertainty in forecasting; observations of the North Atlantic thermohaline circulation; predicting the meridional overturning circulation; and improving the technology for near real-time observations and data assimilation in coupled ocean–atmosphere models.

Three more ADCPs have been deployed in the Faroe–Shetland Channel with the aim of improving our understanding of the variability of the Atlantic inflow. The existing monitoring array (cf. Figure 1(b)) crosses the Faroe–Shetland Channel in a region of high eddy energy, which has made it hard to interpret the existing observations as they include a component of variability from the eddies. Within THOR, researchers will use the additional ADCPs in two different deployment configurations to identify the most suitable location for the monitoring array. In a first phase of the fieldwork the additional ADCPs have been deployed along the Fair Isle–Munken section. Data from these are currently being worked up to see whether adding instrumentation at the existing section improves estimates of Atlantic water transport. In a second fieldwork phase (currently underway), these instruments will be deployed on a new section further to the south-west where analysis of altimeter data has shown eddy energy to be lower.

In addition, observations of surface temperature and salinity are now also being made from ferries such as the *Norröna*, which regularly crosses the Faroe–Shetland Channel on its way from Denmark to the Faroe Islands and Iceland. As this data-set starts to build up it will be helpful in further interpreting the observed variability. In general within THOR, scientists from both modelling and observational backgrounds are working together to improve their understanding of the decadal variability of the North Atlantic thermohaline circulation, and of how the thermohaline circulation might be affected by global climate change. In conclusion, research in the Faroe–Shetland Channel over the past centuries has provided great insight into the details of the circulation between the northern Atlantic and the Nordic Seas, as well as its importance in global ocean circulation. However, the answers to several questions remain outstanding, and perhaps the most important one is: How will anthropogenic climate change influence the northward transport of Atlantic water to the Nordic Seas?

Further Reading

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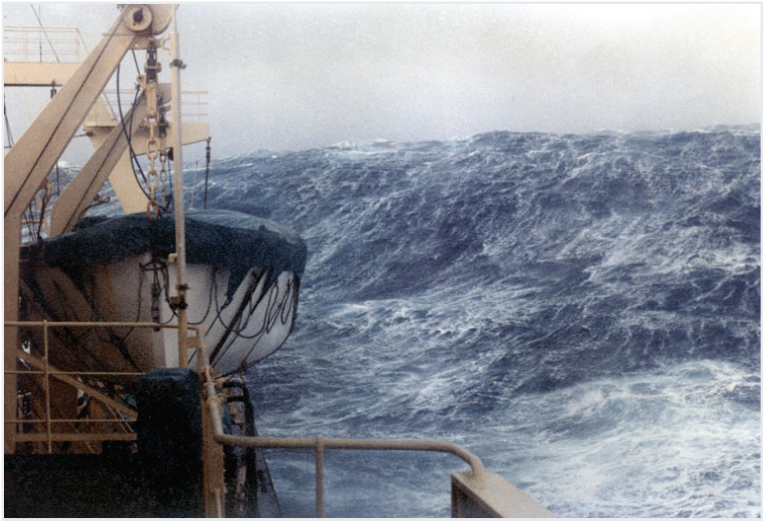

The photo above is by courtesy of George Slesser; the images in the title graphic are by courtesy of Marine Scotland

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A newly discovered contribution to North Atlantic Deep Water

The Denmark Strait overflow water is the largest dense water plume from the Nordic seas to feed the lower limb of the Atlantic Meridional Overturning Circulation. Its primary source is commonly thought to be the East Greenland Current but the recently discovered North Icelandic Jet – a deep-reaching current that flows along the continental slope of Iceland – has called this view into question. The Jet advects overflow water into the Denmark Strait and constitutes a pathway that is distinct from the East Greenland Current. The jet supplies about half of the total overflow transport, and may be the primary source of the densest overflow water. For more see: Kjetil Våge, K., R.S. Pickart, M.A. Spall, H. Valdimarsson, S. Jónsson, D.J. Torres, S. Østerhus and T. Eldevik (2011) Significant role of the North Icelandic Jet in the formation of Denmark Strait overflow water, *Nature Geoscience* **4**, 723–7 doi:10.1038/ngeo1234