



Nordic Council
of Ministers

DEEP WATER EXITING THE NORDIC SEAS

a pacemaker of North Atlantic circulation



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This publication is also available online in a web-accessible version at <https://pub.norden.org/temanord2022-533>.



Summary

This project focused on the deep water exported from the southern boundary of the Nordic Seas at the Greenland-Scotland Ridge through a series of sills. These so-called overflow waters pervade the North Atlantic and global ocean, contributing to the structure and strength of the overturning circulation that is fundamental to our climate system. Further these overflow waters contribute to the deep and long-term storage of heat and carbon that reduces atmospheric increases in heat and carbon and mitigate climate change. In this project we assessed available observations and models and reviewed relevant literature to investigate the knowledge gaps around;

1. overflow water connectivity through the North Atlantic,
2. characterisation of water mass transformation at the overflows
3. variability in overflow water properties

This project brought together Nordic expertise at a three-day workshop in June 2021. The first two days of the workshop included 14 scientific presentations and focussed on 1) Variability in and around the overflows and 2) Fate of the overflows. During the third day we discussed 4 knowledge gaps that had emerged from interactions on the first two days namely inflows, properties at the overflows, transport at the overflows, fate of the overflows. In addition to identifying research questions associated with these knowledge gaps the group came up with a list of recommendations for a strategy for observations and modelling in order to improve future monitoring and understanding.



Project objectives and wider significance

Over the last decade the importance of the oceans in the climate system and their role in delivering goods and services, including climate regulation has been increasingly recognised. In 2015 the G7 Group of Nations took up the prevention of Marine litter as a central theme and in 2016 broadened this into a major initiative on the Future of the Seas and Oceans. This was followed in 2017 with the UN declaring the 2020s the decade of sustainable ocean science, the 2019 IPCC special report on the oceans and cryosphere and the 2019 decision of the UNFCCC to include oceans in the Paris Agreement. Taken together these initiatives reinforce the timeliness for an assessment of observing, modelling and understanding the Nordic overflows.

Table 1: Nordic contributors to project and workshop

Dr. Elaine McDonagh	NORCE	Norway
Dr. Kristin Richter	NORCE	Norway
Dr. Karin Margretha H. Larsen	Faroe Marine Research Institute	Faroe Islands
Dr. Léon Chafik	Stockholm University	Sweden
Dr. Steffen M. Olsen	Danish Meteorological Institute	Denmark
Dr. Steingrímur Jónsson	University of Akureyri	Iceland
Dr. Svein Østerhus	NORCE	Norway
Dr. Bogi Hansen	Faroe Marine Research Institute	Faroe Islands
Dr. Hjálmar Hátún	Faroe Marine Research Institute	Faroe Islands
Dr. Andreas Macrander	Marine and Freshwater Research Institute	Iceland

This project brought together an established group of Nordic Researchers (Table 1) with extensive knowledge and experience of observing, modelling and understanding overflow waters and their climatic significance. This project is formed in recognition

that there is a mismatch in the simple interpretation of existing observations. Namely a reducing transport of overflow water in the subtropical North Atlantic with no systematic change of transport at the overflows. This project will identify a knowledge-based strategy to resolve this apparent inconsistency and other key knowledge gaps relevant to overflow waters in the broader North Atlantic circulation.

This project built on multiple national and international projects and collaborative partnerships that have observed and modelled the overflows. In addition this project made use of the participants project-based expertise on the broader drivers and impact of the overflows in North Atlantic circulation variability and its place in the Earth System.



Solving a problem and Nordic priorities

Overflow water is important: it is part of the Atlantic and global overturning circulation and facilitates deep storage of heat, oxygen and carbon on long timescales. A schematic of the large-scale overturning circulation is shown in Figure 1. Currently the ocean beneath 2000m stores around 10% of the ocean warming and oceanic anthropogenic carbon, with the North Atlantic playing a disproportionately large role in this storage given its size. The importance of the deep ocean and North Atlantic in climate is large and growing in time as more of the deep ocean has been ventilated during the Anthropocene. Programs in the subtropical Atlantic monitoring the strength of the overturning circulation show a decline in recent years, attributed to a change in the supply of deep overflow waters deriving from the Nordic Seas. This is not observed in the contemporaneous overflow records.

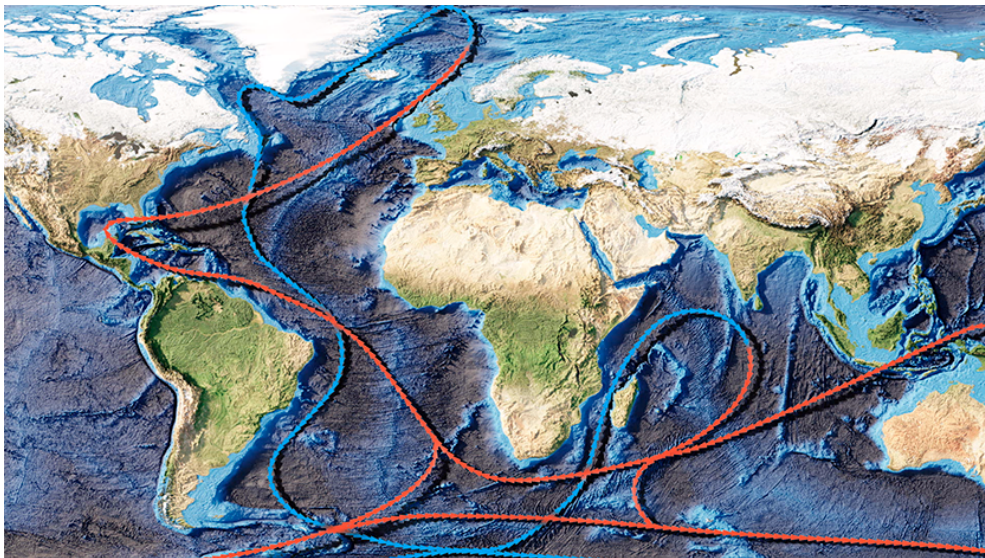


Figure 1. A schematic of the large-scale overturning circulation. In the Nordic Seas northward flowing surface water (red arrows) cools, increases in density and is converted to deep cool water (blue arrows) that flows southward and exits the Nordic Seas at a series of sills. It is the deep flow at these sills that are known as the overflows.

The project contributes to Nordic priorities by promoting a world-leading area of Nordic research in the field of Nordic seas overflow in particular and its role in global ocean circulation in general. Due to the global importance of overflow waters in past, present and future ocean heat and carbon uptake the results of this project indirectly underline the need to move towards a greener society both at the Nordic as well as global level.



Bringing together Nordic expertise

A workshop to address the issues was held on the 1st–3rd June 2021. Due to ongoing travel restrictions relating to the COVID-19 pandemic the workshop was held online, hosted by Elaine McDonagh and Kristin Richter from NORCE, Bergen. The workshop structure was discussed and decided by the projects board, comprising members from 6 Nordic nations, at online meetings in February and April 2021. In addition to experts from the Nordic nations scientists from the US and UK were invited to the workshop.

Objectives of workshop:

- Share state of the art understanding in overflow science.
- Identify knowledge gaps that might stimulate future activities including research projects.

The first two days of the workshop included fourteen science presentations. Four main topics emerged from the scientific presentations and subsequent discussion session. For each topic, knowledge gaps and research questions were identified and are listed under each topic below. In addition *six recommendations* and action areas were identified as priority areas for future activity in the group.

Summary of discussion sessions

Topic 1: Inflows

The warm surface waters that enter the Nordic Seas have undergone significant change in recent decades.

Knowledge gaps and research questions identified in discussion

- How does salinity and temperature variability (both Atlantic and Arctic) impact ecosystems and fisheries?
- What are the dynamics of the surface water changes other than the overturning?

Topic 2: Properties at the overflows and variability upstream

While the quantity of overflow water escaping the Nordic seas has not systematically changed over the observational record, the properties of that water have changed. These changes in properties could affect the rate of entrainment thereby the strength of the drivers of the Atlantic overturning circulation. We will examine the state of knowledge of this change as well as the upstream drivers and downstream fingerprint of this variability.

Knowledge gaps and research questions identified in discussion

- How do properties at the overflows relate to changes in convection characteristics (strength and properties) in the Nordic Seas? (Figure 2)
- Is the property variability at the overflows indicative of a tipping point?
- How do we use models to inform these questions?
- What is the balance between buoyancy forcing vs preconditioning as a driver of deep water formation?
- What is the sensitivity of Deep Sea ecosystems at the overflows to property changes?

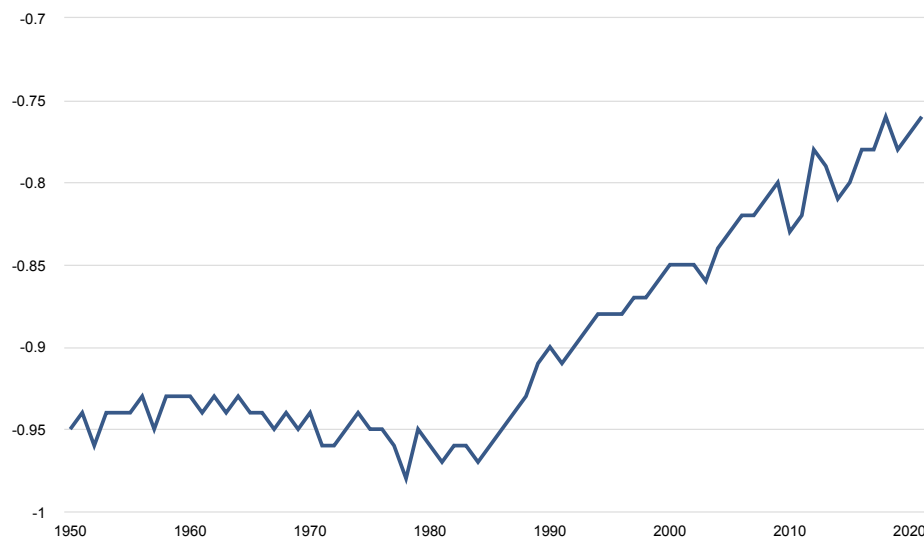


Figure 2: A dramatic warming of deep water has been observed in the Nordic Seas in recent decades.

Topic 3: Transport at the overflows

The complex topography of the overflow region results in significant modification of the overflow water through interaction with the bottom boundary layer and other mixing processes. This is a process by which the entrainment of other water masses more than doubles the strength of the descending waters from the Nordic Seas. These processes are usually poorly represented in the relatively low-resolution general circulation and coupled climate models used for projections. We will assess the gap between high resolution regional models and relatively low-resolution global models.

Knowledge gaps and research questions identified in discussion

- How is the impact of high-resolution knowledge (including Ekman drainage) included in low resolution models?
- What is the balance between density-driven and wind-driven variability?
- What timescales do these drivers work/dominate on?
- What is the vulnerability of the Eastern vs. Western overflows to change?
- What is the regional bottom roughness and how does this impact Ekman layers.

Topic 4: Connectivity and non-steady state

The fate of the overflow waters in the North Atlantic including the state of knowledge on connectivity of the overflows including timescales of spreading, regional convergence and storage of overflow water

Knowledge gaps and research questions identified in discussion

- What are the dynamics that control the deep water exchange from the subpolar to the subtropical gyre?
- What timescales do these controls work on? Can a water mass approach help to separate timescales?

Recommendations and actions

1. Maintaining the overflow monitoring activity is a priority! Ambition to build a sustainable long-term observational system. Advocacy for this activity is ongoing through efforts such as TOS article, link to the Ocean Decade, G7, ASOF and GOOS through OceanSites. Possibly create a virtual data centre for the region.
2. Set up a platform to share information about fieldwork activities in the overflow region, encouraging future collaboration, identifying synergies for observational work and adding value to the national investments in fieldwork activities.
3. Focussed project on observational process study and high-resolution modelling to identify mixing hotspots and feedbacks.
4. Technological priority: bottom-following floats for studying overflows and deploying regional system of sound sources for navigation.
5. Develop techniques to parameterize/represent overflows in lower resolution models such as Earth System Models
6. Analyse inflow to Nordic Seas through synthesised observations, including ADCPs, current meters, hydrography and altimetry. Explore new techniques including machine learning.

Other resources:

Podcast: The disappearance of water in the Nordic seas

<https://bjerknes.uib.no/en/article/news/podcast-disappearance-water-nordic-seas>

Animation: Why care about changes deep down in the Norwegian Sea?

<https://vimeo.com/704110119>

About this publication

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Nordic co-operation promotes regional interests and values in a global world. The values shared by the Nordic countries help make the region one of the most innovative and competitive in the world.

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