Core Theme 3:
Observations of the North Atlantic THC

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Participants: UiB, SAMS, FFL, MRI, UHAM, NERC-NERC, NIOZ, IFM-GEOMAR, MPG-M

Core Theme 3 focuses on the observational component of THOR. It contains three work packages that involve dedicated observations of various components of the North Atlantic THC (NA-THC) and one work package that, in cooperation with SMEs, will develop technology to be used in future monitoring of the NA -THC. The NA -THC is fed from several sources, and WP 3.1, 3.2, and 3.3 are designed to observe all of the sources as well as the total product during the project period. This is done by sustained observations of ocean properties and fluxes through a number of key sections (WP 3.1), monitoring of water mass formation in convection regions south of the ridge (WP 3.2), and process studies aimed at studying entrainment and fresh water control of overflow production (WP 3.3). To a large extent, these activities build on previous efforts and can utilize existing instrumentation. In THOR, the observational systems will be completed and expanded and new technology will be developed with a view, especially, to reduce the requirement for expensive ship time (CT 5). Science outputs of this core theme will feed into an overall assessment of priorities for the development of observing systems and models, required for a quasi-operational decadal THC prediction system. This will be one of the major scientific and technological outputs of THOR.

WP 3.1 Sustained observations of ocean properties and fluxes through key sections

Lead: S. Østerhus (UiB)
Participants: UiB, SAMS, FFL, MRI, MPG-M, NERC-NERC, UHAM

Work Package 3.1 involves sustained observations on a number of different sections with the aim to generate time series of properties (temperature and salinity) as well as volume flux of various components of the NA-THC. The observations include monitoring of the exchanges across the Greenland-Scotland Ridge (Tasks 3.1.1 and 3.1.2), monitoring the outflow from the Labrador Sea (Task 3.1.3), and monitoring the total Overturning Circulation at 26.5°N (Task 3.1.4). This combination will allow a comparison between independently measured contributions to the NA-THC to clarify how consistent, values for various sources and total Overturning Circulation are with one another. We build at least partly on existing instrumentation and will extend time series, which in some cases will exceed a decade in length. These time series will serve as benchmarks, against which, models will be validated (Core Theme 2). This WP has four different tasks:

Task 3.1.1 Monitoring the inflow of Atlantic water to the Nordic Seas

The Atlantic inflow to the Nordic Seas is the northernmost part of the upper limb of the NA-THC. It transports heat northwards along the European coasts, into the Nordic Seas, and the Arctic. Most of this inflow is converted into dense water that overflows the ridge (Task 3.1.2) to feed the NA-THC. The Atlantic inflow has three branches and each of these will be monitored by deploying moorings along sections, which are also occupied regularly by CTD cruises. In THOR, these existing arrays will be augmented, partly to replace old instrumentation, partly to increase spatial resolution of the mooring arrays. For most of the moorings, current measurements will rely on ADCPs, located either on top of single point moorings or bottom mounted in trawl-protected frames.

Task 3.1.2 Monitoring the dense water overflow across the Greenland-Scotland Ridge

The overflow of dense water from the Nordic Seas into the Atlantic contributes the densest component of the North Atlantic Deep Water (NADW) and, when including water entrained on route, it is also by far the largest source for NADW production. The overflow crosses the ridge in four separate branches, but most of the volume flux (~ 80%) is carried by the two dominant branches, which pass through the Denmark Strait, and the Faroe Bank Channel, respectively. In THOR, these two branches will be monitored accurately. The Denmark Strait overflow will be monitored by an array across the sill of the Strait. The array will include 3 ADCPs. This will be augmented by two additional ADCP's in bottom-mounted frames. The Faroe Bank Channel overflow will be monitored by two ADCPs as a continuation of the system that has produced accurate flux time series since 1995. For both of these overflow branches, sensors measuring temperature and salinity will also be deployed and four CTD cruises are planned for each year, although weather and sea-ice conditions may limit the extent to which the observations can be completed. The other two overflow branches, across the Iceland-Faroe Ridge and across the Wyville-Thomson Ridge, will not be as accurately monitored, but instrumentation will be deployed to investigate the key features of these overflows.

Task 3.1.3 Monitoring the export of deep waters at the exit of the Labrador Sea

In the Labrador Sea, overflow water from the Denmark Strait and from the Iceland-Scotland region, which has been modified and augmented by entrainment, joins with newly formed deep water masses, produced by deep convection in the Labrador and Irminger Seas. This water is exported from the Labrador Sea mainly by the boundary current and subsequently out of the subpolar region. As all deep water mass components are included, the total deep water export and variability is one possible indicator of THC-strength and variability. This will be monitored by a moored array across the boundary current. In combination with the current measurements at key depths, both the salinity and temperature field will be measured to derive a transport index for all water masses in the Deep Water range. In THOR, the results will be combined with high resolution modelling and assimilation efforts to both interpret the observations and for adjusting the observational design if necessary. Moored records will be supplemented by repeat hydrography and velocity sections along the former WOCE lines: AR7W and AR7E. Task 3.1.3 aims at interpreting decadal time series of currents and water mass variability in order to:

- Determine inter-annual to decadal boundary current variability
- Develop and continue an index of Deep Water Export (THC-Index) in combination with other available data for validation of model and assimilation products (Core Theme 2).
- Evaluate the penetration of newly formed water masses into the boundary current in combination with other observations (e.g., those derived from the ARGO programme) and THOR model results.

Task 3.1.4 Validating variability of climate models against THC observations

A critical question in assessing the reliability of models to simulate potential slowdown of the THC is their ability to reproduce observed levels of variability. In this Task, we will investigate, to what degree models are capable of reproducing observed variations of various sources for the THC, measured in this project, as well as the strength and structure of the THC at the maximum of the northward heat transport at 26.5°N. Funded by RAPID and RAPID-WATCH in March 2004, a pre-operational prototype array was deployed at 26.5°N to continuously monitor the THC at this latitude. The monitoring array will be recovered and redeployed annually until 2014. This decade-long time series will define the intra-annual, seasonal and inter-annual variability of the THC. With the 26N array in the Atlantic and observations further north we have, for the first time, the capability of putting models to the test of whether they simulate the integral circulation realistically. In this Task, we will use the 26N observations and the observations upstream of this section and the models of MPG-M and other partners. This contribution will provide a critical link between the observational and the modelling parts of THOR, by performing the crucial "reality check" on the consortium's model suite that must be the starting point of all assimilation efforts. Initially, we will provide and analyse the time series up to the project start, together with interpretations of those observations. This will provide an immediate beginning for model-data inter-comparisons. Thereafter, on an annual basis we will update the observational time series and provide these data to THOR modellers, and continue joint model-data comparisons.

WP 3.2 Monitoring watermass formation in convection regions south of the ridge

Lead: J. Fischer (IFM-GEOMAR)

Participants: IFM-GEOMAR, NIOZ

Two areas south of the Greenland-Scotland Ridge are known or hypothesized to experience deep convection of water masses that can contribute to the production of North Atlantic Deep Water. These areas are located in the Labrador Sea and the Irminger Sea and will be monitored within Work Package 3.2 of THOR. The products derived within WP 3.2 are essential:

- To provide information regarding the variability of the processes (convection and water mass formation) on time scales from weeks to several years in areas
- To validate products from the modelling / assimilation efforts
- To be used (T/S) in assimilations for an optimum 50-year THC-estimate. In the Labrador Sea, timely data transfer at 4-6 months periods is aspired through an innovative data shuttle system (WP 3.4)
- To be used to evaluate/calibrate remote sensing products

Task 3.2.1 Monitoring convection in the central Labrador Sea

Task 3.2.1 has the main objective to operate a moored station (close to the position of the former Ocean Weather Ship BRAVO) for observing the heat and freshwater budget of the central Labrador Sea. Key measurement quantities are temperature and salinity and a strong focus is on the freshwater signal. Time series extending from near surface to the depth of maximum winter convection will be established and maintained throughout the time period of THOR; building upon earlier multiyear national efforts. State-of-the-art instruments (e.g. Microcats and acoustic current meters) will be deployed for one to two-year periods. This, in combination with 3-D current measurements will enable us to identify active convection and the depth penetration of the freshwater signal. In addition, shipboard observations and the data from the international fleet of Argo-Floats will be used to relate local information to the large-scale environment.

Task 3.2.2 Monitoring convection in the central Irminger Sea

Task 3.2.2 has as main objective to operate a moored station in the central Irminger Sea close to the former WOCE AR7E line, collecting daily high resolution hydrographic profiles from the near-surface layer to about 2400 m. These CTD profiles will enable us to monitor the spreading of convectively formed intermediate water from the Labrador Sea. In combination with 3-D current observations covering the upper 600 m, the daily profiles will enable us to identify active convection, modifying the upper layers as well as the Labrador Sea Water in the Irminger Sea. In the lower range of the profiler, water originating from the overflow across the Iceland-Scotland Ridge is monitored. Current meters and Seacats in the near-bottom layer enable us to monitor the properties (temperature, salinity/freshwater content) of the Denmark-Strait Overflow water downstream of the sill. The high-frequency hydrographic observations will be analysed in the context of the annual hydrographic surveys of the AR7E section, to evaluate the local changes in the hydrography to the large-scale oceanographic environment.

WP 3.3 Process studies

Lead: B. Rudels (FIMR)

Participants: FIMR, CEFAS, UHAM, SIO, MRI, UiB

A number of different processes affect the NA-THC, but there are especially two processes that play major roles in controlling the production of NADW, but are not well understood at present. One of these is the entrainment of Atlantic water into the overflow plumes after they have crossed the Greenland-Scotland Ridge. The other is the re-direction of fresh water from the East Greenland Current back into the Nordic Seas, where it can affect the formation of overflow water. In order to clarify the role of these processes, two types of studies will be carried out consecutively, partly using the same equipment. This WP has two different tasks:

Task 3.3.1 Entrainment of ambient waters into the overflows

As the overflow waters from the Nordic Seas and the Arctic Ocean descend down the Greenland – Scotland Ridge into the deep North Atlantic, they entrain intermediate water into the overflow plumes, thereby increasing the contribution to the deep boundary current. The entrainment thus increases the strength of the Overturning Circulation and influences the northward advection of warm surface water at least as far north as 60°N. There is a general agreement that the entrainment into the overflows east of Iceland practically doubles the supply to the North Atlantic Deep Water, although the processes involved are not clear. The estimates of the entrainment into the Denmark Strait overflow, however, diverge strongly, ranging from a doubling of the transport to a mere 20% increase in volume flux. In both overflows the mechanisms driving the entrainment are not sufficiently well known, and several mechanisms have been suggested: turbulent entrainment generated by bottom friction, lateral eddy exchanges, eddy generation by vortex stretching and conservation of potential vorticity. In THOR, different approaches to estimate the entrainment are planned:

- Downstream of the Faroe Bank Channel, moorings will be deployed in the area where highly energetic mixing processes are known to induce intensive entrainment of ambient waters into the overflow plume. Downstream of the Denmark Strait, the variations of the strength and properties of the combined overflow and entrained water will be studied from the data obtained from the current meter array at Angmassalik and by hydrographic observations made in connection with the servicing of the moorings. These observations will be compared and evaluated together with measurements of the overflow at the sill (Task 3.1.2) and with upstream observations, in the basins feeding the overflows.

- Dedicated process studies will be carried out both downstream of the Faroe Bank Channel and downstream of the Denmark Strait. In the Denmark Strait, the experiments will be carried out at least once but preferably twice within the project in connection with the yearly hydrographic observations and the replacements of the moored instruments. They will last about one month each time and involve direct observations of the turbulent activity and the mixing and entrainment of ambient water into the overflow plume.

Task 3.3.2 Fresh water transport north of Iceland

The Arctic Mediterranean receives a large freshwater input through river runoff and precipitation and most of that leaves the area in the surface outflows through the Canadian Archipelago and in the East Greenland Current. Present estimates indicate that by far the largest component leaves the Arctic Mediterranean through the Denmark Strait. A smaller component leaves the East Greenland Current to enter the Greenland Sea or the Iceland Sea, where it may affect the production of overflow water. In THOR, measurements will be carried out to determine the amount of fresh water flowing within the East Icelandic Current. It would give a clue to the amount of fresh water diverted from the East Greenland Current into the Iceland Sea and also on the fresh water flow to the Norwegian Sea. Previous studies have shown that it is feasible to estimate this with a single mooring together with regular (4 times/year) CTD measurements on the section. The mooring is planned to be deployed after Task 3.3.1 has been terminated and will use some of the same instrumentation.