MarinERA Publication No. 4

Thermohaline Circulation in European Seas and Oceans

MarinERA *A Posteriori* Clustering Workshop 1: Galway, Ireland, 6th June 2007

November 2007

MarinERA *Facilitating the Coordination of National and Regional Marine RTD Programmes in Europe*

MarinERA: Facilitating the Coordination of National and Regional Marine Research Programmes in Europe (2004 – 2008).

MarinERA, a EU 6th Framework Programme ERA-NET, is a partnership of leading Marine Research Funding Organisations from 13 European countries, supported by the Marine Board – European Science Foundation. Together these organisations invest over €80 million per annum in competitive marine research.

The specific objectives of the MarinERA Project are to:

1. Map European Marine Research Programmes and Specialised Infrastructures to contribute towards the development of the marine component of the European Research Area, facilitating the creation of an internal market and quantifying the existing European marine research capacity.
2. Facilitate the networking of Marine Research Funding Agencies in the European Union, leading to a more cost effective and efficient use of EU Member State and Associate Member State resources including scientific personnel, specialist infrastructures and planned investments;
3. Contribute to the development of a European Marine Research Policy, identifying future challenges and opportunities and the priority research programmes that need to be put in place to address / benefit from them;
4. Provide a basis for sharing available resources to address priority issues that are beyond the capacities of individual EU Member State and Associate Member States;
5. Progress the reciprocal (mutual) opening of EU Member State and Associate Member State Marine Research Programmes - a key objective of the European Research Area.

The MarinERA Project Partners are:

- IFREMER - French Institute for Exploitation of the Sea (Ifremer) - France
- Marine Institute - Ireland
- Research Council of Norway (RCN) - Norway
- Jülich Research Centre GmbH –Project Management Organisation Jülich (FZJ-PTJ) - Germany
- Spanish Ministry of Education and Science (MEC) - Spain
- Academy of Finland (AKA) - Finland
- Netherlands Organisation for Scientific Research (NWO) - The Netherlands
- Natural Environment Research Council (NERC) - UK
- General Secretariat for Research and Technology, Ministry of Development (GSRT) - Greece
- Fundação para a Ciência a Tecnologia (Foundation for Science and Technology, FCT) - Portugal
- Belgian Federal Public Planning Service Science Policy (BELSPO) - Belgium
- Science and Innovation Administration, Ministry of the Flemish Community (AWI) - Belgium
- Malta Council for Science and Technology (MCST) - Malta
- Ministry of Scientific Research and Information Technology (MSRIT) – Poland
- Marine Board – European Science Foundation - Strasbourg, France

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building the confidence to create a favourable climate in which to pursue the enhanced co-operation and reciprocal opening of EU Member State and Associate Member State Marine Research Funding Programmes.

During the lifetime of the MarinERA Project, it is proposed to extend membership to those European coastal/marine countries who are not currently partners.

For further information on the MarinERA Project see: www.marinera.net

MarinERA:
Facilitating the Coordination of National and Regional Marine RTD Programmes in Europe
2004 - 2008

MarinERA Report No 4 (2007)

Thermohaline Circulation in European Seas and Oceans.

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Galway, Ireland, 6th June 2007

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Copies can be downloaded from:
www.marinera.net/dissemination/tec_reports.html

Workshop Participants

Participants in the THC Workshop, Galway, Ireland, 06 June 2007.

Back row (from left):

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Dr Svein Osterhus, Bjerknes Centre for Climate Research, University of Bergen, Norway.

Prof. Dr. Detlef Quadfasel, Centre for Marine and Climate Research, University of Hamburg, Germany.

Dr Martin White, Dept. of Earth and Ocean Sciences, NUI, Galway, Ireland.

Dr Bert Rudels, Finnish Institute of Marine Research, Helsinki, Finland.

Front row (from left):

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Dr Haris Kontoyiannis, Hellenic Centre for Marine Research, Institute of Oceanography, Athens, Greece.

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Dr Saskia Matheussen, Netherlands Organisation for Scientific Research, Netherlands.

Prof. Isabel Ambar, Institute of Oceanography, University of Lisbon, Portugal.

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1.1. Introduction

Mr Geoffrey O'Sullivan (Workshop Convenor) Marine Institute, Ireland.

First of all, I would like to welcome you to our new Marine Institute Headquarters in Galway and thank you for your efforts to travel here to the western edge of Europe for this Workshop.

By way of introduction, the MarinERA project is one of a number of EU pilot ERA-NET projects which aim to provide a platform for European Member State Research Funding Organisations to better integrate their competitive research funding programmes in order to address the scientific challenges and opportunities facing the Union as a whole.

One of the deliverables of Work Package 3 of the MarinERA Project is to organise **three *a posteriori* Clustering Workshops** to bring together researchers, particularly those funded by MarinERA partner Funding Organisations, who are currently working in similar areas to identify and advise on ways to foster closer co-operation and partnership between nationally-funded marine projects to generate both scientific and financial added-value.

In addition, such Workshops offer an important opportunity to exchange information on existing projects, identify research gaps and priorities to be addressed and to explore opportunities for future co-operative research projects.

This, the 1st Workshop in the series, brings together researchers from nine countries working in the area of "*Thermohaline Circulation in European Seas and Oceans*". The second Workshop, which will take place in September in Madrid, will focus on "*Anthropogenic and Climate Impacts on Marine Biodiversity and Ecosystem Function*". The date and venue of the 3rd Workshop, which will focus on "*Marine Technology*", has yet to be decided.

In support of the clustering intitiative, the MarinERA project is in the process of establishing on on-line database of the competitive research projects funded by the 14 participating funding organisations. This database, which will be described by my MarinERA colleague Dr Saskia Matheussen of the Netherlands Organisation for Scientific Research (NWO), will, we believe, provide an invaluable source of information on current research in Europe and a useful tool for networking existing projects.

Given the fact that we have so many eminent scientists to-hand, the first part of the Workshop, the presentations of current research, is being held in our North Atlantic Drift Auditorium, where we can facilitate a wider invited audience including researchers from the Marine Institute, National University of Ireland, Galway and National University of Ireland, Maynooth.

The second part of this Workshop will be hosted in the Brendan the Navigator Suite where we will hold a closed meeting to identify:

- barriers to, and enablers of, co-operation
- gaps in the current research agenda.

You all have a Programme for the Meeting (Annex 1), so it now gives me great pleasure to hand over to my colleague Saskia Matheussen to introduce the Marine Projects Database.

1.2. The MarinERA Projects Database

Dr Saskia Matheussen, Netherlands Organisation for Scientific Research (NWO).

1.2.1. Introduction

In the framework of retrospective or *a posteriori* clustering, an on-line marine projects database is being set up. The database will include summary data (i.e. Project Title, Abstract, Principal Investigator, Host Organisation, Country, Project Start and End Dates, Funding Agency, Country, Grant-Aid, Key Words) on the competitive marine research projects funded by the participating funding agencies since 2004.

1.2.2. Data collection

To date, 861 projects have been identified and included in the database. These projects represent an investment of over €270 million in grant-aid.

Country	Projects	Total grant -aid (€)
United Kingdom	233	81.109.584
Germany	57	60.024.277
Norway	88	35.574.009
Greece	61	21.435.992
Belgium	27	16.241.431
Netherlands	86	16.159.422
Spain	162	15.029.552
Ireland	21	8.063.051
Finland	27	5.952.230
Portugal	46	5.576.789
Poland	34	3.602.300
France	18	1.894.030
Malta	1	65.000
Total	**861**	**€270.727.667**

Table 1.2 1: Number of projects and grant aid per country

1.2.3. Classification Scheme

For the purpose of classification, a simple scheme recognising four main categories is used:

Marine Geosciences 275 projects (32%)
Marine Ecosystems 365 projects (42%)
Marine Technology 152 projects (18%)
Policy & Socio-economics 69 projects (8%)

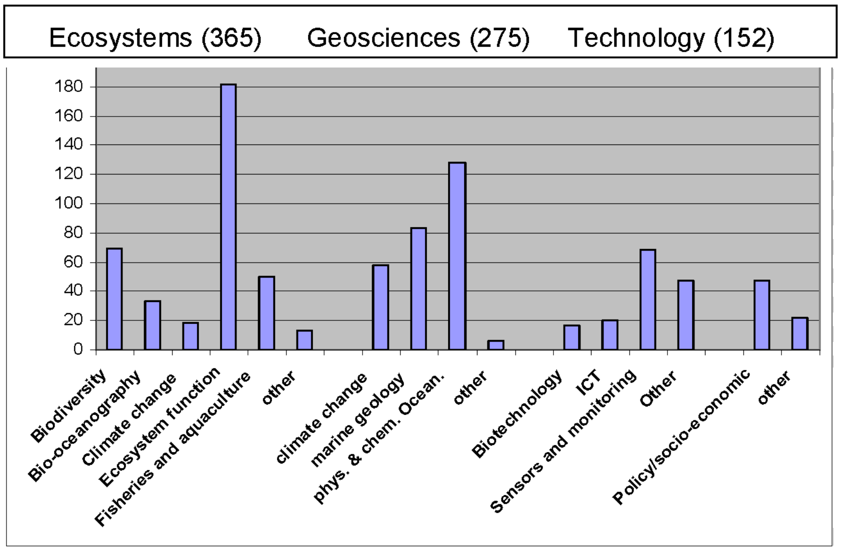

Figure 1.2.1: Number of projects by category.

1.2.4. Preliminary Analysis of project clusters

Within the suite of 861 projects and the four clusters identified, we can recognise a further breakdown as follows:

- **Biodiversity and Ecosystem Function** (251 projects) where two important research fields can be identified:
    - Effects of human activity on biodiversity/ecosystem function.
    - Effects of climate change on biodiversity/ecosystem function.
- **Physical and Chemical Oceanography and Climate Change** (186 projects) of these projects, 73 (39%) are related to "Thermohaline Circulation" and can be further subdivided into the following clusters:
    - Understanding climate change in the past to help understand the future (28).
    - The impact of sea-atmosphere Interaction on climate change (18).
    - Ice-ocean interactions driving global circulation (8).
    - Oceanic cycles of energy and matter / circulation processes (19).
    - UK and NL RAPID projects.
- **Marine Technology** (152 projects). 88 (58%) of these projects are related to marine sensors and monitoring technology research and could be further sub-divided into sub-categories related to:
    - Data management, forecasting and information management.
    - Mathematical modelling.
    - Monitoring.
    - Sensor and Signal processing and Data acquisition.
- **Policy and socio-economics** (47 projects)
    - Coastal Zone Management (20 projects).

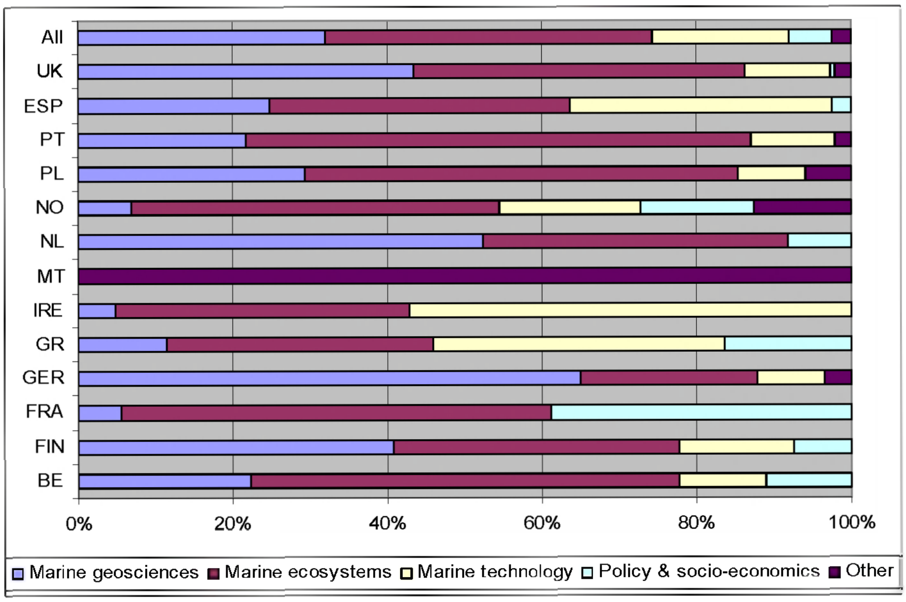

Figure 1.2.2: Projects funded in different countries by main category

1.2.5. Towards an online MarinERA projects database

The next step is to put the Marine Projects Database online. This action will contribute to the visibility of MarinERA, and both scientists and policy makers will benefit from public access. The online representation will be similar to the EurOcean database (www.eurocean.org) and is expected to be published on the MarinERA web-site in September 2007 (www.marinera.net).

Addendum:
The MarinERA Projects data-base went online on 1st October 2007 (www.marinera.net) and currently contains 901 projects.

2.1. The Shelf Edge Current West of Ireland

Dr Martin White, Dept. of Earth and Ocean Sciences, NUI, Galway, Ireland

The presence of a poleward directed residual flow along the NE Atlantic margin is now widely accepted. This shelf edge current (SEC) is important, both as a major transport pathway of warm, saline water to the Nordic seas, and for its role in exchange processes and bio-geochemical cycling at the continental margin. As such, the current has been a focus of study at NUI, Galway in relation to the associated bio-physical interactions that influence fisheries and benthic ecosystems through a number of EU funded projects. In recent years, we have integrated 30 years of observational data from current meters, satellite altimetry data, and modelling results, to assess the continuity, seasonal and inter-annual variability in the shelf edge current west of Ireland. The region is located between the two major gyres of the North Atlantic. The line of zero wind stress curl which divides these gyres runs through the Rockall Trough, close to the major topographic feature of the Porcupine Bank.

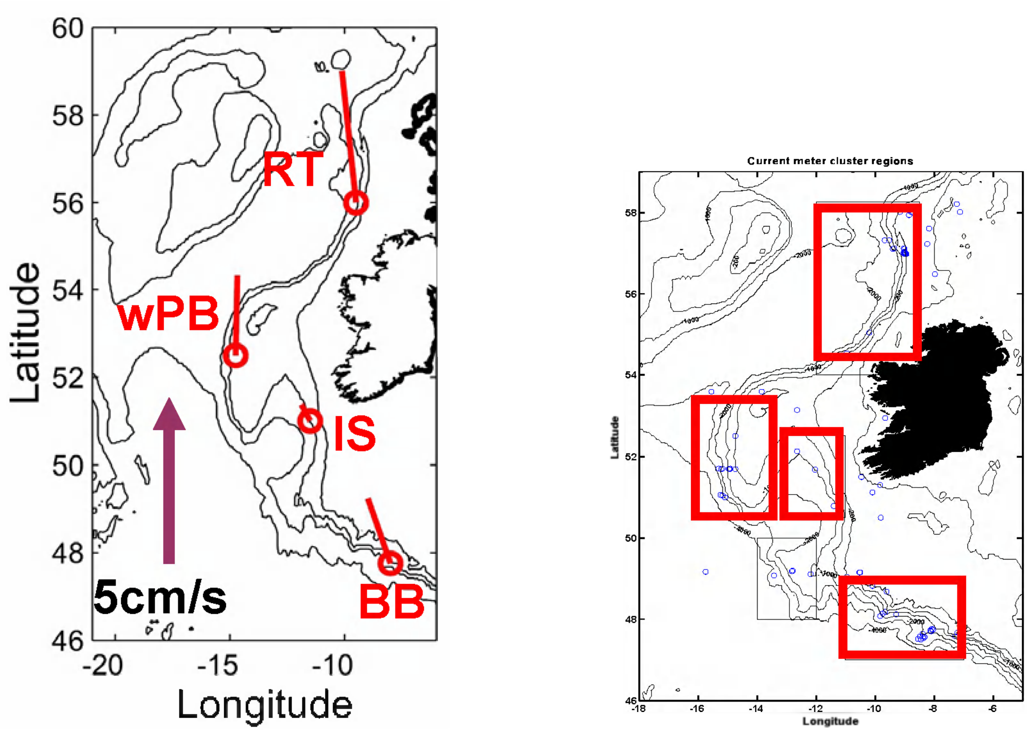

Figure 2.1.1. Mean residual flow derived from 30 years of historical current meter data, compiled for the regions – RT=Rockall Trough, wPB=western Porcupine Bank, IS=Irish Shelf and BB=Bay of Biscay shown by the red boxes in the right hand figure. A scale is given in the bottom left.

Taking regional averages, mean flows generally increase northwards, from 3 cm s^{-1} in the Bay of Biscay to ~7 cm s^{-1} in the Rockall Trough (Figure 2.1.1). Individual measurements from moored instruments indicate poleward residual flows of up to 15 cm s^{-1} along the margin from the Bay of Biscay to the northern Rockall Trough. These data, however, do not take seasonal or inter-annual variability in the measurements into account. Satellite altimetry has been used to assess the seasonal variability in one of the main driving forces for the current – the poleward decline in the deep ocean sea surface height (SSH) relative to that over the continental shelf. Analysis has indicated a 6 monthly periodicity in the meridional oceanic SSH gradient with maxima at the end of the period of deep winter convection and in the autumn after peak summertime heating. Seasonality of the SSH gradient across the continental shelf edge matches that derived from the regional current meter climatology.

The region of the Porcupine Bank is also one where the deep ocean currents, such as the extension of the North Atlantic Current, interact with the continental margin. Year long current meter moorings, together with other data such as from the ARGO program, have been used to assess the mixing of the upper layers west of Porcupine Bank. The region appears to be one with a pronounced frontal structure in the upper 1000m of the water column (Figure 2.1.2). Associated with this is large mesoscale variability from eddies as well as a more zonal flow at the latitudes of the Porcupine Bank (52-54°N). Significant seasonal changes in the deep water currents measured west of Porcupine Bank suggest a link in flow properties related to the onset of deep winter convection and re-stratification. This may, in turn, control the observed seasonality of the shelf edge current. These characteristics further suggest that the region of the Porcupine Bank is a boundary between two different shelf edge regimes – one in the Celtic Sea with both significant seasonal and interannual variability, and a more persistent poleward current regime in the Rockall Trough which again varies with climatic forcing.

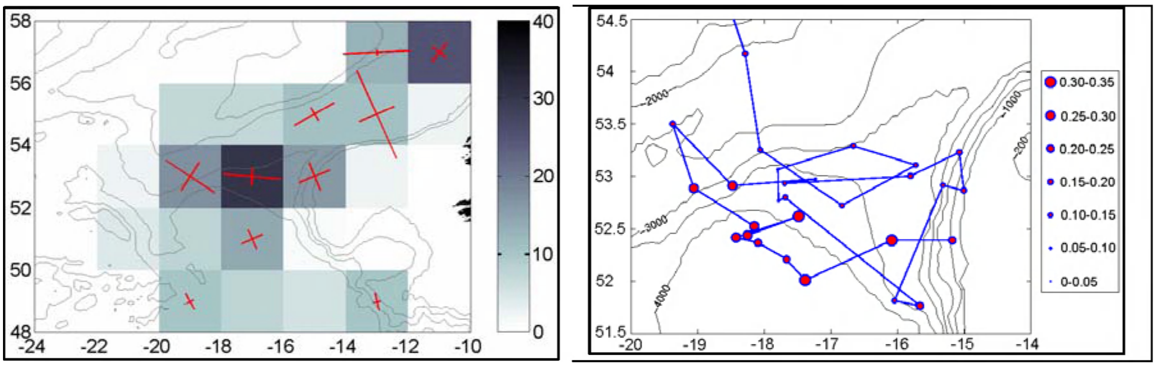

Figure 2.1.2. Ellipse of current variance per 2° square at 1000m derived from Argo floats in region from 2002-2005 (***left***). Number of floats used in the calculation denoted by the shading and scale. The salinity anomaly from typical ENAW characteristics, from the Irish Argo float deployed Oct. 2003, is show ***right*** by the circles.

Future Irish plans will be to increase participation in the ARGO program, together with the use of autonomous gliders for monitoring of the shelf edge dynamics, with modelling activities for operational requirements, bio-physical interaction and process studies. In addition two standard hydrographic sections in the S Rockall Trough will be occupied annually, similar to the older WOCE sections in the region.

2.2. A European initiative to assess and forecast THC variability in the Atlantic – THOR: Thermohaline overturning at risk?

Prof. Detlef Quadfasel, Centre for Marine and Climate Research, University of Hamburg, **Germany**

Within the European FP7 programme, a consortium of partners from ten European countries has recently submitted a proposal to the European Commission. The proposal - *THOR: Thermohaline Overturning – at Risk?* - responds to call the 1st call for proposals (May 2007) Stability of the ThermoHaline Circulation of the FP7 Environment (including Climate Change) Programme.

THOR will establish an operational system that will monitor and forecast the development of the North Atlantic Thermohaline Circulation (THC) on decadal time scales and access its stability and the risk of a breakdown in a changing climate. Together with pre-existing data sets, ongoing observations within the project will allow precise quantitative monitoring of the Atlantic THC and its sources. This will, for the first time, allow an assessment of the strength of the Atlantic THC and its sources in a consistent manner and will provide early identification of any systematic changes in the THC that might occur.

Analysis of palaeo observations covering the last millennium and millennium time scale experiments with coupled climate models will be carried out to identify the relevant key processes and feedback mechanisms between ocean, atmosphere, and cryosphere. In THOR, the combined effect of various global warming scenarios and melting of the Greenland ice sheet will be thoroughly assessed in a coupled climate model. Through these studies and through the assimilation of systematic oceanic observations at key locations into ocean circulation models, THOR will forecast the development of the Atlantic THC and its variability until 2025, using global coupled ocean-atmosphere models.

THOR will also assess induced climate implications of changes in the THC and the probability of extreme climate events with special emphasis on the European/North Atlantic region. THOR builds upon techniques, methods and models developed during several projects funded through FP5 and FP6 as well as many nationally funded projects. The project will contribute to Global Monitoring for Environment and Security (GMES), to the Global Observing System (GOOS), and to the International Polar Year (IPY).

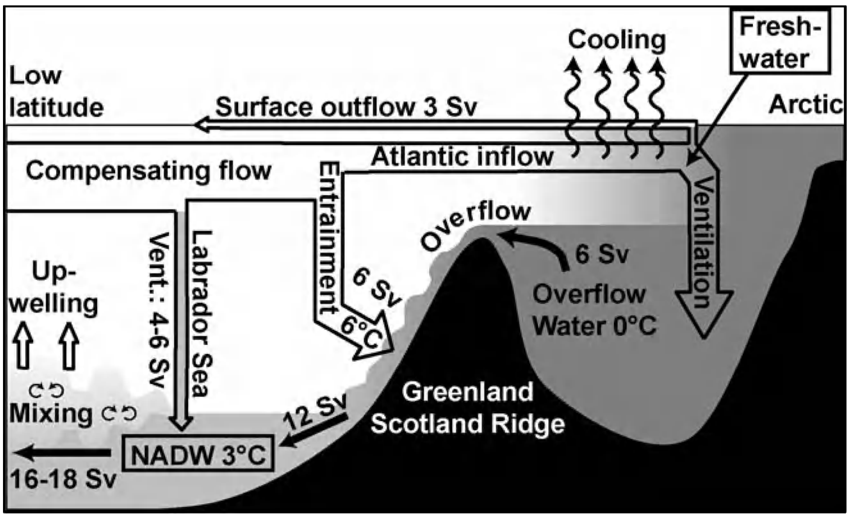

Figure 2.2.1. Schematic of the Meridional Overturning Circulation in the North Atlantic as part of the global Thermohaline Circulation. The main sources for the deep southward flow are the overflows across the Greenland-Scotland Ridge, the subsequent entrainment into the sinking plumes south of the ridge, and the direct ventilation in the Labrador Sea. Each of these processes contribute about one third to the flow of North Atlantic Deep Water, which has a volume transport of about 15 – 20 Sv (1 Sv = 10^6 m^3/s). This deep southward flow is compensated by a northward flow of warm and saline water in the upper layer that keeps large portions of the Nordic Seas and the North Atlantic free of ice. In THOR the variability of this circulation and its related heat transport is addressed by direct observations, the analysis of palaeo data and a suite of coupled ocean-atmosphere general circulation models.

2.3. Mediterranean Outflow: Its contribution to the thermohaline circulation in the North Atlantic Ocean

Prof. Isabel Ambar, Institute of Oceanography, University of Lisbon, Portugal.

The North Atlantic is strongly influenced by the presence of a high salinity and temperature water mass – the Mediterranean Water - lying at intermediate levels and extending as a wedge from the Iberian coast across the Atlantic (Fig. 2.3.1). An overview of different sets of observations in the Gulf of Cadiz, with CTD, XBTs, RAFOS and XCPs, undertaken during the AMUSE, CANIGO and MEDTOP projects, shows some aspects of the space and time variability of the thermohaline characteristics of the MW and of the generation of eddies by the Mediterranean Undercurrent off the Iberian coast.

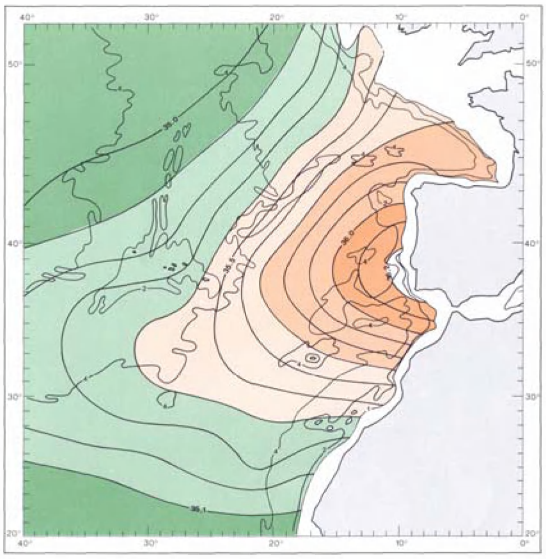

Figure. 2.3.1 Mean salinity at 1200-m level (Maillard C., 1986: Atlas Hydrologique de l'Atlantique Nord-Est, IFREMER, Centre de Brest) showing the influence of MW in the Atlantic Ocean.

The analysis of the CTD data at the Mediterranean Water levels evidences the presence of three Mediterranean Water cores: the Upper and the Lower Cores, respectively centered at about 800 and 1200 m, and a Shallow Core, closer to the upper slope, between 400 and 600 m. In all data sets, some differences between winter and summer seasons were found, with higher temperature and salinity in winter as compared with summer (Figure 2.3.2).

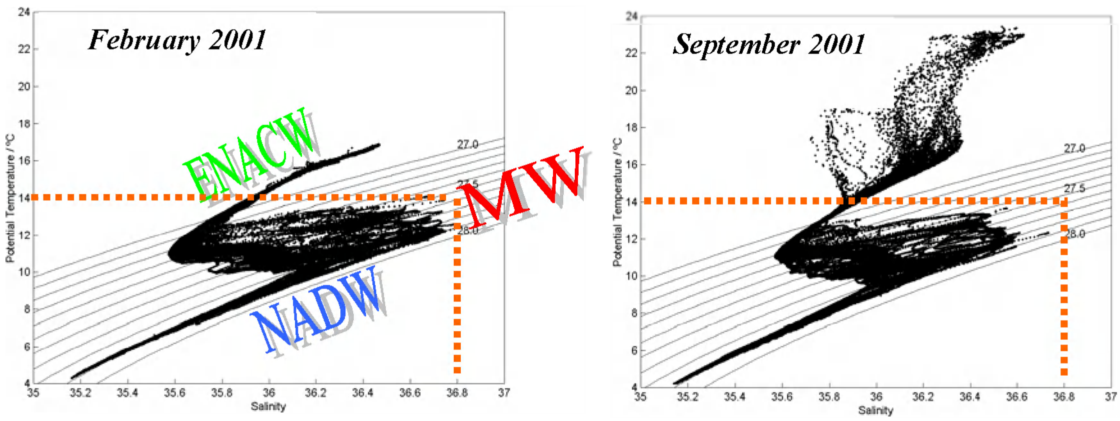

Figure 2.3.2. Potential temperature versus salinity diagrams showing thermohaline differences at the Mediterranean Water levels, between winter and summer conditions during 2001.

The RAFOS floats trajectories evidenced the formation of clockwise rotating eddies at the Mediterranean Water levels, the so-called "meddies", in three sites off the Portuguese coast: in the Portimão Canyon, off Cape St. Vincent and off the Estremadura Promontory.

The analysis of the RAFOS floats trajectories, in conjunction with the thermohaline field at the levels of the Mediterranean Water, also allowed the identification of a dipolar structure (coupled cyclone-anticyclone) in the region of the Portimão Canyon (off south Portugal). This dipole, tracked by floats, followed a large-scale cyclonic circulation around the Gulf of Cadiz. The analysis of the contemporaneous sea surface temperature satellite images showed the surface signature of the eddy motion, thus implying that an upward vorticity diffusion occurs.

Although much has been learnt with the recently collected data, there are still some issues to be clarified. For instance, are there seasonal fluctuations of the Mediterranean Outflow in the Atlantic? If so, are the causes primarily associated with the mixing conditions in the Strait of Gibraltar? What is the rate of Mediterranean Water eddy generation? What is the role of the Mediterranean Water eddies on the biology of the Atlantic Ocean?

To respond to these questions, much work has yet to be done by monitoring the region off Iberia where meddies are formed, using both in situ and satellite remote sensing, and by providing the Atlantic Ocean circulation models with more detailed and realistic data to be assimilated.

Aknowledgements

The AMUSE project was funded by the US National Science Foundation (grants OCE-91-01033 and OCE-91-00724) and by Fundação Luso-Americana para o Desenvolvimento (FLAD). CANIGO project was a EU MAST III project (contract MAS3-CT96-0060). MEDTOP project was funded by the Portuguese Fundação para a Ciência e a Tecnologia (FCT) in the frame of the PDCTM programme (Grant PDCTM/MAR/15301/99).

2.4. Warming of the west Spitsbergen Current

Dr Waldemar Walczowski, Institute of Oceanology, Sopot, Poland.

The Institute of Oceanology Polish Academy of Sciences (IOPAS) in Sopot has carried out research in the Nordic Seas since 1987. IOPAS physical oceanographers are interested in the Atlantic Water flow pathways, their physical properties (temperature, salinity) and northward transport of volume and heat.

IOPAS participates through our own project, AREX, the EU project, DAMOCLES, and other international projects including: GSP, VEINS, ASOF.

Every year during the summer cruise of the Institute's research vessel "Oceania", we investigate the West Spitsbergen Current which is the main heat and salt conduit into the Arctic Ocean (Figure 2.4.1). We have promoted the idea of two different streams of the West Spitsbergen Current, the core flowing along the continental slope and the western branch continuing over the system of underwater ridges.

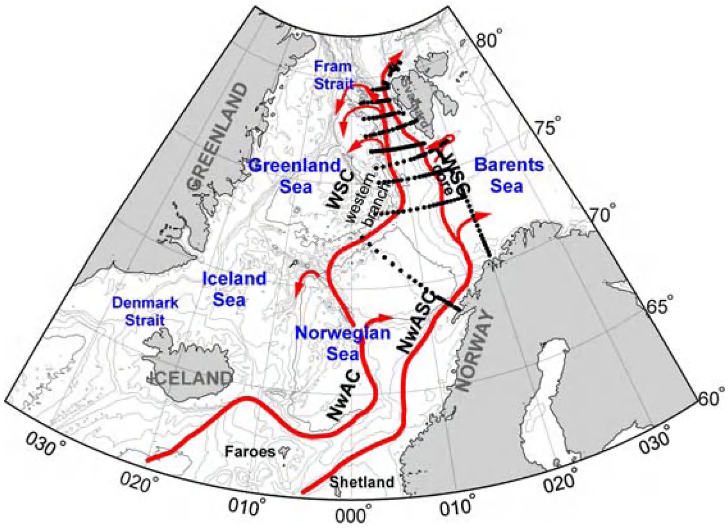

Figure 2.4.1. Region of the IOPAS investigations of the WSC. Sections across the WSC are indicated.

The Institute also conducts process-oriented studies on THC in the North Atlantic and Greenland Sea including investigations on the creation of meanders and eddies at the Arctic Front, migration of warm and salty eddies from the Atlantic Domain into the Greenland Sea Gyre and other processes of transfrontal exchange.

Since 2004, IOPAS has observed an increase of Atlantic water temperature and salinity in the northern Nordic Seas. The warm signal is propagated to the north, towards the Fram Strait. In the summer of 2005, never-before recorded high Atlantic water salinity and temperature values were observed in the West Spitsbergen Current core west of Spitsbergen. The summers of 2005 and 2006 were characterized by an intensification of the northward Atlantic water flow. Unusually large and warm anticyclonic eddies in the western branch carried a large amount of heat northward. These structures transport heat into the Arctic Ocean through the Fram Strait.

During the 2004-2006 period, a shifting of the ocean climate system in the Fram Strait region occurred. Isotherms of 5ºC at 100 m depth moved northward 4º of latitude (Figure 2.4.2), the warm water domain widened, Atlantic water expanded over the Western Spitsbergen shelf and inflowed into the fjords. These changes may have a large impact on the Arctic Ocean climate and ecosystem, particularly the sea ice cover.

The warming, observed by us, is not homogenous. Different velocities of the warm signal propagation have been observed. The signal along the core of the West Spitsbergen Current moved fast, about 3.1 cm/s. It is a barotropic stream of warm Atlantic water, inflowing to the Arctic Ocean along the Spitsbergen shelf break. The signal along the western branch moved two times slower. Heat is carried mostly by the large baroclinic structures, anticyclonic eddies. Part of the water carried by the western branch recirculates before reaching the Fram Strait. Our observations indicate that, depending on the upstream current configuration, part of this water may inflow to the Arctic Ocean as the so-called Yermak Branch.

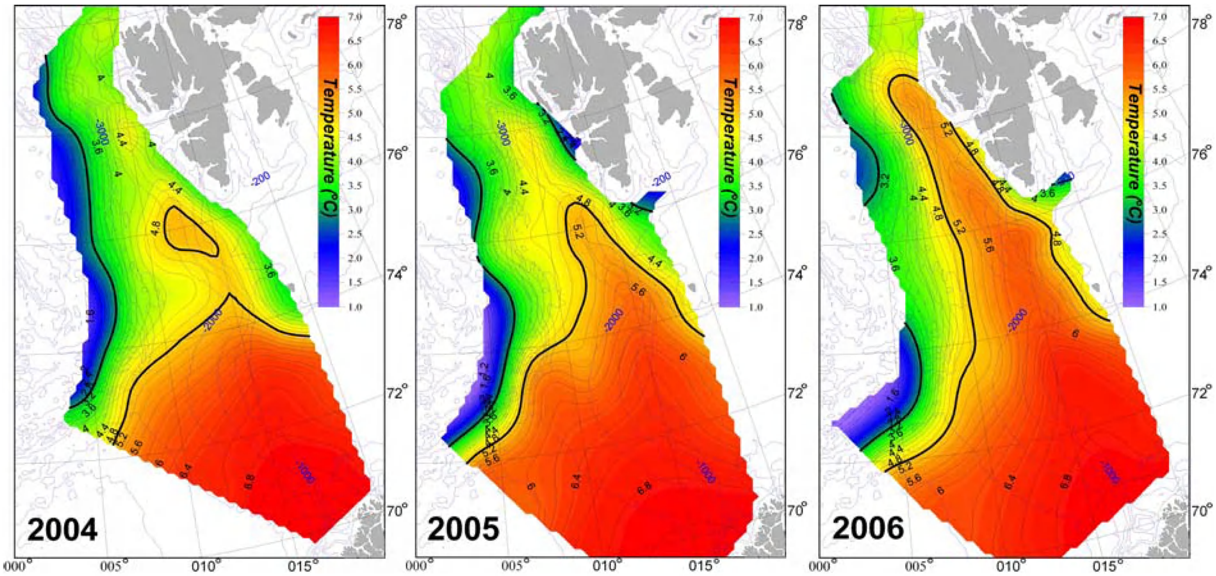

Figure 2.4.2. Summers 2004-2006. Shifting of isotherms at 100 m depth. 5°C isotherm is in bold.

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2.5. Bipolar Atlantic Thermohaline Circulation (BIAC)

Svein Østerhus, Bjerknes Centre for Climate Research, University of Bergen, Norway.

Because they are ventilated in the Polar Regions, a striking feature of the world oceans is that most of the water masses are cold (80% below 5ºC). The main ventilation sites are in the high latitude Atlantic sector, where the densest water masses are formed in the Antarctic and the slightly less dense water masses above are formed either north of the Greenland-Scotland Ridge (GSR) or in the Labrador-Irminger basins. The water mass transformations in the high latitude regions are among the key components in the Meridional Overturning Circulation (MOC). Currently the most fundamental aspects of MOC are under debate and call for thorough bipolar studies.

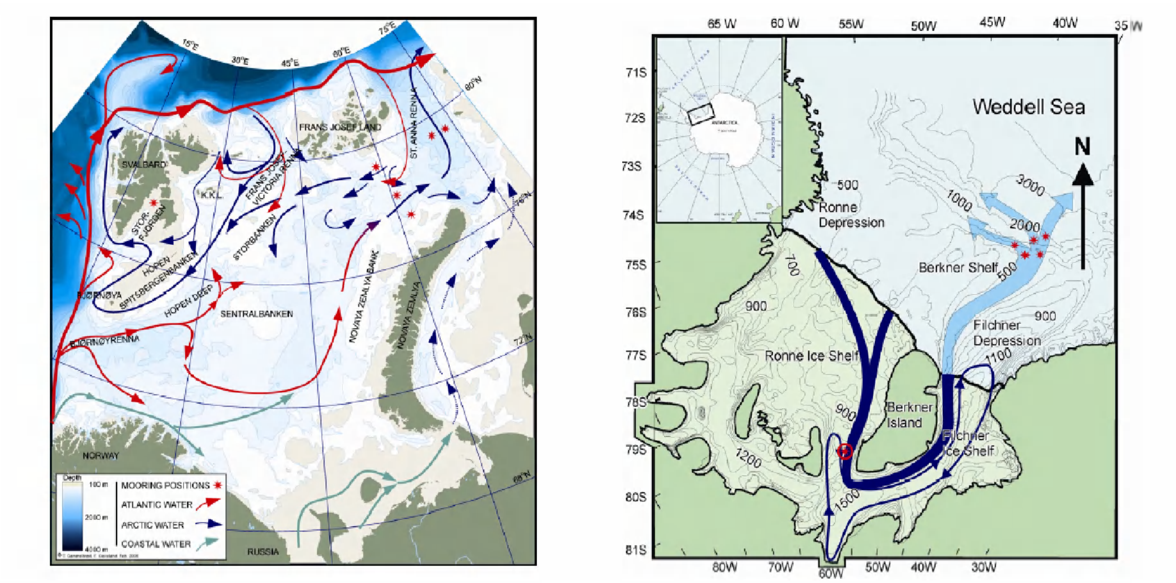

Figure 2.51. Left: Study areas in the Arctic are focused on Storfjorden and the eastern Barents Sea between Novaja Zemlja and Franz Josef Land including the St. Anna Trough. Right: The main study area in the Weddell Sea is concentrated along the path of the Ice Shelf Water. Approximate mooring positions are indicated by (*). The long term monitoring position on the ice shelf south of Berkner Island is marked by a circle.

Cooling, including formation and subsequent brine release determine the characteristics and volume of deep water formation over the continental shelf areas in both polar regions. However there are also significant differences. In the Antarctic, water at great pressures underneath vast floating glaciers is super-cooled with respect to the surface freezing point. Cold water is more compressible, so when this water descends towards great depths, this *thermobaric effect* will tend to increase the down-slope forcing. In the Antarctic the deep water formation sites are adjacent to the world ocean abyss, and the sills separating the Southern Ocean from the rest of the world oceans are more than 3 km deep. In the Arctic, the path of the dense water from the shelves to the deep Atlantic is more complicated. The Atlantic inflow to the Nordic Seas is about 9 Sv with a heat transport of 300 TW. It is totally transformed as the heat is given up in the Artic Mediterranean, and 6 Sv returns across the GSR as dense overflow water that directly links to the Atlantic deep water and overturning circulation. About a quarter of the Norwegian Atlantic Current enters the vast Arctic shelf region through the Barents Sea Opening, and the rest through the Fram Strait. The dense water formed in the north-eastern Barents Sea continues on a long journey (years to decades) around the Arctic perimeters where it mixes with the dense water formed on the shallow shelves. The dense water leaves the Artic via the Fram Strait, follows the east Greenland coast and eventually enters the Norwegian Sea at about 2000 m depth. In BIAC, the mechanisms, manifestation and impact of intermediate and bottom water formation originating from the bipolar Atlantic Ocean shelves will be explored. The **overall goal** is to **evaluate the global ventilation** through circum Arctic and Antarctic shelves and

consequences for the climate by up-scaling results and knowledge gained from two key sites: the **Barents Sea** and the **southern Weddell Sea** (Figure 2.5.1).

Paleo records have revealed temperature variations in the order of 10ºC over only a few decades, possibly as a consequence of reduced ventilation and Gulf Stream transport due to enhanced melt water from inland seas or calving of icebergs. Although the ocean circulation and the north Atlantic climate have been relatively stable for more than 10 millennia, climate models have suggested the release of greenhouse gases and the associated global warming may perturb the balance. Warmer air, enhanced atmospheric moisture transport to the high latitudes, and melting of glaciers and ice sheets will lead to a more stable surface layer and a decreased production of deep water. A bipolar approach is needed to investigate the increasing view that the Southern Ocean dynamics affects the global THC and, in particular, the far northern Atlantic.

Dense water masses form on the Arctic and Antarctic shelves through the freezing of sea ice. The HSSW cascade off the continental shelves is crucial for the global ocean circulation and climate and is a major control on deep water biogeochemistry. As the direct link between the atmosphere and the intermediate and deep oceans, the rate of deep water formation controls the oxygenation of the deep ocean and regulates the response time of the ocean to changing concentrations of CO_2 and other gases in the atmosphere. Shelf processes are impossible to incorporate in climate models, yet they exert significant control over the global circulation. Direct field measurements are urgently needed. The large-scale circulation, hydrography, forcing conditions and dominant mixing mechanisms preconditioning the shelf waters for dense water production must be well-understood to obtain accurate estimates of deep water formation. The mixing which occurs during the cascading process leads to irreversible modifications in the water mass properties further downstream from the production sites. These end products are fundamental in determining the carbon and nutrient fluxes to the deep ocean, and for shelf-deep water exchange in general.

The water masses formed on the polar continental shelves contribute to the deepest branches of global THC and fill the abyss. The Antarctic Bottom Water (AABW) is denser than the northern component North Atlantic Deep Water (NADW) and the AABW resides below the NADW where the two water masses meet. The production rates of NADW and AABW are believed to be each about 8Sv, but even such important quantities are still much disputed. The densest source of NADW is now probably found within the Arctic Ocean, where the shelf processes described here are of fundamental importance and thus a key component in the climate system. The role of the last decades` large scale changes in the hydrographic properties of the North Atlantic-Arctic Mediterranean in the THC is not well understood.

Monitoring of the flow of dense water from its formation area towards the abyss of the world oceans is a key issue for climate research. In the Weddell Sea, formation of high salinity shelf water (HSSW) takes place on the Ronne shelf. Underneath the floating Filchner-Ronne ice shelf the HSSW is transformed to Ice Shelf Water (ISW). The ISW cascade towards the deep Weddell Sea, and its fate in connection with the formation of the WSBW, and finally AABW, are key issues. The North Atlantic is separated into two basins by the Greenland Scotland Ridge (GSR). Most of the ventilation in the northern basin, the Arctic Mediterranean, occurs by formation of HSSW on the Arctic Ocean shelves and by open ocean convection. Cold dense waters pass southwards as a deep overflow across the GSR at a number of sites and together with entrained water feed most of the NADW.

BIAC is IPY cluster #23, and the Norwegian component is one of the main IPY projects in Norway. BIAC is coordinated by Tor Gammelsrød and Svein Østerhus. Please visit the project webpage www.gfi.uib.no/BIAC for more information.

2.6. The Arctic Ocean Impact on the Thermohaline Circulation – Driving or Retarding?

Dr Bert Rudels, Finnish Institute for Marine Research, Finland.

The Arctic Mediterranean Sea, the part of the North Atlantic north of the Greenland-Scotland Ridge, is arguably the most important source of dense water contributing to the North Atlantic Deep Water (NADW), which advects southward and provides the lower limb of the Atlantic Thermohaline Circulation. The major process creating dense waters in the Arctic Mediterranean is the cooling of Atlantic water crossing the Greenland-Scotland Ridge and flowing northward in the Norwegian Atlantic Current. In the northern part of the Norwegian Sea it has already become sufficiently dense to supply overflow water, which after re-crossing the Greenland-Scotland Ridge sinks into the deep North Atlantic.

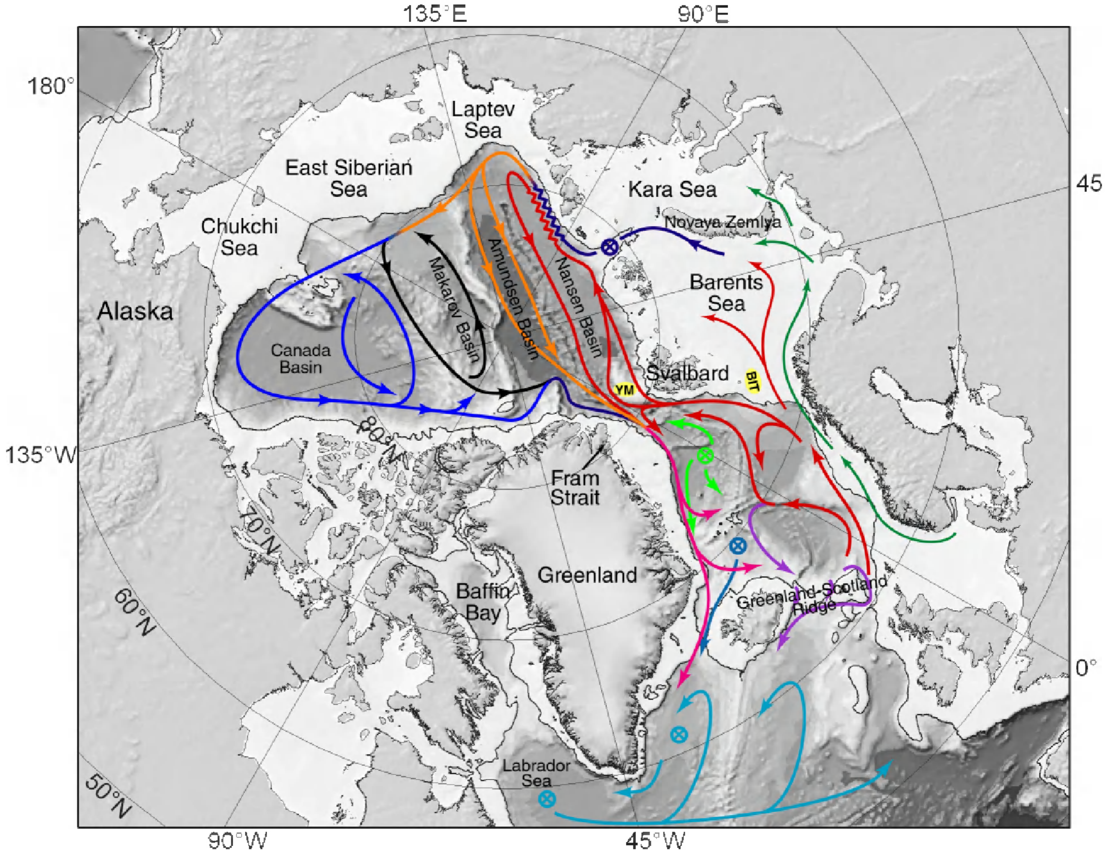

Figure 2.6.1. The Arctic Mediterranean Sea. The arrows indicate the circulation of the intermediate waters in the Arctic Ocean and the Nordic Seas. The northward flowing Atlantic water in the Norwegian Sea and southern Barents Sea (red in the figure) is still at the surface, but in the Arctic Ocean (north of Fram Strait) and in the rest of the Arctic Mediterranean it is covered by a less saline layer of Polar water. The crosses indicate convection areas. (adapted from Rudels et al., 1994. & map by Martin Jakobsson).

As the Norwegian Atlantic Current reaches the Barents Sea opening and the Bear Island Trough (BIT, Fig. 2.6.1), it splits. One part enters, together with the Norwegian Coastal Current (green in Figure 2.6.1), the Barents Sea, while the rest continues northward to Fram Strait as the West Spitsbergen Current. In Fram Strait the current again splits. One branch recirculates towards west and south, forming the Recirculating Atlantic Water, which joins the East Greenland Current and eventually contributes to the overflow. The rest enters the Arctic Ocean in two streams, one over the northern Svalbard shelf, the other west and north of the Yermak Plateau (YM, Fig. 2.6.1). Both streams later merge northeast of Svalbard and continue as a boundary current eastward along the Eurasian continental slope.

North of Svalbard the warm Atlantic water encounters, and melts, sea ice. The melt water is mixed into the upper part of the water column, creating a less saline upper layer that covers the core of Atlantic water. The upper layer remains a part of the boundary current and the heat in the Atlantic water becomes isolated from the sea ice and the atmosphere. In summer a low salinity melt water layer is formed by the seasonal heating, which again is removed in winter, when haline convection homogenises the upper layer down to the Atlantic layer. This situation holds for the entire Nansen Basin.

The part that enters the Barents Sea is more affected by heat loss to the atmosphere. The entire water column becomes colder and also less saline, partly by mixing with less saline water from the Norwegian Coastal Current, partly by the melting of sea ice. A low salinity surface layer, cooled to freezing in winter, is formed, while the underlying core of the Barents Sea branch Atlantic water remains above freezing. In shallow areas, especially west of Novaya Zemlya, lee polynyas develop in winter, which allow for excessive ice formation and brine rejection, creating saline, dense bottom waters at the freezing point.

About 1-1.5 Sv (1 Sv(erdrup) = 1×10^{6} m^3s^{-1}) of the fraction that enters the Arctic Ocean, either through Fram Strait and over the Barents Sea, are then transformed into less dense upper waters, adding to the low salinity Norwegian Coastal Current water and the Bering Strait inflow. The rest becomes denser, mainly through air-sea interactions in the Barents Sea, but also by incorporating saline shelf water, made dense through brine rejection on the shelves and sinking down the continental slopes into the deep Arctic Ocean basins. The less dense water, about 3 Sv including the Norwegian Coastal Current and the Bering Strait inflow, exits through the Canadian Arctic Archipelago (50-60%) and through Fram Strait in the East Greenland Current (40-50%). The denser waters all exit through Fram Strait, the only deep (2600m) passage to the Arctic Ocean.

In addition to providing dense overflow waters, the Arctic Ocean may thus also negatively influence the thermohaline circulation through the export of less saline surface water. The low salinity water could cover the downstream convection areas in the Greenland Sea, the Iceland Sea and the Labrador Sea and thus reduce the production of dense water. However, in the Nordic Sea it appears that the low salinity polar water mostly stays close to the Greenland coast and seldom enters the central Greenland Sea. The Greenland Sea, as well as the Iceland Sea, contributes to the overflow, although the water transformed here in most cases is already dense enough to become overflow water.

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In the case of a warmer climate, the perennial ice in the Arctic Ocean may change into a seasonal ice cover. The ice cover has already been seen to diminish in extent and thickness. This may be caused by less strong cooling and less ice formed. It is also possible that heat from the Atlantic layer contributes, or has contributed, to the reduction of sea ice cover, especially north of Fram Strait and in the Nansen Basin. The heat content of the Atlantic layer has increased in recent years because of warm inflow events. The low salinity surface water has also been temporarily displaced from the Amundsen and Makarov basins to the Canada Basin, which has allowed for the formation of a deep, homogenous upper layer and a direct contact between the Atlantic layer and the sea ice. These oceanic changes were likely due to the high NAO state that prevailed in the 1990s. However, the fact that the heat content in the Atlantic layer has increased might instead indicate that the heat is passively carried around in the different gyres without much being lost to the ice and the atmosphere in the Arctic Ocean.

Many questions are open about the effects of a reduction of the ice cover. Will the ice export increase or decrease? Will the Arctic Ocean still produce dense overflow water on the shelves? Will deep open ocean thermal convection be possible in the Nansen Basin?

2.7. Observing the North Atlantic MOC: The RAPID Programme and Oceans 2025

Valborg Byfield and Meric Srokosz, National Oceanography Centre, Southampton, UK

Rapid Climate Change (RAPID) is a £20 million, seven-year (2001-2008) directed programme of the Natural Environment Research Council (NERC). Using a combination of present day observations, palaeo-data and a hierarchy of models (from local process models to global general circulation models) the programme aims to improve understanding of global and regional impacts of rapid climate change, and the roles played by the thermohaline circulation (THC) and other processes in such change.

Palaeo-records show large and rapid variations in the Earth's climate in the past. During the last glacial, Greenland temperature increased very rapidly (< 40 years) by about 10ºC (the so-called Dansgaard-Oeschger events), and stayed in the warm state for a thousand years or more before returning more slowly to the cold state. Only one documented example exists of anything similar occurring in an interglacial, a rapid cooling about 8200 years ago. Several RAPID projects have confirmed that this 8.2 kyr event is a cooling that lasted for 100-200 years and can be identified in Greenland ice cores and other paleao-records from the North Atlantic region. Such rapid shifts in climate are often attributed to changes in the strength of the Atlantic meridional overturning circulation (MOC), in which warm waters flow north, release heat to the atmosphere, cool and sink to form deep waters that return south. Under some global warming scenarios a freshening of the North Atlantic may prevent this deep-water formation and cause the MOC to slow or even halt. The cause of the 8.2 kyr event is assumed to be drainage of Lake Agassiz, when melt-water broke through the North-American ice sheet. However, while the palaeo-record tells us that rapid changes can occur, and may be linked to MOC changes, we do not yet know if this can occur in a world without large ice sheets around the Atlantic. Modern observations and model simulations are needed to help answer this question.

Coupled ocean-atmosphere models generally agree that the THC will gradually decrease with global warming. At some stage a threshold leading to rapid shutdown may be crossed and some model simulations predict reductions of 4-8°C in air temperatures over northwest Europe and the North Atlantic as a result. However, estimates vary widely. The RAPID thermohaline circulation model inter-comparison (THCMIP) aims to identify reasons for these differences by comparing eight climate models in CO_2 experiments (in which atmospheric CO_2 concentrations increase at a fixed rate) and hosing experiments (in which fresh water is added to the North Atlantic). Results for both types of experiment show a greater slowdown in the THC for the less complex models and also for models with strong 'present day' MOC. Global coupled climate models cannot be run sufficiently often to give a probabilistic assessment of the risk of rapid climate change. An alternative approach involves running a climate model with different input, using the output of several runs to develop an emulator. This is a statistical construct that approximates the original model, but is much faster and can be used to give a probability distribution of MOC strength for different greenhouse gas scenarios and different rates of Greenland ice melt. At present the method has been used only for models of intermediate complexity, but the hope is to use it for more complex models in future.

Another possible way to improve model prediction is assimilation of observations, including RAPID data on the MOC. Analysis of 5 historical sections across the Atlantic at about 25ºN indicate that there may have been a slow-down in the MOC, although this might simply be due to variability. Establishing whether or not the MOC is changing requires continuous observations on sub-annual to decadal time scales. A major objective of RAPID is thus to establish a prototype system to continuously observe the strength and structure of the Atlantic MOC. Central to this effort are the two RAPID arrays: the 26º North array across the Atlantic from Florida to Africa, and WAVE, three arrays in the Deep Western Boundary Current (DWBC) at 40-44ºN (figure 2.7.1), both in collaboration with US scientists.

Since spring 2004, the 26°N array has given continuous data on bottom pressure and top-to-bottom temperature and salinity off the Bahamas, south of the Canaries and on both sides of the Mid-Atlantic Ridge. From these measurements the full depth, basin-scale, mid-ocean geostrophic circulation may be defined. Combined with electromagnetic cable measurements of flow through the Florida Strait (Gulf Stream) and estimates of wind-driven (Ekman) transport from climatologies, allows estimates of the overturning circulation on a daily basis. The first results, shown in figure 2.7.2, indicate that the four independently measured MOC components compensate each other on periods of over two weeks. Internal and external geostrophic flow are balanced by the Florida Current and wind driven flow, a clear indication that the array is measuring correctly. Northward flow in the upper ocean is compensated by southward flow at depth. The data also show that THC flow is highly variable on time-scales up to a year.

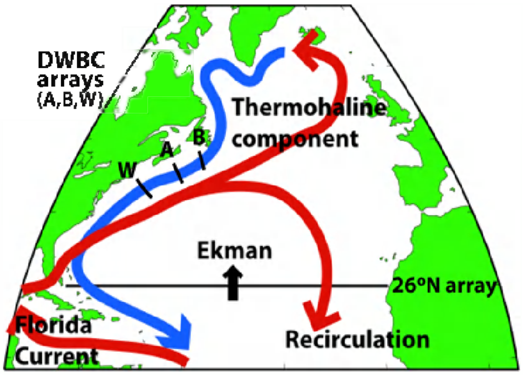

Figure 2.7.1. The Atlantic MOC showing the warm surface circulation (red) and the cold deep western boundary current (blue) with positions of the RAPID arrays in black.

By the end of RAPID four years of MOC data will be available. However, to determine if there is a reduction in the overturning we need longer-term measurements. RAPID-WATCH (**W**ill the **A**tlantic **T**hermohaline **C**irculation **H**alt) will continue the observations until 2014, with a review of the arrays in 2011 to assess the feasibility of moving to an operational system. Money for this has been ear-marked by NERC "in principle", subject to approval of an implementation plan. The prime objectives are (i) to deliver a ten year time series of calibrated, quality-controlled measurements of the Atlantic MOC, and (ii) to exploit the data from the arrays with other observations to determine and interpret recent changes in the Atlantic MOC, assess the risk of rapid change, and investigate the potential for predictions of the MOC and its impacts on climate. The second objective will be met through an open funding call, and through links with Oceans 2025, the NERC marine laboratories' programme for 2007-2012. Oceans 2025 theme 1 "Climate, ocean circulation, and sea level" will help to analyse the MOC data, investigate reasons for MOC variability in observations and models and carry out uncertainty analysis of predicted MOC changes. Theme 10, "Integration of sustained observations in the marine environment" will provide staff time, cruise support and equipment refurbishment, and will contribute other sustained observations needed for the RAPID-WATCH synthesis. Technology development under Theme 8 is also expected to contribute. However, the overall aim of RAPID-WATCH can only be achieved through the use of the MOC data for synthesis and modelling by the wider research community, in the UK, Europe and North America, working to understand the THC and its role in rapid climate change.

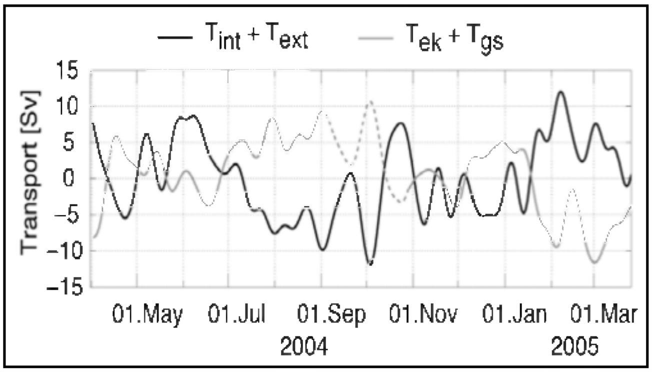

Figure 2.7.2. First year results from the RAPID array at 26°N. Internal (Tint) and external (Text) transport are balanced by wind driven Ekman transport (Tek) and Gulf Stream flow through the Florida Strait (Tgs). 1 Sv = 10^6 m^3 s^{-1}

For more information see the RAPID website at http://rapid.nerc.ac.uk.

2.8. Historical and recent aspects of the Mediterranean thermohaline circulation with emphasis on the Eastern Mediterranean thermohaline cell

Dr Haris Kontoyiannis, Hellenic Centre for Marine Research, Greece.

The Mediterranean Sea, an ocean basin approximately 3700km in length, is located between Southern Europe and the deserts of North Africa. With a volume of ~3.2×10^6 km^3, it covers an area of ~2.26×10^6 km^2 and has an average depth of ~1.4km, while some deep parts of its sub-basins exceed depths of 4km with a maximum depth of 5.2km in the East sub-basin. It is, therefore, characterised as a "miniature ocean", showing a fast response to external forcing.

During most of the year, westerly winds blow over the Mediterranean and mid-latitude and tropical atmospheric features compete as forcing agents. The resulting water flows exhibit a variety of scales ranging from mesoscale to sub-basin to basin; while two deep thermohaline cells exist, one in the West Mediterranean and one in the East Mediterranean. Being a concentration basin, the Mediterranean receives light water masses from the Atlantic Ocean and the Black Sea in the near-surface layers and exports dense saline waters to those basins in the subsurface layers. The salt export of the Mediterranean to the North Atlantic is in principle affecting the North Atlantic thermohaline ocean-atmosphere interaction processes and appears, on a theoretical basis, to have potentially important implications for the global climate. No direct quantification, however, is known to exist with respect to the role of the Mediterranean salt export on the North Atlantic thermohaline processes.

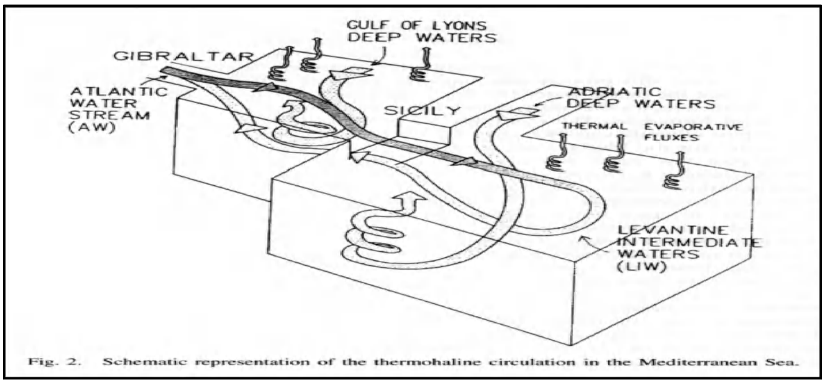

Fig. 2. Schematic representation of the thermohaline circulation in the Mediterranean Sea.

Figure 2.8.1 Schematic representation of the thermohaline circulation in the Mediterranean Sea

The typical formation regions of the deep and bottom Mediterranean water masses are the Gulf of Lyons in the Western Mediterranean and the Adriatic Sea in the East Mediterranean. The Aegean Sea, until the late 80's-early 90's, was contributing dense saline waters in the intermediate layers (1000-1500 m) of the Eastern Mediterranean, whereas it was the Adriatic Sea that, until then, was filling the deep and bottom layers of the East Mediterranean with dense waters characterized by their relatively lower-temperature, lower-salinity signature. This process was interrupted during the period of the early-to-mid 90's, when the Aegean became the area filling the bottom layers of the East Mediterranean with Cretan Dense Water (CDW) of σ_θ>29.2, due to its high salinity content, which was outflowing from the sills to the east and west of Crete. The peak production of CDW was during 1992 when the Cretan Sea was filled up to the depth of ~200 m with CDW. By the late 90's the Cretan Water deep outflow into the Eastern Mediterranean was not dense enough to sink to the bottom. In 1998 the CDW was observed south of Crete to float in a layer between ~1500-2500 m. Progressively in the late 90's-early 2000 there was a return to the previous state of the thermohaline circulation when the source of the bottom waters of the East Mediterranean was again the Adriatic Sea, but in these years the East Mediterranean Deep/Bottom Water of Adriatic origin had slightly increased salinities relative to the late 80's. This multiannual shift in the East-Mediterranean thermohaline cell has been termed as 'The East Mediterranean Transient' (EMT).

The evolution of the EMT, which occurred in a period of internationally increasing attention to the upcoming global change(s), boosted the interest for studies on long-term (extra-decadal) climatic variability of the Mediterranean water properties and circulation in parallel with the corresponding long-term atmospheric driving. Climatic water temperature time-series (1950-2000) in the South Aegean Sea show a long-term cooling trend from 1965 to 1992, with changing behaviour prior to 1965 (no-trend) and after 1992 (warming trend). The same turning points (1965 and 1992) with respect to trend behaviour exist in the meteorological time series of the NAO (North Atlantic Oscillation) index. In addition the temperature time series are characterized by inter-annual oscillations with time-scales of four to six years, several of which co-oscillate with corresponding four to six year cycles in the NAO index. The corresponding (1950-2000) salinity time-series exhibited a different pattern. An increasing salinity trend in the Aegean from the late 1980's- to the mid-to-late 1990's, acting in parallel with the water cooling, resulted in the maximum production of CDW in 1992.

Current meter moorings deployed in the deep channels of the Cretan Straits have provided information on the transport of the CDW outflow into the East Mediterranean. A long-term decrease in CDW outflowing transport is observed from 1992, when the peak outflow transport of bottom CDW was ~3 Sv, through 1994-1995, with CDW outflow near ~0.6 Sv, to 1997-1998 with ~0.15 Sv of intermediate CDW outflow. Observations of the CDW outflowing plumes in January 1998, along the first 20-50 km of their route towards the deeper Levantine-Sea layers, show that the plume behavior with respect to spreading-route shape and dependence of cross-sectional area on the spreading distance are in accord with the theory on bottom gravity plumes in the presence of rotation and bottom friction. However, several questions need to be answered with respect to the plume interaction with the mesoscale dynamic flow structures, the entrainment, mixing, and transformation of their hydrographic properties.

Observations in the Ionian Sea during 2006, in the deepest part of the Mediterranean (~5.2 km) to the southwest of Greece, show a CDW mass between ~2.6 km and ~3.8 km whereas in deeper layer the hydrologic characteristics are indicative of a bottom water mass of Adriatic origin, with a decrease in temperature, salinity and transparency.

The CIESM initiative for the Mediterranean Sea is based on national funds and aims to monitor the water characteristics in the deep basins and straights of the Mediterranean Sea. It is believed that it will offer vital information on the variability of the Mediterranean water masses and their long-term evolution as determined by the thermohaline processes.

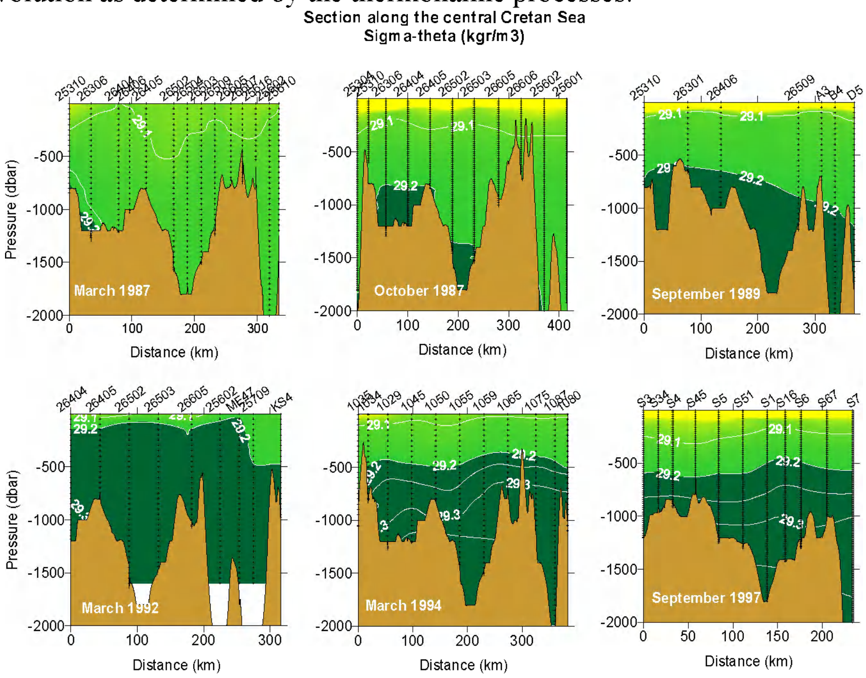

Figure 2.8.2. Evolution of Cretan Dense Water volume (σ_θ>29.2) in the Cretan Sea (section from west (left) to east (right)). From Theocharis *et al.*,1999. Climatic changes in the Aegean Sea influence the Eastern Mediterranean thermohaline circulation (1986-1997), ***GRL***

2.9. Surveying the North Atlantic Ocean

Hendrik van Aken, Royal Netherlands Institute for Marine Research, The Netherlands.

In 1990 the Physical Oceanography Department of the Royal Netherlands Institute for Sea Research (NIOZ) started its participation in North Atlantic hydrographic monitoring by surveying the WOCE AR7E repeat section (a.k.a. A1E) between the continental shelves of Ireland and East Greenland. (Figure 2.9.1). Along this section all major water types contributing to the North Atlantic oceanic thermohaline circulation (THC) are found. Since 1990 the AR7E hydrographic section has been surveyed nearly annually by ZMAW (Hamburg) and NIOZ (Texel), with occasionally a (partial) survey by other groups (NOC, WHOI). After the ending of the WOCE Hydrographic Programme, the survey of the AR7E section was continued as a contribution to the CLIVAR programme. Although from 1991 onwards, two different configurations of the AR7E line were surveyed, the regular survey of the AR7E section has strongly contributed to the identification and understanding of the inter-annual to decadal variations of the North Atlantic hydrography.

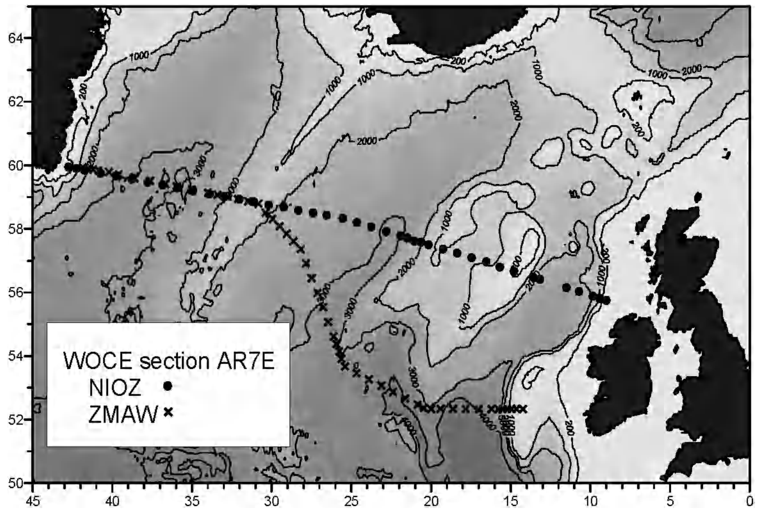

Figure 2.9.1. The survey configuration of the (former) WOCE hydrographic section AR7E. The NIOZ configuration of this section was also surveyed by the RV Charles Darwin in 1991, while the ZMAW configuration of AR7E was surveyed by NIOZ in 1990.

The survey of the AR7E line is focused on the recording of temperature and salinity profiles, determined with a CTD, while dissolved oxygen and nutrients were measured. In 1991 and 2005 the total dissolved inorganic carbon concentration (total CO_2) was also determined. Other research groups used the opportunity of the surveys by NIOZ, e.g. by studying suspended matter or arrow worms. It is the intention of NIOZ to continue the regular hydrographic survey of the AR7E section, hopefully in cooperation with ZMAW. In 2007 short sediment cores (~30 cm) will be collected at each CTD station along the AR7E line.

The western half of both section configurations, coincided in the Irminger Sea, so that an annual resolution of the hydrography there became possible. This provoked questions on hydrographic variability with shorter time scales. Therefore, at two position in the Irminger Sea along the AR7E line, a profiling CTD mooring has been deployed since 2003. With this mooring, daily salinity and temperature profiles are recorded, while ADCPs, mounted on the moorings, record the velocity structure in the upper and lower 600 m of the water column. Special collectors were mounted on the moorings for the determination of the concentration of several man-made organic compounds. Next to the mooring in the central Irminger Sea a mooring with two sediment traps is deployed, in order to determine the variation in the vertical particle flux, including the re-suspension of the sediment, and its relation with the overall hydrographic changes. It is the intention of NIOZ to continue the monitoring programme with the moorings, after 2008.

Apart from the investments for the mooring array, NIOZ did not receive funding for the survey of the AR7E section, in part because regular monitoring is not an activity eagerly funded for long periods by national funding agencies. However, shiptime is quite expensive and it can be expected that in the near future the NIOZ Physical Oceanography Department will have to request funding from the national funding agency.

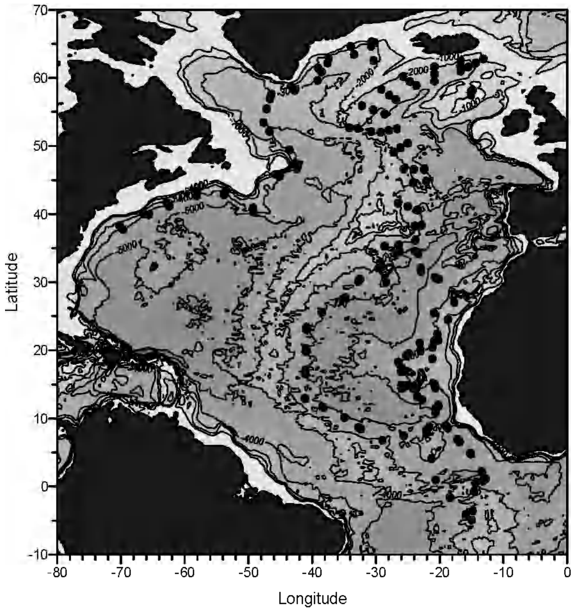

Figure 2.9.2. Hydrographic stations occupied during surveys for the surveys of the TRANSAT and ARCHIMEDES programmes on the deep microbial ecosystem of the North Atlantic Ocean.

The oceanic thermohaline circulation is not only an important part of the global climate system, it also determines the conditions in the deep ecosystems of the oceans, being ventilated by the abyssal branch of the THC. The marine biology department of NIOZ, in cooperation with the physical oceanography department, has initiated a research programme on the microbial ecosystem of the North Atlantic Ocean, with a focus on the meridional change in the abyssal ocean basins. At hydrographic stations along the Mid-Atlantic Ridge and the North American continental margin, water samples were collected from Deep Western Boundary Currents. From these samples, a series of hydrographic and microbiological parameters were determined. It appeared that much of the observed microbiological ecological structure (DNA clustering, proteins, viruses etc.) was related to the observed hydrographic structure. In the core of the Northeast Atlantic Deep Water in the eastern North Atlantic, the meridional biological and hydrographic structure suggest a flushing by Iceland-Scotland overflow water, subsequent ageing, and adaptation of the microbial ecosystem. This research was partially funded (mainly shiptime) by the national funding agency.

3. Round-Table Discussions

Introduction

The afternoon of the Workshop consisted of two Round-Table sessions:

- Round-table 1: Identification of Research Gaps
- Round-table 2: Cooperation/Partnership – Linking Existing Projects

Both sessions lasted approximately 1 hour and fifteen minutes and were chaired by Mr Geoffrey O` Sullivan (Workshop Convenor), Marine Institute, Ireland.

3.1. Identification of barriers to and enablers of co-operation.

In the first round-table discussion, participants were invited to identify and discuss barriers to, and enablers of, co-operation. In addition, a questionnaire identifying 10 barriers and 10 enablers of co-operation[1], which is being further developed under Work Page 2, was used to identify and prioritise such barriers and enablers (Figures 3.1.1 and 3.1.2.).

Availability of Financial Support for Networking

The key enabler identified was that of access to funding for networking. In this context, networking means the ability to physically meet colleagues, to organise short exchanges of expert staff and to organise meetings, seminars and workshops to bring together researchers working in the same or similar areas. Such networking supports should be for relatively small amounts of funding, have minimum bureaucracy attached and be available on a continuous basis with quick turn-around times.

The Workshop organiser noted that many National Programmes did provide such funding for networking and technology transfer, and there was funding available, for example, from the ESF-COST Conference Scheme. Many researchers were not aware of these schemes.

ACTION: MarinERA to investigate preparation of a short report on Member State Networking Supports.

Critical Infrastructures

A main concern of the climate researchers present at the Workshop was the low priority afforded to the establishment and/or maintenance of permanent and strategically placed long-term monitoring stations/platforms which could generate the long time-series datasets which were crucial to understanding climate change.

ACTION: MarinERA to advise partner Funding Agencies on the importance of such infrastructures in supporting climate change research.

Balance between bottom-up and top-down projects in National / EU Programmes

Researchers present voiced concern at the current trend wherein both Member State Funding Programmes and the EU Funding Programmes (e.g. Framework Programme) appeared to be dominated by top-down defined topics and projects. This approach left little scope for testing new ideas and approaches or for innovation. Researchers, while recognising the need for top-down approaches to address immediate policy issues, emphasised the need for more "blue skies" research and noted that it was from such blue skies research would come new and improved understanding and potential solutions to current concerns.

ACTION: MarinERA to advise partner Funding Agencies on the need for a better balance in the definition of Research Funding Programmes between top-down and bottom-up approaches.

[1] Guide to Good Practice: Increasing the impact of National Research Programmes through Transnational Co-operation and Opening (2005). Report prepared by Optimat Ltd – VDI/VDE Innovation and Technik GmbH for EC-DG RTD.

Improving cooperation between existing research projects

BARRIERS

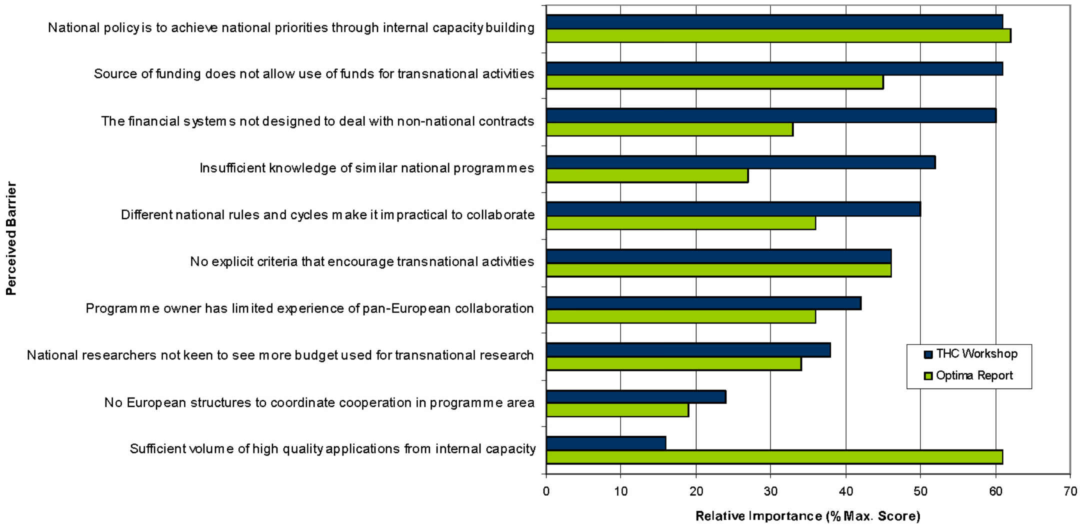

Figure 3.1.1 The relative importance of perceived barriers to the enhancement of interaction between national marine research projects and programmes within Europe.

ENABLERS

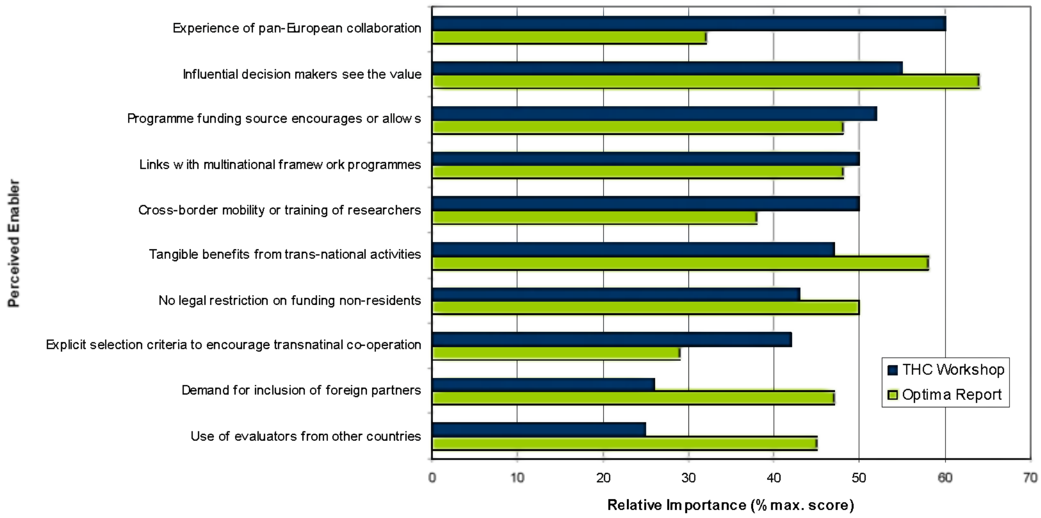

Figure 3.1.2 The relative importance of perceived "enablers" to the enhancement of interaction between national marine research projects and programmes within Europe.

The Barriers and Enablers used above are a sub-set of the Barriers and Enablers identified in:

Guide to Good Practice: Increasing the impact of National Research Programmes through Transnational Co-operation and Opening (2005). Report prepared by Optimat Ltd – VDI/VDE Innovation and Technik GmbH for EC-DG RTD.

3.2. Identification of needs and gaps in European THC research

Workshop Participants, from the nine European countries represented at the Workshop, were asked to identify needs and gaps with respect to European Thermohaline Circulation in European Seas and Oceans research. They were asked to support their comments with a written paragraph outlining a proposal for a research project or programme that would, in their opinion, meet an existing shortfall in the European research effort.

Bert Rudels, Finnish Institute for Marine Research:

The most important information required for evaluating changes in THC is that obtained from **long time series**. Existing time series should be secured and others, at crucial positions, should be started. However, to understand what is happening, **knowledge of processes**, especially mixing, water mass transformations and convection, is crucial. These processes are parameterised in large-scale and global models and are not the primary focus of the modelling community. Detailed knowledge of how mixing and convection operate is necessary to establish what effects changes in the forcing fields: wind, heating and cooling, might have. Scope and funding should exist for medium size projects combining field observations and process modelling. To form a project of a suitable size it might be an advantage that different researchers send their applications to their own funding agencies, indicating that their work will be a part of a larger effort constructed from by different initiative funded by different countries. This would increase the research/logistic ratio, invariably low in ocean research, and make detailed process studies more economically feasible.

Detlef Quadfasel, Centre for Marine and Climate Research:

1. **Set-up of a European Centre for decadal climate forecasting:** Such a centre should develop and apply observational and modelling tools that allow the analysis of decadal-scale climate variability with emphasis on forecasting and assessment of the risk of rapid climate change. It should involve national agencies and act as to create synergy between the activities already carried out there.

2. **Improving air-sea-ice-land flux estimates:** Presently most global integrations of flux climatologies (such as heat and freshwater fluxes) do not balance. Individual estimates vary by quantities much exceeding those expected for fore-coming climate change scenarios. This would make an excellent topic for an FP7 project.

3. **Provide a pool of instrumentation for climate related monitoring research:** As long as the Centre, such as described above, does not exist, most climate related monitoring efforts rely on activities carried out within individual research programs. These usually have a short life time – a few years at most – and sustained observations necessary to detect any climate change are practically impossible. A pool of instrumentation funded by the EU could help scientists to actually do some work rather than chasing for funds supporting such measurements.

Haris Kontoyiannis, Hellenic Centre for Marine Research:

Quantification of the role and the linking between the Mediterranean saline waters, from their origin in the East Mediterranean, **and the North Atlantic thermohaline processes**. Optimum monitoring of water properties and distributions and investigation of the variability and interlinking in key thermohaline ocean-atmosphere processes involved along the route of the Mediterranean saline waters from the East Mediterranean to the North Atlantic on a time-scale of 6-to-7 years. (6-to-7 years constitute the fundamental time-scale of a climatic-salinity oscillation as observed in salinity records of the last half century in the Eastern Mediterranean).

Dynamics of thermohaline plumes around Europe and interactions with background mesoscale circulation structures. Entrainment – mixing - vertical advection and transformation of hydrologic properties. Possible addition of biology and biogeochemistry of the plume environment.

Martin White, Dept. of Earth and Ocean Sciences, NUI, Galway:

- Quantification of the variability in the THC on decadal to centennial timescales, in particular the feedback processes between ocean-atmosphere, ocean-ice and also between key geographical regions.

- The integration of regional data sets, quantification of oceanic boundary fluxes (air-sea and land-ocean) and further development and use of paleo-climate techniques.
- The response of key ecosystems to climate change.

Svein Osterhus, Centre for Climate Research, University of Bergen:

Long term observation system for the Bipolar Atlantic Thermohaline Circulation:

- Establish a system for detecting changes in the THC by deploying sustainable long-term observing systems in key regions in the bipolar Atlantic Ocean (e.g. on the Greenland-Scotland Ridge (GSR), and in the southern Weddell Sea, Antarctica).
- Monitor the northern limb of the THC across the GSR, including both the Atlantic inflow to the Nordic Seas and the deep overflows across the Ridge.
- Monitor the formation of High Salinity Shelf Water (HSSW) and Ice Shelf Water (ISW) in the southern Weddell Sea.
- Study the interaction between the West Antarctic Ice Shelves (WAIS) and the world ocean climate system. This should be done by building on and strengthening existing monitoring systems and infrastructure.

Waldemar Walczowski, Institute of Oceanology, Sopot, Poland:

To improve our knowledge about THC, more complex actions are necessary. First, instead of local and regional investigations, we need a **global view of the THC processes**, integration of available and future observations, and better contact between scientists investigating different regions and processes (workshops, common programmes). The establishment of an international, multi disciplinary institute should be considered. *In situ* observations should go in two directions:

- **long time series** (moorings, cruises);
- **process oriented studies** (fronts, eddies, mixing, ocean-atmosphere heat exchange etc);

All observations (including remote sensing) should be integrated via improved, high resolution, global coupled ocean-ice-atmosphere models. To improve our observations new devices should be developed (we still do not have really good device to measure sea currents from the deck of a research vessel).

Isabel Ambar, Institute of Oceanography, University of Lisbon:

The outflow of Mediterranean Water through the Strait of Gibraltar is characterized by its high salinity. The Mediterranean Undercurrent along the Iberian continental slope sheds eddies, the so-called "meddies", which act as "point sources" enhancing the spreading of this highly saline water in the Atlantic. The **role played by these meddies in the thermohaline circulation of the North Atlantic** has not yet been properly evaluated. Monitoring the meddy rate of formation and estimating their contribution to the maintenance of the North Atlantic highly saline intermediate layer, could strongly contribute to the improvement of the Atlantic circulation modeling and, thus, to more accurate climate prediction. International cooperation is encouraged.

Valborg Byfield and Meric Srokosz, National Oceanography Centre, Southampton, UK

Managing rapid climate change in Europe: **Integrated observation, modelling and statistical analysis to assess the risk to Europe from rapid climate change due to a sudden severe reduction in the thermohaline circulation**. Observations to include *in situ* (physical, chemical) and remote sensing. A probabilistic assessment of the risk of THC collapse, with likely impacts on regional temperature and precipitation. Socio-economic impacts (e.g. on hydrology, crop production, energy demand), including costs of adaptation. How the risk may be reduced, including the cost of mitigation. Decadal prediction of the collapse or slow-down; can we predict in time to (1) mitigate or (2) adapt.

Summary

Needs and gaps identified fell into three broad categories:

1. **Physical infrastructures and long-time series**: strategically placed and reliable observing and monitoring networks, funding for their maintenance and improved modelling

capabilities. These issues were also raised as a priority under the discussion on barriers to and enablers of co-operation.

2. **Process Oriented Studies:** a better understanding of the processes generating THC (especially mixing, water mass transformations and convection) was identified as a need to be addressed. Linked to this were questions relating to air-sea-ice-land flux estimates, the dynamics of thermohaline plumes and meddies. The response of key ecosystems to climate change was also noted though was outside the scope of this Workshop.

3. **Socio-Economic Impacts:** The socio-economic implications of the different climate scenarios, including the costs of adaptation and of mitigation to reduce the risk, and an assessment of the times scales on which such adaptation or mitigation may be possible, was matter of concern.

   Policy makers and planners are concerned about abrupt climate change and are primarily interested in the likelihood of abrupt change occurring (Arnell *et al*., 2005), and in what may be done to reduce the risk. Despite this, there have so far been no scientifically robust estimates of the probability of thermohaline circulation collapse under different carbon emission scenarios. Likewise there are few detailed assessments of the implications of future abrupt climate change across Europe. To allow managers to quantify the risk and potential costs of rapid climate change, such assessments are needed. Management decisions also require some analysis of the relative costs of socio-economic impacts and adaptation to changes on the one hand, and the cost of prevention and mitigation on the other.

Arnell, N., E. Tompkins, N. Adger and K. Delaney (2005). Vulnerability to abrupt climate change in Europe, Tyndall Centre Technical Report 34. www.tyndall.ac.uk/publications/tech_reports/tr34.pdf.

3.3. Scope for future cooperative or EU FP7 projects

The Workshop noted that topics related to **ThemoHaline Circulation** and **Ocean Acidification** were included in the 1st Call for Proposals (May 2007) under Theme 6 (Environment, including Climate Change) Programme. The THOR Proposal (see 2.2) was one response from the scientific community to address the topic of ThermoHaline Circulation. It also noted that Climate Change issues related to Polar Regions would be a focus in the 2nd Call for Proposals (late 2007).

A number of the topics identified above, on process oriented research and socio-economic impacts for example, were, it was considered, very suitable for joint Member State research projects and/or future FP7 topics and should be considered by Member State Funding Agencies and the EU FP7 Environment Programme Committee.

One such project, considered very suitable for an FP7 action, requiring a pan-European input linking the Mediterranean and Atlantic Basins, was that of the **role of the Mediterranean salt and heat export on the North Atlantic thermohaline processes (see Box 3.1).**

Box 3.1: A Potential FP7 PROJECT (2009)

The role of Mediterranean salt and heat export on North Atlantic thermohaline processes.

The salt and heat export of the Mediterranean to the North Atlantic is in principle affecting the North Atlantic thermohaline ocean-atmosphere interaction processes and appears, on a theoretical basis, to have a potentially important implication on the global climate. Yet no direct quantification is known to exist with respect to the role of the Mediterranean salt and heat export on North Atlantic thermohaline processes and circulation.

This project **will provide a better understanding of** Mediterranean thermohaline circulation, exit and attenuation through the Gulf of Cadiz and the processes affecting North Atlantic Thermohaline Circulation, including **its influence on the Eastern Boundary Current .**

Funding scheme: collaborative projects (large-scale integrating projects) (Community contribution from 5 up to 10 million Euros)

Expected impact: Improved understanding and quantification of the role of Mediterranean water on North Atlantic Thermohaline Circulation **and Climate Dynamics**. Improved understanding of how **Mediterranean heat and salt variability** may affect conditions in the North Atlantic.

ANNEX 1:

Thermohaline Circulation in European Seas and Oceans

Location: Marine Institute HQ, Rinville, Galway, IRELAND
Date: Wednesday 6th June 2007.

PROGRAMME

09.00 hrs **Brendan the Navigator Suite (Closed Session)**

Welcome & Introduction: Aims & Objectives of Workshop
Geoffrey O`Sullivan (Convenor – MarinERA WP3 Leader) – Marine Institute, Ireland.

Presentation of the MarinERA Projects database
Dr Saskia Matheussen, Netherlands Organisation for Scientific Research, The Netherlands.

Questions / Answers

10.00 **Auditorium – North Atlantic Drift (Open Session / By Invitation)**

Variability and continuity of the NE Atlantic shelf edge current: Irish research west of Ireland
Dr Martin White, Dept of Earth & Ocean Sciences, National University of Ireland –Galway, **Ireland.**

A European initiative to assess and forecast THC variability in the Atlantic (THOR)
Prof Dr Detlef Quadfasel, Centre for Marine & Climate Research, University of Hamburg, **Germany**.

Mediterranean Outflow: its contribution to the thermohaline circulation in the North Atlantic Ocean
Prof Isabel Ambar, Instituto de Oceanografi, Faculdade de Ciências da Universidade de Lisboa, **Portugal.**

Warming of the West Spitsbergen Current
Dr Waldemar Walczows, Institute of Oceanology, Sopot, **Poland.**

Bipolar Atlantic Thermohaline Circulation (BIAC)
Dr Svein Osterhus, Bjerknes Centre for Climate Research, University of Bergen, **Norway**.

11.15 **Coffee Break**

11.45 The Arctic Ocean impact on the Atlantic Thermohaline Circulation - positive or negative?
Dr Bert Rudels, Finnish Institute of Marine Research, Helsinki, **Finland.**

Observing the North Atlantic MOC: The RAPID programme and Oceans 2025
Dr Val Byfield, Southampton Oceanography Centre, **UK.**

On overview of historical and recent aspects of the Mediterranean thermohaline circulation with emphasis on the Eastern Mediterranean thermohaline cell.
Dr Haris Kontoyiannis, Hellenic Centre for Marine Research, Institute of Oceanography, Athens **Greece.**

Surveying the North Atlantic Ocean
Dr Hendrik van Aken, Royal Netherlands Institute for Sea Research, **Netherlands.**

13.00 **LUNCH**

14.00 **Brendan the Navigator Suite (Closed Session)**

Presentation: Marine Institute (Ireland) planned Climate Change Research
Russell Poole / Joe Silke, Marine Institute.

Round-Table 1: Identification of research gaps

15.30 **Coffee Break**

Round Table 2: Co-operation / partnership – linking existing research projects

17.0 **END**

Marine Institute
Rinville, Galway, Ireland. www.marine.ie

Annex 2: Workshop 1: THC in European Seas and Oceans

2.1 List of Participants

Country	Participant	Organisation
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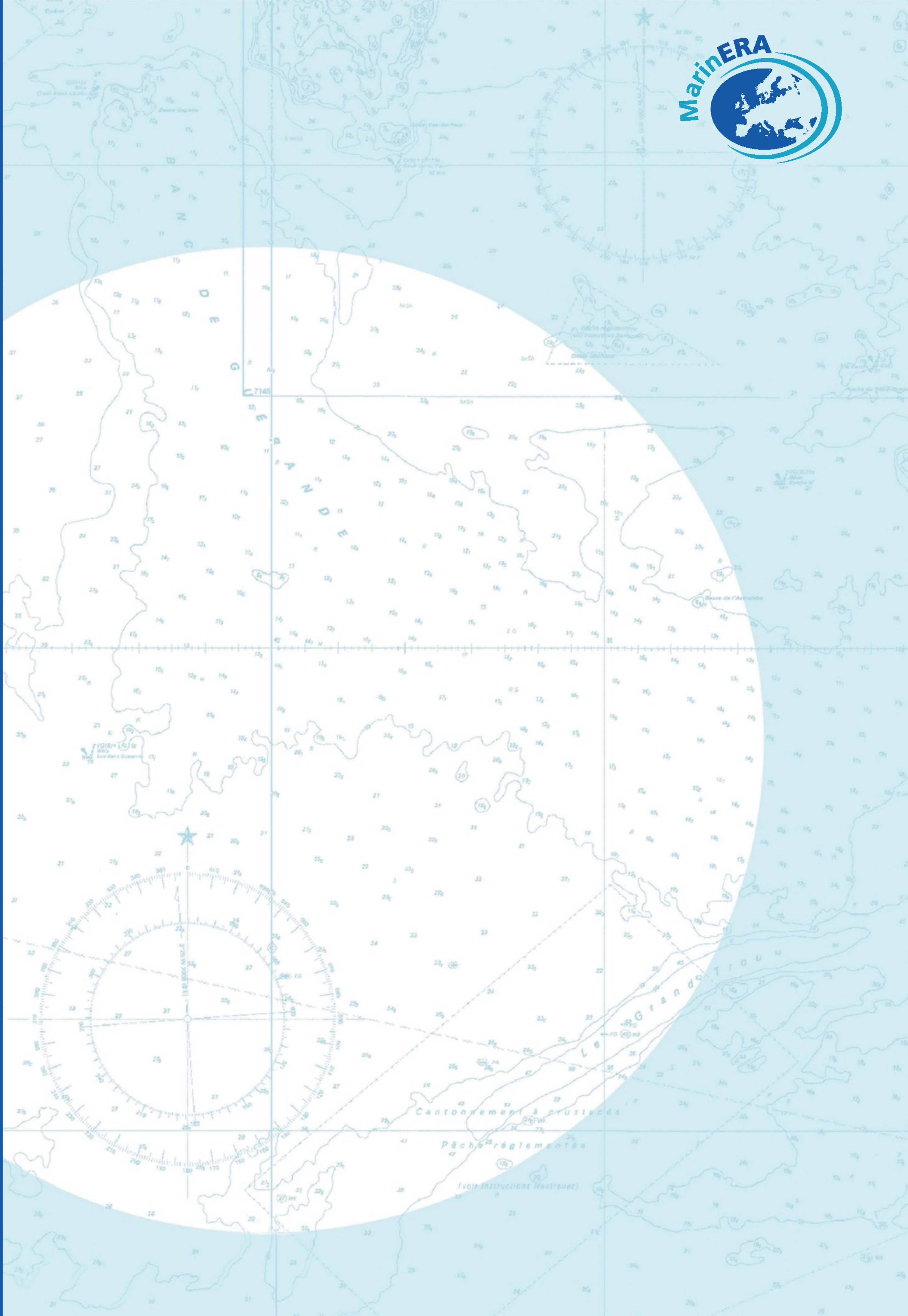
Facilitating the Coordination of National and Regional Marine RTD Programmes in Europe



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