The Subpolar Gyre Experiment

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1. Introduction

The key issues concern the North Atlantic ocean sub-polar gyre's buoyancy budget and its variability. This region is of unique importance for climate variabilty in the world ocean because: It is the site of intense water-mass transformation through vigorous air/sea interaction and interior diabatic mixing. Through this reservoir pass the North Atlantic Current, yielding its heat to moderate Europe's climate, and NADW, a critical, but perhaps fragile, part of the global deep circulation. It also encompasses one center of action of the SST tripole pattern associated with the NAO and has undergone large and sustained changes in the last few decades. Nowhere else does such a small part of the ocean play such a large part in climate and its variability.

Outstanding questions remain regarding the subpolar gyre's buoyancy budget. Critical challenges are: to elucidate the processes by which interior stirring and mixing, and hence water-mass transformation, occurs, to characterize the variability in these proceses, and, to track the propagation of anomalies through the gyre. Only by improving knowledge of these issues can we improve the realism of climate models in this area. And only by an intense field campaign through the seasonal cycle and supported by other field programs can we advance our knowledge.

2. Scientific Priorities:

The overarching priority is to:

Quantify and understand the importance of export of water across the Greenland Scotland Ridge and through Davis Strait in controlling the dense branch of the North Atlantic MOC and its variability. To do this requires better knowledge of the role of local air/sea/ice fluxes in the SPG and mixing with the warm NAC.

The polar outflow waters are clearly influential because:

(a) Dickson et al. (2002) show 40 yrs of freshening in the SPG, while Hansen et al. (2001) see 25% reduction in Faroe Bank Channel outflow since 1950.

(b) There is upstream influence in DSOW of Fram Strait throughflow three years earlier (Dickson et al., 1999).

(c) The fresh, cold EGC, WGC, and Labrador Current are strongly influenced by conditions north of the sills. These shelf currents control open-ocean deep convection, especially in the Labrador Sea (see (h) below).

(d) The Great Salinity Anomaly had a profound effect on the stratification and circulation of the subpolar Atlantic.

On the other hand, local subpolar gyre processes clearly impact the transport and variability of the MOC---both the deep and intermediate branches. For instance:

(e) the transport of the dense branch nearly doubles from Denmark Strait to Cape Farewell. Dickson et al. (2002) have shown that freshening of the ambient entraining water is comparable to the recent freshening as the remote sources. Yet we don't fully understand what sets the properties of the ambient water, or the details of the entrainment.

(f) The intermediate branch of the MOC seems to have a potentially significant contribution from deep convection east of Greenland, which needs to be explored/quantified.

(g) Related to this, we've yet to determine the relative importance of LSW getting imported into the Irminger Sea (from the Labrador Sea), versus local transformation, in ventilating the water in the Irminger Basin (some of which gets entrained into the DSOW).

(h) Shelf-basin exchange seems to be occurring all along the East Greenland continental shelfbreak, which might contribute to waters as dense as the DSOW. Offshore flux of surface fresh water from the boundary current also strongly dictates open-ocean convection in the Labrador Sea. See point (c) above too.

The relative importance of these issues is unknown and they all require further study. They could be addressed in a Subpolar Gyre Experiment located in the Irminger Sea and surroundings which is what we propose.

3. Physical Processes:

The key relevant processes are:

(i) Local ventilation of Irminger Sea SPMW by open-ocean convection (air-sea forcing and preconditioning are important).

(ii) Remote contribution to Irminger Sea SPMW from "upstream" (i.e. from the lighter classes of mode water to the east) as well as "downstream" (mode water advected back to the Irminger Sea from the Labrador Sea).

(iii) The role of shelf-slope exchange in ventilating the Irminger Sea (both the SPMW and DSOW).

(iv) The role of surface freshwater flux from the boundary in dictating formation of SPMW.

(v) Entrainment of the SPMW into the overflows, which to some degree is a function of all of the above.

In summary, our overall experiment is to study the ventilation of the Atlantic subpolar gyre, as seen in the Irminger Sea, and the associated impacts on the transport and variability of the intermediate and deep branches of the MOC. It involves all of the key processes above.

We will focus on the Irminger Sea because it is much less understood than the Labrador Sea. It is where the dense overflow through Denmark Strait first meets the open ocean and undergoes its final significant modification. Important, climatically relevant, local ventilation processes have recently been revealed. It has the largest wind-stress curl forcing of anywhere in the subpolar gyre (by two orders of magnitude!) and buoyancy forcing as large as Labrador Sea storms.

The study aims to understand mechanisms that also occur in several other MOC-critical global locations such as the Weddell Sea, Western Arctic, and Mediterranean outflow. Our study will address their generic features as well as region-specific aspects. We will also address the predictability of these processes and think about the prospects for future change in the subpolar gyre.

3. Specific Plans

We have not yet formulated a detailed plan of field work. Elements of the program might involve:

(a) Detailed process study of East Greenland Current in the Irminger Sea, 60-65N (Cape Farewell to Dickson/Meincke moorings). The process of interest could be the export of shelf water into the deep Irminger Sea. Seasonal coverage is required, including winter. Surveys with ice-avoiding SeaSoar-type towed CTD would be ideal. Moorings or floats could play a part. I129, and CFCs also have excellent potential to help us identify the rates, pathways, and mixing histories of waters circulating in the Irminger Sea.

(b) Rolling Labrador/Irminger/Newfoudland Basin surveys using SeaGliders. The focus here is to document the evolution of the density field on scales of O(10km, 100days) over, say, a 2 year window. These scales of variability are not monitored by any other efforts. The gliders would follow altimeter tracks to help the data assimilation (see below). The gliders would inform the detailed planning of phase (a), and could be directed in real time to specific features of interest (e.g., deep convection events in southern Irminger Sea, export events from East Greenland shelf).

(c) Observations of Denmark Strait overflow and entrainment. This is a critical mechanism that is very hard to observe using traditional instruments. A deliberate tracer release (of SF6 in Denmark Strait, for example) would be an elegant way to monitor the spreading and mixing of DSOW and its recirculation pathways in the subpolar gyre. Shipboard surveys to map the evolution of the tracer would be needed although currently planned fieldwork in the area would provide many opportunities for access. Moored water samplers to give time series at critical locations would also be needed. Again, some of these are already planned by other programs. Microstructure observations to complement the tracer data are necessary too.

(d) Modelling and data assimilation is essential to synthesize the field program with a near real time high resolution (5-10km grid) model of the Irminger Sea. The modelling component will have 3 aims:

(a) To design and optimise the observing program.

(b) To investigate the key physical mechanisms of interest and their predictability. To uncover the generic aspects of these processes to understand how they work in other places.

(c) To estimate quantities that cannot be observed directly, e.g., net transport of mass, heat and freshwater through Denmark Strait, overall water-mass conversion rates.

The data assimilation system will blend diverse observations with the model so that it can accurately track the evolution of the subpolar gyre (and Irminger Sea in particular) through the field program. Data sources apart from those described above include remotely-sensed SSH, SST, sea-level winds, and sea ice cover. The strategy will be to perform a detailed assimilation exercise for the period of the field program. The results will allow the primary science goals to be tackled. An important secondary aim is to design an optimal, reduced cost, outflow monitoring system for long-term (decadal) deployment. The prototypical model/data assimilation system will then be used operationally in near real time to provide accurate analyses of the stratification and circulation in the area. The modeling and assimilation technology is available now (MITgcm, ECCO tools).

4. Readiness and Logistics:

This project is at an early stage of planning and community comment is invited. It uses available, or forseeable, technologies so no special obstacles exist to implementing the program.

The tentative timeline is:

03 - Refine experiment design. Assemble team of PIs.
04 - Propose and secure funding.
05 - Start project. Optimize field program for synergy with other efforts. Configure model.
06 - Begin field program. Configure data assimilation system.
07 - Continue field program. Preliminary model/data assimilation testing.
08 - End field program. Model/data assimilation of field data.
09 - Resolve main scientific questions. Design permanent monitoring array. Hand over model/data assimilation system to operational agency. End project.

No budget estimates have been made, but we forsee a medium-sized program costing around $5-10M. Shiptime on more than 1 ship may be needed.

5. CLIVAR Relevance and Related work:

The study addresses the CLIVAR goals to:

(i) Expand the capability to predict seasonal to interannual climate variability.

(ii) Understand the mechanisms for rapid changes in the MOC and provide essential information to judge the potential for future changes.

(iii) Evaluate and enhance the reliability of models to monitor and predict climate variations.

It will contribute to these goals by improving the instrumental record in a critical place. This will: document ongoing climate change, improve understanding of the mechanisms involved, and provide data to test and improve model/data assimilation systems. It will also lead to the quantification and understanding of specific essential processes that are poorly represented in climate models.

The following programs have excellent links with the Subpolar Gyre Experiment: Arctic-Subarctic Ocean Flux study (ASOF), German SFB460, UK NERC Rapid Climate Change program, Norwegeian NOClim project, and, Canadian programs in Labrador Sea. It links well to current, and planned, WHOI Atlantic field work (Pickart, Irminger Sea; Toole et al., Cape Cod to Bermuda Observatory).