Irminger Sea Regional Science Workshop
IrmingerSea17

Nov 8-9, 2017
National Oceanography Centre, UK

Workshop Summary
Penny Holliday and Robert Weller

1. Aims and Objectives

The workshop was held at the National Oceanography Centre, Southampton U.K. on November 8 and 9, 2017 to foster coordination of international research efforts focused on the Irminger Sea region. The overarching objective was to coordinate international efforts to observe, study, and better understand the Irminger Sea region. Workshop foci included: summaries of present and planned observational, empirical, theoretical, and model-based efforts focused on the physics and biogeochemistry of the Irminger Sea region; presentation of results from recent observational campaigns; identification of key questions and hypotheses related to the physics and biogeochemisty of the region; discussion of sampling strategies to address those questions, including coordination of present, planned and new observational efforts; plans for collaborative analyses and publications; and data sharing in support of coordination and collaboration. An effort was made to bring young investigators to the workshop. The organization used a first day of presentations to share results and plans and a second day with discussion groups running in parallel with the aim of catalyzing collaborative research, analyses, and publications.

2. Presentations

Robert Pickart, WHOI - Preliminary results from the OSNAP west Greenland mooring array
Virginie Thierry, Ifremer - Overview of the OVIDE and RREX projects: results and future plans.

Femke de Jong, NIOZ - Comparison of convection at OOI, CIS and LOCO and future NIOZ plans in the Irminger Sea.
Sue Banahan, COL - Status of OOI Irminger Sea Array
Robert Weller, WHOI - OOI Irminger Sea early results
Michael Vardaro, Rutgers - Introduction to OOI Data Portal
Johannes Karstensen, GEOMAR – Is the OOI node well placed? A regional and a strategic perspective
Sotira Georgiou (TU Delft) -Plans on analyzing the dynamics of deep convection and sinking in the Irminger Sea.
Loic Houpert, SAMS -Multi-scale observations of deep convection in the northwestern Mediterranean Sea during winter 2012/13 using multiple platforms
Loic Houpert, SAMS - Transport Structure of the North Atlantic Current in Subpolar Gyre from gliders
Chesley Baker, Uni Southampton - The effect of mesoscale upper ocean processes on deep ocean carbon flux in the Iceland Basin
Jian Zhao, WHOI - Mesoscale and sub-mesoscale variability in the Iceland Basin
Marilena Oltmanns, Geomar - Seasonal and interannual NAO modulations by surface freshwater in the Irminger Sea
Simon Josey, NOC - Irminger Sea air-sea interaction
Amy Bower, WHOI - Overflow water pathways in the Irminger Sea observed with deep floats
Penny Holliday, NOC - Preliminary results from the UK OSNAP DWBC mooring array
Igor Yashayaev, Bedford Inst of Oceanography (10 min)- Recent boost of convective overturning in the subpoloar North Atlantic
Mattia Almansi, Johns Hopkins - Variability in the Circulation and Hydrography of Denmark Strait from a High-resolution Numerical Model
Isabela Lebras, SIO (10 min)- The seasonality of freshwater in the East Greenland current
Peigen Lin, WHOI - Evolution of the Freshwater Coastal Current at the Southern Tip of Greenland
Hilary Palevsky, WHOI - The North Atlantic biological pump: Insights from the Ocean Observatories Initiative Irminger Sea Array
Hjalmar Hatun, Faroe Marine Inst - The productive Irminger Sea
Nathan Briggs, NOC - update with input from from Herve Calustre (LOV) and Giorgio Dall'Olmo (PML) on BGC floats in the area and from studies analyzing them
Cyril Germineaud, U Grenoble - Design of the BGC-Argo network in the North Atlantic: an ensemble-based probability score approach to compare deployments
Emmanuel Boss, U Maine - NAAMES
Emmanuel Boss, U Maine – SOCCOM
Fiamma Straneo, SIO - First Results from OSNAP: Overturning in the Subpolar North Atlantic Program

3. Discussion Groups

On Day 2, participants were invited to write (on post-it notes) any large or small science question they are interested in, any technical questions or feedback to OOI, and any issues around future plans. We sorted these notes into groups and then broke into small groups to discuss. Groups were asked to consider short terms plans including writing joint papers, and longer-term plans including future collaboration groups. The group discussions are summarized below.

3.1 Large-scale connectivity
Reporter: Jian Zhao

Does convection in the Labrador Sea and Irminger Sea have different behavior?
The deep convection frequency in the Labrador Sea is higher than the Irminger Sea. It would be worth performing statistical analysis for the convection events and investigate how deep the

convections reach and the spatial scale for the convection events. The pre-conditions in the Labrador Sea spread into the Irminger Sea, so that cooling in 2015 could have triggered the deep convection in the Irminger Sea. Deep convection is well quantified by Argo in the Labrador Sea, how about the Irminger Sea? This could possibly be evaluated using the OSNAP array.

What is the dynamical link between Labrador Sea and Irminger Sea, and the rest of the subpolar gyre?
Deep convection in the Labrador Sea and Irminger Sea can spread into different regions of the subpolar North Atlantic, which can change the thermal wind shear and hence the large-scale circulation such as the AMOC. Stuart Cunningham is interested in leading a paper to examine this.

Can we use steric height to quantify the connection in the Labrador Sea, Irminger Sea, and the subpolar gyre? The first EOF mode of the steric height shows coherent structure in the Labrador Sea and Irminger Sea, so they are sometimes in phase, sometimes not. Does this matter to the gyre circulation? There may be time delayed responses of the gyre to the deep convection in the Labrador Sea.

Igor Yashayaev has combined Argo data and K1 mooring (which is near central Labrador, close to the deep convection, deployed from 1997 to now) and constructed hydrographic profiles (0-2000m). Can we do the same thing in the Irminger Sea, using OOI or OSNAP and argo? If done at the Irminger Sea, we can probably evaluate the connection/comparison between two basins. We can calculate the decorrelation scales for moorings. Igor will compare the K1 mooring and random sampled Argo data and create the diagram of differences.

What is the connectivity of various water masses across the 3 subpolar sub-basins?
We have information about water properties, velocity at a number of moorings, and float pathways as well. Would be great to write a paper that brings all this information together for a comprehensive view of how water masses move from the northern sills though the region, into the Labrador Sea and eventually to be exported. Should distinguish between pathways of different density ranges/water masses.

What is the connection between subpolar gyre and subtropics?
We can explore the connection between subpolar gyre and subtropical ocean (26.5N). The NADW observed at the subtropics (26.5N and MOVE at 15N) has little correlation with the Labrador Sea water export. We could use Rafos floats to explore the connection between subpolar and subtropical, and it can be done within OSNAP framework. Next OSNAP PI meeting at 2018 Ocean Science meeting will discuss this topic and make detailed plans, such as find specific postdoc, student to do it.

3.2 Deep convection and re-stratification discussion group
Reporter: Jo Hopkins

Questions that need addressing are:

Need a better handle on spatial-temporal structure of convective events? Gliders would be good for looking at the horizontal scales.
What are the drivers of extreme convection events?
What are the relative importance of the drivers of convection and how much does pre-conditioning (e.g. cold) anomalies matter?
Does deep convection in the Irminger Sea matter? Can we get a volume estimate?
What contribution does LSW/convection make to AMOC and its variability?

Does LSW interact with the overflow fields?
What impact does the eddy field have on the timing and magnitude of convection and re-stratification events?
Mesoscale variability in the winter is not well understood – what drivers 'short' periods of re-stratification and potential for phytoplankton growth?
What impact on convection will fresh anomalies in the Iceland Basin have when the reach the Irminger and Labrador Sea?
Should consider deployments starting at the end of the convective period so that the whole re-stratification processes is captured

3.3 Biogeochemical and physical interaction group discussion
Reporter: Hilary Palevsky

There were two key categories of science questions that we discussed:

Controls on productivity, the spring bloom, and ecosystems
Bottom up versus top down control? Influences on higher trophic levels, species succession, influence on seabirds, fisheries, and other top trophic levels

Carbon flux and sequestration
Both natural (biological, physical, chemical) and anthropogenic carbon fluxes

We discussed the importance of both quantifying rates (since these estimates are very sparse, especially in high latitude regions), and improving understanding of mechanisms controlling these processes, which is necessary to inform future projections.

We discussed key types of physical processes that could influence biogeochemistry:
Warm surface expression eddies (sampled at location of OOI array) can influence productivity, phytoplankton community composition, etc. There are other types of eddies found in other areas of Irminger Sea, Denmark Strait, etc. Convection/restratification changes in mixed layer depth (and importance of winter mixed layer depth)

Note the value of moorings is that they capture the exact timing of MLD changes, versus Argo floats are lower temporal resolution but can cover broader spatial area. Also noted that ML deepening is often a 1D process but restratification can only be understood in 3D context because of eddy slumping, etc. There can also be coupling between stratification and productivity at short time scales (diel), so can be important to have temporal resolution to capture short-term physical changes
Lateral supply (water mass transport) that both supplies nutrients and can be important to account for in biogeochemical mass balance budgets

We discussed the observations needed to address these questions in terms of both what exists (i.e. what science we can do right now) and what we might want to add (i.e. future proposals):

There are additional observations in the region that hadn't come up previously at this meeting: ship of opportunity sampling (CPR, Reykjavik to St John's shipping route, ferry from Denmark to Iceland), Fisheries surveys in the region. It would be beneficial to submit cruise opportunities to POGO database to help community take advantage of existing ship time. Discussed additional sensors that could be added to OOI (examples could be bird camera, imaging flow cytobot, sediment traps) and also need to increase knowledge/use of existing data. Discussed possibility of improving spatial coverage of BGC properties in the region through new BGC-Argo floats and BGC-OSNAP.

3.4 Boundary processes and exchange with the interior
Reporter: Isabela Le Bras

Spill jet
What is the Spill jet contribution to the overturning, can we identify the source of overflow waters? Jake Opher (PhD student, jacher53@bas.ac.uk) looking at this question.
OSNAP can write about connection of overflow water in DWBC-source.

DSOW cyclones
Do they have an SSH signature? Yes, early paper used them, but maybe they get de-coupled downstream. In a model they have a lag (Mattia working on validating high-res regional model downstream of DS). Amy Bower: sometimes sees signature. not consistent enough to track with Aviso gridded product. What about along-track data? Eddies are likely too fast. What about looking at SSH along an isobath? Maybe this points to hotspots?

Could Amy lead a paper on cyclones in the DSOW? Others interested are Loic Houpert (nom. by Stuart Cunningham), Penny Holliday, Jo Hopkins, Isabela Le Bras/ Fiamma Straneo, Bob Pickart, +. Topics to look at include: what they do to mixing laterally and vertically? What is the fate after Bob's (West of Greenland array)? Are they involved in triggering of instability just to the north, Irminger Rings?

Freshwater in subpolar gyre
How do anomalies (from Arctic) propagate around the subpolar gyre?
We have measurements on the shelf, are they capturing the freshwater transport though? Penny: CTD sections in 2014 and 2016 show that freshwater flux is all on the shelf --> Lab shelf big issue. The Davis Strait array coming out of water --> Even more important to measure Lab shelf. What can we learn from surface salinity? We can estimate Lab sea freshwater flux using CTD data. A study has looked at meteoric component vs. freshwater from Beaufort gyre, using data from 2014 BGC cruises, OSNAP, GEOVIDE(Benetti et al, 2017). Difficult to measure in icey regions - Craig Lee and Laura de Steur data loggers send data down with weak links. Gerome Paillait.

3.5 Air-Sea Fluxes
Reporter: Loic Houpert

Science ideas and plans for the air-sea interactions theme:
Interplay of atmospheric scales (large scale: NAO, EAP patterns, ...) vs small scales (e.g. tipjets) on deep convection variability :

- paper in preparation led by Simon Josey and Bob Weller (presentation of OOI air-sea data, especially in the context of the tip jets
- further works combining atmospheric reanalysis, ocean data, PWP models, ...

Ocean feedbacks on the atmosphere, especially the reemergence of mode water
- paper in preparation using multiple historical and recent data (Marilena)
- further works with atmosphere-ocean models

Investigate the interplay of wind- and buoyancy-driven circulation from analyses of local budget (OOI sites) and basin scale budget.

This would involve a range of time scales and build on the results of first question above, since one is large-scale (wind stress curl for wind-driven circulation) and the other one small-scale (local heat fluxes for buoyancy driven circulation).

3.6 Ice and Freshwater
Reporter: Marilena Oltmanns

Considering variability, pathways and impacts of ice and freshwater in the Irminger Sea, the following science questions were identified:

Identify sources of freshwater for the Irminger Sea:

- The East Greenland Current and East Greenland Coastal Current (via lateral mixing, eddies or wind events).
- Fjords in southeast Greenland.
- Sea ice and ice bergs advected into the region.
- Advection of freshwater from the Labrador Sea that originated from the return circulation after Cape Farewell.
- Surface fluxes (precipitation minus evaporation).
- Irminger Current west and north of the Reykjanes ridge (as a source of salt).

<u>*Explain the freshwater variability at the mooring/quantify sources:*</u>

- What are the relative contributions from the identified sources during restratification after convection?
- On what time scales do they vary? Seasonal cycle? Interannual variability? Short-term events (eddies or winds)?
- What is the role of freshwater variability inside the source regions (in particular the coastal currents) compared to mechanical forcing (e.g. variability of eddy shedding/lateral mixing of freshwater from the boundary current into the Irminger Sea)?
- What is the impact of wind events on sea ice and freshwater transports or mixing in the Irminger Sea? Can variations in the halocline be detected?

What is the impact of the freshwater on oceanic and atmospheric variability? (Paper in preparation, lead by Marilena.)

<u>The following papers are planned or in progress:</u>

Transport variability of freshwater across the OSNAP array:

Papers lead by Isabela and Fiamma on freshwater transports in the East Greenland Current and Coastal Current, and by Peigen on the recirculation of freshwater from the West Greenland Current after Cape Farewell. Femke and Laura are working on the Irminger Current; Mattia quantified transports in the Denmark Strait overflow.

The role of strong wind events for ice and freshwater advection based on the mooring observations, remote sensing data of sea ice concentration and ASR; potential comparison of the wind event impact with the effects of eddies and lateral mixing using a regional climate model:

Paper lead by Marilena; model comparison using high-resolution model from Mattia.

Diagnosis of the seasonal cycle and interannual variability of freshwater in the Irminger Sea.

Quantification of the identified sources of the freshwater that restratifies the Irminger Sea after convection, based on the mooring data (including meteorology from surface buoy), transport estimates and the results from the wind events paper. Identification of metrics to relate the analyses from different mooring locations to each other:

Collaborative paper, coordinated by Marilena or Isabela.

3.7 Data, Integration and Synthesis

We discussed whether we could make available value-added products that would enable other research. Example: best air-sea flux product from the buoy data (including evaporation), generated by Bob Weller and Simon Josey, distributed through the OOI portal.

It was noted that the OOI decision not to calibrate the data added a barrier to wide use. Example: biogeochemical data require very careful processing and calibration before use, and if not done properly can give misleading information. Contrast with NOAA who have resources and experts to process/calibrate their data. Can OOI collaborate with NOAA, may be share best practice or use same processing methods? Mike Vardaro will investigate, and it would be a good issue to raise at the OOI Townhall at Ocean Sciences in Feb 2018.

Gliders are continuing to be assessed/adapted to improve technical performance

Hilary's group are developing a method to calibrate glider oxygen sensors, with the potential for the gliders then to be a calibration tool for other assets. We asked whether similar activity was taking place for other bgc sensors including moorings, but this was not known in the room.

The general outcome of this discussion was to note that the community needs people to take the OOI data and generated products that can be used widely. This is not within the scope of the OOI facility, but it is important that it happens for maximizing use of the data.

Penny Holliday noted the importance of the flanking moorings for OSNAP, our future plans are constructed around the continuation of these instrumented moorings.

We discussed sharing ship time between OOI and other programmes. There are two elements to this: one is making berths available on OOI cruises - this is fairly straightforward but is not presently done in a routine way. The second is coordinating large fieldwork elements with other programmes, eg servicing OSNAP moorings on an OOI cruise. The latter requires agency-agency interaction and can be tricky, although there are multi-agency frameworks in place between some countries. It was noted that NSF may be looking for ship sharing opportunities in 2019-2020 as shiptime is expected to be tight. The message here is that science programmes need to have early discussion with ship managers about long-term requirements.

Action (All): send to Lisa Clough and Bob Weller a bibliography of your published work that makes use of OOI data
Action (All): please also send Lisa and Bob details of work you are doing/planning to do using OOI resources

4. Participants

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(WHOI), Susan Lozier (Duke), Johannes Karstensen (GEOMAR), Emmanuel Boss (U. Maine) Penny Holliday (NOC), Femke de Jong (NIOZ), Susan Banahan (COL), Kendra Daly (U. South Florida).

6. Glossary of acronyms

AMOC	Atlantic Meridional Overturning Circulation
ASR	Arctic system reanalysis
BGC	biogeochemical
CIS	Central Irminger Sea
COL	Consortium for Ocean Leadership, Washington DC USA
CPR	continuous plankton recorder
CTD	conductivity, temperature, depth measuring instrument
DS	Denmark Strait
DSOW	Denmark Strait Overflow Water
DWBC	Deep western boundary current
EAP	East Atlantic Pattern
EOF	Empirical Orthogonal Function
GEOMAR	Helmholtz Centre for Ocean Research, Kiel, Germany
GEOTRACES	An international programme which aims to improve the understanding of biogeochemical cycles and large-scale distribution of trace elements and their isotopes in the marine environment
GEOVIDE	A GEOTRACES study along the OVIDE section in the North Atlantic and Labrador Sea
LOCO	Long-term Ocean Climate Observations, an NIOZ project
LOV	Villefranche Oceanographic Laboratory, Villefranche, France
LSW	Labrador Sea water
ML	mixed layer
MLD	mixed layer depth
MOVE	Meridional overturning variability experiment
NAAMES	North Atlantic Aerosols and Marine Ecosystems Study, NASA program
NADW	North Atlantic Deep Water
NASA	National Aeronautics and Space Administration, USA
NAO	North Atlantic Oscillation
NIOZ	Royal Netherlands Institute for Sea
NOC	National Oceanography Centre, Southampton, UK
NSF	US National Science Foundation
OOI	Ocean Observatories Initiative, US National Science Foundation
OSNAP	Overturning in the Subpolar North Atlantic Program
OVIDE	Observatoire de la variabilité interannuelle et décennale en Atlantique Nord
PML	Plymouth Marine Laboratory, Plymouth, UK
POGO	Partnership for the Observation of the Global Oceans
PWP	Price-Weller-Pinkel 1 dimensional ocean model
Rafos	SOFAR (SOund Fixing And Ranging) spelled backwards, a drifting float tracked acoustically
RREX	Reykjanes Ridge Experiment
SAMS	Scottish Association for Marine Science
SIO	Scripps Institution of Oceanography
SOCCOM	Southern Ocean Carbon Chemistry Observations and Modeling program
SSH	Sea surface height
TU Delft	Technical University, Delft, Netherlands
UK	United Kingdom
USA	United States of America

WHOI	Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, USA