Scientific Report MSM54

Two years after the completion of a cruise with the Research Vessels POLARSTERN, SONNE, METEOR, MARIA S. MERIAN, POSEIDON, ALKOR, HEINCKE, or ELISABETH MANN BORGESE, the scientific exploitation of the samples and data obtained have to be documented in a Scientific Report by the chief scientist. This includes the progress with regard to the scientific objectives as outlined in the original cruise proposal and the publication of the results in scientific journals.

Citation:

Scientific Reports are released by the Gutachterpanel Forschungsschiffe (GPF) on a regular basis. Scientific Reports should not be cited in scientific publications. Please cite the appropriate references listed in the Scientific Report instead.
Scientific Cruise Report Meteor MSM54

1. General Information

- MSM54
- MerMet 14-77
- PI:
  - J. Karstensen (PI & Chief scientist). GEOMAR Helmholtz Centre for Ocean Research Kiel, Duesternbrooker Weg 20, D-24105 Kiel, Germany
- Water mass transport and transformation in the Labrador and Irminger Seas
- Subpolar gyre variability
- St. John’s (Canada) – Reykjavik (Iceland), 12.5.2016 to 04.06.2016
- Number and kind of peer-reviewed publications, based on data and samples obtained during the cruise: 10

a) Peer-reviewed publications:


b) Book publications
No

c) Other publications
No

d) Patents, arranged according to registered and issued.
No

2. Summary (max. 1 DIN A4-page)

- Generally comprehensible depiction of the most important scientific progress and if applicable their application aspects

MSM54 was the cruise that recovered the first set of data from the 53°N Array of moorings used for calculating of the subpolar Atlantic Meridional Overturning circulation (AMOC) in the framework of the “Overturning in the Subpolar North Atlantic Program (OSNAP)” . The 7 moorings that form the 53°N Array are an integral part of the OSNAP West section. The first 21-month record reveals a highly variable overturning circulation responsible for the majority of the heat and freshwater transport across the OSNAP line. In a departure from the prevailing view that changes in deep water formation in the Labrador Sea dominate MOC variability, these results suggest that the conversion of warm, salty, shallow Atlantic waters into colder, fresher, deep waters that move southward in the Irminger and Iceland basins is largely responsible for overturning and its variability in the subpolar basin (Lozier et al. 2017; 2018).

Based on the hydrographic data, in combination with UK ships hydrography data, the first synoptic overturning transport estimate was calculated (Holliday et al. 2018). The short term and large amplitude variability of the overturning transport was also found in the synoptic section’s differences. From deep (1000/1500m) drift data from the Argo array in combination with topography following interpolation schemes a circulation and an eddy kinetic energy map of the subpolar gyre were calculated (Fischer et al. 2018). The local mean and Eddy flow were verified using time series data from instruments recovered during MSM54.

The role of changing hydrography (in particular freshwater and heat content) in deep convection regions of the Irminger and Labrador Seas was investigated by Oltmanns et al. (2018). The motivation of the study came from the fact that a shutdown of ocean convection in the subpolar North Atlantic, triggered by enhanced melting over Greenland, is regarded as a potential transition point into a fundamentally different climate regime.
• **Unforeseen issues during the course of the investigation and in regard to the results**

The cruise was shortened by 4 days because of problems with the hydraulic of the A Frame. The CTD program in the Irminger basin had been shortened with some impact on the section analysis.

• **Notes on possible success stories in public media**

MSM54 was the recovery cruise for data was that used for the first round of the OSNAP AMOC calculations which in turn generates public attention.

3. Scientific Results (max. 20 DIN A4 Pages)

• Objectives of the project

The Atlantic Meridional Overturning Circulation (AMOC) is a key component of the global climate system through its transport of heat and freshwater (e.g. Frajka-Williams et al. 2019). The subpolar North Atlantic (SPNA) is a region where the AMOC is actively developed and shaped through mixing and water mass transformation and where large amounts of heat are released to the atmosphere. With contributions from the United States, the United Kingdom, Germany, France, the Netherlands, Canada, and China, the “Overturing in the Subpolar North Atlantic Program (OSNAP)” observing system (Fig. 1) comprises an integrated coast-to-coast array of two sections: OSNAP West, extending from the southeastern Labrador shelf to the southwestern tip of Greenland, and OSNAP East, extending from the southeastern tip of Greenland to the Scottish shelf (Lozier et al. 2017). Part of OSNAP-West are the 7 moorings that form the German 53°N Array. Densely spaced OSNAP mooring arrays which directly measure the temperature, salinity, and velocity fields, are in place at continental boundaries and on both flanks of the Reykjanes Ridge; additional dynamic height moorings at key locations allow us to estimate geostrophic flows. Glider surveys along topographically complex sections of OSNAP East complement the moored arrays (Figure 1).

![Figure 1: Sketch of the OSNAP array that is used for a continuous observation of the overturning in the subpolar North Atlantic. Moorings installed during MSM40 and serviced during MSM54 are marked by yellow circles.](image)

The first 21 months of array data led to the remarkable finding that the mean and variability of the subpolar Meridional Overturning Circulation is dominated by the overturning east of Greenland (Lozier et al. 2019; Figure 2). This new view is counter to the contemporary paradigm that deep water
formation in the Labrador Sea is the dominant forcing for AMOC variability in the subpolar and subtropical North Atlantic.

Figure 2: Overturning transport estimates from the OSNAP array (Lozier et al. 2019). Black, yellow, and blue lines represent the 30-day mean estimates from the full section, OSNAP West, and OSNAP East, respectively, for Meridional Overturning Circulation (MOC) (solid lines) and Ekman transport (dashed lines). Thin gray lines show the 10-day low-pass filtered daily means for the full OSNAP section.

The first synoptic overturning estimate were calculated from MSM54 CTD and (l)ADCP data in combination with UK ships data (Holliday et al. 2018). Using the two hydrographic transbasin sections along the OSNAP Line in the summers of 2014 and 2016 provided a highly spatially resolved views of the SPNA velocity and property fields. Estimates of the AMOC, isopycnal (gyre-scale) transport, and heat and freshwater transport were derived from the ship observations (Figure 3).

Figure 3: The May–August 2016 (OS2016) section (including MSM54 data) velocity (m/s) and transport (Sv), overlaid with volume transport in segments separated geographically (vertical lines) and by isopycnals 27.50, 27.70, and 27.80 kg/m3 (black lines). Bottom panel is top-to-bottom accumulated transport (west to east). Positive is to the north of the section; uncertainties are estimated from lowered Acoustic Doppler current profiler measurements.

The overturning circulation, the maximum in northward transport integrated from the surface to seafloor and computed in density space, has a high range (Table 1), with $20.6 \pm 4.7$ Sv in June–July 2014.
and 10.6 ± 4.3 Sv in May–August 2016. In contrast, the isopycnal (gyre-scale) circulation was lowest in summer 2014: 41.3 ± 8.2 Sv compared to 58.6 ± 7.4 Sv in 2016. The heat transport (0.39 ± 0.08 PW in summer 2014, positive is northward) was highest for the section with the highest AMOC, and the freshwater transport was largest in summer 2016 when the isopycnal circulation was high (−0.25 ± 0.08 Sv). Up to 65% of the heat and freshwater transport was carried by the isopycnal circulation, with isopycnal property transport highest in the western Labrador Sea and the eastern basins (Iceland Basin to Scotland).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>OS2014</th>
<th>OS2016</th>
</tr>
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<tbody>
<tr>
<td>AMOCrr-max</td>
<td>20.6 ± 4.7 Sv</td>
<td>10.6 ± 4.3 Sv</td>
</tr>
<tr>
<td>AMOCrr-ni</td>
<td>23.3 ± 4.7 Sv</td>
<td>13.0 ± 4.3 Sv</td>
</tr>
<tr>
<td>Maximum isopycnal transport</td>
<td>−41.4 ± 8.2 Sv</td>
<td>−58.6 ± 7.4 Sv</td>
</tr>
<tr>
<td>Total heat flux (HT)</td>
<td>0.39 ± 0.08 PW</td>
<td>0.32 ± 0.13 PW</td>
</tr>
<tr>
<td>Isopycnal heat transport (HTgyre)</td>
<td>0.17 ± 0.02 PW</td>
<td>0.21 ± 0.02 PW</td>
</tr>
<tr>
<td>Total freshwater flux at section (FT)</td>
<td>−0.21 ± 0.03 Sv</td>
<td>−0.25 ± 0.08 Sv</td>
</tr>
<tr>
<td>Isopycnal freshwater transport (FTgyre)</td>
<td>−0.10 ± 0.02 Sv</td>
<td>−0.16 ± 0.03 Sv</td>
</tr>
</tbody>
</table>

The mean circulation and EKE distribution in the Labrador Sea Water level of the subpolar North Atlantic was estimated by by Fischer et al. (2018) using Lagrangian floats (Argo float drift). Moored observations were used to verify the Lagrangian flow statistics in key regions. A long-term mean flow field for the subpolar North Atlantic region with a horizontal resolution of approximately 25 km was created by gridding Argo-derived velocity vectors using two different topography-following interpolation schemes. The 10-day float displacements in the typical drift depths of 1000 to 1500 m represent the flow in the Labrador Sea Water density range. Both mapping algorithms separate the flow field into potential vorticity (PV) conserving, i.e., topography-following contribution and a deviating part, which we define as the eddy contribution. To verify the significance of the separation, we compare the mean flow and the eddy kinetic energy (EKE), derived from both mapping algorithms, with those obtained from multiyear mooring observations.

![Figure 4](image_url) Gridded EKE (in cm2 s−2) map from the GI method with selected EKE values from moored observations (numbers in boxes). Mooring fluctuations are low-pass filtered at 10 days cut-off for better comparability of mooring time series with 10-day displacement velocity from Argo data. Mooring location markers are colored with respect to the EKE from the moored record; color map is identical to that of the background field (Fischer et al. 2018).
The PV-conserving mean flow is characterized by stable boundary currents along all major topographic features including shelf breaks and basin-interior topographic ridges such as the Reykjanes Ridge or the Rockall Plateau (Figure 5). Mid-basin northward advection pathways from the north-eastern Labrador Sea into the Irminger Sea and from the Mid-Atlantic Ridge region into the Iceland Basin are well-resolved. An eastward flow is present across the southern boundary of the subpolar gyre near 52°N, the latitude of the Charlie Gibbs Fracture Zone (CGFZ). The mid-depth EKE field resembles most of the satellite-derived surface EKE field. However, noticeable differences exist along the northward advection pathways in the Irminger Sea and the Iceland Basin, where the deep EKE exceeds the surface EKE field. Further, the ratio between mean flow and the square root of the EKE, the Peclet number, reveals distinct advection-dominated regions as well as basin-interior regimes in which mixing is prevailing.

Figure 5: Surface EKE derived from the AVISO geostrophic surface flow that is high-pass filtered at 180-day cut-off (in cm² s⁻²) as an estimate of the geostrophic turbulence. Overlaid is the Argo-derived mean (PV-related) flow at 1000–1500 m depth, with flow speeds below 1.5 cm s⁻¹ omitted; this better reveals the major advective pathways.

The last of the here reported results concern the impact of freshwater fluxes in deep convection regions on the seasonal sea surface temperature evolution in the subpolar gyre. The motivation of the study came from the fact that a shutdown of ocean convection in the subpolar North Atlantic, triggered by enhanced melting over Greenland, is regarded as a potential transition point into a fundamentally different climate regime. Noting that a key uncertainty for future convection resides in the relative importance of melting in summer and atmospheric forcing in winter, we investigate the extent to which summer conditions constrain convection with a comprehensive dataset, including hydrographic records that are over a decade in length from the convection regions. We find that warm and fresh summers, characterized by increased sea surface temperatures, freshwater concentrations and melting, are accompanied by reduced heat and buoyancy losses in winter, which entail a longer persistence of the freshwater near the surface and contribute to delaying convection (Figure 6). By shortening the time span for the convective freshwater export, the identified seasonal dynamics introduce a potentially critical threshold that is crossed when substantial amounts of freshwater from one summer are carried over into the next and accumulate. Warm and fresh summers in the Irminger Sea are followed by particularly short convection periods. We estimate that in the winter 2010–2011, after the warmest and freshest Irminger Sea summer on our record, ~40% of the surface freshwater was retained.
Figure 6: Summer constraints on hydrographic evolution in the Labrador Sea. a,b,c, Correlation of salinity (a), temperature (b) and stratification (c) in the Labrador Sea with FIS, where stratification is expressed by means of the vertical potential density gradient. d,e,f, Correlations of the same respective measures, but with FLS. Thick contours delineate the 95% confidence level and thin contours represent isolines at intervals of 0.2. The underlying hydrographic time series were obtained from the mooring and Argo float observations (Oltmanns et al. 2018).


M. Oltmanns, R.S. Pickart, A.L. Ramsey, D. Rayner, F.

- Development of the work carried out including deviations from the original concept, potentially scientific failures, problems in the project organization or the technical implementation
  no

- Who contributed to the project (the most important national and international cooperation partners involved in the dissemination of the cruise data)

This MSM54 cruise contributed data for scientific analysis conducted in the framework of the BMBF RACE project. The data collection was supported by the Helmholtz Association large investment “Advanced Remote Sensing – Ground-truth demo and test facilities” (ACROSS) and contributed also to the Helmholtz Association Portfolio “Earth System Knowledge Platform” (ESKP). International collaborations with Netherland (Femke de Jong, Laura de Steur, NIOZ), UK (P. Holliday, NOCS; S. Cunningham, SAMS), US (S. Lozier, Duke University; B. Pickart, WHOI; U. Send, SIO) and Canadian (B. Greenan, I. Yashayaev, BIO; D. Wallace, HMRI; Eugene Collburn, St. Johns) scientists is acknowledged. The cruise also contribution to the EU FP7 project NAACLIM. The moorings are registered in the OceanSITES time series network and contribute to the GCOS (Global Climate Observation System) and GOOS (Global Ocean Observing System) frameworks.

- Qualification of undergraduates and graduates in context with this project (e.g. bachelor thesis, master thesis, as well as PhD thesis etc.) by listing the number of theses, which based on samples and data obtained during the cruise
  - Number of bachelor theses: 4
  - Number of master theses: 1
  - Number of PhD theses: 1

Thesis:

Baumann, T.M (2015) Thermohaline variability of the Atlantic Deep Western Boundary Current at 53°N on monthly to decadal timescales, Master thesis


Bunsen, F. (2016) Mixed-layer chlorophyll concentrations in the Central Irminger Sea: satellite versus in-situ data, BSc Thesis

Schulzki, T.G. (2016) Zum Einfluss von Transportprozessen auf die Wassermassenenerneuerung in der Irminger See, BSc Thesis

Seemann, A.K (2015) Interpretation of observed multiannual temperature trends in the Labrador Sea, BSc Thesis

- Status of the data and sample availability: Please state in form of a table the exact links and dates of the data and sample availability, as well as contact persons.

Real-time data:
During the cruise the CTD data was transmitted daily to the Coriolis data center in Brest, France, for further distribution over the Global Telecommunication System (GTS).
Archived Data:
Karstensen, Johannes; Wölfl, Anne-Cathrin (2017): Raw multibeam EM122 data: transits of Maria S. Merian cruise MSM54 (Labrador Sea). PANGAEA, https://doi.org/10.1594/PANGAEA.883146

Wölfl, Anne-Cathrin; Wheeler, Benjamin; Schade, Martin (2018): AtlantOS data products from multibeam EM122 data: Maria S. Merian cruise MSM54 (North Atlantic). PANGAEA, https://doi.org/10.1594/PANGAEA.896605


All other data is in the submission queue for Pangaea.de at the Kiel OSIS System

4. Publishing of Data as Abstracts from Scientific Reports
If necessary, the GPF is entitled to publish the summary (2. Summary), and publications (as of 1. General Information) in the conference proceedings of the status conference. In this regard, the template for the status conference proceedings is to be considered. Publications can only be accepted, if the relevant cruise (Cruise No.) is indicated and the guidelines at 1. General Information for publications are followed.