MARIA S. MERIAN-Berichte 11-3

Strength of the Subpolar Gyre and the Formation of Deep Water

Cruise No. 12, Leg 3

July 14 – August 22, 2009, Reykjavik (Iceland) – Bremerhaven (Germany)

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1 Summary

The objectives of the cruise are (i) to estimate the deepwater formation rate in the Labrador Sea from inventories of the anthropogenic trace gases chlorofluorocarbons (CFCs) and sulphurhexafluoride (SF_6), (ii) to infer the transport variability of the subpolar gyre through combined data from moored Inverted Echo Sounders (PIES), moored instruments, shipboard measurements, float profiles from the ARGO programme, and satellite altimetry, (iii) to study the transports and water mass characteristics in the Flemish Pass, and in the deep western boundary current off Newfoundland using shipboard measurements and time series from moored sensors (velocity, temperature and salinity), and (iv) to study the changes in water mass characteristic in the eastern Atlantic along the former WOCE section A2. The cruise is part of the German joint research project 'Nordatlantik' and is supported by the German Ministry of education and research, BMBF.

Zusammenfassung

Auf diesem Fahrtabschnitt wurden Messungen durchgeführt, um folgende Fragestellungen zu untersuchen: (i) Wie sind die Änderungen in der Bildungsrate von Labrador Seewasser? Dies soll durch Änderungen in den Spurenstoff-Inventaren von FCKWs und Schwefelhexafluorid (SF_6) berechnet werden. (ii) Wie sind die zeitlichen und räumlichen Schwankungen im Transport des Subpolarwirbels? Hier werden Zeitreihen aus verankerten Bodenecholoten und konventionellen Verankerungen mit Altimeter- und Argo- Profilen kombiniert. (iii) Wie groß ist der Transport im tiefen westlichen Randstrom vor Neufundland und wie stark ändern sich die Eigenschaften der tiefen Wassermassen und die Transporte? Neben Schiffsmessungen sollen hier Zeitreihen von verankerten Strömungsmessern und T/S Sensoren ausgewertet werden. (iv) Wiederholung des WOCE A2-Schnittes im Ostatlantik, um die langjährigen Zeitreihen fortzusetzen und die Änderungen insbesondere der tiefen Wassermassen zu untersuchen. Die Fahrt ist Teil des BMBF Verbundvorhabens ‚Nordatlantik', TP 2.1.

2 Participants

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3 Research Program

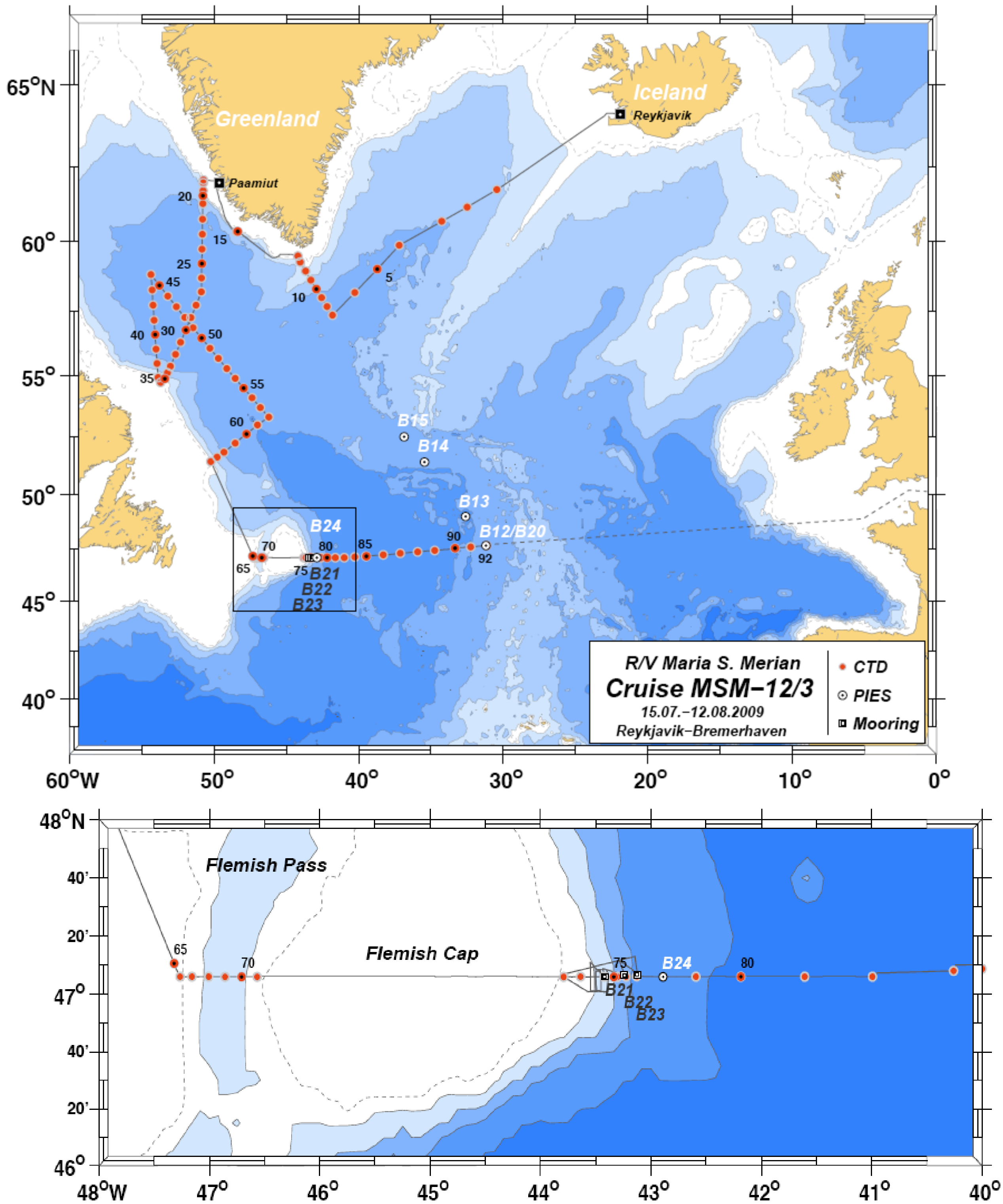

Fig. 3.1 A) Cruise map of R/V MERIAN Cruise MSM12-3, the activities near Flemish Pass and off Newfoundland are shown in more detail in B). B21-B23: Bremen DWBC moorings, B24: PIES deployed during the cruise. The planned measurement east of the MAR and along the MAR could not be carried out due to technical problems of RV MERIAN

The cruise is part of the BMBF priority Programme NORDATLANTIK. The objectives of the cruise MSM12/3 are

- to estimate the deepwater formation rate in the Labrador Sea from inventories of the anthropogenic trace gases chlorofluorocarbons (CFCs) and sulphurhexafluoride (SF_6),

- to infer the transport variability of the subpolar gyre through combined data from moored Inverted Echo Sounders (PIES), moored instruments, shipboard measurements, float profiles from the ARGO program, and satellite altimetry,

- to study the transports and water mass characteristics in the Flemish Pass, and in the deep western boundary current off Newfoundland using shipboard measurements and time series from moored sensors (velocity, temperature and salinity), and

- to study the changes in water mass characteristic in the eastern Atlantic along the former WOCE section A2.

4 Narrative of the Cruise

R/V MERIAN left Reykjavik (Iceland) as scheduled (July 15, 8 UTC), and – after calibrating the compass - headed south into the Irminger Sea. The weather was favourable, and R/V MERIAN reached the first CTD station at 61°45’N, 30°26’W at July 16, 9 UTC. The station was only partly successful. About half of the bottles didn’t close. The failure was due to the malfunctioning of the electronic release unit. After exchange of the unit, the system worked without failure during the following stations. The weather remained calm. The station distance was between 70 and 100 nm till 57°21’N, 41°48’W, where R/V MERIAN shifted course towards Greenland and the boundary section started at July 18, 8 UTC. The station spacing was reduced to 23 nm. Unfortunately, several technical problems prevented the onboard measurements of the tracers Sulphurhexafluoride SF_6 and Chlorofluorocarbon component CFC-12. Instead, offline samples were taken (i.e. water samples were taken from the Niskin bottles and flame-sealed), and will be analysed in the home lab. The boundary section towards Greenland was finished at 59°34’N, 44°15’W at July 19, 10 UTC. R/V MERIAN headed afterwards along the Greenland coast to Cap Desolation at 60°22’N, 48°24’W.

On July 19, 23 UTC, the research was abandoned due to a medical emergency, and R/V MERIAN set course to Paamiut (61°59’N, 49°40’W), where the patient was delivered to the hospital. The ship had to stay in Paamiut for several hours, since the water preparation unit had a malfunction, and freshwater had to be filled in one of the ballast tanks. Before filling could start, the tank had to be cleaned. R/V MERIAN left Paamiut at July 20, 20 UTC. In order to minimize the time loss, the station plan was altered and R/V MERIAN sailed to the next station at 62°04’N, 50°44.5’W close to Paamiut, where the research was resumed with CTD 17. The SF_6 / CFC analysis directly on board started and replaced the offline sampling done in the Irminger Sea.

R/V MERIAN set course to reach the WOCE A1W section at 58°13’N, 50°53’W. The station spacing was between 5 and 15nm at the continental shelf and increased in the basin interior to

30nm. The vm-ADCP velocities showed a strong northward West Greenland Current (up to 40cm/s) hugging the continental slope. R/V MERIAN reached the WOCE A1W section at 58°13'N, 50°53'W on July, 22, 12 UTC, and changed course towards Canada. The weather remained calm, and the working conditions were excellent.

The performance of the used winch (ELW1) deteriorated with each station, although the wire had been replaced in Reykjavik. Starting with CTD 24, the winch ELW2 was used and the system worked excellently. On the morning of July, 22, the system had to be switched back to the ELW1 winch due to a technical problem, but was switched back to ELW2 after one station (CTD 26). On CTD 27, several stops on the way up were done in order to calibrate the Microcats (T/S sensors), which will be deployed off Flemish Cap. At the CTD stations 32 and 33 two acoustic releasers respectively were fixed at the wire several meters above the rosette and tested when the package was at the bottom. The WOCE section was finished at July 24, 2 UTC at 54°38'N, 53°56'W, and R/V MERIAN turned north into the northern central Labrador Sea. The calibration of the Microcats to be moored at the western boundary off Newfoundland continued as well as the testing of the releasers. The section north into the central Labrador Sea was finished at July 25, 14 UTC, (58°50'N, 54°22'W, CTD 44) and the weather continued to provide comfortable working conditions. The testing of the releasers and calibration of the Microcats for the boundary current moorings was finished before reaching that position.

R/V MERIAN is now bound southeast on the section along the central Labrador Sea, and the southern end was reached on July 28, 6:15 UTC at 53°20'N, 46°13'W (CTD 58). During the whole time period the weather and sea stayed calm, and R/V MERIAN proceeded with 13kn. The last 6 CTD stations in the Labrador Sea were carried out on a boundary section to 51°25'N, 50°17'W, and were finished at July 29, 10 UTC. Afterwards, R/V MERIAN headed towards the Flemish Pass at 47°06'N, 47°16'W. The Flemish Pass was sampled with 7 CTD/LADCP casts including tracer sampling in order to estimate the transport of newly formed Labrador Sea Water through that channel. The Flemish Pass might be a shortcut for LSW on the way to the subtropics. Also nutrient and alkalinity samples were taken on 4 profiles in the centre of the Pass.

On July 31, the three Bremen boundary current moorings were deployed east of the Flemish Cap at the continental slope at the positions 47°06'N, 43°25'W, 43°13'W, and 43°07'W. The two outer moorings are 12nm apart, and the bottom slopes from 1300m to 3500m depth. The relatively steep slope focuses the deep western boundary current and allows to measure transports and T/S characteristics with these moorings. The moorings were successfully deployed between 8 and 18 UTC. Towards the end of the deployment, the weather conditions deteriorated, and for the first time during that cruise, the winds reached 7-8 Bft. After the topography near the moorings have been surveyed by the ship's multibeam echo sounder, the CTD station work resumed at July 1, 2 UTC at 47°06'N. Near the continental slope, the station spacing was between 3 and 6nm, and increased gradually to 48nm in the interior of the Newfoundland basin. The LSW found here were fresher than the LSW found in the Flemish Pass, indicating a younger age.

On August 1, 16:40 UTC, a PIES (No. B24) was deployed in 3500m depth at 47°06'N, 42°53.5'W. On August 2, wind reached again 8 Bft, but the CTD stations could be carried out without problems and without time delay. Between the stations, the speed of R/V MERIAN went up to 14kn due to the westerlies and the strong eastward flowing North Atlantic Current (NAC).

When the current direction reversed, the speed decreased to 12kn. On August 4, at about 5UTC, the propulsion system on the port side malfunctioned. Lowering a camera to the propulsion showed that the damage was not caused by an obstacle, that could endanger the starboard propulsion. So the research was resumed, but with only the starboard pod functional. R/V MERIAN proceeded with reduced speed between the stations of 9-10 kn. This speed reduction has serious consequences for the future station planning, loosing about 20-30% of the allocated station time to transit.

On August 5, 3:40 UTC the position of the southernmost Bremen PIES array (B20) at 47°40'N, 31°09'W was reached, and we started to recover the data of the PIES by acoustic telemetry. Although the instrument reacted to the acoustic commands and first provided reliable ranging estimates, telemetry failed on all positions R/V MERIAN could occupy without using the pumpjet continually. The use of the pumpjet creates too much noise on the PIES frequencies. Therefore the PIES was released at 6:27 UTC. The PIES reacted to this command by pinging every 4 seconds, and two pings should be received on board, i.e. the direct ping and the ping first reflected at the bottom. Some pings were received, but without the recognizable pattern caused by the ascent. Most likely the PIES did not leave the bottom. The PIES should have reached the surface at 7:40 UTC. No visual or radio contact was detected in the next hours, and neither could the few acoustic pings which the PIES might have sent be interpreted. The active search was abandoned at 11:30, and a CTD at the location of the PIES was carried out.

Starting at August 5, 14 UTC, the remaining active propulsion unit was tested. It turned out that its condition required an immediate stop of the research and R/V MERIAN steamed to Bremerhaven, supported by favourable winds conditions. R/V MERIAN arrived at August 12, 7 UTC, i.e. 10 days sooner than planned.

5 Preliminary Results

5.1 CTDO$_2$ measurements

Temperature, pressure, conductivity and oxygen were measured by means of a Sea-Bird SBE 911 plus profiling instrument, and a SBE 43 dissolved oxygen sensor. The device was connected to a water sampler carousel with 22 10 l Niskin bottles, the other two bottles had been replaced by LADCPs. Starting at profile 68, spikes in the oxygen data occurred in the upper few hundred meters of the upcast profile. Profile 84 was aborted at about 800 dbar, since oxygen and conductivity peaks appeared even during the downcast. After cleaning the electronic contacts of the CTD pump cable, conductivity was measured without any further disturbances. The spikes in the oxygen data, however, remained until profile 90, but had no further consequences.

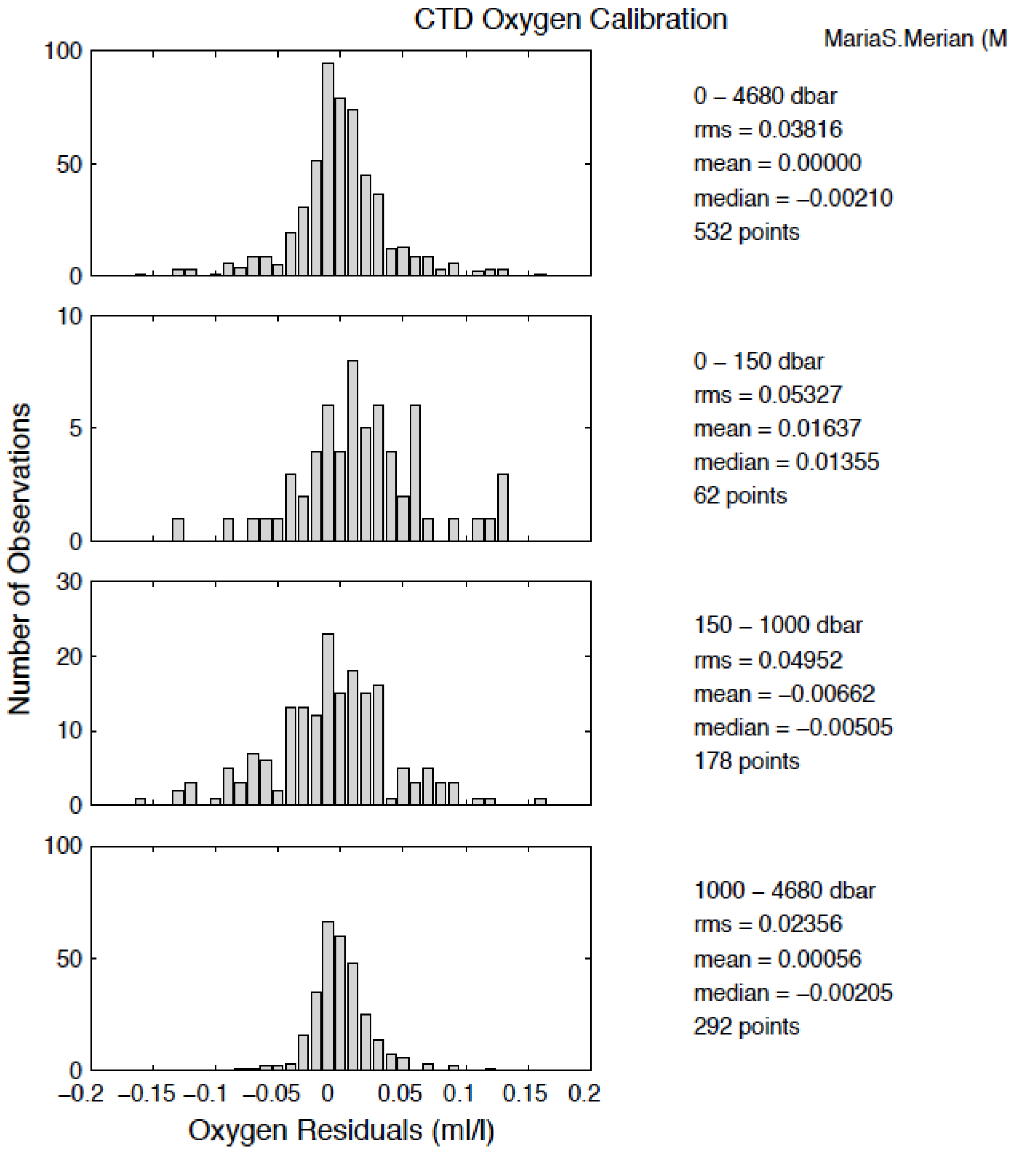

Fig.5.1 Oxygen calibration for Stations 1-33, and 39-92, MSM 12/3.

The SBE 43 dissolved oxygen sensor was calibrated by means of oxygen samples, analysed by manual Winkler titration by the IUPHB/Ifm-Geomar group.

In average, 6-7 oxygen samples per station were taken. On some stations at 47°N, oxygen was sampled from all bottles (see below).

The thiosulfate solution was checked with the Iodate Standard each day in order to calculate the oxygen concentration in the seawater. On July 23, a new Iodate Standard was prepared and used to calculate the oxygen concentration of CTD profiles 32 and 33. In the evening, after measuring profile 33, we prepared also a new working solution, used for profiles 34 -38. After comparing the titrated concentrations with the CTD oxygen sensor we realized that data from profile 32 -- 38 were higher in O_2 with a mean of 0.11 ml/l. On July 24 (starting from profile 39) a new oxygen standard solution was used, which remedied the problem.

In the second part of the cruise from July 30 to August 8, we collected 350 oxygen samples for the CTD calibration and for the analysis of long term trend of O_2 on the WOCE A2 transect. For this purpose we collected more samples for each profile, and especially focused on the area where the oxygen is consumed by remineralisation processes. We also collected on 13 stations 190 bottle samples of nutrients, dissolved inorganic carbon (DIC), Alkalinity, and $\delta^{13}C$ that will be measured in the laboratory in Kiel (IFM-GEOMAR). The goal is to quantify decadal trends in the uptake and storage of anthropogenic carbon, nutrients and oxygen concentrations in the North Atlantic. The precision determined from the O_2 double samples from all the stations was about 0.4 µmol/l with an error of 0.20%. We also computed the error due to the standard factor, that is 0.18%. At the end our quadratic error that include the error due to the measurements and the error due to the standard factor is 0.27%.

The calibration of the oxygen sensor was done for profiles 1-36 and 37-92 separately, since the SBE 43 oxygen sensor showed a shift, which could not be corrected by a linear fit (Fig. 5.1). The calibration procedures were done in two steps: First, the sensor calibration coefficients were recalculated, then an additional offset and correction terms proportional to time, oxygen, pressure, and temperature were determined. The rms difference between calibrated CTD-O and bottle oxygen was 0.023 ml/l for profiles 1-36 and 0.038 ml/l for profiles 37-92 respectively (0.020 ml/l and 0.024 ml/l below 1000 dbar).

For calibration of the conductivity sensor (Fig. 5.2), 3 to 4 salinity samples per profile from the Niskin bottles were taken and analysed by a Guildline Autosal 8400A. The salinometer was standardized with IAPSO standard seawater batch P149. The precision estimated by substandard measurements is about 0.001. The correction applied to the CTD conductivity only consists of an additive constant of 0.00892 mS/cm. The rms difference between calibrated CTD and bottle salinities is about 0.0019 (0.0017 below 100 dbar).

A pressure offset of -0.6 dbar was determined from the recorded CTD pressure values at the beginning of the profiling measurements, when the CTD was still on deck and pressure should be zero.

The CTD data of the upper 1000m were sent shortly after the stations were carried out to the Coriolis centre.

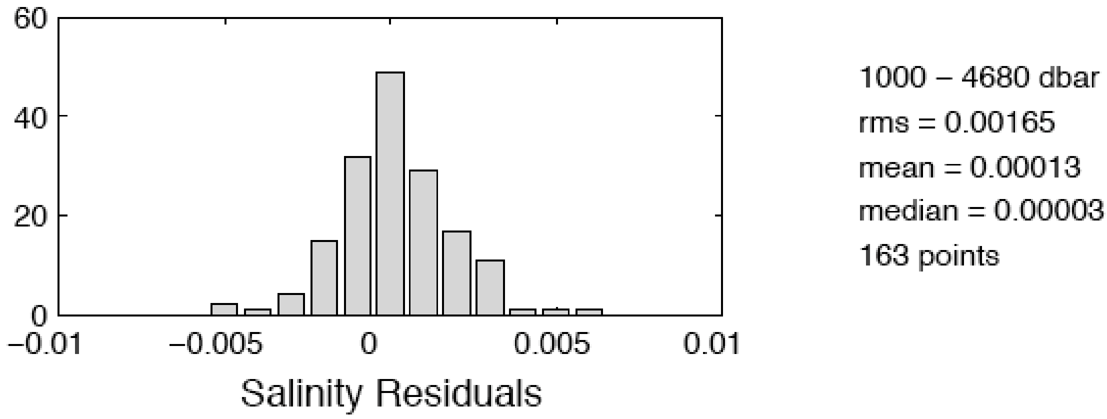

Fig. 5.2 Salinity calibration, cruise MSM12/3

In order to check the temporal consistency of the CTD data between MSM12/3 and cruises in the subpolar North Atlantic from previous years, data from the mooring position B12/B20 are compared. This mooring is located at the western flank of the Mid-Atlantic Ridge at 47°40'N, 31°09'W. There, the variability of hydrographic properties in the bottom water is expected to be small. Fig. 5.3 shows that the difference in salinity measured between 2006 and 2009 is not larger than 0.005.

Part of this difference could be caused by the use of different batches of the salinity standard. MSM09/1 (cyan) and MSM12/3 (blue) have been calibrated with salinity batch P149 and are very close (Fig.5.3), although the measured in different years. The same holds for RV PELAGIA cruises PE341 (red) and PE278 (yellow) (batch P149), but cruise MSM05/1 (magenta) was calibrated with batch P147 and is about 0.002-0.003 fresher (Fig. 5.3).

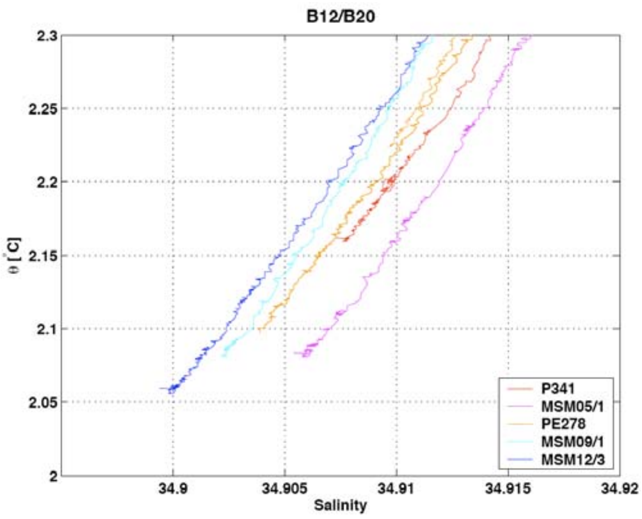

Fig. 5.3 T-S diagram of CTD profiles taken in the vicinity of the position of PIES mooring B20 on different cruises: P341, salinity batch P145 (2006), MSM05/1, batch P147 (2007), PE278 batch 145 (2007), MSM09/1 batch P149 (2008), and MSM12/3 batch P149 (2009).

5.2 Tracer Measurements of Sulphur Hexafluoride and Chlorofluorocarbon

During cruise MSM-12/3 we simultaneously measured sulphur hexafluoride (SF_6) and chlorofluorocarbon CFC-12 in water and air. The separation of the two compounds was performed by gas chromatography, the detection with electron capture detection (ECD).

At the beginning of the cruise, compounds from the previous sample interfered with the SF_6 and CFC-12 of the present sample. This problem only occurred while analyzing seawater samples and was not observed in the home lab. Therefore, the flow - direction towards the large trap for thermal desorption and the temperature for the pre-column had to be changed. While the analysis system was modified and stabilized, about 150 offline CFC-only samples were taken at CTD stations 3-14, i.e. along the Irminger Sea sections. They will be analyzed later in the home laboratory at Bremen University. Starting with CTD 15, direct measurements of SF_6 and CFC-12 were resumed and lasted until the cruise had to be aborted due to technical problems with the ship's propulsion.

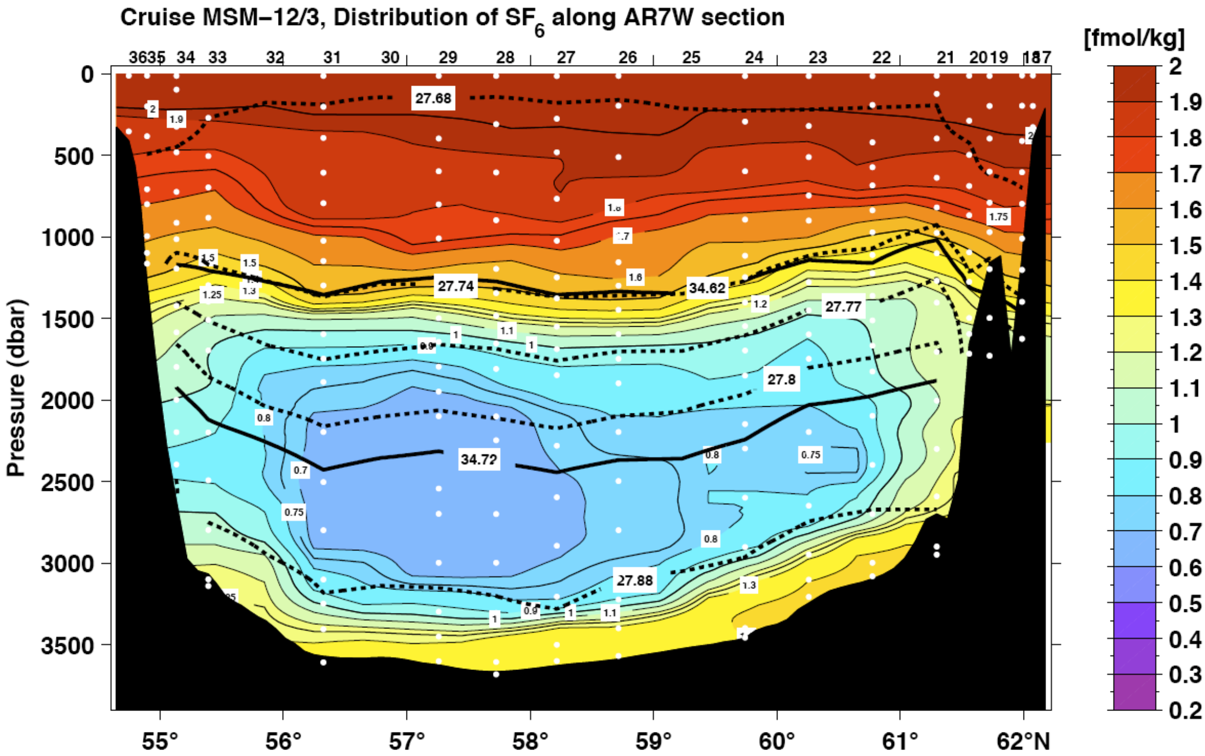

Fig. 5.4 SF6 section across the Labrador Sea. The contrast between the tracer poor deeper and denser Labrador Sea Water modes (bound by isopycnals σΘ 27.74 and 27.80) and the SF6 rich upper LSW modes (bound by isopycnals σΘ 27.68 and 27.74) is clearly visible. The maximum at the bottom characterizes Denmark Strait Overflow Water (DSOW), σΘ >27.88). Preliminary data

Up to 19 seawater samples were collected in 200 ml glass ampoules from 10 l Niskin bottles. In comparison to the previous cruise MSM-09/1 carried out in July 2008 only 110 ml instead of 160 ml of seawater were transferred to a water purge chamber. After purging of the water, the compounds were trapped in a 1/8", large ID Porapak-Q trap. After thermal desorption the gases held in the trap were flushed onto a MS5A pre-column, where SF_6 and CFC-12 were separated from nitrous oxide and other late eluting gases. The compounds were then refocused on a 1/16" Porapak-Q packed trap to narrow their chromatographic peaks and enhance their detection. After thermal desorption onto a GS Gaspro capillary column (0.32 mm ID x 30 m), SF_6 and CFC-12 peaks were detected on a micro-ECD.

In total, 832 water-samples were taken on 60 stations (Fig. 5.4). Concentrations of SF_6 and CFC-12 in air, seawater samples, and gas standards are reported on the SIO-98 scale. Gas standards were prepared and calibrated at CMDL, Boulder, Colorado. Based on the analysis of replicate water samples, we estimate precisions of 2.0 % for SF_6 and 1% for CFC-12. The overall accuracy, including that of the calibration scale, is estimated to be 3% for SF_6 and 1.5% for CFC-12. The uncertainty is higher for SF_6 since the gas standard measurement turned out to be more uncertain for SF_6 than for CFC-12.

Throughout the cruise the background chromatographic baseline was very noisy. To reduce this noise, further improvements in the trapping and separation techniques is necessary in the future, including the choice of trap and column materials.

On all stations both, SF_6 and CFC-12 showed too high concentrations in the surface water. It was discovered the degassed seawater volume was larger than the volume of freshwater, which was used for calibration in the home lab. The tracer concentrations will be corrected in the home laboratory after careful recalibration of the sample volume. At present, tracer concentrations appear to be too high by about 4 %.

5.3 Lowered ADCP Profiles

Two RDI Workhorse Monitor ADCPs with a frequency of 300 kHz were mounted to the carousel water sampler. The system was operated in a synchronized Master-and-Slave mode, with the Master looking in downward direction and the Slave looking in upward direction. For self-contained operation the instruments were powered by an external battery supply consisting of 35 commercial quality 1.5V batteries in an Aanderaa pressure housing. In total, three instruments have been used during the cruise. The compasses of all three instruments were calibrated in Reykjavik (Iceland) prior to the cruise to avoid calibration on the ship. The system was set up to a ping rate of 1Hz and a bin length of 10m.

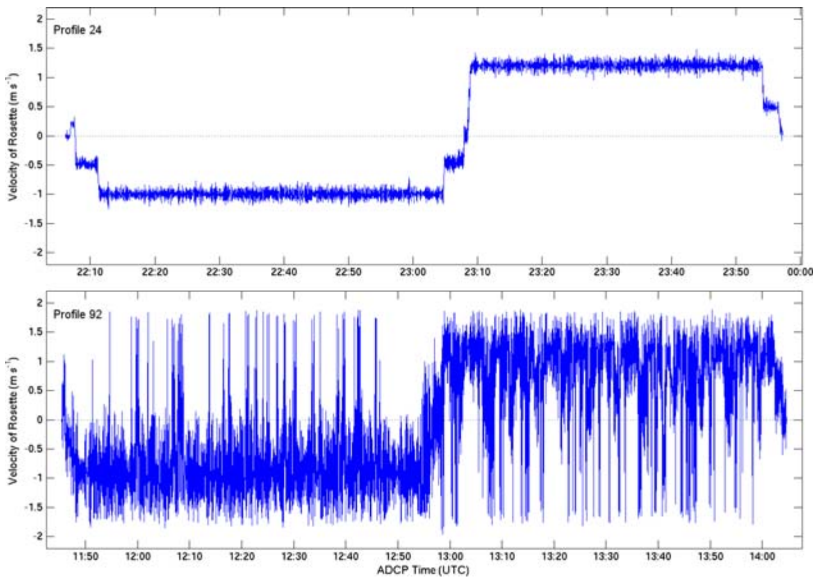

Fig.5.5 Vertical instrument velocity during profile 24 (top) and profile 92 (bottom). For both profiles, nominal lowering and heaving velocities were 1m/s and 1.2m/s, resp. During profile 92, the rolling motion of the ship caused heavy up- and down movements of the water carousel.

In total, 88 LADCP profiles were occupied during the cruise. No ADCP data was recorded during profile 21 due to instrument failure. Temporary communication problems between Master and Slave required to run profiles 82 and 83 with a single ADCP that was looking in downward direction.

Profiles, that were recorded in the beginning (1-7) and in the end (85-92) of the cruise, suffered from intense roll motions of the ship, which resulted in strong vertical accelerations of the instrument package during lowering and heaving (Fig.5.5). Nevertheless, the carousel water sampler was well balanced and experienced no tilt of more than 10°.

Especially in the beginning of the cruise, the instruments were rotating with up to 0.6 turns per minute (Fig. 5.6), but the angular velocity reduced with time, until no more rotations occurred during profile 11. Later on, rotations occurred again, but in fewer number and with lower angular velocity. There was a general trend to more and faster rotations during the upcast. The sense of rotation changed in the course of the cruise, but only in the upper part of the profile. In deep water, the rotation always kept its direction.

The range of the a single instrument was up to 150m in shallow water, and decreased down to 50m at large depth, so the instrument package had a total range between 100m and 300m. With lowering and heaving velocities of 1m/s to 1.2m/s the number of shear estimates was well above 100 at depth and reached more than 400 in shallow water. Only profiles with a single ADCP (82 and 83) had no more than 100 shear estimates at depth and about 200 in the upper water column.

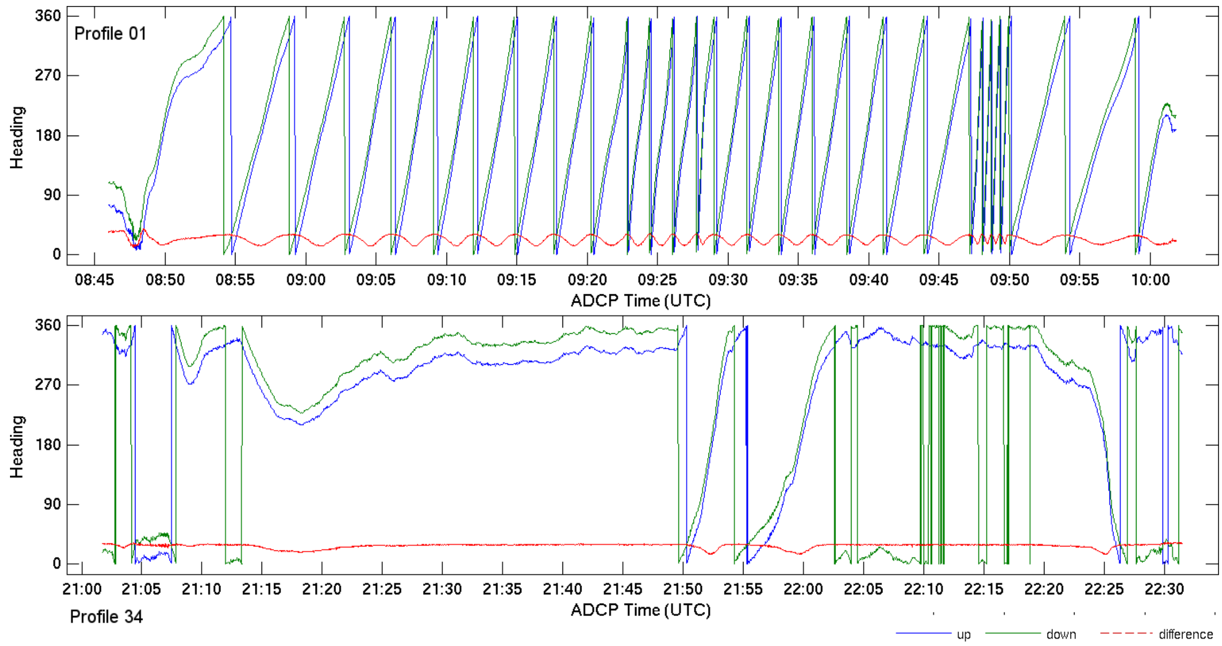

Fig. 5.6 Heading of the two ADCP mounted to the carousel water sampler during profile 01 (top) and profile 34 (bottom). In the beginning, the measurements suffered from strong rotations. During profile 34, there were hardly any rotations. Note that some of the vertical lines indicate no rotation, but the jump from 360° to 0°, and vice versa.

Most profiles were processed with an inverse method, which directly uses the velocity measurements. For 13 profiles that were all recorded during the first third of the cruise (4-5, 13, 16, 18, 22, 25-31), the inverse solution was contaminated with spikes or bad bottom track data. Then, the traditional forward method based on shear was used. The profiles that suffered from ship motion and rotations in the beginning and in the end of the cruise were still high quality. When the sea was calm and only few rotations disturbed the profiling as for most profiles in the middle of the cruise, the velocity profiles reached excellent quality.

5.4 Vessel Mounted Acoustic Doppler Current Profiler (VMADCP)

An RDI Ocean Surveyor 75kHz ADCP mounted in the ship's hull permanently recorded velocity in the upper 800m. The system was operated in narrowband mode and bin length was set to 16m for large range surveying. Depending on the strength of ship motion and especially on transit velocity, the maximum range of 800m was often reduced to approximately 700m. During station work the instrument was sometimes disturbed by the ship's pump jet, which prevented meaningful records if its outflow hits the instruments transducers.

Since the VMADCP has no further inbuilt sensors, all additional data on heading and tilt as well as the GPS position were obtained from the ship's Seapath database. Recording and transformation into earth coordinates was carried out with the RDI VmDas Software. All systems operated flawless throughout the cruise, except for three short interruptions of the GPS transmission. The interruptions occurred during night at about 0:45 UTC and took no longer than 5min.

During post processing of the VMADCP data a water-track calibration was performed to determine phase and amplitude of the transducer misalignment. An amplitude factor of 1.003±0.019 and a misalignment angle of -3.24°±0.91° were obtained.

In general, the velocity estimates from the VMADCP and the LADCP show good agreement (Fig. 5.7). Only single profiles, usually recorded during intense ship motion, have a barotropic bias. The baroclinic structures are, however, always in good agreement. Since the VMADCP was operated without bottom tracking, the ocean bottom was often not recognized, when the shelf was approached. The required correction has to be applied in the further analysis.

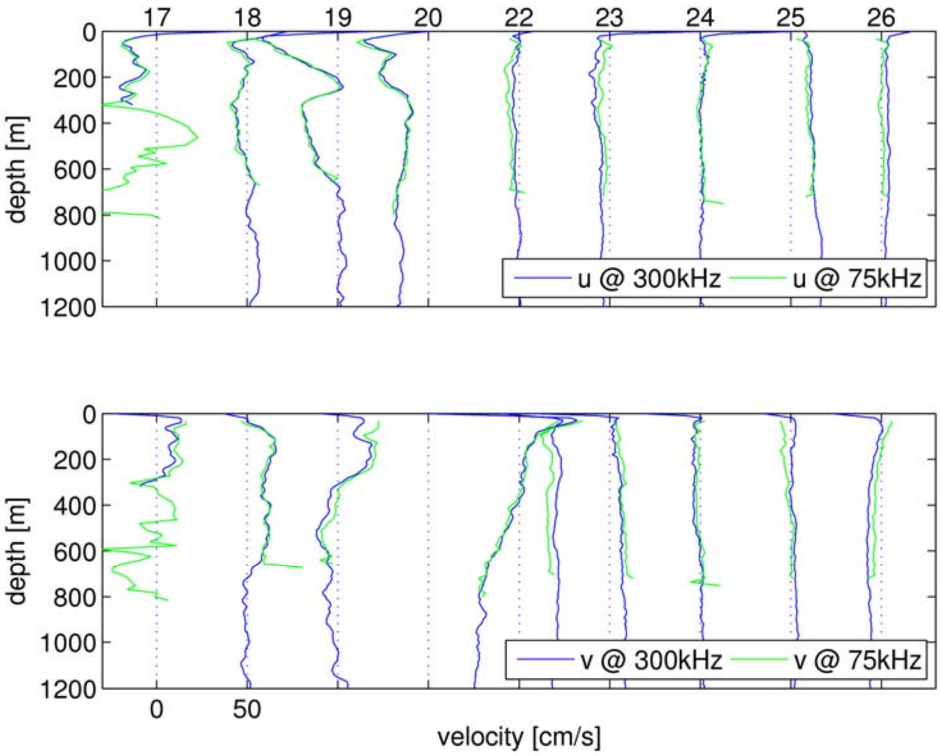

Fig. 5.7 Comparison between VMADCP (75kHz) and LADCP (300kHz) velocity estimates for profiles 17 to 26. Shown are the eastward velocities u (top) and the northward velocities v (bottom). During profile 17, the VMADCP did not recognize the ocean bottom. There is no profile 21 due to LADCP instrument failure.

5.5 Moorings

It is still an open question whether the decrease in the formation rate of LSW leads also to a decrease in the transport of the Deep Western Boundary Current (DWBC). Former measurements at about 42°W from BIO (A. Clarke, Canada) and IFM-GEOMAR (F. Schott, Kiel) showed annual constant transport rates in the years 1993-1995, and 1999-2001. Since that time, the LSW formation weakened significantly, and it is important to know what the response of the circulation will be. The Bremen mooring array was deployed at a latitude of 47°06’N, where the continental slope is sufficiently steep to focus the DWBC, so that the number of moorings necessary remains small. The slope should however be smooth enough to facilitate deployment. Most of the bathymetry at the locations of the moorings had been surveyed in 2007 (MSM05/1) and 2008 (MSM09/1) with the Multibeam system of R/V MERIAN, which enabled us to find suitable locations. The remaining gaps in the bathymetry maps were filled on this cruise with assistance from the R/V MERIAN's system operator. The moorings are equipped with Microcats (T/S sensors) and acoustic current meters (RDI, Aanderaa). Mooring B22, which is in the centre of the DWBC is additionally equipped with an Argos watchdog. The moorings were deployed on July 31, from 8 -18 UTC. Due to the technical problems with the propulsion system, the three moorings at the Faraday Fracture Zone could not be deployed. This could be carried out in November 2009 with the Icelandic research vessel ARNI FRIDRIKSSON (chief scientist A. Ströh, Uni Bremen).

5.6 Deployment and acoustic reading of PIES

The aim of the PIES-related investigations is to estimate the transport variability of the North Atlantic Current (NAC) along the Mid Atlantic Ridge (MAR). The PIES measure the acoustic round trip travel time (tau) from the instrument located at the sea bottom to the sea surface and back by transmitting an acoustic pulse at a frequency of 12.00 kHz. The high precision bottom pressure sensor allows the detection of relative bottom pressure variations, i.e., pressure variations exerted by the water column of changing height moving across the sensor. Since the installed PIES are planned to stay on-site for a period of up to five years, they have been configured prior to deployment to allow transmission of recorded data via acoustic telemetry. Acoustically transmitted data consist of daily averages of tau and pressure.

In the afternoon of August 1, R/V MERIAN arrived at the location of PIES B24. The PIES was successfully deployed at 16:42 UTC in 3440 m depth. The deployment position was 47°05.985' N and 42°53.358' W. After the deployment the ship was positioned so the descending PIES was straight ahead. To record the descending and later on the exact position of the PIES, signals sent by the PIES were received via the ship's hydrophone which was attached to an acoustic deck unit of type "Benthos DS-7000". During all the transmissions all echo-sounders and the pump-jet were switched off. After 68 minutes at 17:50 UTC the PIES reached the bottom. To record the exact position of the PIES, the ship was positioned at four different spots around 0.5 nm apart from the deployment point. At each station we ranged the PIES using the "Benthos" deckunit in combination with a computer to log the exact position, time and ranges. The exact position and depth of the PIES B24 calculated trough an inverse system is: 47°05.903' N and 42°53.732' W with a resulting depth of 3446 m, calculated from the different ranging times.

On August 5, 3:40 UTC the position of B20 at 47°40.258' N, 31°08.965' W was reached, which is the southernmost PIES of the Bremer MAR PIES array. It was planned to recover the data of all four PIES, starting with B20, by acoustic telemetry. Although the instrument reacted to the acoustic commands and provided reliable ranging estimates on all positions R/V MERIAN could occupy without using the pump-jet, because it creates too much noise on the PIES frequencies. The telemetric data transmissions failed on all this positions after the first few pings. Therefore the PIES was released at 6:26 UTC. The PIES reacted to this command by pinging every 4 seconds which means that the burn wire release is unlatched. For every ping, two pings should be received on board that would reflect the ascent, i.e. the direct ping and the ping first reflected at the bottom. Some pings were received, but without a recognisable ascending pattern. Most likely the PIES did not leave the bottom. The PIES should have reached the surface at 7:40 UTC. No visual or radio contact was detected in the next hours, and neither could the few acoustic pings which the PIES might have sent be interpreted. The active search was abandoned at 11:30. The data recorded during the ranging from the different positions prior to the telemetry, which were not optimal spread around the expected position, could be used to recalculate the position of B20 on the ground. It is at 47°40.393' N and 31°08.640' W with a resulting depth of 4079 m. Due to the immediate stop of the research after the next and therefore last CTD station at this position, none of the remaining PIES could be read out. The acoustic telemetry was successfully carried out late in November 2009 with the Icelandic research vessel ARNI FRIDRIKSSON (chief scientist: A. Ströh, Uni Bremen).

The PIES B20 was later in the year found off Galway (Ireland). Fortunately the finders responded to the information about the owner on the instrument and the promise of a fee. The instrument was intact, but unfortunately stopped the recording of data several weeks after deployment. The reason for that failure is still unknown. The PIES was sent for refurbishment and will be deployed again in 2010 during METEOR cruise M82/2.

5.7 Underway measurements during MSM-12/3

The underway measurements have been logged by the DavisShip-System (DSHIP) installed on RV MERIAN in time steps of 1 second. Acquired data include navigational information, near surface hydrography (temperature, conductivity, and thus salinity) measured by the ship's thermosalinograph, water sounding data recorded either by the hydrographic single beam echo sounder EA-600 or the multibeam echo sounder EM-120 as well as meteorological parameters recorded by the DWD weather station. All underway data relevant to this cruise were exported from the database and stored as Matlab-readable netCDF-files. In the early morning hours of four succeeding days the SEAPATH system occasionally failed to deliver position data for a few seconds. The reason for these events is unknown. To fill these gaps missing data have been generated by linear interpolation between the last valid entry before the break happened and the first entry after data recording was resumed again.

Thermosalinograph (TSG) Data acquired by the TSG during leg MSM-12/3 were compared to independently calibrated 6-dbar-values recorded at the 92 CTD stations. While the raw temperature data of the TSG was warmer compared to CTD-derived temperatures, the corresponding raw salinity followed the CTD values quite well. To match CTD data as closely as possible, both, T and S, time series of raw TSG data were at first despiked. This was done by moving a process window with a half-width of 3600 seconds along the data series. Then, calibration coefficients for T and S were derived by applying a least squares linear fit to the TSG data to account for the observed deviations.

The following equations have been applied:

$$T_{corr} = T_{raw} - [A1 \times T_{raw} + A2]$$
$$S_{corr} = S_{raw} - [B1 \times S_{raw} + B2]$$

with A1 = -0.01231554, A2 = 0.459929421, and B1 = 0.006395351, B2 = -0.213471283. Analysis of the calibration results (Fig. 5.8) showed that after calibration the CTD and TSG temperatures agreed within an *rms* error of 0.09°C, while salinities agreed within an *rms* error of 0.01.

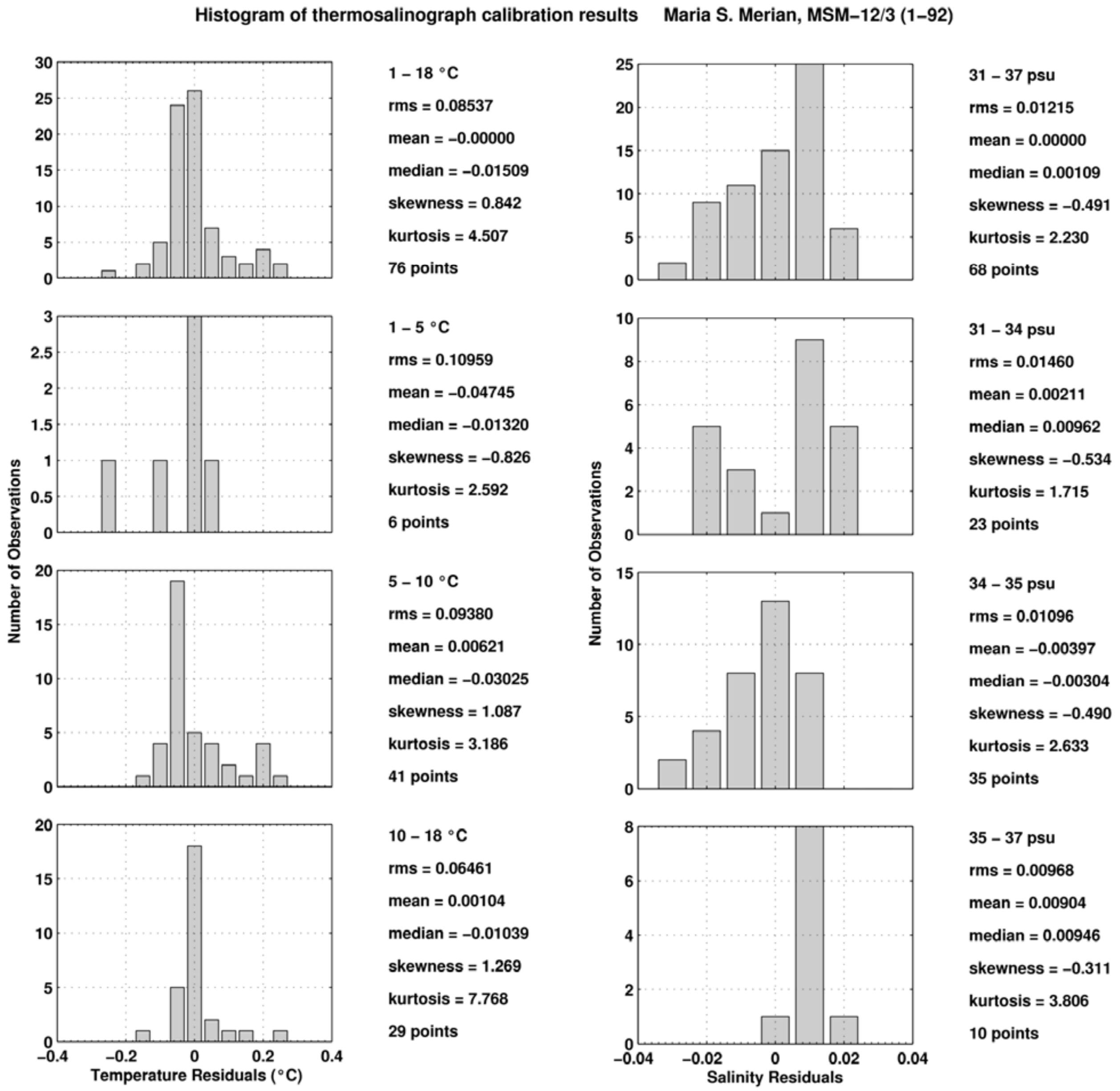

Fig. 5.8 Calibration of the thermosalinograph, MSM 12/3. Right column: temperature, left column: salinity.

Time series shown in Fig. 5.9 indicate that the calibration improved the TSG temperature, whereas the TSG salinity only needed a minor correction. Between profile 14 and profile 17, R/V MERIAN was more or less on transit, and only two CTD values support the temporal evolution within this time frame. The drop down to very low salinities is reasonable. At that time R/V MERIAN operated close to the Greenland shelf within very fresh surface waters, which occasionally revealed drifting icebergs. Also the elevated salinities observed while transiting across Orphan Basin and Flemish Cap appear reasonable though they are not supported by CTD values due to lack of respective measurements. After the transit was finished, TSG values always matched again CTD values.

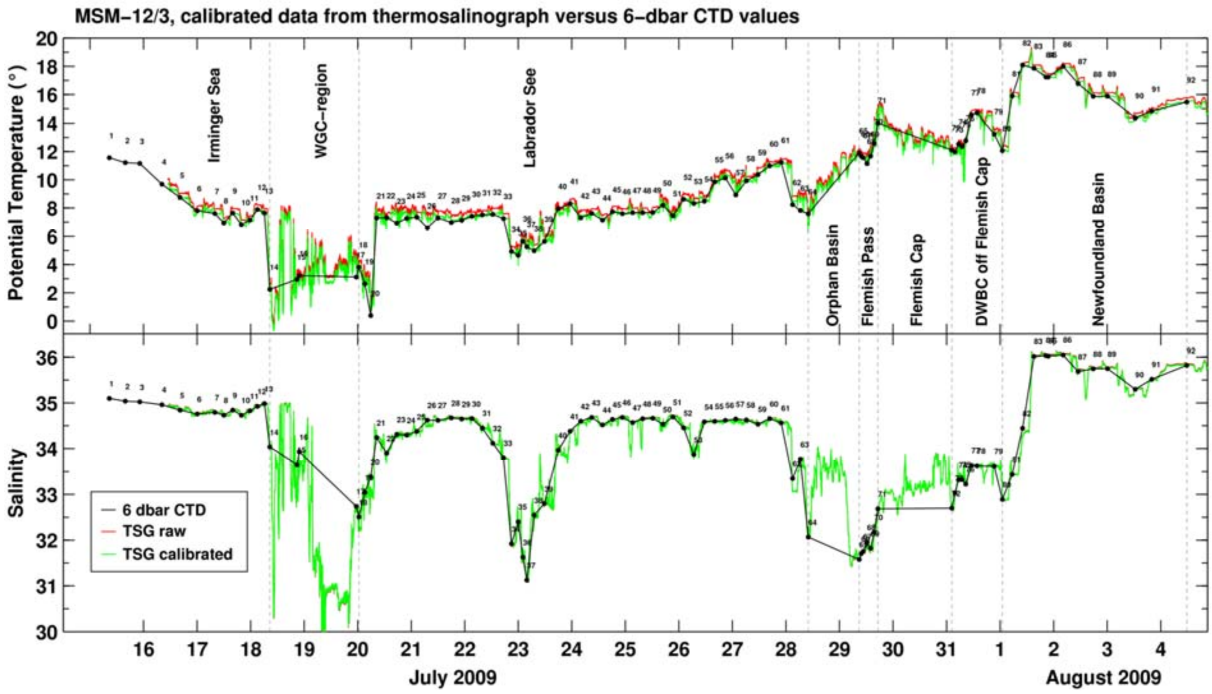

Fig. 5.9 Calibrated data of the thermosalinograph, cruise MSM 12/3.

Different from our previous cruise on R/V MERIAN (MSM-09/1, 07/2008), no additional seawater was pumped in for scientific analysis. Therefore, the TSG obviously has operated without further disturbances or failure and has produced reliable data.

6 Weather conditions

Weather conditions during leg MSM-12/3 were mostly pleasant and fairly stable. South of Greenland air temperatures dropped below the freezing point, but after Flemish Pass was reached, temperatures remained above 10°C. On July 31, the Bremen moorings B21-B23 were deployed. Weather conditions became more and more severe throughout the day, as can bee seen from the large drop in air pressure. Throughout the cruise wind speeds were mostly in the order of 3-5 Bf. Higher wind speeds were experienced in the southern Irminger Sea, and maximum wind speeds of 7-8 Bf were faced in the Newfoundland Basin (Fig. 6.1).

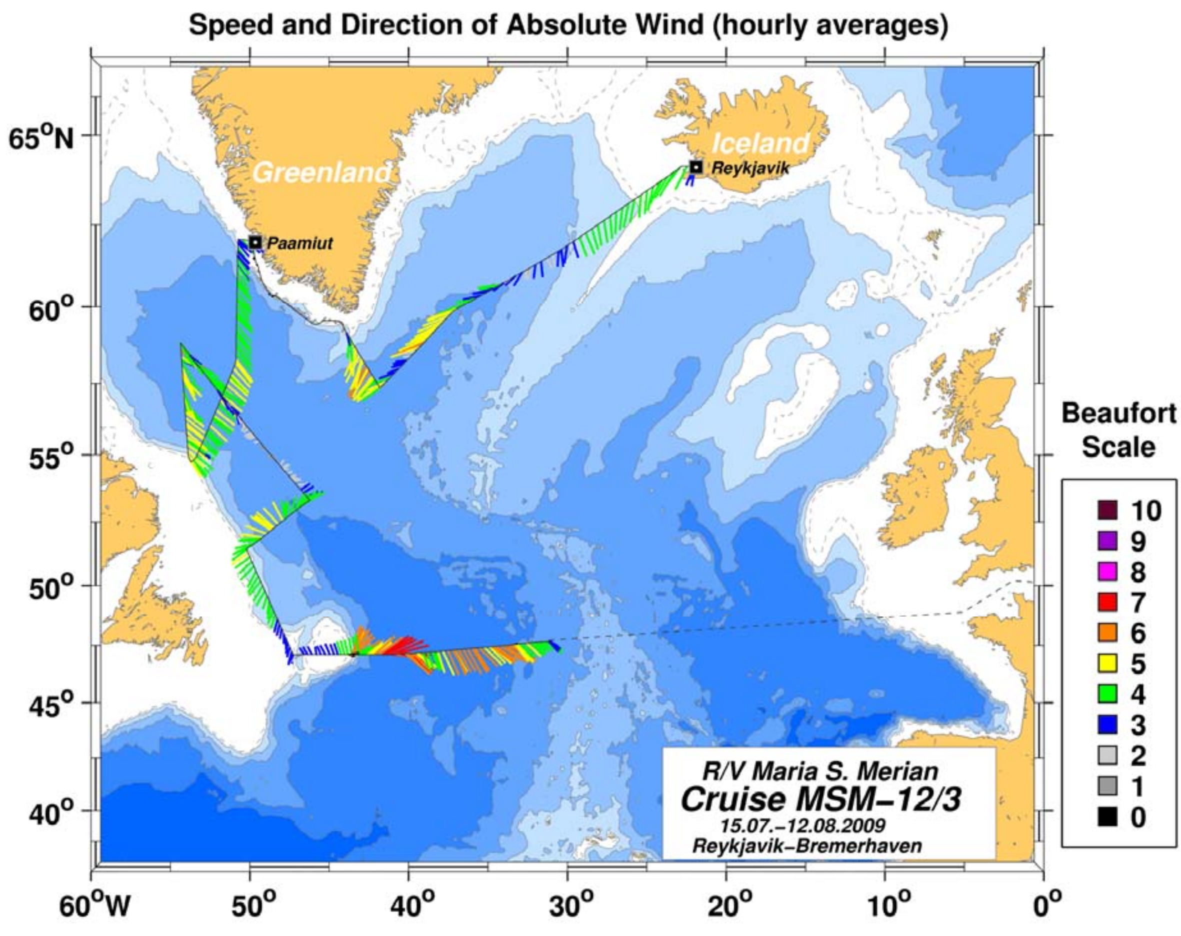

Fig. 6.1 Wind speed (Bft) and direction along cruise track MSM12/3

7 Station Lists MSM12-3

Tab 7.1 PIES activities

Name	PIESNo	Latitude	Longitude	Depth	Deployment
B24	235	47°05.903‘N	42°53.732‘W	3446m	01.08.2009, 16:42

Name	PIESNo	Latitude	Longitude	Depth	Telemetry
B20	186	47°40.393‘N	31°08.640‘W	4080m	04.8.2008,03:50-06:25, failed

Name	PIESNo	Latitude	Longitude	Depth	Recovery
B20	186	47°40.393‘N	31°08.640‘W	4080m	04.8.2008,06:26-11:30, failed

PIES: Inverted Echo Sounder with Pressure sensor
Time in UTC

Tab 7.2 Boundary Current Moorings

Name	Latitude	Longitude	Depth	Deployment	*Recovered*
B21	47°06.01‘N with radio beacon, flashlight	43°25.06‘W	1290m	31.7.2009, 17:46	
B22	47°06.45’N with radio beacon, flashlight, Argos-watchdog	43°14.47’W	2985m	31.7.2009, 15:22	
B23	47°06.07’N with radio beacon, flashlight	43°07.21’W	3500m	31.7.2009, 11:32	

Tab 7.3 CTD/LADCP/tracer station list. The second column named 'Sta' denotes the official R/V MERIAN Station number.

Maria S. Merian		MSM12/3		CTD Stations				Measurements						Page 1
Prof.	Sta.	Date	Time	Latitude	Longitude	Water Depth	Prof. Depth	CFC	SF_6	O_2	Nuts	Alk., DIC, ^{13}C	LADCP	Comments
1	658	2009/07/16	08:39	61° 45.48' N	30° 26.04' W	2067	2063	-	-	x	-	-	x	
2	659	2009/07/16	15:52	61° 10.92' N	32° 29.15' W	2640	2624	-	-	x	-	-	x	
3	660	2009/07/16	22:18	60° 42.00' N	34° 14.51' W	2996	2988	x	-	x	-	-	x	
4	661	2009/07/17	08:15	59° 52.51' N	37° 11.58' W	3104	3097	x	-	x	-	-	x	
5	662	2009/07/17	16:19	59° 2.14' N	38° 42.59' W	3096	3087	x	-	x	-	-	x	
6	663	2009/07/18	00:04	58° 11.53' N	40° 15.52' W	3163	3156	x	-	x	-	-	x	
7	664	2009/07/18	07:57	57° 20.99' N	41° 48.48' W	3279	3273	x	-	x	-	-	x	
8	665	2009/07/18	12:00	57° 40.55' N	42° 11.15' W	3305	3295	x	-	x	-	-	x	
9	666	2009/07/18	16:00	57° 59.99' N	42° 33.53' W	3204	3196	x	-	x	-	-	x	
10	667	2009/07/18	19:52	58° 18.96' N	42° 55.51' W	2918	2909	x	-	x	-	-	x	
11	668	2009/07/18	23:45	58° 38.49' N	43° 18.00' W	2162	2153	x	-	x	-	-	x	
12	669	2009/07/19	03:07	58° 57.99' N	43° 40.01' W	1626	1616	x	-	x	-	-	x	
13	670	2009/07/19	06:12	59° 16.99' N	44° 2.51' W	1642	1640	x	-	x	-	-	x	
14	671	2009/07/19	08:37	59° 30.20' N	44° 12.32' W	196	184	x	-	x	-	-	x	
15	672	2009/07/19	20:48	60° 21.45' N	48° 21.88' W	526	524	x	x	x	-	-	x	
16	673	2009/07/19	21:49	60° 20.54' N	48° 27.21' W	1900	1814	x	x	x	-	-	x	
17	674	2009/07/20	23:23	62° 4.49' N	50° 44.45' W	340	327	x	x	x	-	-	x	
18	675	2009/07/21	00:31	61° 59.20' N	50° 45.04' W	1608	1604	x	x	x	-	-	x	
19	676	2009/07/21	03:13	61° 43.46' N	50° 45.97' W	1707	1707	x	x	x	-	-	x	
20	677	2009/07/21	05:50	61° 33.57' N	50° 46.63' W	1587	1695	x	x	x	-	-	x	
21	678	2009/07/21	08:30	61° 17.76' N	50° 46.53' W	2914	2901	x	x	x	-	-	-	
22	679	2009/07/21	13:01	60° 46.48' N	50° 48.02' W	3077	3031	x	x	x	-	-	x	
23	680	2009/07/21	17:33	60° 15.50' N	50° 48.98' W	3160	3155	x	x	x	-	-	x	
24	681	2009/07/21	22:00	59° 44.49' N	50° 50.00' W	3405	3398	x	x	x	-	-	x	
25	682	2009/07/22	02:31	59° 13.97' N	50° 50.97' W	3499	3463	-	-	x	-	-	x	
26	682	2009/07/22	07:16	58° 42.95' N	50° 51.99' W	3341	3507	x	x	x	-	-	x	
27	684	2009/07/22	11:58	58° 12.96' N	50° 52.99' W	3613	3538	x	x	x	-	-	x	Microcat calib.
28	685	2009/07/22	17:59	57° 43.49' N	51° 14.57' W	3583	3628	x	x	x	-	-	x	
29	686	2009/07/22	22:40	57° 15.49' N	51° 36.00' W	3545	3540	x	x	x	-	-	x	
30	687	2009/07/23	03:14	56° 47.49' N	51° 57.51' W	3500	3526	-	-	x	-	-	x	
31	688	2009/07/23	07:55	56° 19.46' N	52° 18.98' W	3552	3548	x	x	x	-	-	x	
32	689	2009/07/23	12:35	55° 51.49' N	52° 40.00' W	3287	3279	-	-	x	-	-	x	
33	690	2009/07/23	17:22	55° 23.46' N	53° 1.48' W	3176	3093	x	x	x	-	-	x	
34	691	2009/07/23	20:57	55° 7.97' N	53° 13.54' W	2560	2547	x	x	x	-	-	x	
35	692	2009/07/23	23:56	54° 53.65' N	53° 24.51' W	1200	1152	x	x	x	-	-	x	
36	693	2009/07/24	02:05	54° 44.79' N	53° 42.43' W	366	353	x	x	x	-	-	x	
37	694	2009/07/24	03:50	54° 56.47' N	53° 52.49' W	538	521	-	-	x	-	-	x	Microcat calib.
38	695	2009/07/24	07:06	55° 29.94' N	53° 56.46' W	2767	2721	-	-	x	-	-	x	
39	696	2009/07/24	11:41	56° 3.48' N	54° 1.02' W	3258	3250	-	-	x	-	-	x	
40	697	2009/07/24	17:57	56° 36.96' N	54° 4.99' W	3296	3232	x	x	x	-	-	x	
41	698	2009/07/24	23:14	57° 9.92' N	54° 9.00' W	3324	3316	x	x	x	-	-	x	
42	699	2009/07/25	03:59	57° 43.50' N	54° 13.47' W	3354	3350	x	x	x	-	-	x	
43	700	2009/07/25	08:58	58° 16.98' N	54° 17.51' W	3401	3385	-	-	x	-	-	x	
44	701	2009/07/25	13:46	58° 50.48' N	54° 21.96' W	3432	3373	x	x	x	-	-	x	
45	702	2009/07/25	18:14	58° 26.93' N	53° 46.99' W	3644	3402	x	x	x	-	-	x	
46	703	2009/07/25	22:41	58° 3.48' N	53° 12.01' W	3536	3465	x	x	x	-	-	x	

Maria S. Merian MSM12/3 CTD Stations Measurements Page 2

Prof.	Sta.	Date	Time	Latitude	Longitude	Water Depth	Prof. Depth	CFC	SF_6	O_2	Nuts	Alk., DIC, ^{13}C	LADCP	Comments
47	704	2009/07/26	03:15	57° 39.98' N	52° 36.90' W	3498	3493	x	x	x	-	-	x	
48	705	2009/07/26	07:49	57° 16.01' N	52° 1.90' W	3516	3510	x	x	x	-	-	x	
49	706	2009/07/26	12:18	56° 52.49' N	51° 26.96' W	3558	3555	-	-	x	-	-	x	
50	707	2009/07/26	16:51	56° 28.95' N	50° 51.94' W	3601	3597	x	x	x	-	-	x	
51	708	2009/07/26	21:23	56° 5.49' N	50° 17.51' W	3664	3664	x	x	x	-	-	x	
52	709	2009/07/27	02:04	55° 42.01' N	49° 42.51' W	3656	3656	x	x	x	-	-	x	
53	710	2009/07/27	06:43	55° 17.97' N	49° 7.50' W	3667	3664	-	-	x	-	-	x	
54	711	2009/07/27	11:24	54° 54.50' N	48° 32.53' W	3806	3806	x	x	x	-	-	x	
55	712	2009/07/27	16:07	54° 30.98' N	47° 57.46' W	3788	3788	-	-	x	-	-	x	
56	712	2009/07/27	20:49	54° 7.51' N	47° 22.45' W	3513	3613	x	x	x	-	-	x	
57	714	2009/07/28	01:32	53° 43.50' N	46° 47.96' W	3692	3693	x	x	x	-	-	x	
58	715	2009/07/28	06:15	53° 20.00' N	46° 12.98' W	3959	3963	x	x	x	-	-	x	
59	716	2009/07/28	11:28	53° 0.51' N	46° 59.93' W	4167	3981	-	-	x	-	-	x	
60	717	2009/07/28	16:42	52° 37.52' N	47° 45.99' W	3881	3894	x	x	x	-	-	x	
61	718	2009/07/28	21:51	52° 14.50' N	48° 32.49' W	3628	3645	x	x	x	-	-	x	
62	719	2009/07/29	02:58	51° 51.01' N	49° 19.01' W	3006	3000	x	x	x	-	-	x	
63	720	2009/07/29	06:31	51° 38.54' N	49° 47.52' W	2293	2274	-	-	x	-	-	x	
64	721	2009/07/29	09:58	51° 27.25' N	50° 13.32' W	488	475	-	-	x	-	-	x	
65	722	2009/07/30	08:48	47° 10.62' N	47° 19.18' W	606	302	-	-	-	-	-	x	
66	723	2009/07/30	09:43	47° 6.01' N	47° 15.97' W	470	457	x	x	x	-	-	x	
67	724	2009/07/30	10:39	47° 6.00' N	47° 9.46' W	872	858	x	x	x	x	x	x	
68	725	2009/07/30	12:20	47° 6.01' N	47° 0.47' W	1125	1114	x	x	x	x	x	x	
69	726	2009/07/30	13:56	47° 5.98' N	46° 51.51' W	1165	1155	x	x	x	x	x	x	
70	727	2009/07/30	15:37	47° 5.98' N	46° 42.50' W	1135	1123	x	x	x	x	x	x	
71	728	2009/07/30	17:14	47° 5.99' N	46° 34.03' W	548	536	x	x	x	x	x	x	
72	733	2009/08/01	02:22	47° 5.99' N	43° 47.45' W	580	571	-	-	x	-	-	x	
73	734	2009/08/01	03:45	47° 6.02' N	43° 38.28' W	764	756	x	x	x	-	-	x	
74	735	2009/08/01	05:25	47° 6.00' N	43° 25.40' W	1265	1258	x	x	x	-	-	x	
75	736	2009/08/01	06:57	47° 5.99' N	43° 20.17' W	1890	1792	x	x	x	-	-	x	
76	737	2009/08/01	08:37	47° 5.98' N	43° 18.10' W	2495	2501	x	x	x	x	x	x	
77	738	2009/08/01	11:05	47° 6.02' N	43° 13.56' W	3002	3000	x	x	x	-	-	x	
78	739	2009/08/01	13:39	47° 6.17' N	43° 7.68' W	3409	3412	-	-	x	x	x	x	
79	741	2009/08/01	21:22	47° 6.00' N	42° 35.51' W	3656	3652	x	x	x	-	-	x	
80	742	2009/08/02	01:04	47° 6.04' N	42° 11.08' W	4098	4090	x	x	x	x	x	x	
81	743	2009/08/02	05:26	47° 6.03' N	41° 36.41' W	4285	4287	x	x	x	-	-	x	
82	744	2009/08/02	10:05	47° 6.05' N	40° 59.56' W	4475	4483	x	x	x	x	x	x	single ADCP
83	745	2009/08/02	15:09	47° 8.06' N	40° 15.42' W	4525	4546	x	x	x	-	-	x	single ADCP
84	746	2009/08/02	20:30	47° 10.05' N	39° 29.47' W	4577	807	-	-	-	-	-	x	bad CTD data
85	747	2009/08/02	21:38	47° 10.11' N	39° 27.43' W	4578	4582	x	x	x	-	-	x	
86	748	2009/08/03	04:14	47° 13.97' N	38° 17.95' W	4580	4592	x	x	x	x	x	x	
87	749	2009/08/03	10:56	47° 18.43' N	37° 6.60' W	4426	4417	x	x	x	-	-	x	
88	750	2009/08/03	17:45	47° 22.46' N	35° 55.08' W	4340	4334	-	-	x	x	x	x	
89	751	2009/08/04	00:08	47° 26.48' N	34° 43.94' W	4077	4066	x	x	x	-	-	x	
90	752	2009/08/04	12:35	47° 32.96' N	33° 19.20' W	4194	4181	x	x	x	x	x	x	
91	753	2009/08/04	19:59	47° 36.48' N	32° 14.86' W	4007	3995	x	x	x	x	x	x	
92	754	2009/08/05	11:41	47° 40.21' N	31° 8.89' W	4000	4075	x	x	x	-	-	x	

8 Data and Sample Storage and Availability

The data are part of the BMBF priority programme NORDATLANTIK. The data are available to its members. After publication, the data will be submitted to PANGAEA and other international data centres.

Die obersten 1000m der CTD Daten wurden möglichst sofort nach der Datengewinnung zum Coriolis Datencenter in 10 dbar Auflösung geschickt (wird benutzt für eine Erstvalidierung der Argo Daten und für operationelle Modelle). Metadaten wurden bei Beendigung der Fahrt ans DOD sowie an Kooperationspartner weitergeleitet. Die geeichten und finalisierten Daten sind bereits für unsere Partner im Verbundvorhaben „Nordatlantik“ frei gegeben. Nach Projektende und nachdem alle Promotionen, die auf diese Daten angewiesen sind, abgeschlossen wurden und die Daten veröffentlicht sind, werden sie an PANGAEA und an CCHDO sowie die World Ocean Data Base abgegeben. Die Tracerdaten gehen auch an die neue Version von GLODAP, GLODAPv2. Die voraussichtliche völlige Freigabe der Daten erfolgt 2014.

9 Acknowledgements

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10 References

One manuscript with data from cruise MSM12-3 has been submitted in February 2010, and is now published

Rhein, M., D., Kieke, S., Hüttl-Kabus, A., Ströh, C., Mertens, R., Meissner, B., Klein, C., W. Böning and I. Yashayaev,. Deep-water formation, the subpolar gyre, and the meridional overturning circulation in the subpolar North Atlantic. *Deep-Sea Res. II*, 58 (2011) 1819–1832. doi:10.1016/j.dsr2.2010.10.061

Further plans are the preparation of a manuscript dealing with the interpretations of the transport time series of the subpolar gyre transport inferred from the moored PIES (Rössler et al., 2011), and the calculation of the deep water formation rates from CFCs and SF_6 inventories (Kieke et al., 2011).