Maria S. Merian-Berichte

***NOAC***
***(North Atlantic Changes)***

Cruise No. MSM-28

May 09 – June 20, 2013,
St. John's (Canada) – Tromsoe (Norway)

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# 1 Summary

Cruise *MSM-28* was dedicated to investigating the circulation system and the water mass structure in the western subpolar North Atlantic. A special focus was on the Labrador Sea, the Newfoundland Basin and the West European Basin. One of the objectives of cruise *MSM-28* was to obtain a large-scale water mass inventory regarding the anthropogenic tracers $SF_6$ and CFC-12. These will serve to estimate spreading and aging of Labrador Sea Water (LSW) and allow for inferring respective formation rates since 2011. Two mooring arrays recovered during cruise *MSM-27* in Flemish Pass and in the region of the DWBC off Flemish Cap were intended to be redeployed again during cruise *MSM-28*. Due to severe instrument loss (one DWBC mooring could not be recovered during cruise *MSM-27*) the deployment of the DWBC array was entirely canceled, and the instruments were brought to Bremen for further inspection. As another consequence resulting from the instrument loss the redeployment of the Flemish Pass mooring array, by intention shifted from cruise *MSM-27* to cruise *MSM-28*, was reduced to one out of two moorings. Canadian partners from the *Bedford Institute of Oceanography* in Dartmouth/Canada, however, deployed a second mooring in the Labrador Current passing through Flemish Pass in June 2013. So, this array presently consists of two moorings, though with adjusted locations. The deep-sea mooring array located at the western flank of the Mid-Atlantic Ridge (MAR) was successfully recovered and, extended by a fourth mooring, redeployed again at the MAR. Along the same line four inverted echo-sounders equipped with pressure sensors (PIES) were serviced, and four additional instruments were deployed in the Newfoundland Basin along 47°N. These instruments serve to estimate variations of baroclinic and barotropic transports of the subpolar gyre. Measurements carried out during cruise *MSM-28* and corresponding results contribute to the BMBF-funded project RACE, WP 1.2, and to the DFG-funded project FLEPVAR.

## Zusammenfassung

Die Reise *MSM-28* diente der Erforschung der Zirkulation und der Wassermassenstruktur im westlichen subpolaren Nordatlantik. Ein regionaler Schwerpunkt lag auf der Labradorsee, dem Neufundlandbecken und dem Westeuropäischen Becken. Eines der Ziele der Reise MSM-28 bestand darin, ein großskaliges Wassermasseninventar in Bezug auf die anthropogenen Spurenstoffe $SF_6$ und CFC-12 zu erhalten. Mit diesen lassen sich die Ausbreitung und Alterung von Labradorseewasser (LSW) verfolgen und entsprechende Bildungsraten seit 2011 ermitteln. Zwei Verankerungsarrays, die während der Reise *MSM-27* in der Flämischen Passagen und im Randstromgebiet östlich der Flämischen Kappe geborgen wurden, sollten während *MSM-28* ursprünglich wieder ausgelegt werden. Aufgrund von massivem Geräteverlust (eine Randstrom-Verankerung konnte während *MSM-27* nicht geborgen werden) wurde das Randstrom-Array nicht wieder neu ausgelegt und die Geräte zwecks weiterer Inspektion nach Bremen gebracht. Als weitere, aus dem Geräteverlust resultierende Konsequenz, wurde das Array in der Flämischen Passage von zwei auf eine Verankerung reduziert. Kanadische Partner vom *Bedford Institute of Oceanography* in Dartmouth, Kanada, legten jedoch im Juni 2013 eine zweite Verankerung in den Labradorstrom-Bereich in der Flämischen Passage aus, so dass dieses Array gegenwärtig aus zwei Verankerung besteht, wenn auch mit angepassten Positionen. Das Tiefsee-Verankerungsarray am Mittelatlantischen Rücken (MAR) wurde erfolgreich geborgen und, um eine vierte Verankerung erweitert, wieder neu ausgebracht. Entlang derselben Messlinie wurden

vier mit Drucksensoren ausgestattete Bodenecholote (PIES) angesprochen und vier neue Geräte im Neufundlandbecken entlang 47°N ausgebracht. Diese Instrumente dienen der Bestimmung von barotropen und baroklinen Transportschwankungen des Subpolarwirbels. Die während MSM-28 durchgeführten Messungen und entsprechende Ergebnisse tragen zum BMBF-Projekt RACE, AP 1.2, bei sowie zum DFG-geförderten Projekt FLEPVAR.

## 2 Participants

| Name | Discipline | Institution |
|---|---|---|
| Kieke, Dagmar, Dr. | chief scientist | IUP |
| Abels, Lotte | CTDO/LADCP watch | IUP |
| Böke, Wolfgang | technics, PIES/CTD/IUP moorings | IUP |
| Bulsiewicz, Klaus | tracer analysis | IUP |
| Denker. Claudia | CTDO/LADCP watch | BSH |
| Hauck, Dennis | technics, BSH moorings/float deployment | BSH |
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| Koopmann, Nikolaus | CTDO/LADCP watch | IUP |
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| Stendardo, Ilaria, Dr. | oxgen analysis | IUP |
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| BSH | Bundesamt für Seeschifffahrt und Hydrographie, Hamburg, Germany |
| IUP | Universität Bremen, Institut für Umweltphysik, AG Ozeanographie, Bremen, Germany |

## 3 Research Program

Measurements conducted during cruise *MSM-28* contribute to the cooperative research project *RACE* (**R**egional **A**tlantic **C**irculation and Global Chang**E**), which is funded by the German Federal Ministry of Education and Research (BMBF). Investigations were carried out in the framework of work package 1.2 (*NOAC*, **NO**rth **A**tlantic **C**hanges), affiliated to the University of Bremen, Germany, and the German Federal and Maritime Hydrographic Agency (BSH), Hamburg, Germany. The primary objectives of cruise MSM-28 were:

1. To exchange two deep-sea mooring arrays installed across the Deep Western Boundary Current (DWBC) east of Flemish Cap at 47°N and along the western flank of the Mid-Atlantic Ridge (MAR). Both arrays serve to measure the velocity structure and

temperature and salinity of different components of North Atlantic Deep Water (NADW) as well as of the North Atlantic Current (NAC). Since the DWBC mooring array could not be completely recovered during the previous cruise *MSM-27*, it was not redeployed.

2. To analyze the strength and variability in the strength of the exported NADW in relation to the variations in the strength of the NAC in the Newfoundland Basin.

3. To infer the main pathways of the NADW components and the NAC in the open subpolar North Atlantic and the strength of the subpolar gyre as it crosses the MAR.

4. To estimate the present rate of formation of Labrador Sea Water (LSW), inferred from changes of tracer inventories.

5. To assess the role of LSW formation and different NAC circulation patterns for the lateral propagation of heat and freshwater anomalies.

# 4 Narrative of the Cruise

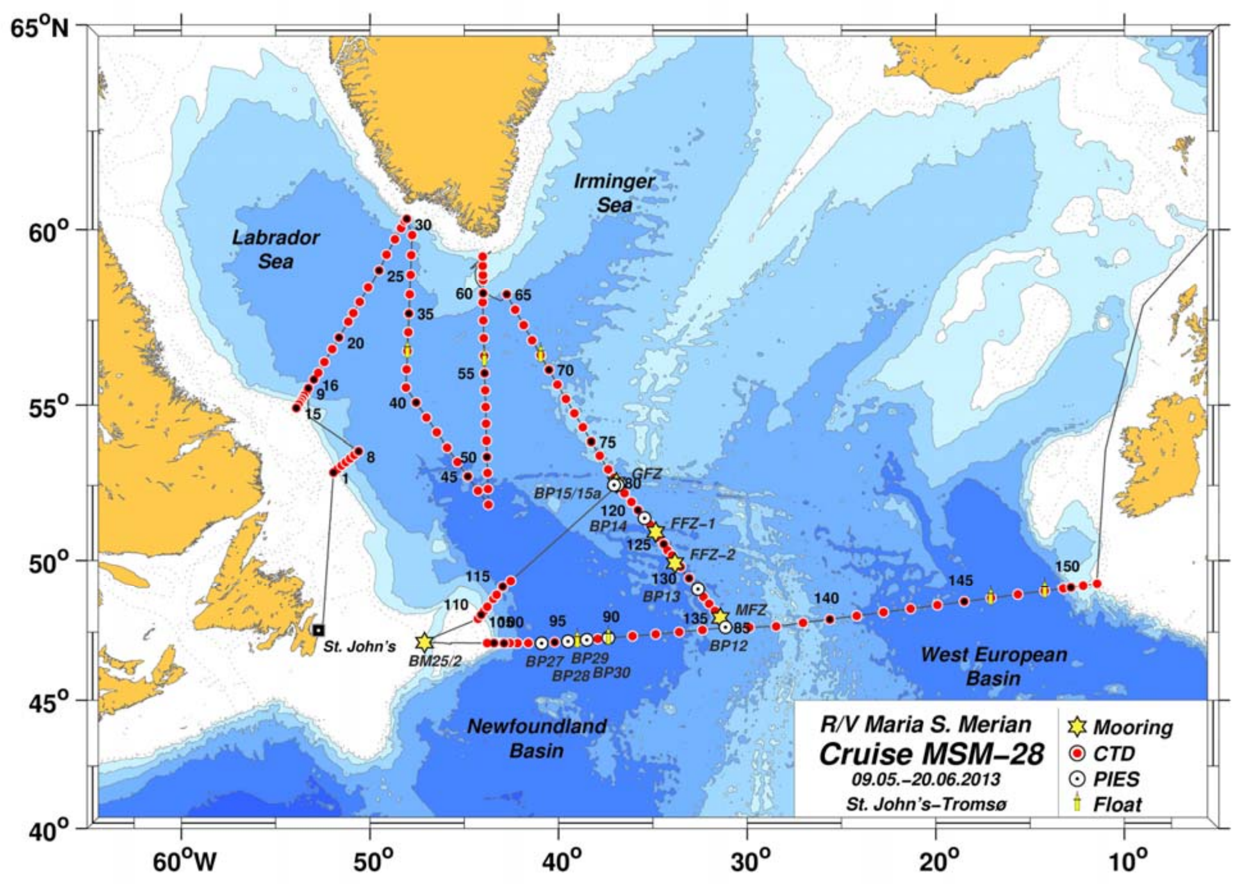


**Fig. 3.1**. Track chart of R/V MARIA S. MERIAN Cruise MSM-28. Numbers indicate hydrographic profiles.

RV MARIA S. MERIAN left St. John's/Newfoundland on May 09th, 2013, at 14:15 UTC. Having passed the 12 nm-zone[1], continuous logging of underway data (thermosalinograph and vessel-mounted Acoustic Doppler Current Profilers (ADCP), operated at 38 and 75 kHz) was switched on at 16:56 UTC. Northern course was set, and station work began on May 10th, 2013, 16:55 UTC, by conducting a first hydrographic section consisting of stations 271/001 to 278/008 (Table 6) that crossed the Deep Western Boundary Current (DWBC) at the latitude of ~53°N. Station work included vertical casts carried out with a conductivity-temperature-depth-oxygen (CTDO) sensor package and two lowered ADCPs operated at 300 kHz and attached to a water sampler unit. Water samples were taken with respect to analyze oceanic concentrations of chlorofluorocarbon-12 (CFC-12), sulphurhexafluoride ($SF_6$), salinity and oxygen. The latter two parameters were used to calibrate the conductivity and oxygen sensors of the CTDO sensor package.

Having finished this section on May 11th, RV MARIA S. MERIAN headed towards the northwest to begin station work along the approximate course of the so-called *AR7W* section. This hydrographic repeat line crosses the central Labrador Sea in northeastern direction from the Canadian to the Greenland continental shelf. The presence of an ice field on the Labrador Shelf, however, made a small detour necessary. Station work along the *AR7W* section, therefore, started at a water depth of around 3000 m and was carried out towards the Canadian shelf again.

Having finished the shallowest station on the Canadian side of the section (May 12th, station 285/015, 450 m), the vessel turned towards the northeast and continued hydrographic station work at a water depth of 3100 m (May 12th, station 286/016). At station distances varying between 15 and 33 nm, RV MARIA S. MERIAN crossed the central Labrador Sea but on its way faced severe cross seas due to variable wind and wave conditions. On May 15th, the shallowest station on the Greenland side of the AR7W section was conducted (station 300/030). Afterwards, the vessel turned south and followed the 48°W meridian back into the central Labrador Sea again. On May 16th, the first out of seven *APEX* floats (Table 2) contributing to the global *Argo* program was deployed.

Having reached the southernmost station of the 48°W-section (May 17th, station 309/039), a southeastern course was set towards the *Northwest Corner* of the Newfoundland Basin, station distances were 32-34 nm as was the case for the 48°W section. On May 19th, the southernmost station of the section that followed the axis of the Labrador Sea was carried out (station 317/047). Subsequently, course was set towards north, and RV MARIA S. MERIAN started her ascend towards Kap Farvel at the southern tip of Greenland (station distances of 31 nm). Before entering the Greenlandic Exclusive Economic Zone (EEZ) the second *APEX* float was deployed. Very calm sea state and favorable low winds were experienced until May 21st. Wind rapidly increased while approaching Greenland. On May 22nd, wind speeds exceeded 12 Beaufort (Bf). Though station work could still be carried out at 10 Bf (station 334, 64), it had to be interrupted subsequently due to very unfavorable weather conditions.

Work was presumed again on May 23rd, when RV MARIA S. MERIAN headed towards the southeast and approached the Mid-Atlantic Ridge (MAR, station 350/080). On May 24th, the third *APEX* float was deployed. Between May 26th and May 29th, the deep-sea mooring *GFZ* (Table 4) was recovered and redeployed at the western exit of Charlie-Gibbs Fracture Zone, deep-sea moorings *FFZ-1* and *FFZ-2* were recovered at the western exit of Faraday Fracture

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1 nm = nautical mile

Zone, as well as four locations with inverted echo-sounders equipped with pressure sensors (PIES) installed at the sea-bottom were visited (Table 3). Recorded PIES data consisting of measurements of acoustic travel time and pressure was retrieved via acoustic telemetry, another instrument was placed next to PIES *BP-1*5 (new location BP-15a), and PIES station *BP-13* was given up by recovering the installed instrument and preparing it for redeployment at another location.

On May 28th, RV MARIA S. MERIAN reached the latitude of 47°N and turned west. While station distances were about 50 nm in the beginning, spacing was reduced to 2 nm when crossing the DWBC east of Flemish Cap (stations 355/085 to 377/107). During May 31st and June 1st, four additional PIES were deployed along the 47°N section in the deep Newfoundland Basin. Furthermore, two more *APEX* floats were deployed on May 31st. While crossing the DWBC unfavorable wind and sea state conditions led to kinks in the conducting sea cable of the vessel's winch EL2 that was successfully used until then. Stations 371, 373, 375-377 were run using winch EL1, after which station work using winch EL2 was presumed again. This winch was in operation for the entire remaining time of the cruise.

Having finished hydrographic station work east of Flemish Cap, RV MARIA S. MERIAN left the DWBC region and sailed 136 nm towards Flemish Pass. On June 3rd, mooring *BM-25/2* was placed on the western side of Flemish Pass at a water depth of ~1000 m. After another transit of 126 nm, station work was presumed again on June 4th at the northeastern flank of Flemish Cap. Another hydrographic section crossing the DWBC at station distances of 11 to 22 nm followed (stations 379/109 to 386/116).

RV MARIA S. MERIAN then crossed the Newfoundland Basin and headed again on a northeastern course towards the northern end of the PIES-line at the MAR (transit of 309 nm). On June 6th, hydrographic station work was continued along the PIES line following the western flank of the MAR (hydrographic stations 387/117 to 406/136). Between June 7th and June 9th, deep-sea moorings FFZ-1 and FFZ-2 were redeployed again, and the entire array was extended by adding a fourth mooring (MFZ) at the western exit of Maxwell Fracture Zone further south.

On June 9th, RV MARIA S. MERIAN arrived again at 47°N and continued its course along this approximate latitude towards the eastern side of the subpolar North Atlantic. Station distances of 58 nm were chosen to be able to cross the West European Basin while measuring in the remaining time of the field period of cruise *MSM-28*. The last two *APEX* floats were deployed in the West European Basin on June 13th. On June 14th, the last hydrographic stations crossing the boundary current on the eastern side of the subpolar North Atlantic were conducted. Station distances were reduced to 18-38 nm. Station work was finished at 09:33 UTC the same day, when RV MARIA S. MERIAN started a transit of 1556 nm towards Tromsø/Norway, the intended port of arrival. Continuous logging of underway data was stopped on June 19th, 16:00 UTC. On June 20th, 04:00 UTC, the vessel arrived at the pilot station and docked in Tromsø harbour at 06:40 UTC the same day, when cruise *MSM-28* was finished.

# 5 Preliminary Results

## 5.1 CTDO Measurements and Sensor Calibration

### 5.1.1 CTDO Performance

(R. Steinfeldt)

Profiling measurements of conductivity, temperature, pressure/depth, and oxygen (CTDO) were performed with a *Sea-Bird Electronics* (SBE) *9plus* underwater unit with attached with sensors for temperature, conductivity, and dissolved oxygen. This sensor assembly was operated via a *SBE-11plusV2* deckunit. An overview of sensor types and serial numbers is provided in Table 5.1.

| **parameter** | **sensor model** | **serial number** | **comments** |
|---|---|---|---|
| pressure | SBE-9plus | 60962 | all profiles |
| temperature | SBE-3plus | 03P4156 | all profiles |
| conductivity | SBE-4C | 042646 | all profiles |
| oxygen | SBE-43 | 430547 | profiles #1-#35 |
| | SBE-43 | 430267 | profiles #36-#152 |
| pump | SBE-5 | 053138 | all profiles |

**Tab. 5.1** Summary of CTDO-related sensors used during cruise MSM-28.

The CTDO package was lowered together with a carousel water sampler system of type *SBE-32* carrying 22 Niskin bottles (10 l), an altimeter, and two lowered ADCPs. From the Niskin bottles, water samples for ship-board analysis of CFC-12 and $SF_6$, offline samples for CFC-12 and CFC-11, tritium and helium (at 4 stations only) as well as samples for salinity and oxygen were drawn. The latter two served for the calibration of the conductivity and oxygen sensors, so the number of samples for these two parameters was only about three per profile.

CTDO measurements could be performed without disturbances from top to bottom for each profile. The only malfunction occurred at station #286/16, when the Niskin bottles could not be closed. Typically, the CTDO/water sampler system was at first deployed to a depth of about 10 m. After the pumped had switched on the system was heaved back to the surface from where it was lowered towards the sea bottom. In those cases of harsh sea conditions, the entire system was deployed quickly to depths of 10 to 20 m, and after the pumped switched on, the system was immediately lowered to avoid formation of kinks in the conducting wire. In case, the pump start was below the mixed layer, the upper part of the profile was reconstructed from the upcast data (stations #375/105, #376/106, #400/130, #402/132, #403/133, and #405/135). At station #420/150 salinity and thus density showed spurious oscillations. These could be reduced by setting a time delay of 0.1 s for the temperature sensor relative to the conductivity sensor.

The oxygen data of the CTDO system showed large oscillations up to 0.3 ml/l especially at higher pressure (above ~1500 dbar). Therefore, after station #305/35 the oxygen sensor was changed (cf. Tab. 5.1). With increasing time of operation also the second sensor began to oscillate, although at a lower amplitude (up to 0.2 ml/l).

An offset of the system's pressure sensor of -0.5 dbar was determined from the recorded pressure values at the beginning and end of the CTDO casts.

### 5.1.2 Oxygen Analyis

(I. Stendardo)

In order to perform the calibration of the oxygen sensor of the CTDO sensor package 380 samples in total were collected during the entire duration of the cruise, with an average of 3 to 4 samples per station. However, starting from station #329 samples were not always taken at every station. Starting from station #341, samples were taken periodically every second station. The total number includes also 53 double samples, which were measured for every second station to estimate the final precision of the measurements.

To measure dissolved oxygen from seawater samples standard Winkler titration was performed with a *Metrohm 848 Titrino plus* system, where the endpoint is determined with an electrode. The system is owned and was kindly made available by the oceanography group of D. Quadfasel, University of Hamburg. The machine was set to dynamic equivalence point titration mode, where the reagent was added in variable volume steps. The volume increments varied as a function of the slope of the curve.

The reagents used for the titration were Manganese(II)Chloride ($MnCl_2$) with the concentration of 300 g dissolved in 500 ml of pure water and the Alkaline solution (NaOH-KI) with a concentration of 180 g of NaOH and 75g of KI dissolved in 500 ml of pure water. These two reagents were used during the sampling with the quantity of 0.5 ml each. Sulfuric acid ($H_2SO_4$), 500 ml dissolved in 1000 ml of pure water, was used with the quantity of 1 ml. Sodium thiosulfate ($Na_2S_2O_3$) with the concentration of 0.1 N (Normal) was used as stock solution, and $Na_2S_2O_3$ 0.01 N was used as a working solution by diluting the stock solution to 1:10. However, we also had ready-made vials of working solution of $Na_2S_2O_3$ (0.01 N), which only needs to be made up to final volume of 1000 ml by adding pure water. For the standard two solutions were prepared: potassium iodate ($KIO_3$) with a concentration of 0.1 N, prepared from a ready-made vial where the solution needed only to be made up to the exactly volume of 1000 ml; and potassium iodide (KI), prepared by diluting 50 g of KI in 500 ml of water. The standard was performed by mixing 1 ml of $KIO_3$, 1 ml of $H_2SO_4$ (50%) and 5 ml of KI to 100 ml of pure water and then run a normal titration. Usually for 1 ml of $KIO_3$ 10 ml of $Na_2S_2O_3$ are needed. The titration was performed three times, and then a mean concentration was calculated. The standard was determined by dividing the amount of $Na_2S_2O_3$ usually needed to titrate 1 ml of $KIO_3$ (10 ml) and the mean volume determined by the three titrations.

Originally it was intended to use the ready-made 0.01 N solution of $Na_2S_2O_3$. These ready-made solutions are used directly for the titration, are quite stable, and if the titration is run within the next 2-3 days the calculation of the standard factor can be neglected. However, only a limited amount of these ready-made working solutions were left (only 3 vials left for the entire cruise), while 9 vials of stock solutions (0.1 N) were still available. These 9 vials were supposed to be used as a backup in case the vials of the working solution finished. The stock solution is stored for longer time and it needs an additional dilution to get from the 0.1 N to the 0.01 N. The stock solution is subject to deterioration and must be standardized with the $KIO_3$. The amount of acid available for the entire cruise was calculated according to the amount of samples needed to calibrate the sensor and not to perform the standard factor. Due to the limited amount of acid, we decided to calculate the standard only every second day.

Oxygen sampling started on May 09th when the test station was carried out. Analysis of the data measured until May 13th revealed that the bottle samples were strikingly too low in oxygen when compared to data from previous years. As a consequence the stock solution was considered faulty. Indeed from May 09th to May 12th (stations #271/1 to #288/18) all working solutions were prepared from the stock solution prepared on the previous cruise MSM-27. The stock solution was finished and replaced with a new one on May 12th. Starting from May 13th, station #289/19, the working solution was prepared from the new stock solution. Until this day no standard was performed due to technical problems. The standard was performed starting from station #307/37 on May 17th.

From May 17th until June 06th standards were calculated every second day or when a new working solution was prepared from the stock solution. Starting on June 07th the standard analysis was performed every day. New stock solutions were prepared on May 21st , on June 06th, and on June 07th, after realizing that the standard factor was too high (1.008). On May 21st, the $MnCl_2$ solution was replaced with a newly prepared solution and was used starting from station #331/61. On May 22nd also the NaOH-KI solution was prepared and used starting from station #359/89.

Figure 5.1 shows the differences between the oxygen derived from the CTDO system and inferred from bottle samples. Due to the fact that the bottle measurements were observed to be too low in oxygen, an adjustment of 1% to 3% to the bottle oxygen was applied in order to reduce the differences between the CTD and bottle measurements. The error estimated by computing the difference between the double samples is 0.016 ml/l (0.25%) with a standard deviation of ±0.014 ml/l (Figure 5.2). The error estimated from the calculation of the standards is 0.014 ml/l (0.22%). The quadratic error, which includes the error due to the measurements and the error due to the standard factor, is 0.021 ml/l (0.33%), which stands for the final precision of the measurements. Figure 5.2 shows the absolute differences between all the doubles, its mean and its standard deviation. Until the end of the cruise, although all reagents were changed, the standard was calculated and the stock solution periodically prepared, the oxygen measurements derived from bottle samples were found to be always too low. There is yet no clear reason for this offset, as it increased from the beginning of the cruise from 1% to 3% for the last stations.

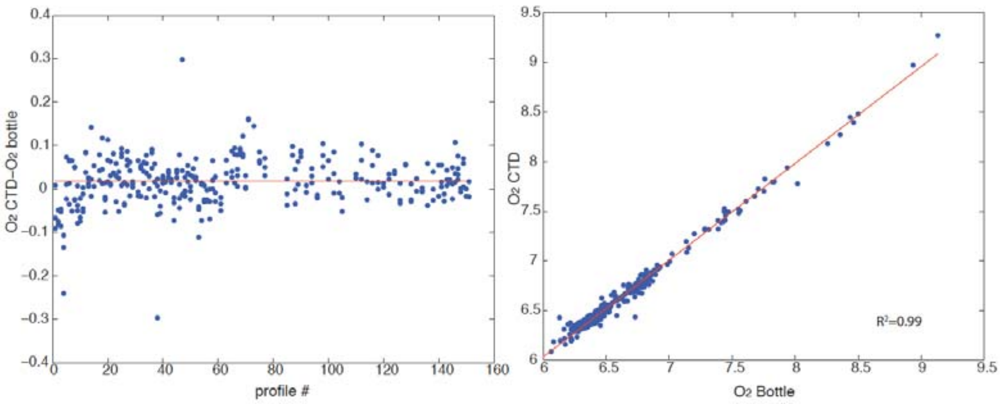


**Fig. 5.1** Left: Absolute difference [ml/l] between oxygen measured by the CTDO sensor package ($O_2$ CTD) and oxygen derived from bottle samples via Winkler titration ($O_2$ bottle) for all 152 hydrographic profiles. Right: bottle $O_2$ [ml/l] versus the CTDO-derived $O_2$ with linear fit (red line), $R^2$=0.99.

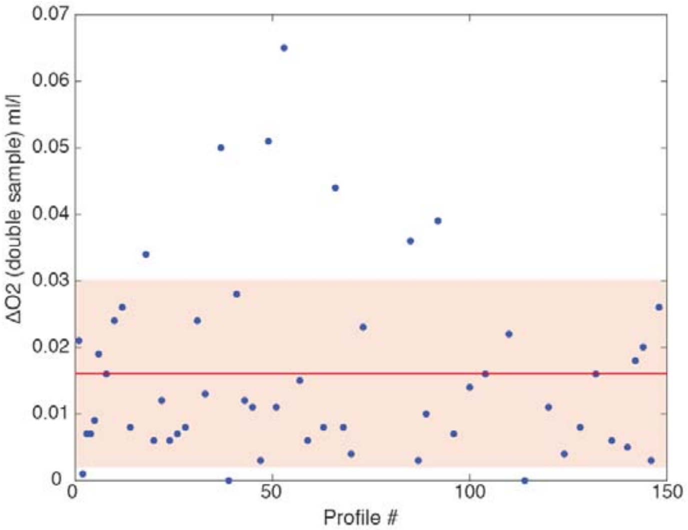


**Fig. 5.2** Absolute difference [ml/l] of the particular oxygen double samples, displayed against profile number (cf. Chapter 7). Red line: mean value, red shading: standard deviation

### 5.1.3 CTDO Sensor Calibration
(R. Steinfeldt)

For the calibration of the conductivity sensor, salinity samples were analysed with a *Guildline Autosal 8400A*. *IAPSO* standard seawater of batches P153 and P155 was used for the standardization of the salinometer. A direct comparison of the two batches did not show a deviation of the salinity measured by the *Autosal* from the salinity given for the batches. The CTD-derived conductivity needed a correction with a small additive offset of 0.0014 mS/cm. The mean rms-error between bottle and CTD salinity is 0.002. Together with the uncertainty of the salinometer (~0.001) and the seawater batch (<0.001), the overall accuracy of the CTD-derived salinity is about 0.0025 (see Fig. 5.3).

The resulting temperature-salinity properties at the location of the inverted echo-sounder BP-12 and at the deepest part of the eastern 47°N section (Fig. 5.4), where the temporal variability is expected to be very small, shows a good agreement with previous cruises. The maximal deviation is 0.002 (at 47°N, eastern basin) and 0.004 (at PIES BP-12), i.e. all profiles overlap within the 2-sigma error interval.

Using the oxygen values determined from the bottle samples for the calibration of the two CTD oxygen sensors results in an apparent temporal drift of the sensors. The introduction of this temporal dependence of the CTD oxygen in the calibration coefficients, however, leads to small oxygen values especially for the later profiles in comparison with earlier cruises from the same region. Thus, the temporal drift was ascribed to the titrated bottle oxygen, maybe due to degradation of the chemical solutions or of the measurement device. Therefore, the bottle oxygen was enlarged by 1 % (starting at station #275/4), 2% (from station #283/13 on) and 3% for station from #387/117 on, respectively, (also compare section 5.1.2).

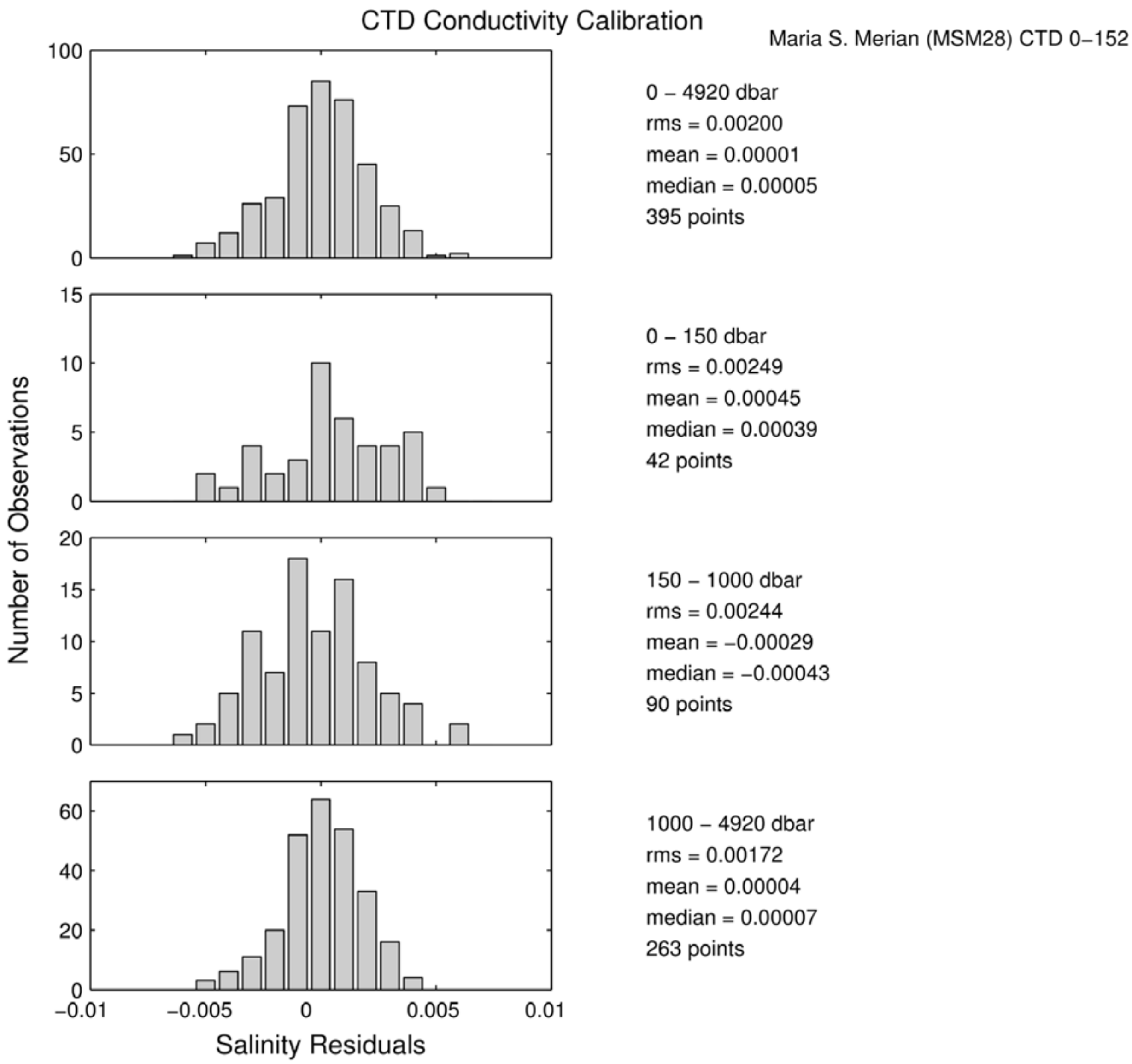


**Fig. 5.3** Histogram of salinity residuals displayed against number of observations and split into different depth ranges (top to bottom is shown in the top panel).

With this enhancement, the calibration of the CTD oxygen does not show a temporal dependence, only a constant offset, and corrections proportional to pressure, temperature and the oxygen concentration itself have been applied. For the second oxygen sensor, the calibration was done for the station #306/36 to 404/134 and #405/135 to #421/151 separately. Otherwise, the misfit of the calibration would be quite large (up to 0.1 ml/l) for the last profiles. The rms error between bottle and CTD oxygen is between 0.05 ml/l and 0.026 ml/l for the two sensors. As for salinity, the oxygen within regions of low temporal variability have been compared with data from previous cruises. For the deepest part of the section along the Mid-Atlantic Ridge (stations #387/117 to #406/136, not shown) and the 47°N-east line (Fig. 5.5) the agreement is better than 0.05 ml/l, justifying the multiplicative correction applied to the oxygen data derived from bottle measurements.

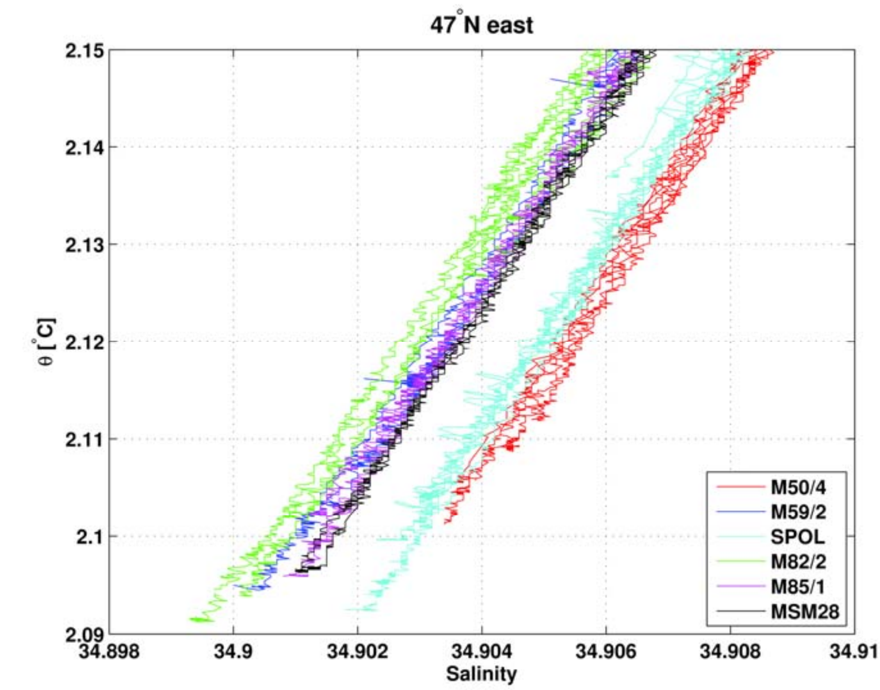


**Fig. 5.4** Comparison of temperature plotted against salinity for the deepest part of the West European Basin and shown for different cruises, when the respective location was visited. (cruise M50/4 in 2001 to cruise MSM-28 in 2013).

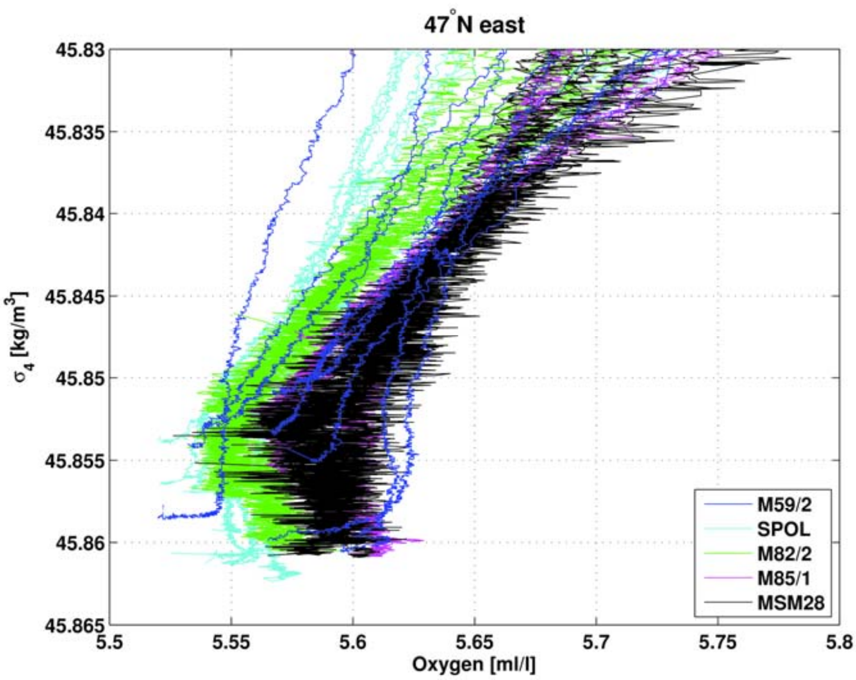


**Fig. 5.5** Comparison of oxygen [ml/l] plotted against potential density $\sigma_4$ [kg/m$^3$] for the deepest part of the West European Basin and shown for different cruises, when the respective location was visited. (cruise M59/2 in 2003 to cruise MSM-28 in 2013). Data of cruise MSM-28 show a higher noise level.

## 5.2 Sampling and Analysis of Transient Tracers

### 5.2.1 Analysis of Sulphurhexafluoride ($SF_6$) and Chlorofluorocarbon-12 (CFC-12)

(K. Bulsiewicz)

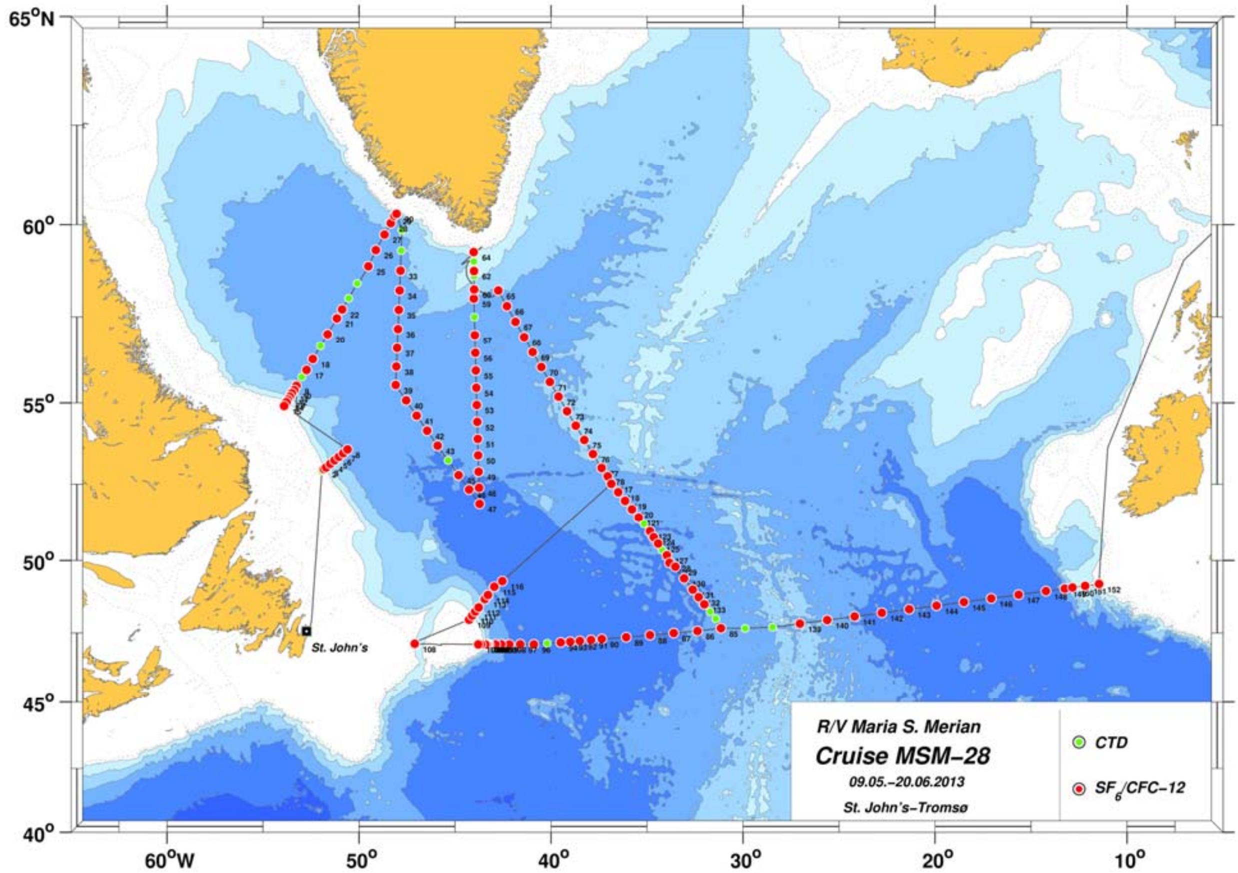


**Fig. 5.6** Location of hydrographic stations with $SF_6$/CFC-12 sampling and respective ship-board analysis (red dots). Numbers indicate profile numbers, see Chapter 7.

During cruise MSM-28 we used an analytical technique for on-board measurements of the trace gases sulphur hexafluoride ($SF_6$) and the chlorofluorocarbon component CFC-12. The determination of the two compounds was performed by analysis with gas-chromatography with electron capture detection. Some parts of the system were changed in comparison to previous cruises. These changes increased the chromatographic peak signal, peak-shape and enhanced the limit of detection.

Water-samples were collected in 250 ml glass ampoules from 10 l Niskin bottles. 140 ml of this water were transferred to a water purge chamber. After purging of the water, the compounds were trapped in a 1/8" ID *Porapak-Q* trap. After thermal desorption the sample gases held in the trap were flushed onto a packed 1/8" *MS5A* column to remove nitrous oxide. The compounds were refocused then on a 1/16" *Porapak-Q* packed trap to narrow their chromatographic peaks and enhance their detection. After thermal desorption $SF_6$ and CFC-12 were first separated from later compounds on a pre-column of type *Alumina BOND/CFC* (0.54 mm ID x 3m). $SF_6$ and

CFC-12 were then separated on a main capillary column of type *Alumina BOND/CFC* (0.54 mm ID x 30m). Both tracers were then detected on a micro-ECD.

Altogether 1693 water-samples were taken on 128 stations. Based on the analysis of replicate water samples, we estimated precisions of 0.7% for $SF_6$ and 0.4% for CFC-12. Overall accuracy, including that of the calibration scale, was estimated to ~1.5% for CFC-12 and ~2.0% for $SF_6$, with a limit of detection for $SF_6$ of ~0.005 fmol/kg and ~0.001 pmol/kg for CFC-12. There was no analytical blank for $SF_6$ and ~ 0.001 pmol/kg for CFC-12.

The analytical system was calibrated using a standard gas of known CFC-12 and $SF_6$ composition. The compressed gas standard was prepared in a 29-L *Aculife*-treated aluminium cylinder by Brad Hall, NOAA Earth System Research Laboratory. The values for CFC-12 and $SF_6$ are based on the SIO-98 calibration scale.

The concentrations of CFC-12 and $SF_6$ in the deep water revealed two distinct maxima, which indicated the presence of recently ventilated water masses (Fig. 5.7). The upper maximum was located within the density range of Upper Labrador Sea Water (ULSW). Highest values were found directly in the Labrador Sea and adjacent regions. The lower maximum close to the bottom is attributed to the Denmark Strait Overflow Water (DSOW). Following the Deep Western Boundary Current from Greenland to 47°N, the CFC-12 and $SF_6$ concentrations in the DSOW decreased downstream. Whereas the penetration of DSOW is restricted to the western basin due to the Mid-Atlantic Ridge, the CFC-12/$SF_6$ maximum related to ULSW was found throughout the whole subpolar North Atlantic. Lower tracer values in the ULSW are often correlated with higher salinities. This is an indication for the recirculation of older, more saline water within the North Atlantic Current and the penetration of Mediterranean Outflow Water into the eastern Atlantic.

In the overflow waters, some data points showed a high $SF_6$/CFC-12 ratio. This excess $SF_6$ can be interpreted as the remnant of a tracer release experiment in the Greenland Sea in 1996. Some of the deliberately released $SF_6$ left the Nordic Seas via Denmark Strait within the DSOW and the Faroe Bank Channel within the Iceland Scotland Overflow Water (forming the North East Atlantic Deep Water, NEADW) and is still present in the subpolar North Atlantic.

Even the oldest deep water in the deep West European Basin along 47°N showed $SF_6$ concentrations above the detection limit (minimum measured concentration 0.0065 fmol/kg).

The analyses of air samples gave mixing ratios of 522 ppt for CFC-12 and 8 ppt for $SF_6$, which is in good agreement to recently reported atmospheric values. Based on these atmospheric mixing ratios, the mean saturation of CFC-12 and $SF_6$ in the mixed layer during the whole cruise was 101.5% and 102.5% respectively, i.e. there was no significant difference in the saturation of the two components (Fig. 5.8). Undersaturation mainly occurs at low surface temperatures (< 5°C). The highest supersaturations (>=108% for both CFC-12 and $SF_6$) were found at stations #369/99 to #378/108, i.e. in a region of strong mixing of warm water from the North Atlantic Current and cold water from the Labrador Current.

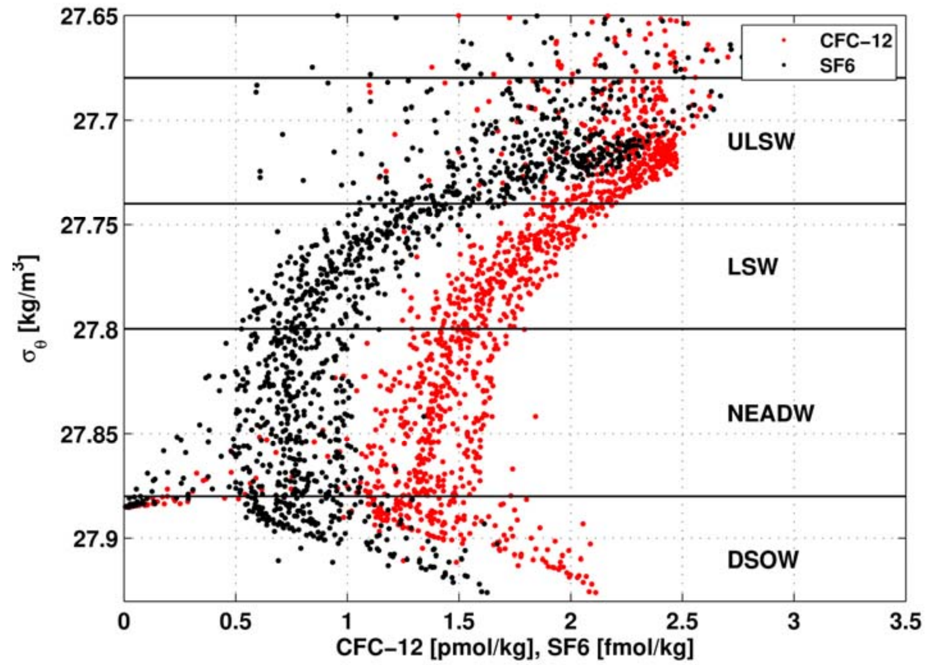


**Fig. 5.7** Concentrations of CFC-12 [pmol/kg] (red) and $SF_6$ [fmol/kg] (black) plotted against potential density $\sigma_\Theta$ [kg/m₃]. Density ranges of Upper Labrador Sea Water (ULSW), Labrador Sea Water (LSW), Northeast Atlantic Deep Water (NEADW) and Denmark Strait Overflow Water (DSOW) are highlighted.

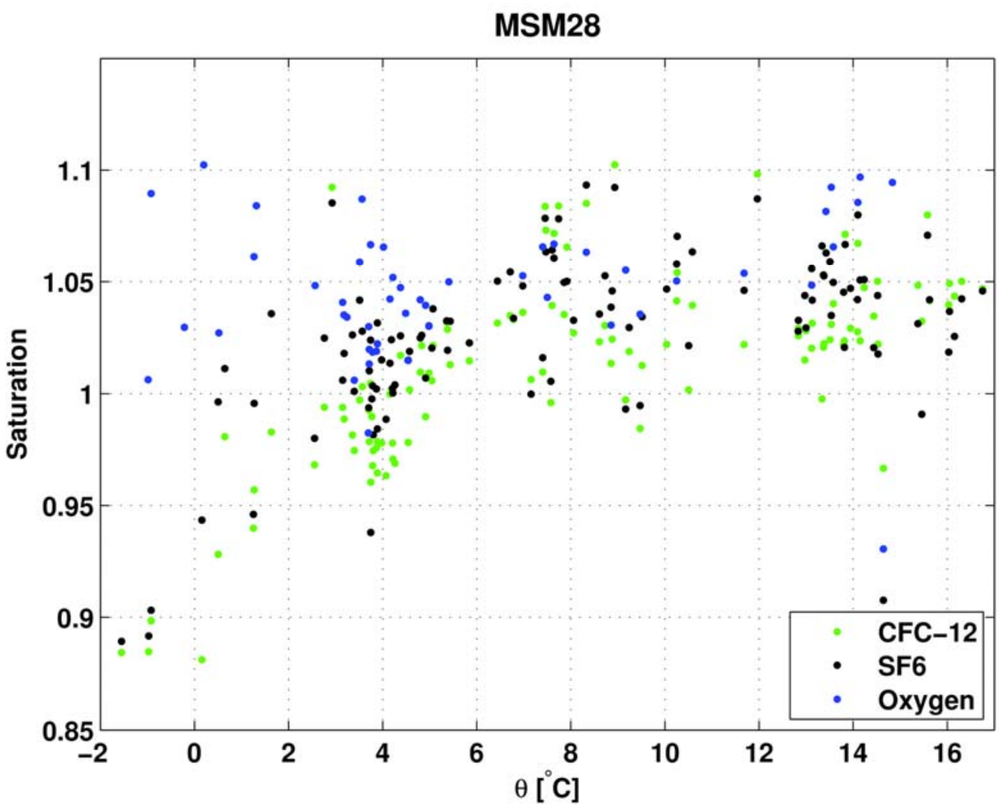


**Fig. 5.8** Saturation of CFC-12 (green), $SF_6$ (black), and oxygen (blue) derived from near-surface samples and displayed against temperature. A value of 1 equals a saturation of 100%.

### 5.2.2 Offline-Sampling of Chlorofluorocarbon Components
(D. Kieke)

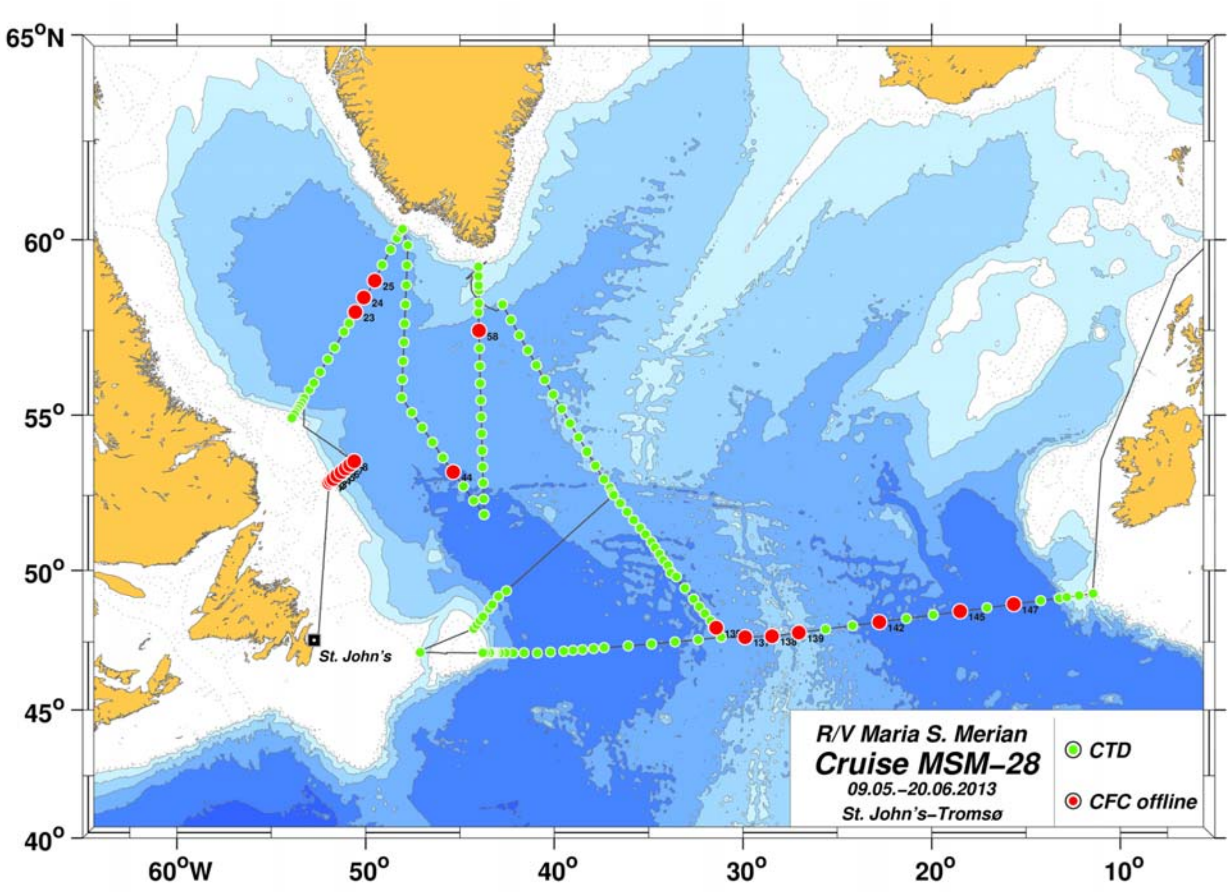


**Fig. 5.9** Location of hydrographic stations with CFC-offline sampling and subsequent sample storage (red dots). Numbers indicate profile numbers, see Chapter 7.

For selected stations also so-called offline samples were taken from the Niskin bottles, with the intention to analyze the content of the chlorofluorocarbon components CFC-12 and CFC-11 in seawater at the home laboratory in Bremen. Offline sampling was considered at the beginning of the cruise (stations 271/1 to #278/8, Fig. 5.9), when the $SF_6$/CFC-12 analytical system (cf. section 5.2.1) was not yet in processing mode. Offline sampling was occasionally considered later on, when the $SF_6$/CFC-12 analytical system was either run in calibration mode or when system checks needed to be carried out (both cases did not allow analysis of samples). A small number of stations was chosen (see Chapter 7), where first $SF_6$/CFC-12 samples were tapped from the Niskin bottles, which was followed by immediate tapping of offline samples. These offline samples shall serve to compare the performance of the ship-board analytical system with the home-based analytical system. The latter does not provide $SF_6$ data but beside CFC-12 delivers information on CFC-11 concentrations. Between 12 and 20 offline samples were taken at the respective station which results in typical depth intervals between 100-400m. Double samples shall allow for a later verification of the precision of the CFC data.

Sample processing was done similar to the previous cruise *MSM-27* with RV MARIA S. MERIAN. A volume of ~90 ml of seawater was collected in so-called flow-through containers, consisting of a glass ampoule which is connected to a head carrying a movable central and a fixed side tubing.

By avoiding any contact to the atmosphere and thus preventing any contamination of the water sample the containers were detached from the *Niskin* bottles. CFC-free purified nitrogen was inserted into the glass ampoule to create a head space which is required to accommodate the thermal expansion of the included seawater sample. The glass ampoules were flame-sealed by closing the open end of the ampoule with a burner fueled with propane gas. After the flame-sealing processes was finished and time for cooling of the sealed glass was allowed the remaining glass pieces were stuck on the labeled glass ampoule. Together with the precise dead weight of the glass ampoule which was carefully determined earlier in the Bremen laboratory, knowledge of the total weight of the flame-sealed glass ampoule is necessary for determining CFC concentrations later on.

The analysis of the samples at the Bremen home-lab is expected to be finished in 2014. Together with large-scale tracer data obtained during the previous cruise MSM-27 with RV MARIA S. MERIAN, these data will be used to calculate tracer inventories for the different types of LSW and to infer the respective rate of formation since 2011.

### 5.2.3 Sampling of Noble Gas Isotopes and Tritium

(D. Kieke)

During cruise *MSM-28* a very limited number of water samples were taken with respect to measuring helium isotopes ($^3$He, $^4$He), neon, and the radio-active hydrogen isotope tritium at the Bremen laboratory for helium isotopes analysis *helis* (www.noblegas.uni-bremen.de). The overall intention was to study the correlation of tritium and its decay product $^3$He with CFCs in the central Labrador Sea in relation to the stations located close to the Greenland coast. Altogether 48 samples for helium/neon isotope analysis and 48 samples for tritium analysis were taken at three stations close to the Greenland shore (#314/44, #328/58, #334/64) and one station in the central Labrador Sea (#291/21), see Chapter 7.

Helium isotopes and neon will be analyzed from the same water sample, with each water sample being stored in a gas-tight copper tube. Water samples for tritium analysis were stored in 1 L glass bottles that were water-vapour tight. Consequently, tritium as HTO molecules in oceanic water samples will be indirectly detected through measurement of the tritium decay product $^3$He. For this reason, the sample will be injected into an extraction unit that removes all dissolved gases and reduces the helium content of the water sample by a factor of $10^6$. For several months the increase of $^3$He resulting from the radioactive decay of tritium is accumulated in the sample, and the $^3$He and $^4$He content will be measured subsequently using a sector-field mass spectrometer. Measuring $^4$He is required here to identify potential contamination from atmospheric air. In contrast, helium isotopes and neon contained in water samples stored in copper tubes will be detected by firstly, stripping of all dissolved gases from the water and transferring them into glass ampoules. Under vacuum conditions the resulting gas samples are transferred into a multi-step cryogenic system that removes all gases except helium and neon. The sample will be injected into quadrupol mass spectrometer for $^4$He and $^{20}$Ne analysis and subsequently into a sector-field mass spectrometer for $^3$He and $^4$He. The mass-spectrometric sample analysis is expected to be finished in fall 2014.

## 5.3 Performance of Lowered Acoustic Doppler Current Profilers

(A. Roessler)

The lowered acoustic Doppler current profiler (LADCP) setup in use consisted of two *Teledyne RD Instruments* (TRDI) *Workhorse Monitor* ADCPs, operating at 300 kHz and attached to the carousel water sampler. The instruments were configured to operate in a synchronized master (s/n 7915) and slave (s/n 1973) configuration, where the downward looking master triggers the upward looking slave. The configuration was the same as on preceding cruise MSM-27 with RV MARIA S. MERIAN. The instruments were powered by an external battery supply, which consisted of 35 commercial quality 1.5 V batteries lasting around 38 h to 40 h. These were assembled in a modified *Aanderaa* pressure housing. The system was configured to a ping rate of 1 Hz and 10 m depth cell size (bin length). Due to configuration of the carousel water sampler with additional weights installed, the instruments were very stable in the water column. Throughout all stations the devices had a mean tilt of -0.5° with a standard deviation of 1.2°. It only increased due to strong currents or especially due to the rolling of the ship, but never reached the maximum tolerable angles. LADCP data were recorded on all CTDO casts. In total 152 CTDO/LADCP casts were made. Profile 102 only consists of a downcast profile due to a battery failure and the profiles 59 and 111 have to be analysed in more detail due to weird compass information, partly corrupt files. At some occasions the communication with the instruments via the battery case connection did not function properly, but a proper cleaning of all plug connections did help most of it. On one of such events, the communication cable between the computer and the battery case was found broken. The break occurred just next to the underwater plug due to a high stress exerted on the material when plugging and end-plugging the connections before and after each station. After replacing the cable no further problems arose.

Data processing was done using the LADCP-toolbox for MATLAB, version 1.2.1, of the University of Bremen. An inverse method incorporating the bottom track velocities was used for most of the post-processing of the raw data. For the those profiles, when applying the inverse method resulted in a large number of spikes or unreliable velocity estimates, the mean of the down- and up-cast shear solution was used. The main reason for the spiky and/or noisy inverse solutions were the ship movements which led to vertical instrument velocities oscillating usually by ±0.5 m/s around the nominal heave and veering velocities (Fig. 5.10). During storm events or rougher sea states the rolling of the ship led even to velocities of up to +0.7 m/s although the CTDO system was lowered with -1 m/s. This resulted in vertical movements of the carousel water sampler carrying the sensor package of up to 6 m.

Beside this ship movement, which induced most of the spikes and noise in the inverse solution, the overall performance of the two instruments was very good (Fig 5.11). The range of each instrument was typically 150 m in the upper parts of the water column and about 50 m at depths exceeding 2000 m. Thus, the total range of both instruments varied from 150 to 300 m. With lowering and heaving velocities of 1 m/s - 1.2 m/s, this range corresponds to around 200 estimates of current shear in each depth cell in the deep water, and much more towards the sea surface, depending on the abundance of scatterers.

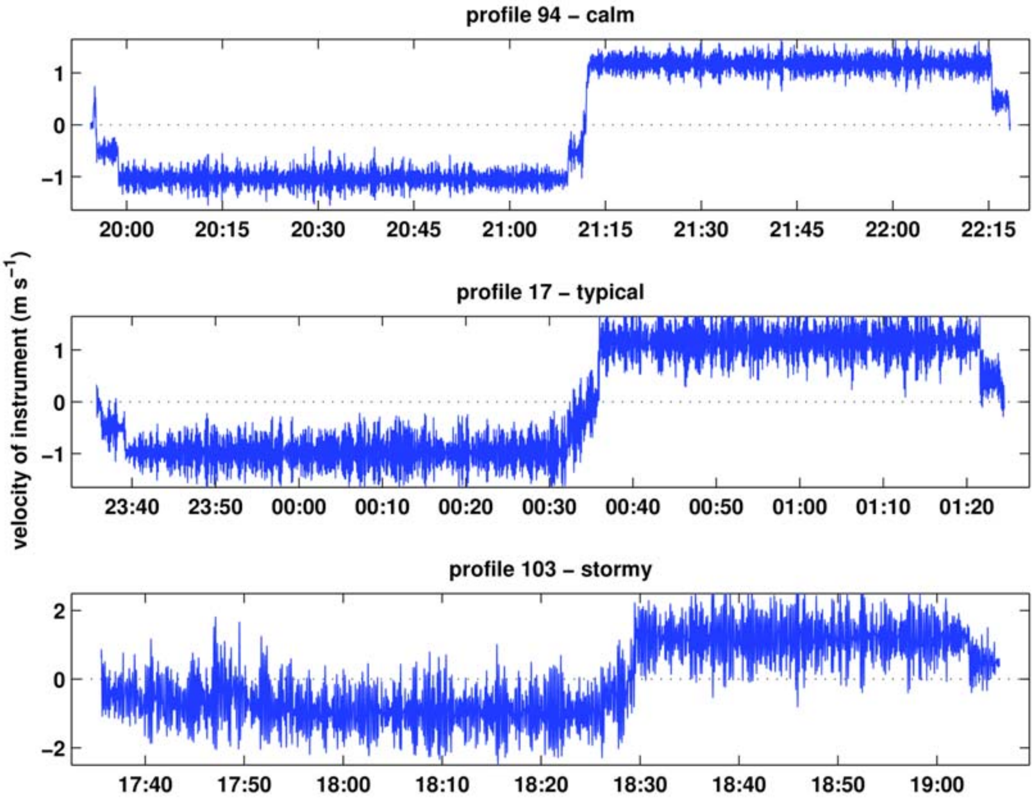


**Fig. 5.10** Vertical velocity [m/s] of the LADCP/CTDO instrument package recorded during calm (top), typical (middle), and stormy, i.e. wavy, conditions (bottom).

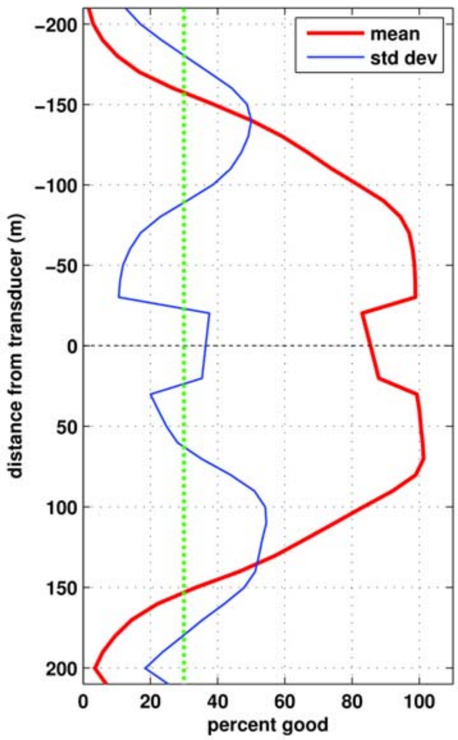


**Fig. 5.11** Percent good of the received data (red) and the corresponding standard deviation (blue) over all four beams from all profiles over all depth levels. The green broken line depicts the 30 % level which was used as the lower threshold.

## 5.4 Performance of Vessel-Mounted Acoustic Doppler Current Profilers

(A. Roessler)

Two vessel-mounted acoustic Doppler current profilers (VMADCP) from *Teledyne RD Instruments* (TRDI) were used simultaneously for continuous recording of single-ping velocity data in the upper water column: a 75 kHz *Ocean Surveyor* (OS) and a 38 kHz OS, both with flat phased-array transducers. The 75 kHz OS was mounted into the hull of the ship, and the 38 kHz instrument was installed in the sea chest of the ship.

Since the VMADCPs do not have any further inbuilt sensors, all additional data on heading and tilt as well as the GPS position were obtained from the ship's *Seapath* system. Recording was carried out with the *TRDI VmDas* software. The measurements were started on May 09$^{th}$ at 17:17 UTC, while the recording of usable data started on May 10$^{th}$ at 11:53 UTC due to some problems with the software settings. Recording stopped on June 19$^{th}$ at 16:00 UTC. All systems operated flawless throughout the cruise, except for three interruptions of one of the three GPS transmission channels. The interruptions occurred when the recording was stopped and restarted to produce a new set of data files. Due to the redundancy of the information these interruptions only resulted in a failure of the standard data conversion and water-track calibration routines in MATLAB, while the data can be opened and analysed with the TRDI WinADCP software without problems. A more thorough investigation is needed to solve this MATLAB coding problem. The corresponding gaps are visible in Figure XX, one on the section between the 48°W/44°W-sections and the second just west of the Mid-Atlantic Ridge on 47°N.

Data of the 38 kHz OS were collected in 32 m bins in narrowband mode to achieve maximum range around 1400 m. The 75 kHz OS was set to a bin length of 16 m in narrowband mode, which resulted in a range around 700 m. Depending on the ship motion and wave activity the maximum ranges were often reduced. This occurred especially during station work, when the instruments were disturbed to a varying degree by the ship's pump jet, which prevented meaningful records or increased the noise level of the measurements, if its outflow of the pump jet hit the instruments transducers. The strongest decrease was found in the 38 kHz OS data during stations with lots of ship movement (up to half of the maximum range) or during the storm experienced near Cape Farewell (temporal complete loss of signal).

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 0.998 and a misalignment angle of -0.89° were obtained for the 38 kHz OS. For the 75 kHz device the amplitude factor and misalignment angle were determined as 0.99 and -3.31°, respectively. These values are nearly the same as in the previous cruise MSM-27 with RV MARIA S. MERIAN.

Data processing was done using the VMADCP-toolbox OSSI for MATLAB, version 14, of the *Geomar Helmholtz Centre for Ocean Research Kiel*. Figure 5.12 shows the velocity structure of the upper ocean (50-100 m), where especially the boundary currents of the Labrador Sea as well as the North Atlantic Current off Flemish Cap, in the Northwest Corner and west of the Mid-Atlantic Ridge stand out.

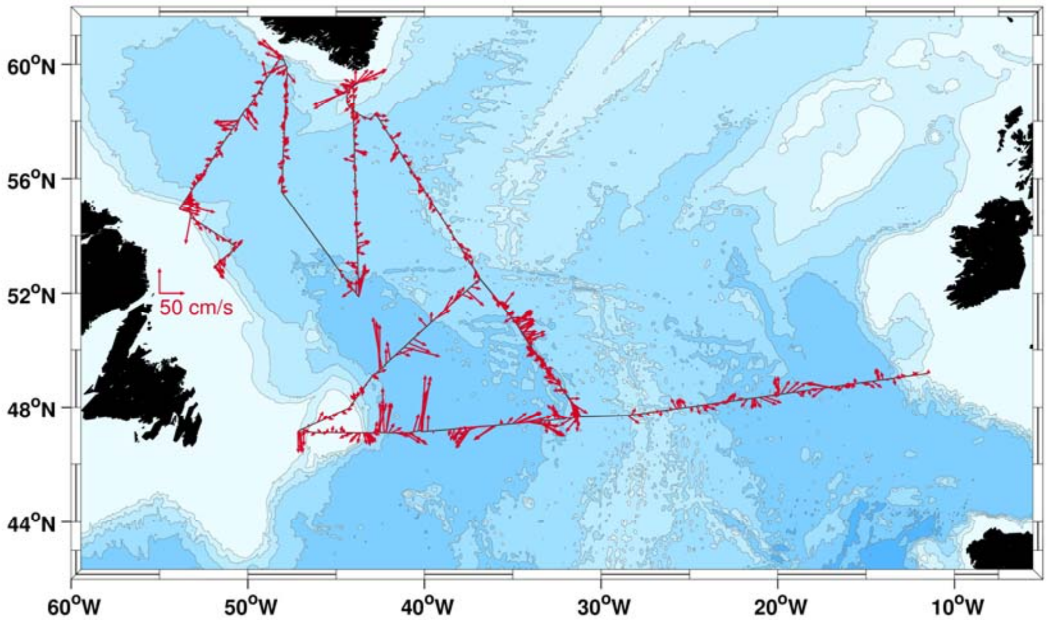


**Fig. 5.12** Mean current velocity and direction averaged over 10 minutes and derived from the merged VMADCP data in the top 50 to 100 m of the water column (plotted once every hour for better visualisation).

## 5.5 Recovery, Deployment, and Acoustic Telemetry of PIES

(A. Roessler)


**Fig. 5.13** Inverted echo-sounder equipped with pressure sensor (PIES, s/n 303) which is fixed on a tripod that serves as a bottom weight. Attached are a flag and a pick-up line that will facilitate retrieval and recovery at the end of its mission. Photo by A. Roessler.

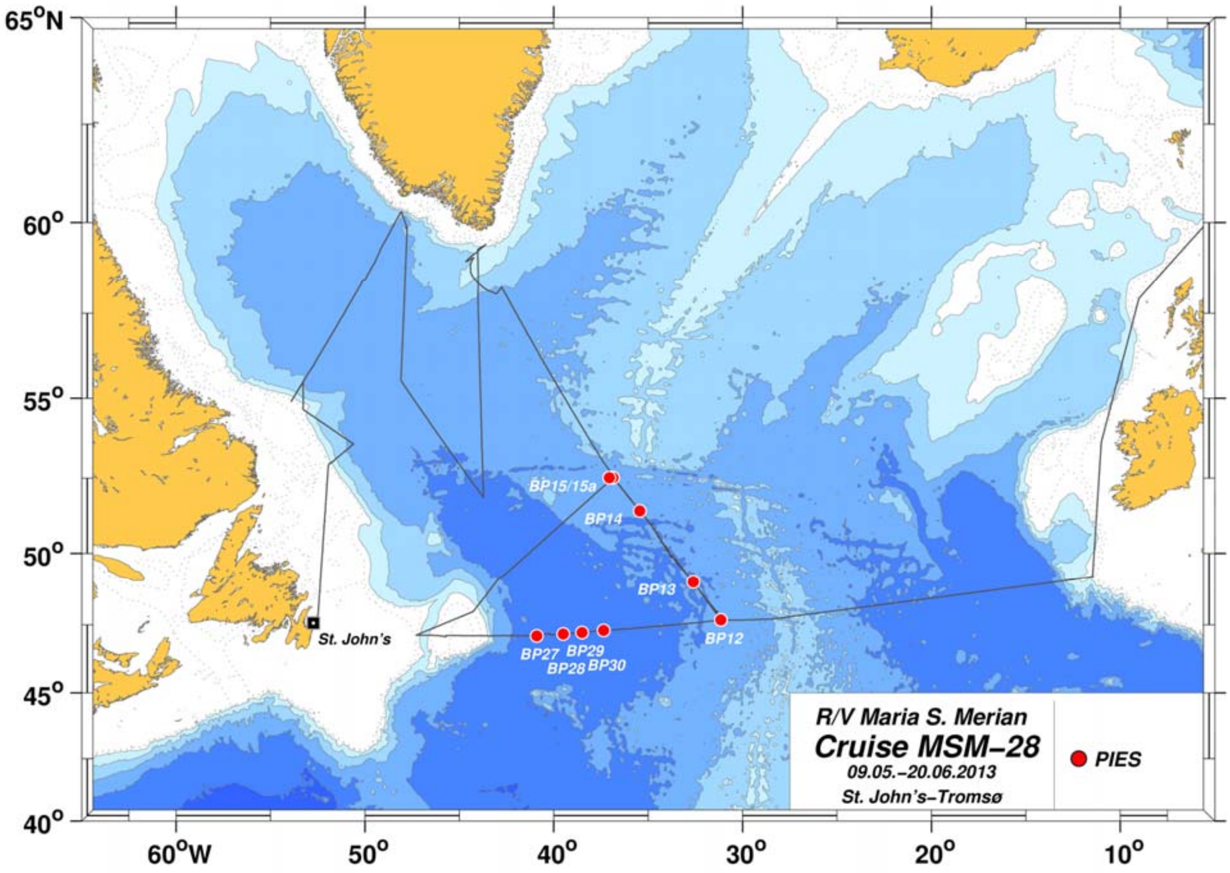


**Fig. 5.14** Map showing the location of inverted echo-sounders equipped with pressure sensors (PIES) that were serviced and/or installed during cruise MSM-28.

Starting in 2006 an array of four inverted echo-sounders equipped with pressure sensors (PIES, Fig. 5.13) was deployed to the west of Mid-Atlantic Ridge (MAR) to estimate the transport variability of the North Atlantic Current (NAC) as it crosses from the western to the eastern basin (BP-12 to BP-15, Figure 5.14). Another previously existing extension along the western part of the 47°N section was re-rigged with new devices at four new locations (BP-27 to BP-30, Fig. 5.14) with the intention to investigate the transport variations of the NAC in the interior of the basin, mainly the re-circulation.

PIES are deployed free-falling and are mounted on a tripod to stand on the sea floor (Fig. 5.13). They measure the acoustic round trip travel time between the acoustic transducer and the sea surface by sending a ping at a frequency of 12 kHz. Every 30 minutes 12 pings are sent, alternating 16 s and 18 s to avoid aliasing by surface waves. The high precision bottom pressure sensor allows the detection of relative bottom pressure variations caused by the water column as it moves across the PIES. The devices are planned to stay on-site for a period of three years and have been configured to allow transmission of recorded data via acoustic telemetry. Acoustically transmitted data consist of daily averages. By recovering the entire instrument and directly reading out the data, the full resolution time series can be retrieved.

Table 5.2 summarises the PIES-related activities carried out during cruise MSM-28. These activities include recovery of one instrument, deployment of five of them, including the recovered PIES and reading out the data of the four installed devices via acoustic telemetry.

| PIES ID | s/n | Latitude | Longitude | Depth [m] | Deployment Date/Time | Telemetry Date/Time | Recovery Date/Time | CTD Profile |
|---|---|---|---|---|---|---|---|---|
| BP-12/4 | 201 | 47°40.11'N | 31°08.95'W | 4090 | --- | 29 May 2013 10:57-13:30 | --- | 355/085 406/136 |
| BP-13/3 | 272 | 49°01.15'N | 32°36.69'W | 3952 | --- | 28 May 2013 17:26-22:06 | 28 May 2013 22:27-23:48 | 354/084 |
| BP-14/2 | 271 | 51°25.70'N | 35°26.33'W | 3604 | --- | 27 May 2013 04:41-07:54 | --- | 351/081 391/121 |
| BP-15/2 | 075 | 52°30.50'N | 36°51.60'W | 3386 | --- | 26 May 2013 03:00-05:38 | --- | 439/079 387/117 |
| BP-15a/1 | 235 | 52°30.48'N | 36°51.63'W | 3386 | 26 May 2013 05:51-06:59 | --- | --- | 349/079 |
| BP-27/1 | 272 | 47°05.84'N | 40°52.53'W | 4498 | 01 Jun 2013 11:23-13:15 | --- | --- | 366/096 |
| BP-28/1 | 240 | 47°09.68'N | 39°30.06'W | 4584 | 31 May 2013 22:26-00:25 | --- | --- | 364/094 |
| BP-29/1 | 302 | 47°12.52'N | 38°31.09'W | 4610 | 31 May 2013 11:39-13:33 | --- | --- | 362/092 |
| BP-30/1 | 303 | 47°17.52'N | 36°21.47'W | 4546 | 31 May 2013 00:25-01:58 | --- | --- | 360/090 |

**Tab. 5.2** List of PIES activities carried out during cruise MSM-28. PIES: Inverted echo-sounder with pressure sensor. All instruments were equipped with flags, radio senders and flashers. All times are given as UTC.

The first telemetric data transmission started on May 26$^{th}$ with the retrieval of the data of PIES BP15-2 from the last year. The ship's hydrophone on the pneumatic extension worked very well, and nearly no interferences were recorded, so it was not necessary to use our own hydrophone which is otherwise hung over the side of the ship and lowered up to 20 m under the ship's hull. All further telemetric data recordings and communication with the devices were done using the ship's hydrophone. Due to noise and bubbles inflicted by the use of the pump jet to keep the ship on position, this year it was just possible at one station (BP-14/2) to read out the data via telemetry while doing at the same time a CTD cast.

After the successful data transmission a second PIES was deployed at the same position (BP-15a/1). The idea of having two devices at this position was based on the knowledge that towards the northern end of the MAR-PIES-array the importance of the barotropic transports increases. This, however, can only be measured by from the pressure variations recorded by the bottom pressure sensor of the PIES. The respective signal is hardly gained via alternative methods. This is in contrast to the baroclinic transports, which are derived from the measured round trip travel times, where eventual data gaps can be reconstructed from satellite altimetry data. Installing two devices with a temporally and spatially overlapping deployment scheme will secure the availability of pressure records at the northern end of the array.

After the deployment it was not possible to measure the exact bottom position of PIES BP-15a/1, because the device did not respond properly to the ranging command. On the other hand, it started the expected half-hourly measurements and transmitted successfully the first measured values via burst-telemetry.

On May 27th the data of the last year was recovered from BP-14/2. This station was the only on where it was possible to start the telemetry session during the CTD cast. The data was transmitted, although the connection was not the best and the gain of the deck unit had to be set 8/9. After the end of the CTD cast and when the pump jet was turned off, the gain could be reduced to 6. The pump jet evoked a strong damping of the transmitted signals at this station.

After the successful telemetric data transmission of PIES BP-13/3 (May 28th), the respective device was recovered since it was intended to be placed at a new location. Data retrieval was done before recovering via. After the release command was sent, the ascend of the PIES was closely followed by recording ping signals every 4 s. Based on the "ascending-y", which consists of the direct ping and the reflected ping on the sea floor, the distance above the sea floor can be determined (Fig. 5.15). After spotting the device at the sea surface, it was recovered within 15 minutes by the ship's crew.

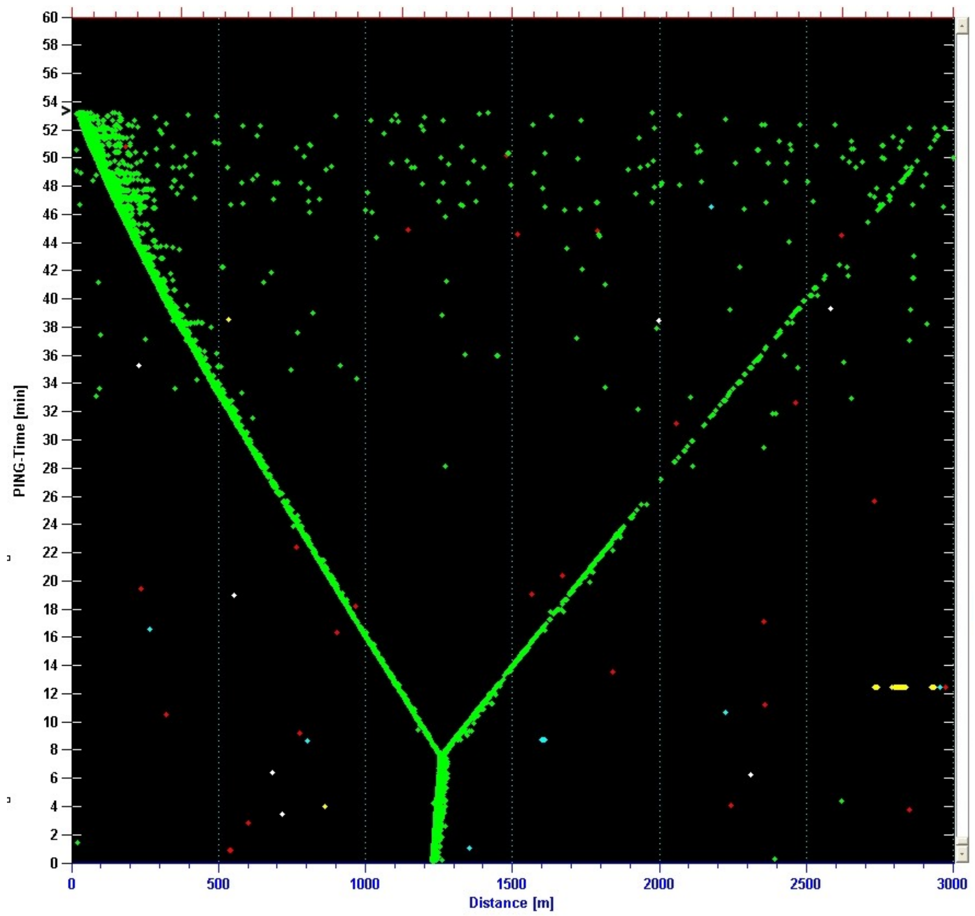


**Fig. 5.15** Output of the PIES data processing software showing the expected "Y" that indicates the ascend of PIES BP-13/3 towards the sea surface after having received the 'release' command and having detached itself from the bottom weight. Green dots indicate 12 kHz acoustic signals.

The last telemetric data transmission session took place on May 29th with the intention to retrieve data recorded by the PIES BP-12/4. The telemetry was also started after the end of the CTD cast, but was twice disturbed from the noise of pilot whales, which were passing by the ship. The disturbances were short enough, so that the telemetry session had not to be halted.

After all these successful telemetry sessions, we turned west to continue our cruise towards Flemish Cap along 47°N to deploy the four remaining devices.

The four PIES locations in the Newfoundland Basin were chosen based on the mean transport computed from LADCP measurements of three previous cruises, to best resolve the recirculation of the NAC at 47°N. The PIES at position BP-30/1 was the first one, which was deployed shortly after midnight on May 31st, while the next two devices (BP-29/1 and BP-28/1) followed around noon and late evening the same day. The last PIES (BP-27/1) was deployed on June 1st. The exact bottom position could only be determined of the latter three, since BP-30/1 showed the same behavior as the newly deployed BP-15a/1 discussed above. The exact position of the instruments on the sea floor has to be determined via trilateration. For this reason, the distance between the PIES and the vessel slowly moving along a hook-like track with the presumable PIES location in the center of the hook, was measured using the *ranging* mode of the PIES. This information was further on used to determine the point of intersection. The three instruments drifted 889 m, 384 m and 680 m during their deployment, respectively.

## 5.6 Mooring Activities

Mooring activity during *MSM-28* consisted of recovering and redeploying an array of deep-sea moorings to the west of the Mid-Atlantic Ridge (MAR, BMBF-funded project RACE) and installing a current meter mooring in Flemish Pass (DFG-funded project FLEPVAR).

### 5.6.1 Mid-Atlantic Ridge Moorings

(C. Denker)

| Mooring ID | Latitude | Longitude | Depth [m] | Deployment Date/Time | Recovery Date/Time | CTD Profile |
|---|---|---|---|---|---|---|
| GFZ/1 | 52°35.00'N | 36°56.00'W | 3269 | --- | 26 May 2013<br>09:20 – 12:52 | 350/080 |
| GFZ/2 | 52°35.00'N | 36°56.00'W | 3269 | 26 May 2013<br>16:09 – 19:35 | --- | 350/080 |
| FFZ-1/4 | 50°58.35'N | 34°51.00'W | 4327 | --- | 27 May 2013<br>11:15 – 15:03 | 352/082 |
| FFZ-1/5 | 50°58.35'N | 34°51.00'W | 4335 | 07 Jun 2013<br>06:57 – 11:37 | --- | 393/123 |
| FFZ-2/4 | 49°55.66'N | 33°49.66'W | 4194 | --- | 28 May 2013<br>06:45 – 10:45 | 353/083 |
| FFZ-2/5 | 49°55.01'N | 33°49.90'W | 4030 | 08 Jun 2013<br>07:02 – 11:03 | --- | 398/128 |
| MFZ/1 | 47°59.99'N | 31°24.99'W | 4020 | 09 Jun 2013<br>07:02 – 11:03 | --- | 405/135 |

**Tab. 5.3.** Moorings deployed/recovered at the Mid-Atlantic Ridge. All times are given as UTC. All recovered moorings were equipped with *Iridium* beacons and flags. GFZ/2 was also deployed with an attached *Iridium* beacon.

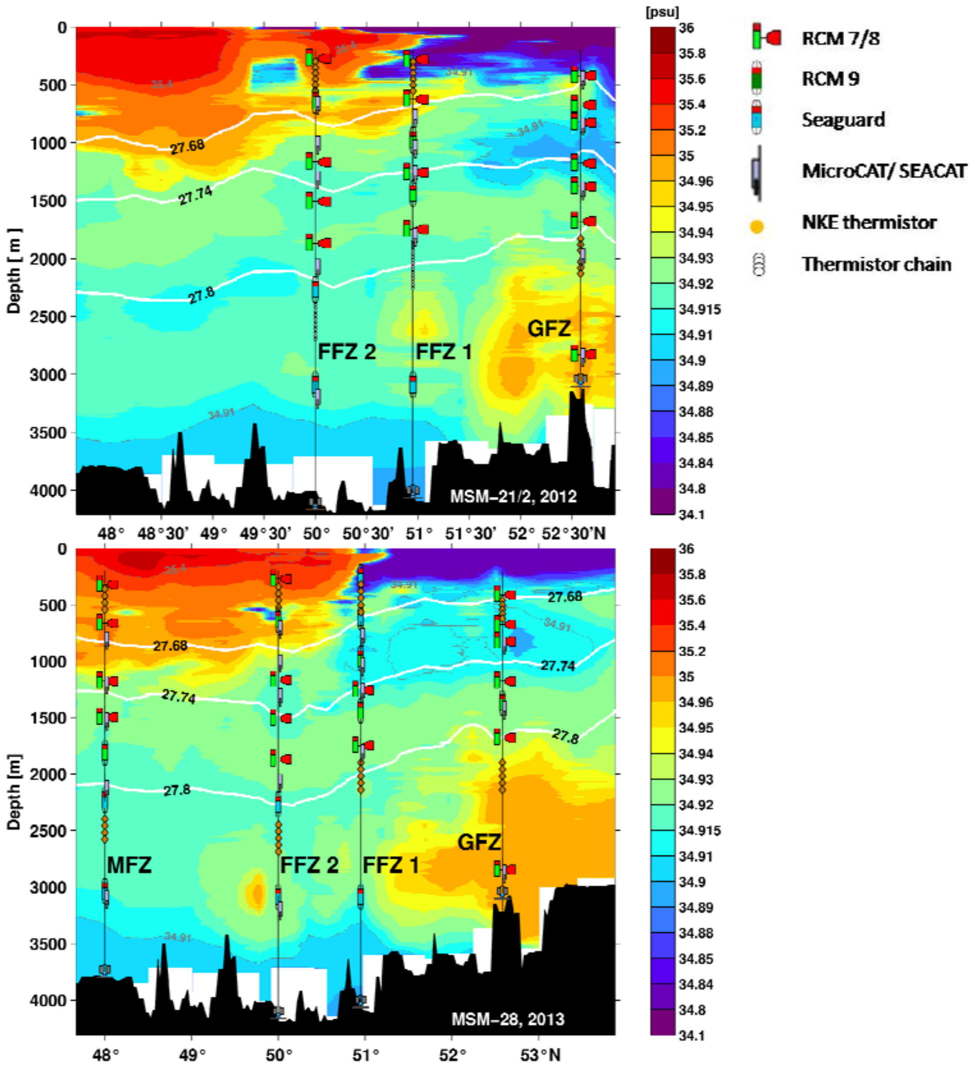


**Fig. 5.16** Array-design of deep-sea moorings installed at the Mid-Atlantic Ridge in 2012/2013 and recovered during cruise MSM-28 (top) and moorings deployed along the same line in summer 2013 (bottom).

### 5.6.1.1 Instrumentation

All recovered moorings were equipped with an *Iridium* beacon attached to the top buoy. These beacons use an *Iridium Short Burst Data* (SBD) mode for transmitting positional information at defined intervals. Below the surface the beacon sits in a stand-by (underwater) mode for energy efficiency. There was one *Iridium* beacon at each mooring (GFZ/1, FFZ1/4, and FFZ-2/4). The beacons at GFZ/1 and FFZ-1/4 did not send any information due to an empty battery. The beacon at FFZ-2/4 was still in the underwater mode during the recovery but while on deck the beacon sent the positional information after waking up from its underwater mode. One beacon got a new battery pack and was attached to the new mooring (GFZ/2). The housing of the other two beacons was damaged and was later on sent in for repair.

Each mooring is equipped with 18 – 21 instruments to measure the temperature, conductivity, pressure, current velocity, and direction along the water column. The instruments are attached to the wire between 300m and 3100m depth.

The *NKE* thermistors have temperature and pressure sensors that measure in a five minute sampling interval. The temperature precision is ±0.05°C in a 0°C/20°C range with a maximum resolution of 0.01°C. The ceramic membrane pressure sensor has a precision of 12m (0.3%) and a resolution of 1.2m.

*AADI* Aanderaa Recording Current Meters (RCM 7/8/9 and Seaguards) measure speed, direction, temperature, and pressure (optional) in a 60 minutes sampling interval. The accuracy of the temperature sensor is ±0.05°C, of the optional pressure sensor ±0.5% of the full range, the resolution of the compass is 0.35° and its accuracy ±5°, and the precision of the speed sensor is ±1 cm/s.

SBE (*Sea-Bird Electronics*) 37-SM MicroCATs were programmed to measure the temperature, conductivity, and pressure (optional) in a five minute sampling interval. Their accuracies are 0.0003 S/m for the conductivity sensor, 0.002°C for the temperature sensor, and 0.1% of full scale range for the optional pressure sensor.

SBE 16plus V2 SEACATs measure the same parameters as MicroCATs but due to their high battery consumption and smaller memory space they were programmed to measure in a 30 minute sampling interval. The conductivity sensor of a SEACAT has an accuracy of 0.0005 S/m, the temperature sensor 0.005°C, and the optional pressure sensor 0.1% of full scale range.

#### 5.6.1.2 Calibration

Before their deployment the 10 SEACATs were strapped onto the water sampler unit carrying a CTD sensor package for calibration (station 306, profile #36; station 311, #41). The water sampler was stopped at 3000dbar, 2000dbar, 1000dbar, and 500dbar for 10 minutes at each depth. Instruments were programmed to measure in a 15 seconds interval. The mean temperature offset was around ±1.3e-3°C. The conductivity sensor had an offset of about ±1.32e-1 S/m. The one SEACAT with a pressure sensor had an offset of ±1.25 dbar.

The recovered 14 MicroCATs and 17 NKE thermistors have also been strapped onto a CTD water sampler unit for calibration (station 384, profile # 114). The sampling interval was set to 10 seconds. The CTD was stopped four times (3500dbar, 3000dbar, 2000dbar, and 1000dbar) for 10 minutes.

The mean calculated offsets for the MicroCATs are about ±4.5e-4°C for the temperature sensor, around ±2.7dbar for the pressure sensor, and about ±4.1e-4 S/m for the conductivity sensor.

The mean calculated offset for the NKE thermistors is around ±7.7e-3°C for the temperature sensor. One of the NKE thermistors (s/n 32018) had a malfunction and wasn't included in the calculation of the mean offset.

#### 5.6.1.3 Recovery and redeployment

The first mooring to be recovered was the northern GFZ mooring on May 26$^{th}$. The release code was sent at 09:35 UTC. The *IXSEA OCEANO* deck unit did not detect a response from the release devices. Next to the *IXSEA* deck unit the *Benthos DS7000* deck unit connected to the ship's hydrophone was used to listen for any responds of the acoustic release. The *Benthos* deck unit was able to detect the ping signals and was able to follow their way up towards the surface.

Ten minutes after the first release code was sent the top buoy was seen at the surface. The *Iridium* beacon did not send any information about its position. At 12:45 UTC the mooring was recovered completely. All 18 instruments (seven current meters, five MicroCATs, and six NKE thermistors) worked properly.

At 19:53 UTC the GFZ mooring had been redeployed at 3270m depth equipped with seven current meters, three SEACATs, and ten *NKE* thermistors.

On May 27th at 11:25 UTC the release code for mooring FFZ-1 was sent. After five minutes the top buoy was seen at the surface and at 15:03 UTC the mooring was back on deck. The mooring included 18 instruments (seven current meters, four MicroCATs, six *NKE* thermistors, and one thermistor chain). During the recovery one of the *NKE* thermistors (s/n 32013) was loose and couldn't be recovered. Two current meters (RCM9: s/n 309 and RCM7: s/n 11995) had a water leak which destroyed all data. Due to battery loss another current meter (Seaguard s/n 243) stopped recording on March 9th, 2013.

Mooring FFZ-1 was redeployed on June 7th at 11:37 UTC (top buoy drawn under surface) with 21 instruments (seven current meters, four SEA-/ MicroCATs, and ten *NKE* thermistors) which will record data for the next 12 month.

The recovery of mooring FFZ-2 took place at May 28th. 10 minutes after the release code was sent (06:44 UTC), the top buoy was discovered at the surface. The beacon at the top buoy had not sent any signals until it was back on deck. At 10:45 UTC the mooring was completely recovered. The mooring FFZ-2 was equipped with 19 instruments (seven current meters, five MicroCATs, six NKE thermistors, and one thermistor chain).

One current meter (Seaguard s/n 104) did not record any data due to an empty battery. The other Seaguard (s/n 242) stopped recording on March 9th, 2013 due to a battery failure. The thermistor chain got a water leak which damaged all data.

The redeployment of mooring FFZ-2 was on June 8th. The top buoy left the surface at 11:03. The mooring contains 21 instruments (seven current meters, five SEA-/ MicroCATs, and nine NKE thermistors).

A fourth mooring (MFZ) was placed at the western entrance of the Maxwell Fracture Zone. It was deployed on June 9th at 21:32 UTC, equipped with 20 instruments (seven current meters, five SEA-/ MicroCATs, and eight *NKE* thermistors).

The GFZ is the only mooring which is equipped with an Iridium beacon for the upcoming period. Due to mentioned failures and some connection problems the other Iridium beacons will be sent in for repair.

### 5.6.2 Deep Western Boundary Current Moorings

(D. Kieke)

Originally, it was intended to re-install the array of deep-sea moorings in the Deep Western Boundary Current (DWBC) east of Flemish Cap. These moorings were recovered during the previous cruise *MSM-27* with RV Maria s. Merian. However, one out of three moorings could not be recovered during cruise *MSM-27* and consequently was considered lost. Instruments and material of the two recovered moorings showed considerable traces of material corrosion. For this reason the redeployment of the DWBC-array was canceled, but instead the entire mooring equipment was sent to Bremen for detailed inspection and instrument refurbishment.

### 5.6.3 Flemish Pass Moorings

(D. Kieke)

| Mooring ID | Latitude | Longitude | Depth [m] | Deployment Date/Time | CTD Profile |
|---|---|---|---|---|---|
| BM-25/2 | 47°07.11'N | 47°06.38'W | 1014 | 03 Jun 2013<br>16:54 – 17:10 | 378/108 |

**Tab. 5.4** Overview of Flemish Pass mooring activities conducted during cruise MSM-28. All times are given as UTC. The mooring was equipped with two radio beacons, two flashers, and a flag.

As part of the DFG-funded project FLEPVAR, one mooring (BM-25/2) was deployed on the western side of Flemish Pass on June 03rd. Originally, it was intended to install another mooring in the center of Flemish Pass and occupy the location of the mooring BM-26/1, previously recovered during cruise MSM-27, once again. Due the loss of instruments installed in the DWBC, any acoustic release device could no longer be provided. Therefore, just one mooring, consisting of an Acoustic Doppler Current Profiler (ADCP) of type *Longranger*, an SBE-MicroCAT, buoyancy, and one acoustic release was installed. After consulting Canadian cooperation partners, the group around B. Greenan (Bedford Institute of Oceanography, Dartmouth, Canada), deployed a second current meter mooring at 47°N in the Labrador Current passing through Flemish Pass. Deployment was carried out in June 2013 during a Canadian research cruise with RV HUDSON, so, presently, the Flemish Pass array consists of two moorings again.

## 5.7 Deployment of Profiling Floats

(C. Denker)

All floats were equipped with *SBE* sensors for pressure, temperature, and conductivity. The respective floats were programmed to drift for 10 days at a fixed pressure of 1500 dbar. From this parking depth the floats will descend down to a profiling pressure of 2000 dbar before rising and collecting profiles of pressure, temperature, and conductivity on their way to the surface. At the surface they will transmit the collected data via satellite. After finishing their transmission the floats will descend to its parking depth, and the profile cycle starts all over again. The floats have a typical life time of around four years. All data is usually available within hours after collection from the *Argo* data centers. Table 5.5 lists all APEX floats, Figure 5.17 shows the deployment positions.

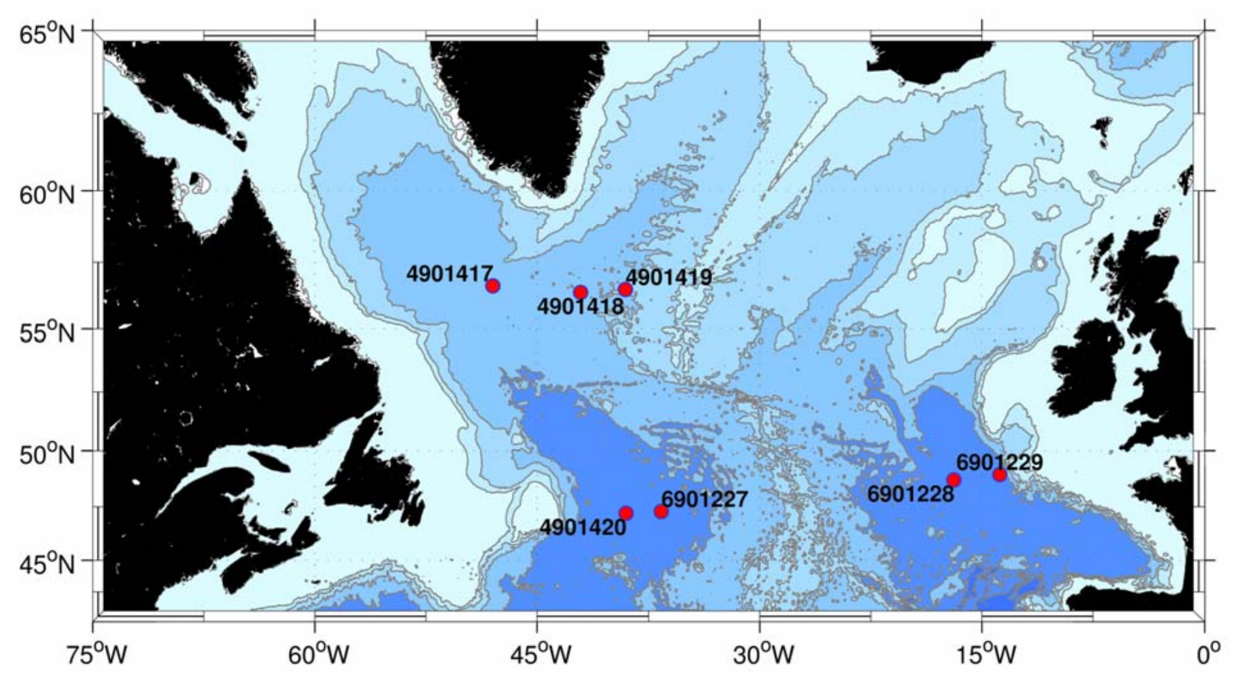


**Fig. 5.17** Map showing the location of deployed Argo-floats. Numbers indicate WMO-numbers.

| Float s/n | WMO-ID | Argos-ID | Latitude | Longitude | Deployment Date/Time | CTD-Profile |
|---|---|---|---|---|---|---|
| 6655 | 4901417 | 128461 | 56°36.65'N | 48°00.75'W | 16 May 2013 23:14 | 307/037 |
| 6656 | 4901418 | 124862 | 56°22.39'N | 43°56.16'W | 20 May 2013 23:26 | 326/056 |
| 6657 | 4901419 | 128463 | 56°29.51'N | 40°57.48'W | 24 May 2013 05:24 | 339/069 |
| 6658 | 4901420 | 128464 | 47°11.18'N | 39°00.49'W | 31 May 2013 18:03 | 363/093 |
| 6659 | 6901227 | 128465 | 47°17.57'N | 37°21.38'W | 31 May 2013 02:22 | 360/090 |
| 6660 | 6901228 | 128466 | 48°42.67'N | 17°05.72'W | 13 Jun 2013 03:22 | 416/146 |
| 6661 | 6901229 | 128467 | 48°57.45'N | 14°13.33'W | 13 Jun 2013 18:45 | 418/148 |

**Tab. 5.5** Argo-floats deployed during cruise MSM-28. All times are given as UTC.

Float-related activities conducted during cruise *MSM-28* consisted of seven profiling floats of type APEX deployed on behalf of the BSH. They were deployed along the cruise track with a regional focus on the western and eastern subpolar North Atlantic. The float deployments contribute to the international *Argo* program. *Argo* is a global array of free-drifting profiling floats.

# 6 Underway Measurements

(D. Kieke)

Underway measurements carried out during cruise *MSM-28* by RV MARIA S. MERIAN were logged in time steps of 1 second by the vessel's *Davis-Ship* system (DSHIP). Acquired data of interest included navigational information, near surface hydrography (temperature, conductivity, and thus salinity) measured by the vessel's thermosalinograph (TSG) or the automatic weather station operated by the German Weather Service (DWD) (water temperature only), water sounding data recorded by the echo-sounder system as well as further meteorological parameters recorded by the weather station. All underway data relevant to this cruise were exported from the database on a daily basis and converted into *MATLAB*-readable netCDF-files.

## 6.1 Meteorological Data

Meteorological parameters were recorded by the automatic weather station aboard RV MARIA S. MERIAN, operated by the DWD. Noteworthy meteorological conditions were snowfall in the western Labrador Sea (May 11$^{th}$/12$^{th}$) and several storm situations with peak absolute wind speeds exceeding 20 m/s (9-12 Beaufort) on May 22$^{nd}$, June 02$^{nd}$, June 12$^{th}$, and June 14$^{th}$. Meteorological conditions and sea surface state particularly hampered station work to the south of Kap Farvel at the southern tip of Greenland (May 22$^{nd}$/23$^{rd}$). Consequently, station work had to be interrupted by one day and the section crossing the Irminger Sea in southeast direction was not started until reaching the 3000m isobaths (Fig. 3.1, Chapter 7). Shallower casts, therefore, could not be carried out. High wind and sea state conditions also affected hydrographic station work when crossing the DWBC east of Flemish Cap (June 02$^{nd}$) as well as crossing the West European Basin (June 12$^{th}$ and 14$^{th}$). Atmospheric pressure was in general variable and ranged from about 1000 hPa to 1030 hPa. Atmospheric temperatures ranged from -2°C (recorded during snow fall in the western Labrador Sea) to up to +16°C. Figure 6.1 presents time series of the major meteorological parameters recorded by the automatic weather station.

## 6.2 Thermosalinograph Data

Thermosalinograph (TSG) data were recorded by respective sensors integrated into the vessel's clean seawater system installed in the vessel's echosounder room. Two water suction points exist at a water depth of about 6.2 to 6.8m. The flow rate measurement system consists of two seawater measurement containers, with one being active at a time and the second one being on stand-by. Use of containers typically switches after 12 hours. Throughout the cruise, twice a day seawater samples were drawn by the ship's staff from the two different seawater containers. These samples were measured onboard using a salinometer of type *Guildline Autosal*, model 8400A. At the end of the cruise respective salinometer and TSG data was sent by the ship's officers to the IfM-ZMAW in Hamburg, where the quality of the TSG data of RV MARIA S. MERIAN is checked on a routine basis. Figure 6.2 shows a first and preliminary comparison of raw TSG data and calibrated CTD values recorded at 6 dbar, which matches about the depth of the water inlet point.

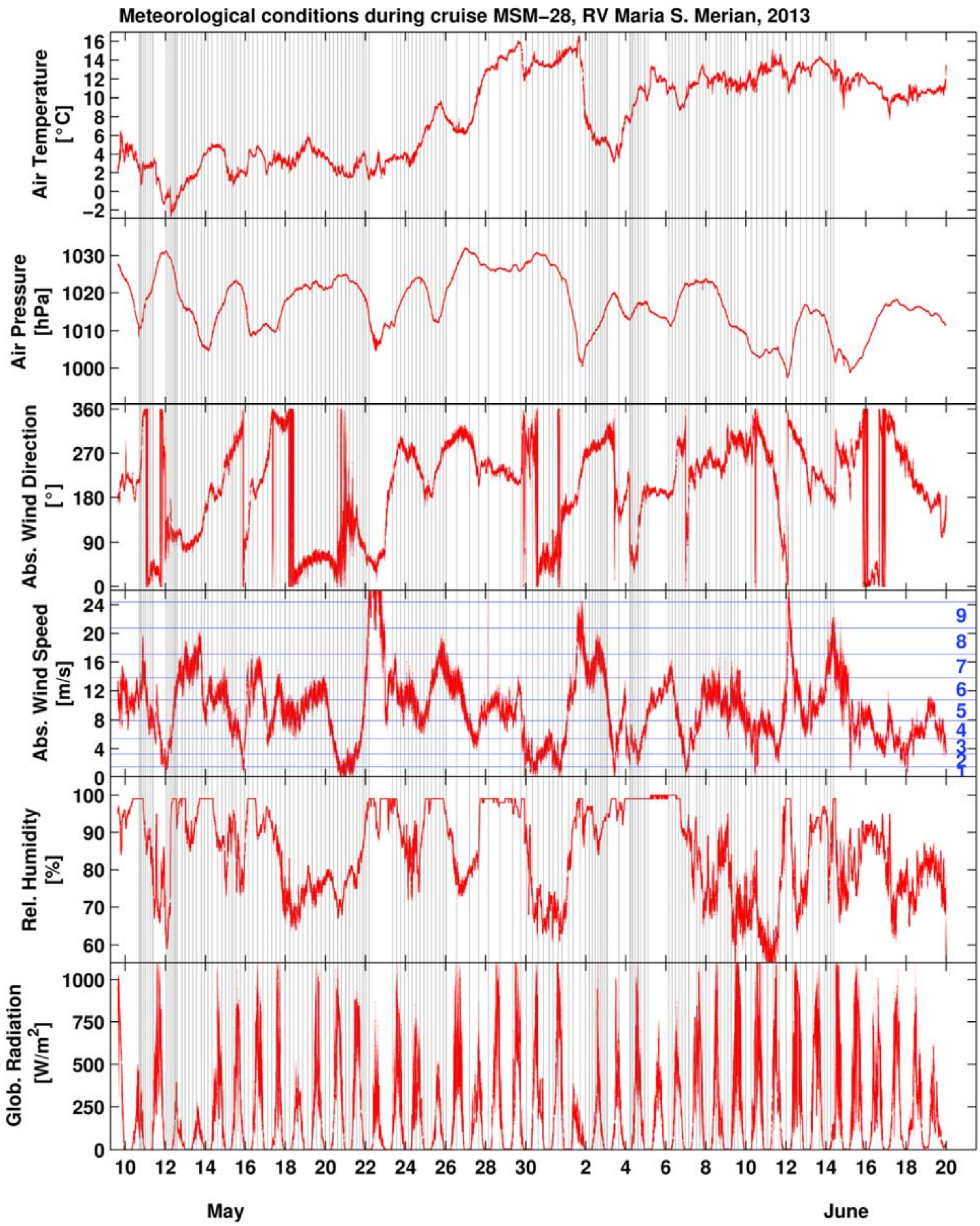


**Figure 6.1.** Meteorological conditions observed during May 09th to June 20th, 2013, cruise *MSM-28*. Gray thin lines denote the beginning of CTD station activities, blue horizontal lines and scale on the right side of the figure indicate absolute wind speeds reported on the Beaufort scale.

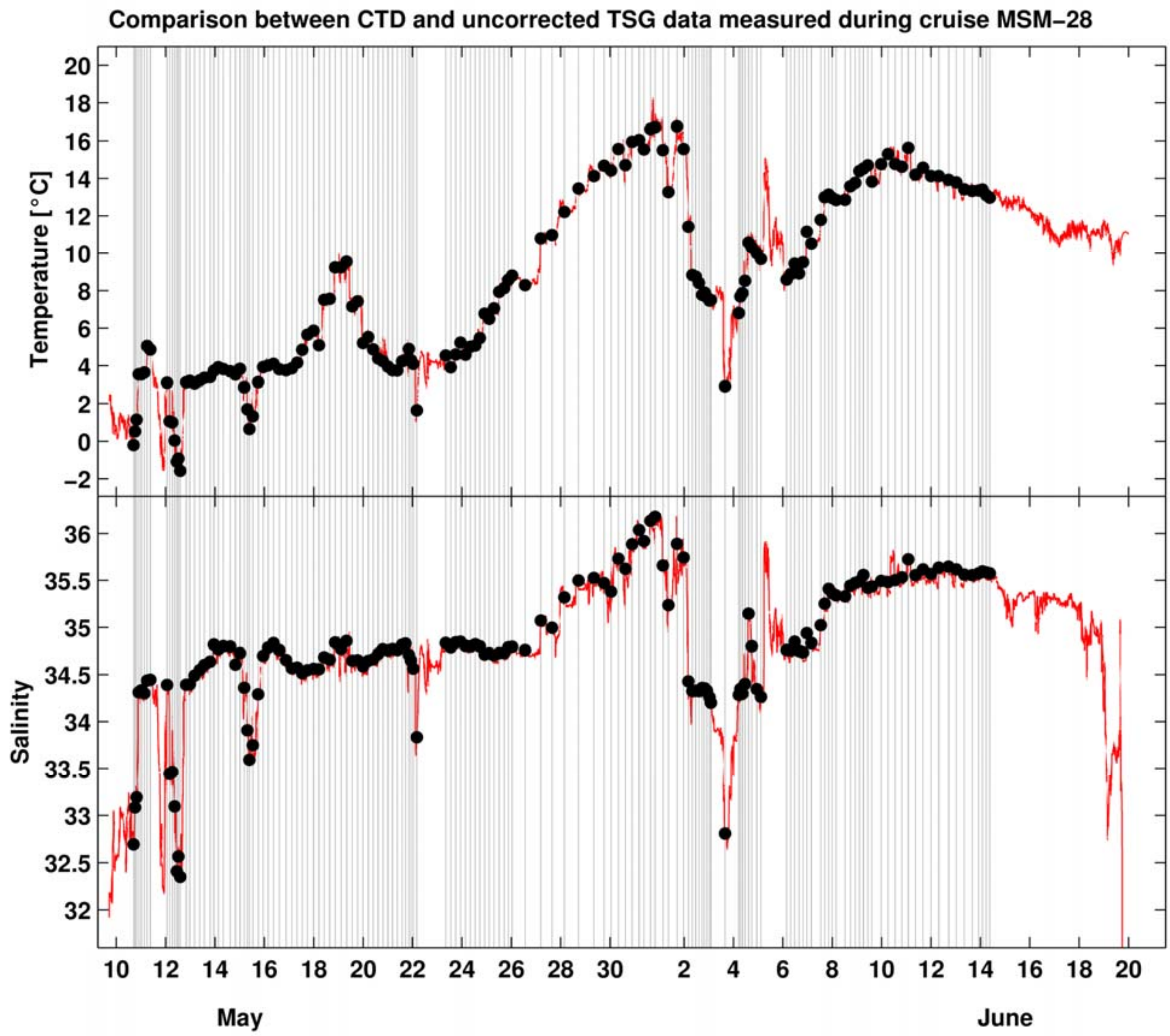


**Figure 6.2.** Comparison of raw TSG data (red lines) recorded during cruise MSM-28 by RV MARIA S. MERIAN and calibrated CTD values recorded at 6 dbar (black dots). Gray thin lines denote the beginning of CTD station activities. High salinity/temperature events e.g. recorded on May 31st and June 01st denote those situations when the warm and saline North Atlantic Current was crossed, low salinity/temperature events indicate the crossing of the fresh and cold Labrador Current on the western side of the subpolar North Atlantic.

## 7 Station List MSM-28

| Station | Profile | Date | Time | Latitude | Longitude | Water Depth [m] | Max. Pressure [dbar] | SF6/ CFC-12 | CFC Offline | Noble Gases & Tritium | Bottle Oxygen | Bottle Salinity | LADCP | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MSM-271 | 1 | 2013/05/10 | 16:52 | 52°54.82'N | 51°56.15'W | 453 | 446 | - | - | - | x | | x | |
| MSM-272 | 2 | 2013/05/10 | 18:07 | 52°58.74'N | 51°49.79'W | 998 | 1009 | x | x | - | x | | x | |
| MSM-273 | 3 | 2013/05/10 | 19:41 | 53°01.46'N | 51°42.83'W | 1449 | 1376 | x | x | - | x | | x | |
| MSM-274 | 4 | 2013/05/10 | 21:49 | 53°08.23'N | 51°29.60'W | 2104 | 2092 | x | x | - | x | | x | |
| MSM-275 | 5 | 2013/05/11 | 00:21 | 53°14.92'N | 51°16.20'W | 2655 | 2647 | x | x | - | x | | x | |
| MSM-276 | 6 | 2013/05/11 | 03:10 | 53°21.61'N | 51°02.89'W | 2943 | 2936 | x | x | - | x | | x | |
| MSM-277 | 7 | 2013/05/11 | 06:00 | 53°28.34'N | 50°49.47'W | 3090 | 3091 | x | x | - | x | | x | |
| MSM-278 | 8 | 2013/05/11 | 09:01 | 53°35.09'N | 50°36.21'W | 3279 | 3269 | x | x | - | x | | x | |
| MSM-279 | 9 | 2013/05/12 | 01:18 | 55°30.47'N | 53°15.61'W | 3030 | 3013 | x | - | - | x | | x | |
| MSM-280 | 10 | 2013/05/12 | 03:57 | 55°22.46'N | 53°22.38'W | 2949 | 2933 | x | - | - | x | | x | |
| MSM-281 | 11 | 2013/05/12 | 06:28 | 55°16.91'N | 53°30.17'W | 2660 | 2652 | x | - | - | x | | x | |
| MSM-282 | 12 | 2013/05/12 | 08:46 | 55°10.85'N | 53°36.10'W | 2091 | 2085 | x | - | - | x | | x | |
| MSM-283 | 13 | 2013/05/12 | 10:48 | 55°05.66'N | 53°42.26'W | 1570 | 1564 | x | - | - | x | | x | |
| MSM-284 | 14 | 2013/05/12 | 12:26 | 55°01.29'N | 53°46.85'W | 1100 | 1081 | x | - | - | x | | x | |
| MSM-285 | 15 | 2013/05/12 | 14:05 | 54°54.41'N | 53°54.29'W | 451 | 442 | x | - | - | x | | x | |
| MSM-286 | 16 | 2013/05/12 | 19:52 | 55°46.13'N | 52°58.71'W | 3166 | 3156 | x | - | - | x | | x | |
| MSM-287 | 17 | 2013/05/12 | 23:30 | 55°58.27'N | 52°44.09'W | 3325 | 3305 | x | - | - | x | | x | |
| MSM-288 | 18 | 2013/05/13 | 04:09 | 56°17.51'N | 52°24.56'W | 3534 | 3517 | x | - | - | x | | x | |
| MSM-289 | 19 | 2013/05/13 | 09:03 | 56°40.12'N | 52°00.23'W | 3538 | 3526 | x | - | - | x | | x | |
| MSM-290 | 20 | 2013/05/13 | 13:37 | 57°00.29'N | 51°38.30'W | 3542 | 3530 | x | - | - | x | | x | |
| MSM-291 | 21 | 2013/05/13 | 19:08 | 57°27.40'N | 51°09.13'W | 3510 | 3491 | x | - | x | x | | x | |
| MSM-292 | 22 | 2013/05/13 | 22:53 | 57°42.46'N | 50°53.00'W | 3595 | 3583 | x | - | - | x | | x | |
| MSM-293 | 23 | 2013/05/14 | 03:07 | 58°01.08'N | 50°32.63'W | 3550 | 3537 | - | x | - | x | | x | |
| MSM-294 | 24 | 2013/05/14 | 08:05 | 58°25.72'N | 50°05.83'W | 3530 | 3516 | - | x | - | x | | x | |
| MSM-295 | 25 | 2013/05/14 | 14:52 | 58°53.47'N | 49°30.95'W | 3457 | 3443 | x | x | - | x | | x | |
| MSM-296 | 26 | 2013/05/14 | 19:48 | 59°19.65'N | 49°07.31'W | 3348 | 3335 | x | - | - | x | | x | |
| MSM-297 | 27 | 2013/05/15 | 00:19 | 59°44.35'N | 48°40.43'W | 3177 | 3168 | x | - | - | x | | x | |
| MSM-298 | 28 | 2013/05/15 | 04:17 | 60°02.24'N | 48°21.04'W | 2881 | 2872 | x | - | - | x | | x | |

| Station | Profile | Date | Time | Latitude | Longitude | Water Depth [m] | Max. Pressure [dbar] | SF6/ CFC-12 | CFC Offline | Noble Gases & Tritium | Bottle Oxygen | Bottle Salinity | LADCP | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MSM-299 | 29 | 2013/05/15 | 07:23 | 60°13.70'N | 48°09.30'W | 2980 | 1414 | x | - | x | x | | x | |
| MSM-300 | 30 | 2013/05/15 | 09:24 | 60°16.86'N | 48°03.03'W | 537 | 516 | x | - | x | x | | x | |
| MSM-301 | 31 | 2013/05/15 | 12:43 | 59°51.16'N | 47°45.80'W | 2829 | 2818 | - | - | - | x | | x | |
| MSM-302 | 32 | 2013/05/15 | 18:00 | 59°18.77'N | 47°48.26'W | 3066 | 3059 | - | - | - | x | | x | |
| MSM-303 | 33 | 2013/05/15 | 22:45 | 58°46.40'N | 47°50.77'W | 3210 | 3198 | x | - | - | x | | x | |
| MSM-304 | 34 | 2013/05/16 | 03:38 | 58°14.00'N | 47°53.32'W | 3364 | 3354 | x | - | - | x | | x | |
| MSM-305 | 35 | 2013/05/16 | 08:54 | 57°41.64'N | 47°55.72'W | 3315 | 3305 | x | - | - | x | | x | |
| MSM-306 | 36 | 2013/05/16 | 14:28 | 57°09.22'N | 47°58.24'W | 3502 | 3490 | x | - | - | x | | x | SEACAT calibration |
| MSM-307 | 37 | 2013/05/16 | 21:07 | 56°36.77'N | 48°00.69'W | 3646 | 3633 | x | - | - | x | | x | |
| MSM-308 | 38 | 2013/05/17 | 02:37 | 56°04.40'N | 48°03.20'W | 3636 | 3627 | x | - | - | x | | x | |
| MSM-309 | 39 | 2013/05/17 | 07:53 | 55°31.96'N | 48°05.67'W | 3409 | 3385 | x | - | - | x | | x | |
| MSM-310 | 40 | 2013/05/17 | 12:41 | 55°04.52'N | 47°32.83'W | 3541 | 3531 | x | - | - | x | | x | |
| MSM-311 | 41 | 2013/05/17 | 17:52 | 54°37.10'N | 47°00.05'W | 3534 | 3526 | x | - | - | x | | x | SEACAT calibration |
| MSM-312 | 42 | 2013/05/17 | 23:47 | 54°09.60'N | 46°27.23'W | 3494 | 3486 | x | - | - | x | | x | |
| MSM-313 | 43 | 2013/05/18 | 04:59 | 53°42.12'N | 45°54.42'W | 3706 | 3702 | x | - | - | x | | x | |
| MSM-314 | 44 | 2013/05/18 | 10:03 | 53°14.66'N | 45°21.59'W | 3994 | 3988 | - | x | - | x | | x | |
| MSM-315 | 45 | 2013/05/18 | 15:28 | 52°47.18'N | 44°48.72'W | 3981 | 3968 | x | - | - | x | | x | |
| MSM-316 | 46 | 2013/05/18 | 20:49 | 52°19.75'N | 44°15.99'W | 4163 | 4159 | x | - | - | x | | x | |
| MSM-317 | 47 | 2013/05/19 | 02:34 | 51°52.32'N | 43°43.14'W | 4195 | 4193 | x | - | - | x | | x | |
| MSM-318 | 48 | 2013/05/19 | 07:51 | 52°22.99'N | 43°44.62'W | 4169 | 4166 | x | - | - | x | | x | |
| MSM-319 | 49 | 2013/05/19 | 13:20 | 52°53.65'N | 43°46.17'W | 3744 | 3739 | x | - | - | x | | x | |
| MSM-320 | 50 | 2013/05/19 | 18:41 | 53°24.30'N | 43°47.65'W | 4042 | 3629 | x | - | - | x | | x | |
| MSM-321 | 51 | 2013/05/19 | 23:49 | 53°54.65'N | 43°49.14'W | 3930 | 3598 | x | - | - | x | | x | |
| MSM-322 | 52 | 2013/05/20 | 04:58 | 54°25.65'N | 43°50.63'W | 3475 | 3467 | x | - | - | x | | x | |
| MSM-323 | 53 | 2013/05/20 | 09:48 | 54°56.34'N | 43°52.08'W | 3398 | 3390 | x | - | - | x | | x | |
| MSM-324 | 54 | 2013/05/20 | 14:35 | 55°26.98'N | 43°53.62'W | 3283 | 3275 | x | - | - | x | | x | |
| MSM-325 | 55 | 2013/05/20 | 19:07 | 55°57.65'N | 43°55.11'W | 3346 | 3337 | x | - | - | x | | x | |
| MSM-326 | 56 | 2013/05/21 | 00:06 | 56°28.32'N | 43°56.60'W | 3354 | 3346 | x | - | - | x | | x | |
| MSM-327 | 57 | 2013/05/21 | 04:36 | 56°59.00'N | 43°58.07'W | 3439 | 3429 | x | - | - | x | | x | |
| MSM-328 | 58 | 2013/05/21 | 09:09 | 57°29.65'N | 43°59.59'W | 3429 | 3417 | - | x | - | x | | x | |
| MSM-329 | 59 | 2013/05/21 | 13:50 | 58°00.38'N | 44°01.08'W | 3062 | 3050 | x | - | - | x | | - | severe ADCP compass problems |
| MSM-330 | 60 | 2013/05/21 | 17:07 | 58°15.64'N | 43°59.96'W | 2561 | 2549 | x | - | - | - | | x | |

| Station | Profile | Date | Time | Latitude | Longitude | Water Depth [m] | Max. Pressure [dbar] | SF6/ CFC-12 | CFC Offline | Noble Gases & Tritium | Bottle Oxygen | Bottle Salinity | LADCP | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MSM-331 | 61 | 2013/05/21 | 20:30 | 58°37.64'N | 44°00.35'W | 1678 | 1669 | - | - | - | x | | x | |
| MSM-332 | 62 | 2013/05/21 | 22:22 | 58°45.92'N | 44°00.72'W | 1597 | 1589 | x | - | - | - | | x | |
| MSM-333 | 63 | 2013/05/22 | 00:46 | 59°01.12'N | 44°01.14'W | 1774 | 1763 | - | - | - | x | | x | |
| MSM-334 | 64 | 2013/05/22 | 04:08 | 59°16.31'N | 44°01.51'W | 1381 | 1362 | x | - | x | - | | x | |
| MSM-335 | 65 | 2013/05/23 | 08:20 | 58°13.96'N | 42°44.92'W | 3038 | 3024 | x | - | - | x | | x | |
| MSM-336 | 66 | 2013/05/23 | 13:13 | 57°47.87'N | 42°17.95'W | 3254 | 3247 | x | - | - | x | | x | |
| MSM-337 | 67 | 2013/05/23 | 18:00 | 57°21.76'N | 41°50.99'W | 3302 | 3295 | x | - | - | x | | x | |
| MSM-338 | 68 | 2013/05/23 | 22:40 | 56°55.61'N | 41°24.21'W | 3363 | 3358 | x | - | - | x | | x | |
| MSM-339 | 69 | 2013/05/24 | 03:27 | 56°29.51'N | 40°57.28'W | 3332 | 3328 | x | - | - | x | | x | |
| MSM-340 | 70 | 2013/05/24 | 08:11 | 56°03.41'N | 40°30.39'W | 3455 | 3447 | x | - | - | x | | x | |
| MSM-341 | 71 | 2013/05/24 | 12:54 | 55°37.29'N | 40°03.49'W | 3003 | 2995 | x | - | - | - | | x | |
| MSM-342 | 72 | 2013/05/24 | 17:26 | 55°11.16'N | 39°36.60'W | 3109 | 3103 | x | - | - | - | | x | |
| MSM-343 | 73 | 2013/05/24 | 21:59 | 54°45.08'N | 39°09.70'W | 2776 | 2767 | x | - | - | x | | x | |
| MSM-344 | 74 | 2013/05/25 | 02:35 | 54°19.01'N | 38°42.68'W | 2814 | 2799 | x | - | - | - | | x | |
| MSM-345 | 75 | 2013/05/25 | 07:08 | 53°52.85'N | 38°15.89'W | 2923 | 2915 | x | - | - | x | | x | |
| MSM-346 | 76 | 2013/05/25 | 12:13 | 53°26.71'N | 37°48.92'W | 3015 | 3004 | x | - | - | - | | x | |
| MSM-347 | 77 | 2013/05/25 | 17:03 | 53°00.59'N | 37°22.06'W | 3755 | 3742 | x | - | - | x | | x | |
| MSM-348 | 78 | 2013/05/25 | 21:03 | 52°44.87'N | 37°02.88'W | 3553 | 3545 | x | - | - | - | | x | |
| MSM-439 | 79 | 2013/05/26 | 00:48 | 52°30.52'N | 36°51.62'W | 3386 | 3371 | - | - | - | - | | x | |
| MSM-350 | 80 | 2013/05/26 | 13:20 | 52°35.00'N | 36°55.98'W | 3266 | 3254 | - | - | - | - | | x | |
| MSM-351 | 81 | 2013/05/27 | 04:41 | 51°25.70'N | 35°26.26'W | 3606 | 3597 | - | - | - | - | | x | |
| MSM-352 | 82 | 2013/05/27 | 15:31 | 50°58.37'N | 34°50.96'W | 4323 | 4313 | - | - | - | - | | x | |
| MSM-353 | 83 | 2013/05/28 | 03:37 | 49°56.26'N | 33°48.34'W | 4151 | 4146 | - | - | - | - | | x | |
| MSM-354 | 84 | 2013/05/28 | 17:19 | 49°01.16'N | 32°36.67'W | 3953 | 3950 | - | - | - | - | | x | |
| MSM-355 | 85 | 2013/05/29 | 08:22 | 47°40.08'N | 31°08.91'W | 4090 | 4073 | x | - | - | x | | x | |
| MSM-356 | 86 | 2013/05/29 | 18:12 | 47°34.44'N | 32°22.39'W | 4141 | 4125 | x | - | - | - | | x | |
| MSM-357 | 87 | 2013/05/30 | 00:54 | 47°29.97'N | 33°36.59'W | 4103 | 4105 | x | - | - | x | | x | |
| MSM-358 | 88 | 2013/05/30 | 08:09 | 47°25.53'N | 34°50.74'W | 4131 | 4129 | x | - | - | x | | x | |
| MSM-359 | 89 | 2013/05/30 | 14:56 | 47°21.09'N | 36°05.10'W | 4295 | 4272 | x | - | - | x | | x | |
| MSM-360 | 90 | 2013/05/30 | 21:32 | 47°17.50'N | 37°21.49'W | 4546 | 4520 | x | - | - | x | | x | |
| MSM-361 | 91 | 2013/05/31 | 04:16 | 47°15.30'N | 37°55.05'W | 4585 | 4584 | x | - | - | - | | x | |
| MSM-362 | 92 | 2013/05/31 | 08:54 | 47°13.16'N | 38°29.99'W | 4612 | 4604 | x | - | - | x | | x | |

| Station | Profile | Date | Time | Latitude | Longitude | Water Depth [m] | Max. Pressure [dbar] | SF6/ CFC-12 | CFC Offline | Noble Gases & Tritium | Bottle Oxygen | Bottle Salinity | LADCP | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MSM-363 | 93 | 2013/05/31 | 15:18 | 47°11.48'N | 39°00.01'W | 4585 | 4581 | x | - | - | - | | x | |
| MSM-364 | 94 | 2013/05/31 | 19:49 | 47°09.97'N | 39°30.05'W | 4583 | 4578 | x | x | - | x | | x | |
| MSM-365 | 95 | 2013/06/01 | 03:25 | 47°08.13'N | 40°12.02'W | 4558 | 4553 | - | - | - | - | | x | |
| MSM-366 | 96 | 2013/06/01 | 08:45 | 47°05.80'N | 40°54.01'W | 4496 | 4481 | x | - | - | x | | x | |
| MSM-367 | 97 | 2013/06/01 | 17:11 | 47°06.09'N | 41°36.31'W | 4297 | 4282 | x | - | - | - | | x | |
| MSM-368 | 98 | 2013/06/01 | 23:32 | 47°05.91'N | 42°10.81'W | 4117 | 4098 | x | - | - | x | | x | |
| MSM-369 | 99 | 2013/06/02 | 04:03 | 47°05.98'N | 42°35.46'W | 3677 | 3658 | x | - | - | - | | x | |
| MSM-370 | 100 | 2013/06/02 | 07:59 | 47°05.94'N | 42°53.65'W | 3469 | 3433 | x | - | - | x | | x | |
| MSM-371 | 101 | 2013/06/02 | 11:20 | 47°06.08'N | 43°07.10'W | 3527 | 3517 | - | - | - | x | | x | Test of acoustic release s/n 125 |
| MSM-372 | 102 | 2013/06/02 | 14:22 | 47°05.99'N | 43°13.52'W | 3039 | 3008 | x | - | - | x | | x | only LADCP downcast available |
| MSM-373 | 103 | 2013/06/02 | 17:32 | 47°06.02'N | 43°17.84'W | 2560 | 2567 | x | - | - | - | | x | |
| MSM-374 | 104 | 2013/06/02 | 19:59 | 47°05.90'N | 43°20.11'W | 1875 | 1753 | x | - | - | x | | x | |
| MSM-375 | 105 | 2013/06/02 | 22:15 | 47°05.98'N | 43°25.22'W | 1287 | 1267 | x | - | - | x | | x | |
| MSM-376 | 106 | 2013/06/03 | 00:35 | 47°06.00'N | 43°38.43'W | 775 | 747 | x | - | - | - | | x | |
| MSM-377 | 107 | 2013/06/03 | 02:01 | 47°06.00'N | 43°47.54'W | 588 | 564 | x | - | - | - | | x | |
| MSM-378 | 108 | 2013/06/03 | 15:50 | 47°07.09'N | 47°06.20'W | 1014 | 992 | x | - | - | - | | x | |
| MSM-379 | 109 | 2013/06/04 | 05:11 | 47°58.19'N | 44°16.15'W | 600 | 583 | x | - | - | - | | x | |
| MSM-380 | 110 | 2013/06/04 | 06:48 | 48°06.73'N | 44°06.33'W | 958 | 938 | x | - | - | x | | x | |
| MSM-381 | 111 | 2013/06/04 | 08:37 | 48°15.29'N | 43°56.45'W | 1900 | 2391 | x | - | - | - | | x | LADCP file corrupt |
| MSM-382 | 112 | 2013/06/04 | 11:07 | 48°23.81'N | 43°46.58'W | 2544 | 2524 | x | - | - | x | | x | |
| MSM-383 | 113 | 2013/06/04 | 14:43 | 48°40.87'N | 43°26.82'W | 3384 | 3366 | x | - | - | - | | x | |
| MSM-384 | 114 | 2013/06/04 | 17:48 | 48°49.38'N | 43°17.04'W | 3760 | 3735 | x | - | - | x | | x | MicroCAT calibration |
| MSM-385 | 115 | 2013/06/04 | 22:32 | 49°06.45'N | 42°57.31'W | 3989 | 3964 | x | - | - | - | | x | |
| MSM-386 | 116 | 2013/06/05 | 02:36 | 49°17.97'N | 42°31.98'W | 4231 | 4213 | x | - | - | x | | x | |
| MSM-387 | 117 | 2013/06/06 | 03:36 | 52°30.53'N | 36°51.54'W | 3408 | 3363 | x | - | - | - | | x | |
| MSM-388 | 118 | 2013/06/06 | 07:30 | 52°14.54'N | 36°30.11'W | 3614 | 3589 | x | - | - | x | | x | |
| MSM-389 | 119 | 2013/06/06 | 11:30 | 51°57.89'N | 36°08.45'W | 3868 | 3842 | x | - | - | - | | x | |
| MSM-390 | 120 | 2013/06/06 | 15:41 | 51°41.45'N | 35°47.19'W | 3670 | 3634 | x | - | - | x | | x | |
| MSM-391 | 121 | 2013/06/06 | 19:40 | 51°25.72'N | 35°26.35'W | 3618 | 3596 | x | - | - | - | | x | |
| MSM-392 | 122 | 2013/06/06 | 23:18 | 51°12.82'N | 35°09.57'W | 3612 | 3597 | - | - | - | x | | x | |
| MSM-393 | 123 | 2013/06/07 | 03:42 | 50°58.36'N | 34°50.99'W | 4300 | 4313 | x | - | - | - | | x | |
| MSM-394 | 124 | 2013/06/07 | 12:54 | 50°46.48'N | 34°39.21'W | 4259 | 4244 | x | - | - | x | | x | |

| Station | Profile | Date | Time | Latitude | Longitude | Water Depth [m] | Max. Pressure [dbar] | SF6/ CFC-12 | CFC Offline | Noble Gases & Tritium | Bottle Oxygen | Bottle Salinity | LADCP | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MSM-395 | 125 | 2013/06/07 | 16:47 | 50°33.69'N | 34°25.18'W | 4159 | 4143 | x | - | - | - | | x | |
| MSM-396 | 126 | 2013/06/07 | 20:29 | 50°20.82'N | 34°13.02'W | 3733 | 3719 | x | - | - | x | | x | |
| MSM-397 | 127 | 2013/06/08 | 00:00 | 50°10.33'N | 33°58.22'W | 3718 | 3711 | x | - | - | - | | x | |
| MSM-398 | 128 | 2013/06/08 | 03:39 | 49°54.99'N | 33°49.92'W | 4032 | 4009 | x | - | - | x | | x | |
| MSM-399 | 129 | 2013/06/08 | 12:28 | 49°47.00'N | 33°31.32'W | 4224 | 4204 | x | - | - | - | | x | |
| MSM-400 | 130 | 2013/06/08 | 17:36 | 49°23.69'N | 33°04.42'W | 3781 | 3762 | x | - | - | x | | x | |
| MSM-401 | 131 | 2013/06/08 | 22:23 | 49°00.63'N | 32°37.01'W | 3944 | 3928 | x | - | - | - | | x | |
| MSM-402 | 132 | 2013/06/09 | 02:27 | 48°45.02'N | 32°18.83'W | 3721 | 3713 | x | - | - | x | | x | |
| MSM-403 | 133 | 2013/06/09 | 06:20 | 48°30.03'N | 32°01.02'W | 4219 | 4200 | x | - | - | - | | x | |
| MSM-404 | 134 | 2013/06/09 | 10:28 | 48°14.96'N | 31°42.95'W | 3872 | 3853 | - | - | - | x | | x | |
| MSM-405 | 135 | 2013/06/09 | 14:39 | 47°59.97'N | 31°24.94'W | 4021 | 4004 | - | x | - | - | | x | |
| MSM-406 | 136 | 2013/06/09 | 23:30 | 47°40.13'N | 31°08.94'W | 4090 | 4074 | - | - | - | x | | x | |
| MSM-407 | 137 | 2013/06/10 | 06:15 | 47°39.98'N | 29°53.23'W | 3418 | 3404 | - | x | - | - | | x | |
| MSM-408 | 138 | 2013/06/10 | 13:05 | 47°02.20'N | 28°27.83'W | 2914 | 2899 | - | x | - | x | | x | |
| MSM-409 | 139 | 2013/06/10 | 19:45 | 47°49.72'N | 27°02.28'W | 1744 | 1737 | x | x | - | - | | x | |
| MSM-410 | 140 | 2013/06/11 | 01:59 | 47°57.24'N | 25°36.90'W | 3592 | 3581 | x | - | - | x | | x | |
| MSM-411 | 141 | 2013/06/11 | 08:56 | 48°04.78'N | 24°11.45'W | 3997 | 3986 | x | - | - | x | | x | |
| MSM-412 | 142 | 2013/06/11 | 16:12 | 48°12.31'N | 22°46.05'W | 4309 | 4304 | x | x | - | x | | x | |
| MSM-413 | 143 | 2013/06/11 | 23:56 | 48°19.80'N | 21°20.60'W | 4435 | 4429 | x | - | - | x | | x | |
| MSM-414 | 144 | 2013/06/12 | 07:34 | 48°27.35'N | 19°55.08'W | 4265 | 4258 | x | - | - | x | | x | |
| MSM-415 | 145 | 2013/06/12 | 17:07 | 48°34.87'N | 18°29.65'W | 4300 | 4297 | x | x | - | x | | x | |
| MSM-416 | 146 | 2013/06/13 | 00:37 | 48°42.45'N | 17°04.23'W | 4785 | 4750 | x | - | - | x | | x | |
| MSM-417 | 147 | 2013/06/13 | 08:24 | 48°49.92'N | 15°38.79'W | 4827 | 4819 | x | x | - | x | | x | |
| MSM-418 | 148 | 2013/06/13 | 16:03 | 48°57.47'N | 14°13.32'W | 4566 | 4562 | x | - | - | x | | x | |
| MSM-419 | 149 | 2013/06/13 | 22:14 | 49°02.65'N | 13°14.51'W | 3579 | 3573 | x | - | - | x | | x | |
| MSM-420 | 150 | 2013/06/14 | 02:01 | 49°04.84'N | 12°50.11'W | 1790 | 1783 | x | - | - | x | | x | |
| MSM-421 | 151 | 2013/06/14 | 05:38 | 49°08.25'N | 12°10.91'W | 1003 | 993 | x | - | - | x | | x | |
| MSM-422 | 152 | 2013/06/14 | 09:07 | 49°12.13'N | 11°27.14'W | 492 | 476 | x | - | - | - | | x | |

## 8 Data and Sample Storage and Availability

All meta information, underway, and bathymetric data was sent after the end of the cruise to the *German Oceanographic Data Centre* (DOD). The respective cruise summary report is inventoried at DOD under reference number 20130051. Already aboard, raw and processed scientific oceanic data was merged into the data collections of the University of Bremen and BSH Hamburg which facilitates any exchange of data products and results among project partners. All scientific data is immediately available to project partners and can be obtained on request by interested cooperating scientists. Hydrographic data was already exchanged with cooperating scientists from the Bedford Institute of Oceanography, Dartmouth, Canada. TSG and respective salinometer data obtained during the cruise was sent to the *Control Station German Research Vessels*. Respective staff members will forward it to those in charge of taking care of the quality control of the vessel's TSG system.

Scientific data of cruise *MSM-28* will be made public and submitted to international data centers like the CLIVAR & Carbon Hydrographic Data Office (cchdo.ucsd.edu) and PANGAE (www.pangaea.org) in quarter 3 of year 2016. Both serve as open access long-term archives providing free access to the scientific data.

## 9 Acknowledgements

Cruise *MSM-28* was probably one of the longest cruises conducted with *RV Maria S. Merian*. Thus, team spirit, enthusiasm and close cooperation between the different scientific teams, and the scientific group and the ship's crew cleared the way for the great success of this cruise. For this reason, we would like to thank the master of *RV Maria S. Merian*, Ralf Schmidt, and his entire crew for the assistance and support granted to us during cruise *MSM-28* which made our stay aboard very comfortable, even at times of very unfavorable weather and sea state conditions. Further thanks goes to the "helping hands" at our home laboratories and the agencies (*BMBF*, the *Senatskommission für Ozeanographie*, and the *Leitstelle Deutsche Forschungsschiffe*) that provided the necessary ship time, funding, and support to pursue all scientific work.