MARIA S. MERIAN-Berichte 10-1

Tracer Survey in the Cape Verde Region

Cruise No. 10, Leg 1

October 31 – December 06, 2008
Ponta Delgada (Portugal) – Mindelo (Cape Verde Islands)

SFB 754

Martin Visbeck, Oliver Baars, Severin Bancala, Donata Banyte, Meike Becker, Marcus Dengler, Georg Drees, Sandra Fehsenfeld, Tim Fischer, Fritz Karbe, Rudi Link, Anne Manke, Wilfried Rickels, Christian Schlosser, Anke Schneider, Martina Schuett, Karen Stange, Lothar Stramma, Toste Tanhua, Sara Wilcken, Johanna Zocher

Editorial Assistance:

Senatskommission für Ozeanographie der Deutschen Forschungsgemeinschaft
Alfred-Wegener-Institut für Polar- und Meeresforschung, Bremerhaven

Leitstelle METEOR/MERIAN
Institut für Meereskunde der Universität Hamburg

2010

The MARIA S. MERIAN-Berichte are published at irregular intervals. They are working papers for people who are occupied with the respective expedition and are intended as reports for the funding institutions. The opinions expressed in the MARIA S. MERIAN-Berichte are only those of the authors.

The reports are available in PDF format from http://www.dfg-ozean.de/. The MARIA S. MERIAN expeditions are funded by the *Deutsche Forschungsgemeinschaft* and the *Bundesministerium für Bildung und Forschung*.

Address of the editor:

Prof. Dr. Martin Visbeck
Leibniz-Institut für Meereswissenschaften
an der Universität Kiel
IFM - GEOMAR
Dienstgebäude Westufer
Düsternbrooker Weg 20
D-24105 Kiel, Germany

Phone: +49 (0)431 / 600 4100
Fax: +49 (0)431 / 600 4102
E-Mail: mvisbeck@ifm-geomar.de

Citation:

Visbeck M (2010) (Ed) Tracer Survey in the Cape Verde Region, Cruise No. 10, Leg 1, October 31 – December 06, 2008. MARIA S. MERIAN-Berichte 10-1, 33 pp, Universität Hamburg

ISSN 1868-8543

MARIA S. MERIAN-Berichte 10-1

Tracer Survey in the Cape Verde Region
Traceraufnahme in der Kapverdenregion

Cruise No. 10, Leg 1

October 31 – December 06, 2008
Ponta Delgada (Portugal) – Mindelo (Cape Verde Islands)

SFB 754

Martin Visbeck, Oliver Baars, Severin Bancala, Donata Banyte,
Meike Becker, Marcus Dengler, Georg Drees, Sandra Fehsenfeld,
Tim Fischer, Fritz Karbe, Rudi Link, Anne Manke, Wilfried Rickels,
Christian Schlosser, Anke Schneider, Martina Schuett, Karen Stange,
Lothar Stramma, Toste Tanhua, Sara Wilcken, Johanna Zocher

Editorial Assistance:

Senatskommission für Ozeanographie der Deutschen Forschungsgemeinschaft
Alfred-Wegener-Institut für Polar- und Meeresforschung, Bremerhaven

Leitstelle METEOR/MERIAN
Institut für Meereskunde der Universität Hamburg

2010

Table of Contents (MSM10/1)

1 Summary

The research cruise MSM10/1 was extremely successful. All programs were able to collect high quality data and the anticipated goals of the expedition were fully met. We have been able to carry out the first comprehensive survey of a tracer release in the Guinea Upwelling region (GUTRE) roughly seven month after the tracer was released at 8°N 23°W in April 2008. We have estimated that a total of 40% of the tracer was found during this cruise. While the horizontal spreading and mixing was larger than anticipated, the vertical extent of the tracer found was small. The low vertical tracer spreading rate estimates are supported by the micro structure profile data. The extensive survey of the upper 1000m of the oxygen minimum zone (OMZ) allowed comparing our sections with several previous surveys. We found that the lowest oxygen values in the core of the OMZ have dropped at record low values below 40 µmol/kg. The preliminary findings from the trace metal work focused on Fe ligand measurements shows a slight higher excess ligand concentration in the surface (50m) for three stations. The two other stations show a slight decrease at this depth. A large number of biochemical samples were taken and were analyzed in Kiel for DNA and RNA diversity. The tracer release experiment provided an ideal environment for repeated biochemical sampling in the same water mass.

Zusammenfassung

Die Forschungsfahrt MSM10/1 war ausgesprochen erfolgreich. Alle Messgruppen waren in der Lage qualitativ hochwertige Datensätze zu sammeln und die Ziele der Reise wurden vollständig erreicht. Wir konnten die erste umfassende Tracervermessung in der Guinea Auftriebsregion (GUTRE) ca. 7 Monate nach der Tracerausbringung bei 8°N 23°W im April 2008 durchführen. Eine Abschätzung ergab, dass insgesamt 40% des ausgebrachten Tracers auf der Fahrt wiedergefunden wurden. Während die horizontale Ausbreitung und Vermischung größer als erwartet waren, war die vertikale Ausdehnung gering. Die geringen vertikalen Tracerausbreitungsraten wurden durch Mikrostrukturmessungen bestätigt. Die intensive Vermessung der obersten 1000 m der Sauerstoffminimumzone (OMZ) erlaubte den Vergleich mit mehreren früheren Reisen. Die niedrigsten Sauerstoffwerte in der OMZ waren auf Rekordtiefen von unter 40 µmol/kg abgesunken. Die vorläufigen Ergebnisse der Spurenstoffgruppe konzentrierten sich auf Eisenligandenmessungen und zeigten einen erhöhten Ligandenwert in den obersten 50 m an 3 Stationen. Zwei andere Stationen zeigten einen niedrigeren Wert in diesen Tiefen. Eine große Anzahl biochemischer Proben wurden gesammelt und wurden nach der Reise in Kiel bezüglich DNA und RNA Diversität untersucht. Das Tracer Release Experiment lieferte eine ideale Umgebung zur gleichzeitigen biogeochemischen Probennahme in denselben Wasserschichten.

2 Participants MSM10/1

Name	Discipline	Institution
Visbeck, Martin, Prof. Dr.	Fahrtleiter / *Chief Scientist*	IFM-GEOMAR
Baars, Oliver	Spurenstoffe / trace elements	IFM-GEOMAR
Bancala, Severin	CTD & microstructure	IFM-GEOMAR
Banyte, Donata	CTD & microstructure	IFM-GEOMAR
Becker, Meike	Tracer & CFC	IFM-GEOMAR
Dengler, Marcus, Dr.	CTD & microstructure	IFM-GEOMAR
Drees, Georg	CTD & salinometer	IFM-GEOMAR
Fehsenfeld, Sandra	DNA / RNA sampling	IFM-GEOMAR
Fischer, Tim	CTD & microstructure	IFM-GEOMAR
Karbe, Fritz	CTD & microstructure	IFM-GEOMAR
Link, Rudolf	CTD & microstructure	IFM-GEOMAR
Manke, Anne	Tracer & CFC	IFM-GEOMAR
Rickels, Wilfried	CTD & microstructure	IfW- Kiel
Schlosser, Christian, Dr.	Spurenstoffe / trace elements	IFM-GEOMAR
Schneider, Anke	Tracer & CFC	IFM-GEOMAR
Schuett, Martina	Tracer & CFC	IFM-GEOMAR
Stange, Karen	Sauerstoff / oxygen	IFM-GEOMAR
Stramma, Lothar, Dr.	CTD & salinometer	IFM-GEOMAR
Tanhua, Toste, Dr.	Tracer & CFC	IFM-GEOMAR
Wilcken, Sara	Sauerstoff / oxygen	IFM-GEOMAR
Zocher, Johanna	Tracer & CFC	IFM-GEOMAR

Participating Institutions

IFM-GEOMAR Leibniz-Institut für Meereswissenschaften an der Universität Kiel, Wischhofstr. 1-3, 24148 Kiel / Germany, e-mail: info@ifm-geomar.de, www.ifm-geomar.de

IfW-Kiel Institut für Weltwirtschaft an der Universität Kiel, Hindenburgufer 66, 24105 Kiel / Germany, e-mail: info@ifw-kiel.de, www.ifw-kiel.de

3 Research Program

This expedition had three goals: A) First survey of the dispersion of the chemical marker substance (tracer) deployed in April 2008 at 8ºN 23ºW. B) Obtain a significant number of microstructure profiles to estimate the local diapycnal mixing for comparison with the tracer dispersion. C) Document the extent and small scale structures of the oxygen minimum zone within the eastern tropical North Atlantic.

In order to accomplish the various research objectives a rough cruise plan was developed and refined in response to the amounts of tracer found. The first days were occupied with a transit from the Azores south towards the region where tracer could be expected (Fig. 3.1, inset). A few CTD stations were taken on the way several profiling Argo floats deployed. Underway SADCP measurements were performed continuously. At several stations we added a few microstructure casts after the CTD profile to measure the oceanic turbulence levels over the upper 400m depths.

In addition to the tracer survey several zonal and meridional sections were carried out to survey the vertical and horizontal extend of the North Eastern Tropical Atlantic oxygen minimum zone. A few extra stations were included to sample for trace metal species using special GOFLO samplers.

Additional samples were taken for nutrients, DNA/RNA analyses and N_2O. Several other small programs were added that needed no extra station time such as spectral light measurements to detect dust in the atmosphere and an effort to develop a more reliable method to calibrate the new oxygen optical measurements. All programs were able to collect high quality data and the anticipated goals of the expedition were fully met.

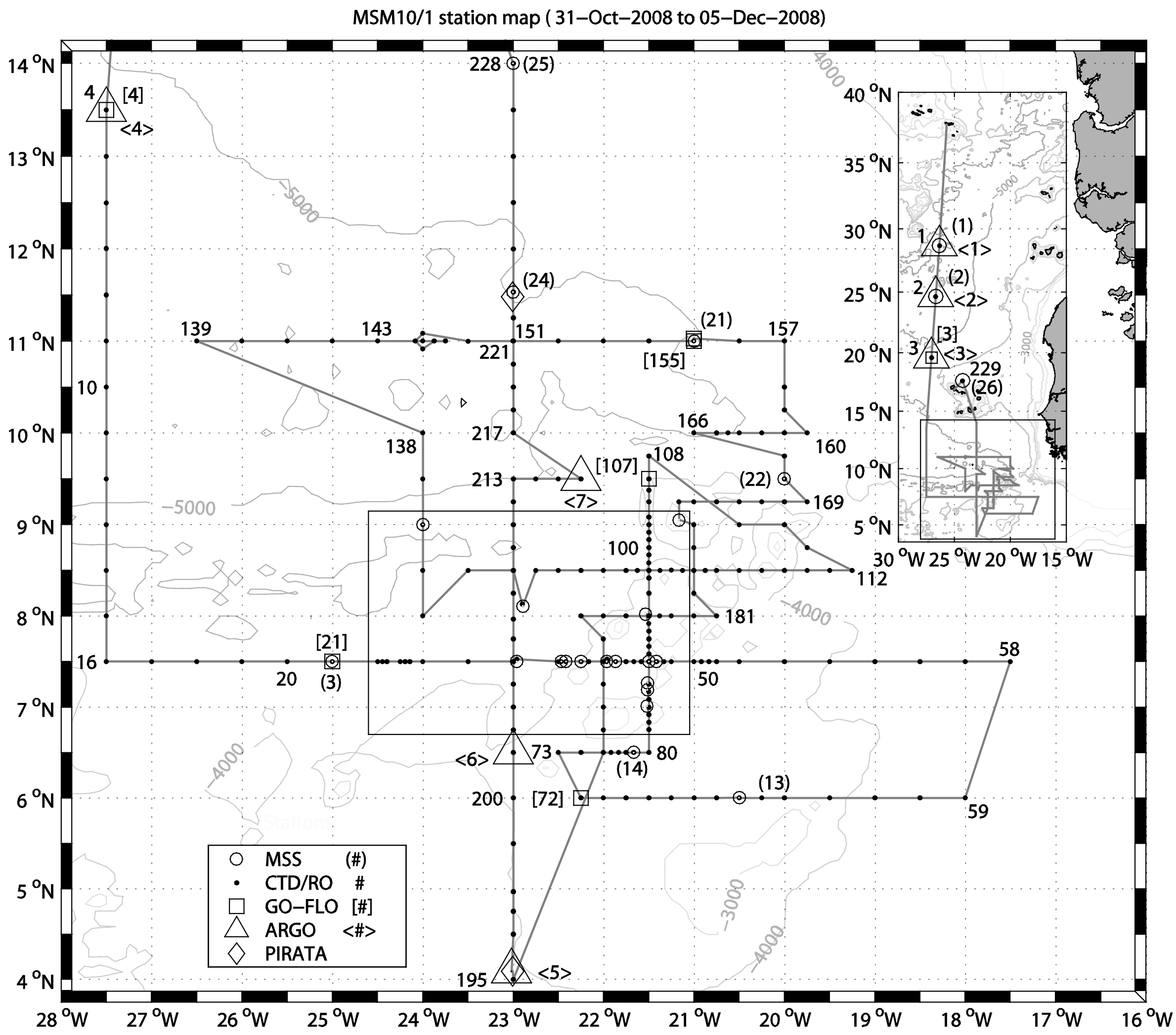

Fig. 3.1 Station map of MSM10/1 cruise

4 Narrative of the Cruise

October 31: All scientists went on Board MERIAN in Ponta Delgada, unpacked containers and installed our gear in the laboratories. At 23:00 we departed 12 hours early because of a potential worker strike at Ponta Delgada.

November 1: All the sampling and analysis equipment was readied, laboratories were prepared and instruments checked. Abandon ship procedures were practiced.

November 2: First CTD station in the afternoon down to 2000m depth followed by an MSS down to 500m depth and an Argo float deployment at 28º 42'N and 26º 20'W at 20:20 UTC.

November 3: Second CTD station in the afternoon down to 2000m depth followed by three MSS down to 500m depth and an Argo float deployment at 24º 39'N and 26º 39'W at 18:57 UTC.

November 4: Third CTD station in the evening down to 2000m depth followed by a GOFLO test cast to 400m depth and an Argo float deployment at 19º 34'N and 27º 01'W at 21:45 UTC.

November 5: No stations, transit south.

November 6: At 2:00 am start of 27.5°W transect at 13.5°N first station with GOFLO cast to 800m depth. Argo float deployed at 13° 30'N and 27° 30'W at 06:03 UTC. Beginning of 27°30'W section with 1000m CTD stations every 30 miles.

November 7: Argo float #5 did not start up, thus we canceled deployment. Continued CTD section southward along 27°30'W. At 23:00 we reached the southernmost point and turned east along 7°30'N with a station spacing of 30'.

November 8: Continued east along section. In the afternoon at 25°W a GOFLO station and 3 MMS profiles were added to the normal CTD station.

November 9: At 2:00 am on station 22 at 7°30'N and 24°W we encountered the tracer. In the following closely spaced stations ample tracer was found in typically 6 sampling bottles per cast. The first tracer patch had a dimension of about 15 nm. In the evening a second patch of tracer was found at 23°W.

November 10-11: Chasing the tracer. We alternated between survey stations and tracer hunt stations and found a lot of places with tracer. Once in a while a MSS was interspersed. All systems were running well.

November 12: Last station on 7°30'N 17°30'W was reached after lunch followed by a transit to the next waypoint where shortly before midnight a westward heading section began at 7°30'N 18°W.

November 13: Sampling west towards the next suspected location of the tracer.

November 14: About midday we have reached the end of the short section at 21°15W without a trace of SF_5CF_3. The final station was also used for a deeper CTD and GO-FLO cast. After dinner we started a new section heading east along 6° 30'N at 22°30'W a very small amount of SF_5CF_3 was detected.

November 15: About midday we have reached the end of the short section at 21°30W with a nice streak of tracer. After it faded we turned north to sample along 21°30W a section which is located between two of the Argo float positions that marked the tracer.

November 16: Repairs to both SF5 GCs took them out of service for a few hours each. After lunch both systems were running again. Continued CTD section along 21°30'W and found quite a few streaks of tracer. MSS profiles showed mixing events for the first time.

November 17: Finished 21°30W at 9°45'N where the tracer faded away after some very significant concentrations earlier. We steamed eastward along 9°N.

November 18: Two stations at 9°N at 20°30'W and 20°00'W showed large tracer concentration. At 8°30'N and 19°30'W we met POLARSTERN on their journey towards Cape Town. Both ships stopped their science and an exchange of scientific and ships personal happened. Three hours later Polarstern continued the journey south but here on board we had a few more hours of scientific downtime culminating in a mid-cruise party.

November 19-21: Station work resumed in the early morning hours with a transect along 8°30'N from 19°15'W heading west with 15nm nominal station spacing. We found small patches of tracer enroute to the release site at 8°N 23°W. There we also took water samples 30m off the bottom to check for spills during the injection. But fortunately no tracer could be detected there.

November 22-24: After a transit towards the west we began an eastward section along 11°N at 26°W 30'. The main focus of this section is on dissolved oxygen. Again we discovered record low dissolved oxygen values. At one station near 24°W a rather significant peak of SF5 appeared somewhat surprisingly to us. Close to the end of the section we took our last GOFLO station and also measured N_2O profiles and the oceans microstructure.

November 25-26: After completing the 11°N transit with the easternmost station at 20°W just a few miles away from the Senegal EEZ we began to work our way south again sampling between sections we have surveyed earlier.

November 27-28: We worked our way south along several short zonal and meridional transsects surveying in more detail the extent of the tracer patch. So far we had never found really high tracer concentrations but several stations above 250 fmol/l.

November 29: In the early morning we began a transit towards 4°S 23°W the southernmost point of the cruise. From there we embarked on the final section along 23°W northward in the afternoon. We sailed by the PIRATA buoy and found it to be in good condition and deployed an ARGO float nearby.

November 30 – December 3: Just 30nm north of the PIRATA buoy a small patch of tracer was found at a rather unexpected southward position some 300km south of the release site. From time to time some smaller amounts of tracer were found south of the release site (8°N). At 11°N we saw once again some isolated patches of tracer, but north of 11°30'N no more tracer was detected. On the 3rd at 16:00 we began the transit towards the Cape Verde Island.

December 4-5: Arrived at 14:30 the TENATSO time series site at 17°38'N and 24°15'W and performed a CTD cast to the bottom followed by a large number of micro structure measurements. On December 5 at 2:00 am the MSS was back on deck and we departed for Mindelo port.

5 Preliminary Results

5.1 Hydrographic and Oxygen Sampling

(Lothar Stramma, Fritz Karbe, Martin Visbeck, Rudi Link, Karen Stange)

CTD-calibration:

During MSM10/1 a total of 229 CTD-profiles were collected in most cases either to 1000m depth for the survey of the oxygen minimum layer or to 500m for targeted tracer survey stations. However, 1 cast was done to full ocean depth at the location where the tracer had been released, and on 6 stations 5 of them where floats were released, the CTD casts were made to 2000 m depth. The final cast #229 was full water depth at the TENATSO site (3650m).

During the whole cruise the IFM-GEOMAR SBE#4 (S/N 09P34783-0752) with a Seabird SBE 9 CTD rosette system has been used. The CTD system was equipped with one Digiquartz pressure sensor (s/n 89964) and double sensor packages (temperature 1 = s/n 4823, temperature 2 = s/n 4234, conductivity 1 = s/n 3366, conductivity 2 = s/n 2443, oxygen 1 (sbe 43) = s/n 0145, oxygen 2 (sbe 43) = s/n 0735). Data acquisition was done using Seabird Seasave software version 7.12. The CTD was mounted on the GO4 rosette frame with a 21 bottle rosette sampling system with 10 l bottles. Three bottles were removed to accommodate a lowered ADCP to the rosette. The final calibration of the CTD data was done using the primary set of sensors. This primary sensor package performed well during the whole cruise and also the secondary sensor set worked without problems.

The IFM-GEOMAR Guildline Autosal salinometer #8 was used for conductivity cell calibration (operated by L. Stramma and G. Drees). The Guildline Autosal salinometer #4 was available as backup, but had not been used. Calibration during operation was done in two ways: IAPSO Standard Seawater (P149, K15=0.99984) was measured at the beginning and end of the salinometer use. In addition, a so called “substandard” (essentially a large volume of water with constant but unknown salinity), obtained 3 times from deep bottles from the CTD casts was used to track the stability of the system. The substandard and the IAPSO standard showed on some measurement days an increasing trend, which was removed from the measured salinity samples. However, on many days the AS8 was stable during the entire measurement time.

The conductivity calibration of the downcast data was performed using a linear fit with respect to temperature, pressure and time ($C\_corrected = C\_observed + 0.0018894 + 1.4455e\text{-}07 * P + 8.125e\text{-}05 * T – 0.00025532 * C$). Tests with quadratic fits in pressure did not improve the quality of the fit in a significant manner. Using 67% of the 470 samples for calibration a r.m.s. of 0.00025 S/m corresponding to a salinity of 0.0026 PSU was found for the downcast. Although the upcast suggests a slightly better fit to the salinity samples with an r.m.s. of 0.00022 S/m we chose the downcast as final dataset as: 1) Sensor hysteresis starts from a well defined point, and 2) the incoming flow is not perturbed by turbulence generated by the CTD-rosette.

Oxygen measurements:

One standard deviation of the oxygen concentration determined from the titration is 0.3 µmol kg^{-1} based of 80 duplicate measurements. The standard solution for the titration was found to be accurate to better than 0.27% based on comparison to two independent reference materials; from WAKO inc. (USA) and Bjerknes Center in Bergen. Furthermore, oxygen concentrations in deep water samples were compared to all relevant historical cruises in both the Global Ocean Data Analysis Project (GLODAP) and CARINA databases, as well as more recent data. Our oxygen data are consistent with both GLODAP and CARINA to within 1.3% based on the weighted mean of the absolute offset for 12 crossover comparisons. The CTD oxygen sensor calibration resulted in an estimated accuracy of 0.8 µmol kg^{-1} when one third of the data with largest deviation compared to the titration were removed. The CTD downcast has been calibrated using 67% of the 692 data samples and led to an rms difference of 0.74 µmol/kg using a linear correction for temperature, pressure, oxygen itself and time (o_corrected = o_observed(µmol/kg) – 4.0443 + 0.0038668 * P + 0.40653 * T + 0.0068968 * O).

Nutrient measurements:

285 samples for determination of nutrients were frozen to -20°C and measured at the lab in Kiel after the cruise (measurements preformed on January 15-20/2009). The nutrient data all showed excessive scatter vs. P. Therefore all nutrient values were flagged as questionable.

Results:

The second objective of the RV Merian cruise MSM10/1 was to map the distribution of the OMZ in the region of the tracer survey area in the context of the SFB-754. The large scale horizontal distribution of the lowest oxygen value within the OMZ as measured with the CTD oxygen sensor during MSM10/1 (Fig. 5.1) shows the expected distribution of higher oxygen values in the region of the eastward North Equatorial Under- und Countercurrents at 4 to 9°N while in the so called Guinea Dome region and the station closest to the African continent the lowest values were observed. The density range where the oxygen minimum was reached is σ_θ = 26.74-27.14 kg/m^3 with a mean density of 26.91 kg/m^3 and a mean pressure of 423 dbar. What is surprising, however, is that the values are lower than previously observed in this area, reaching at several locations values of less than 40 µmol/kg. The electric CTD oxygen measurements were constantly checked and calibrated by bottle samples analyzed by Winkler titration. The Winkler titration was cross-checked by two additional persons well experienced in oxygen titration, so we are convinced that the observed low values are real.

One major aim of the SFB-754 is to investigate possible changes in the OMZ and some recent literature results (e.g. Stramma et al. 2008) indicated decreasing oxygen levels during the last few decades. The observed distribution of the minimum values (Fig. 5.1) supports these findings. For a direct comparison we repeated a part of a WOCE cruise carried out by RV Atalante in March 1993 along 7.5°N (Fig. 5.2). The isopycnal σ_Θ= 27.1 kg/m3 marks the boundaries between the South Atlantic Central Water (SACW) and the Antarctic Intermediate Water (AAIW). The oxygen minimum is located in both water masses with the minimum in the lower reaches of the SACW. While in March 1993 the 60 µmol/kg isoline forms the lowest large-scale isopycnal layer, in November 2008 in wide regions the 50 µmol/kg isoline is present, and oxygen falls to record low values below 40 µmol/kg at some locations. A comparison of all oxygen profiles from both cruises between 17° and 28°W shows the profiles with lower oxygen values and a shift of the minimum to shallower depth in November 2008 when compared to March 1993.This results also in a shift to slightly lower densities for the oxygen minimum (Figures not shown). A test near the surface and near 1000 dbar showed that there the oxygen profiles from both cruises show no shift, hence the change is restricted mainly to the oxygen minimum layer. Rather surprisingly there is not a vertical widening of the OMZ, but instead in the upper SACW at 100 to 300 m depth the oxygen content increased.

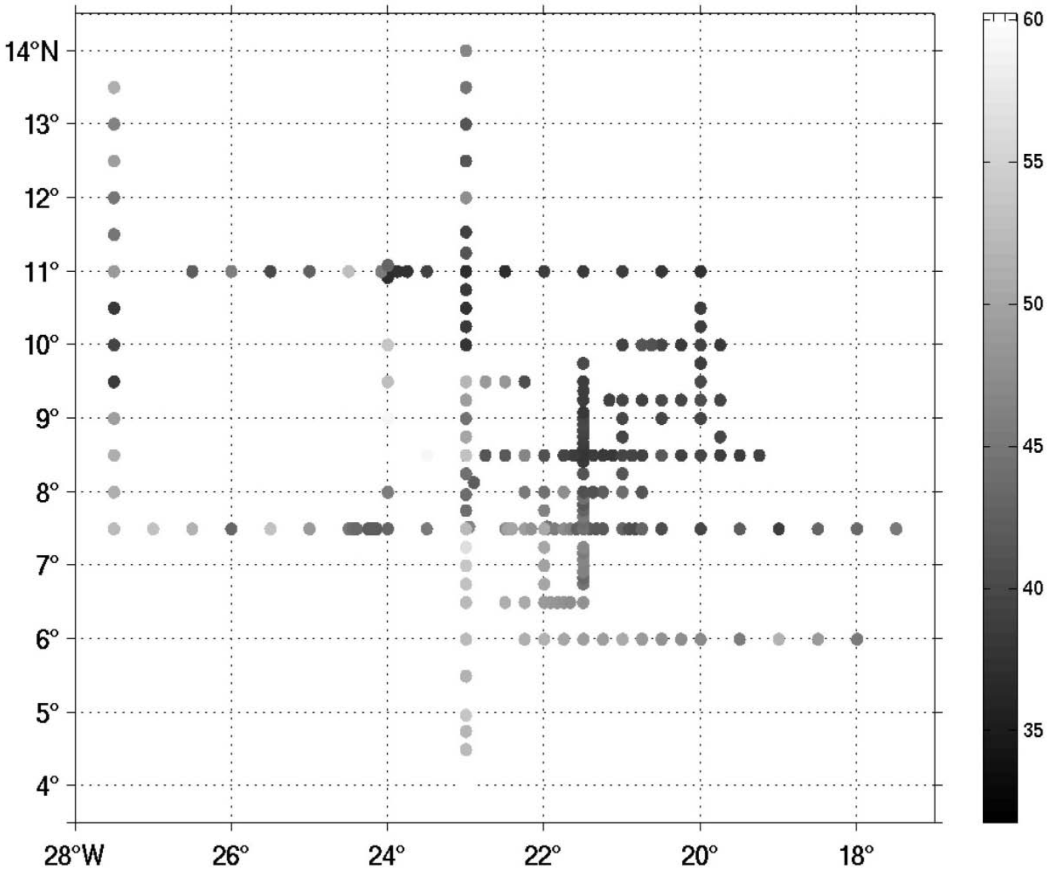

Fig. 5.1 Distribution of the lowest oxygen minimum values in µmol/kg in the oxygen minimum layer at 300 to 600 m depth from MSM10/1 CTD stations in November and December 2008

A second example for a direct comparison is presented for 11°N for a section made in November 2002 at 10° to 11°N with RV Meteor and in November 2008 during MSM10/1 (Fig. 5.3). Although in November 2002 the station spacing was wider and the profiles reached only to about 600 m depth the results from the 7.5°N section are confirmed. Again the November 2008 oxygen minimum is lower. While in November 2002 the 50 µmol/kg isoline is the lowest continuous contour in November 2008, the 40 µmol/kg contour covers the eastern half of the section. In the upper part of the SACW the oxygen increased as was the case at 7.5°N. A deoxygenation rate of ~0.5 µmol/kg/a during the last decades resulted for the two repeat sections at 7.5°N and 11°N (Stramma et al. 2009).

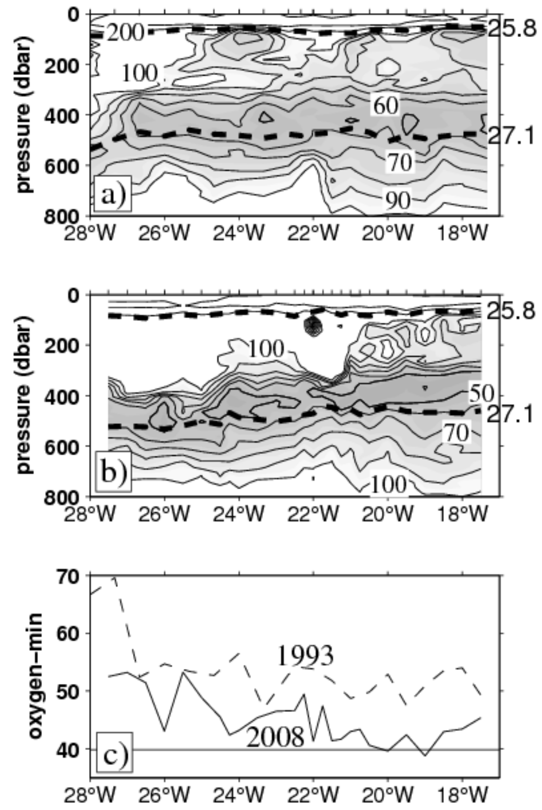

Fig. 5.2
Dissolved oxygen section along 7.5°N with 10 µmol kg^{-1} contour intervals below 100 µmol kg^{-1} and 50 µmol kg^{-1} contour intervals for oxygen larger than 100 µmol kg^{-1} for a) March 1993 cruise and b) data from November 2008. The isopycnals σ_θ=25.8 and 27.1 kg/m^3 are included as dashed lines which mark the boundaries between Tropical Surface Water and the South Atlantic Central Water (SACW) and between the SACW and the Antarctic Intermediate Water. The lowest oxygen values reached in the depth range 300 to 600 m are shown in c) for March 1993 (dashed line) and November 2008 (solid line) with 40 µmol kg^{-1} marked as line (Stramma et al. 2009)

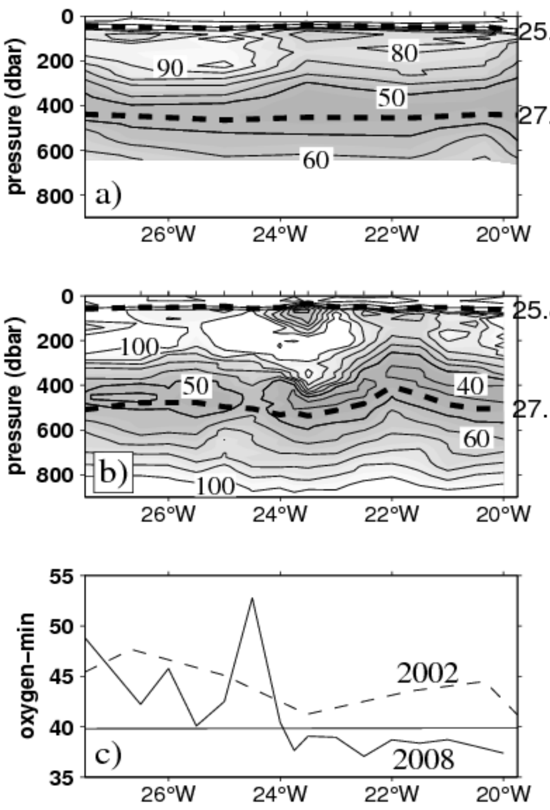

Fig. 5.3
Dissolved oxygen section along about 11°N with 10 µmol kg^{-1} contour intervals below 100 µmol kg^{-1} and 50 µmol kg^{-1} contour intervals for oxygen in excess of 100 µmol kg^{-1} for a) RV Meteor cruise in November 2002 and b) data from November 2008. As in the previous figure the isopycnals σ_θ=25.8 and 27.1 kg/m^3 are included. The lowest oxygen values reached in the depth range 300 to 600 m are shown in c) for November 2002 (dashed line) and November 2008 (solid line) with 40 µmol kg^{-1} marked as line (Stramma et al. 2009)

5.2 Current Observations

5.2.1 Vessel Mounted ADCP

(Tim Fischer, Marcus Dengler and Martin Visbeck)

RV MERIAN is equipped with a hull mounted RDI OceanSurveyor ADCP of 75 kHz. For almost the entire cruise it was operative for underway current measurements. To avoid acoustic interferences, it was necessary to have the on-board 75 kHz Doppler Velocity Log switched off, which is usually possible.

The OceanSurveyor recorded single pings, pinging every 1.6 seconds. For some days along the 27.5°W-section it worked in narrowband mode, reaching depths of about 700m. After that it was switched to broadband mode in order to get profiles of velocity shear of higher precision, for comparison to shear measurements from the microstructure profiler (see MSS). In broadband mode only depths of about 600m could be reached.

Navigational data directly available for the ADCP system were supplied solely but continuously from the integrated SEAPATH-system: GPS-position, and heading, pitch, roll calculated from 2-dimensional GPS and gyros.

There was no synchro heading fed to the ADCP deck unit. In order to have more than one source of heading information, unprocessed heading output from the FibreOpticGyro was stored via the DAVISShip database.

For calculating velocities from the ADCP output, it proved useful to correct time shifts in the navigational data. Recording times of heading data as well as position data did not exactly match the ping times of the transducer. Best results were obtained when shifting position data 2 seconds back in time, while shifting heading data 8 seconds forth. The standard deviation of the estimated transducer misalignment angle - as a measure of navigation data quality - resulted in 0.25 degrees for 10-minute-average velocities. This is an extraordinarily low value in comparison to past cruises with OceanSurveyor ADCPs.

The higher precision of the broadband mode in conjunction with the high quality navigational data results in fine resolution of currents in space and time, here an example of 20-second-average velocities above a seamount (Fig. 5.4).

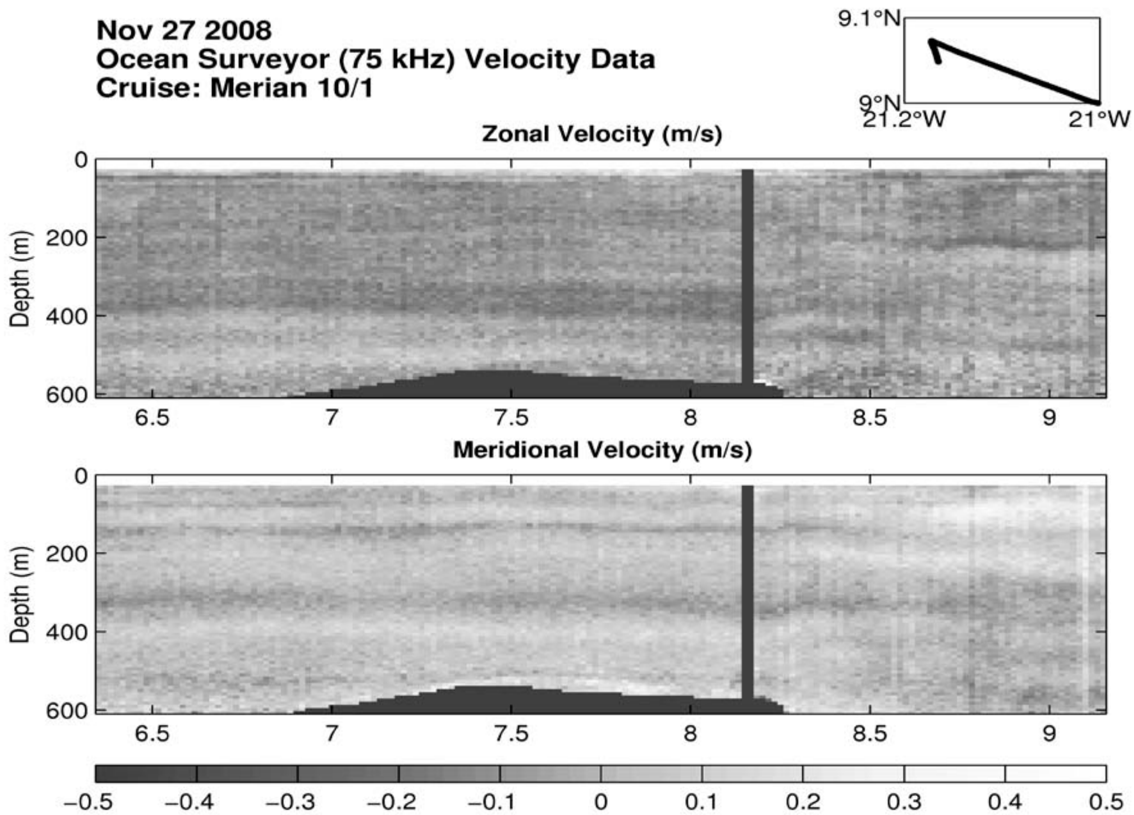

Fig. 5.4 Velocity versus time (UTC) above a seamount at 9°03'N 21°10'W. Time resolution is 20 seconds making a resolution in space of 10m (ship speed 1 kn at that time)

From the main sections completed during this cruise (27.5°W, 23°W, 7.5°N, 8.5°N, 11°N) we give the one along 27.5°W as an example (Fig. 5.5).

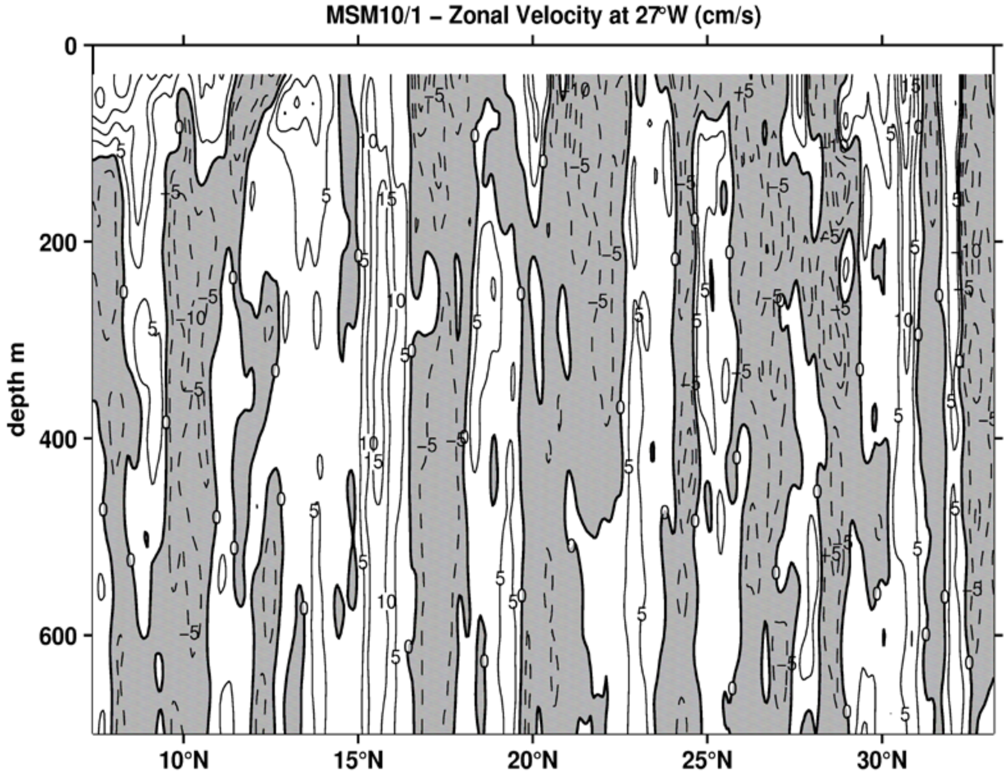

Fig. 5.5 Zonal velocity along 27.5°W, showing alternating current bands of roughly 200 to 300 km length scale

5.2.2 Lowered ADCP Sampling

(Martin Visbeck and Fritz Karbe)

The CTD-System used was equipped with two Teldyne RDI WH 300 kHz ADCPs. They are mounted within the CTD-Rosette with especially manufactured frames protecting the instruments and giving free way for the acoustic beams. A battery pack is mounted between the downlooking master instrument (SN #680) and the uplooking slave instrument (SN #2141), both ADCPs are connected to it as it is the connection point for the data interface cable. Both instruments were run with the same setup of 25 bins with 10 m binsize and singleping mode, time between pings was 0.9 seconds. The lADCP was usually used in conjunction with the CTD-Survey Stations which had a maximum depth of 1000 m except for a few deeper Stations. At the Tracer Stations, which were sampled only to 500 m no lADCP sampling took place. There would be no gain in information since the vessel mounted Teledyne RDI Ocean Surveyor 75 kHz ADCP showed good quality data up to 700 m of depth. During casts #005-006 troubles with the data transmission between the instruments and the controlling computer appeared, both ADCPs did not record data. This could be fixed easily in the following. During cast #064 the batteries had gone out of power because the lADCP was not stopped after a Cast before and recorded on deck for a couple of hours, leading to much more power consumption than expected. At cast

#115 beam 1 of the uplooking slave instrument showed up to be broken, therefore we will have only three beam solutions uplooking for the following casts of the cruise.

Data processing took place during the cruise with the IFM-GEOMAR LADCP processing software V10.6, which includes both shear and inversion methods to derive an absolute velocity profile. As additional data necessary for the processing the corresponding pre processed CTD files for the cast P T S, time and navigation data were used. Furthermore processed data from the vessel mounted Teledyne RDI OS 75 kHz ADCP was used.

The LADCP velocity profiles will aide the analysis of internal wave induced vertical velocity shears and the regional/mesoscale circulation.

5.3 Measurements of CFC-12 and SF_5CF_3

(Toste Tanhua und Martina Schütt)

During the cruise, two Gas Chromatograph / Purge-and-Trap (GC/PT) systems were used in parallel. The systems are modified versions of the set-up normally used for the analysis of CFCs (Bullister and Weiss, 1989) modified in the following way to optimize the analysis of SF_5CF_3: The trap was a 12 cm long 1/8 " SS tube packed with Heysep D. The trapping was performed at -30°C, and the trap was desorbed at 120°C. The pre-column was a 30 cm long Porasil C 1/8" column, whereas the main column consisted of a 200 cm 1/8" column packed with 180 cm Carbograph 1AC (60-80 mesh) and a 20 cm Molsieve 5A. Detection was performed on a Electron Capture Detector (ECD). This set-up allowed efficient analysis of SF_5CF_3 and CFC-12 (that elutes slightly after, but well separated from, SF_5CF_3). Due to slightly differently packed main-columns, the two systems were operated at different temperatures, 45 and 60°C, respectively.

Standardization was performed by injecting small volumes of a working standard containing both SF_5CF_3 and CFC-12. This working standard was prepared by the company Dueste-Steiniger (Germany), and also serves as the reference standard for SF_5CF_3. However, the SF_5CF_3 standard is only accurate to ±10%, and no other reference standards exist today for SF_5CF_3. The CFC-12 concentration in the standard has been calibrated vs. a reference standard obtained from R.F. Weiss group at SIO, and the CFC-12 data are reported on the SIO98 scale. Another calibration of the working standard will take place in the lab after the cruise, to determine any possible drift in the working standard. Calibration curves were measured daily or bi-daily, depending on work load, to determine the non-linearity of the detector. Point calibrations were always performed between stations to determine the short term drift in the detector.

During the entire cruise, at least one sample from each station was measured on both systems in order to determine any systematic biases between the two systems. This sample was usually from the Niskin bottle that was closed at the target density. In addition normally one additional replicate measurement was run on each instrument for each station. The results of the cross-check of the two instruments relieved no significant biases, and the results normally agreed within 1%. The standard deviation of the measurements determined from these replicate measurements are listed in Table 5.1. The detection limits for CFC-12 and SF_5CF_3 were determined to 7 and 0.2 fmol/kg (10-15 mol/kg), respectively.

During the cruise we distinguished between two forms of CTD stations: Tracer stations (max 500m) and Hydrographic stations (max 1000m). If time allowed, and if no SF_5CF_3 was found, we measured a complete CFC-profile on the hydrographic stations. For hydrographic stations where SF_5CF_3 was found and for the tracer stations, only samples around the target density was measured until the tails of the tracer distribution was closed (i.e. until zero SF_5CF_3 concentrations were found). Samples were collected in 100 ml ground glass syringes, and an aliquot of about 21 ml was injected into the analytical system.

A profile from a typical station is shown in Figure 5.6, the density of the SF_5CF_3 release is within a very sharp gradient in CFC-12 values. Also relatively large gradients can be observed in the horizontal distribution of CFC-12, with the lowest CFC-12 concentrations (i.e. oldest water) found in the southern part of the region, Figure 5.7.

During the cruise, 2601 water samples from 226 stations were analyzed for its content of CFC-12 and SF_5CF_3, of these 541 were replicate measurements.

Table 5.1 Precision of tracer measurements determined from replicate measurements determined from replicate measurements (n). The precision is reported in units of fmol/kg or percent, depending on what gives the largest error. For SF_5CF_3, only measurements higher than 20 fmol/kg were used for the calculations. The cross-system precision is somewhat lower than for the individual instruments, and might be a measure of the total accuracy of the method

	System #1 precision	System #2 precision	Cross-system precision
CFC-12	7.2 fM 1.1 %	10.1 fM 1.9 %	10.8 fM 1.9 %
SF_5CF_3	0.9 fM 2.1 %	0.6 fM 1.2 %	1.1 fM 2.5 %

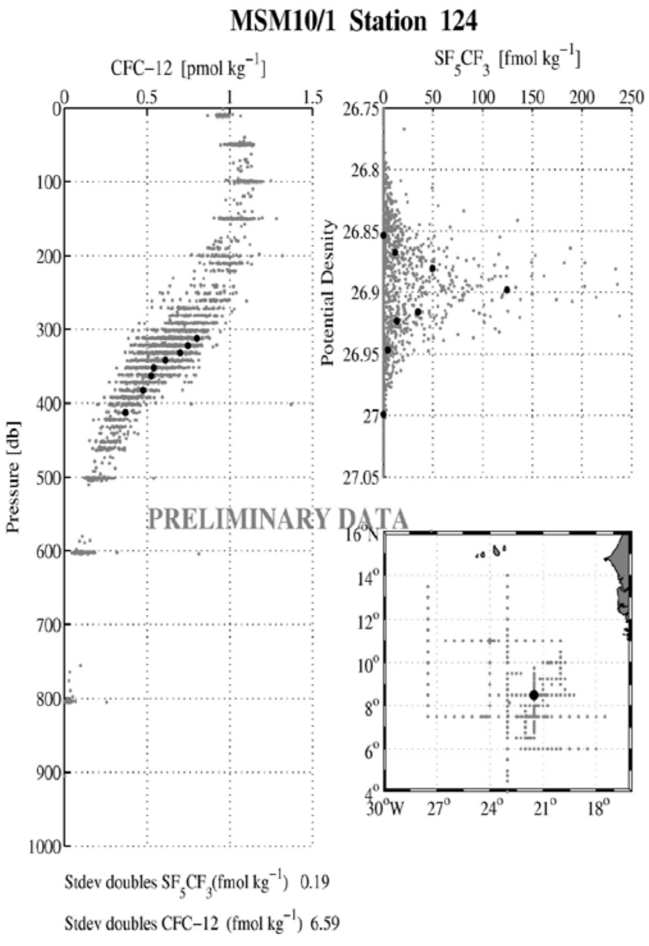

Fig. 5.6
Profiles of CFC-12 and SF_5CF_3. The CFC-12 concentration is plotted vs. depth, and the SF_5CF_3 concentration is plotted vs. potential density. The grey dots are all measurements and the black dots are the data from station 124 (note that this is preliminary data)

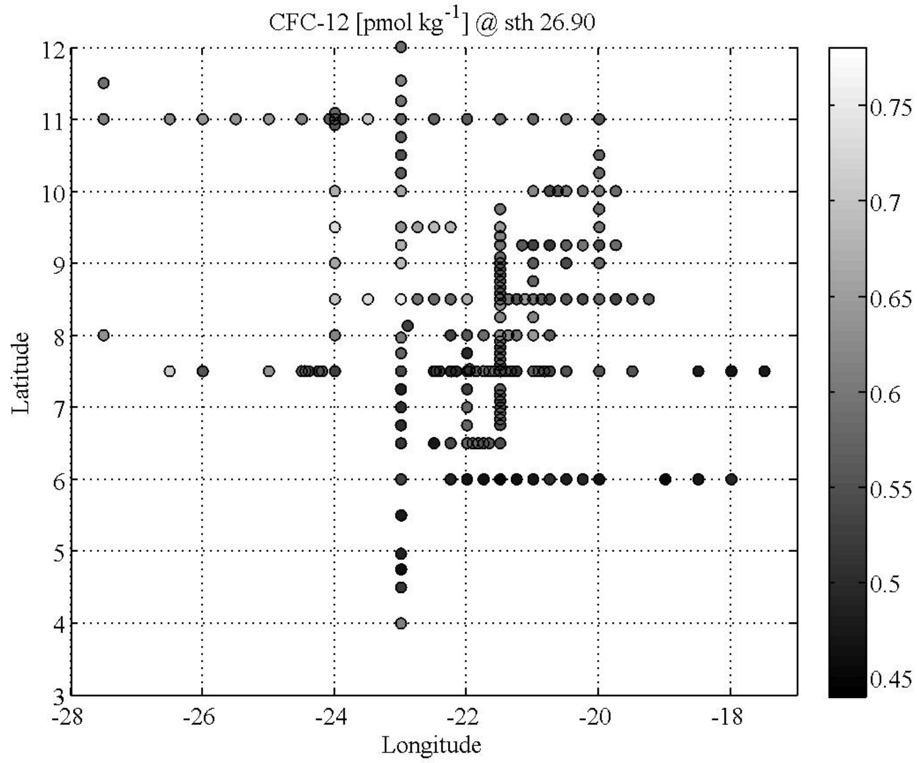

Fig. 5.7
The CFC-12 concentrations interpolated to potential density anomaly 26.90 (i.e. the density of the released tracer) for the tracer survey area

5.4 SF_6 Measurements

(Anke Schneider and Toste Tanhua)

SF_6 is an anthropogenic tracer, which has been produced and released to the atmosphere since the 1970's. In contrast to CFC11 and CFC12 its atmospheric concentration is still increasing rapidly. It is very useful as transient tracer to estimate ocean circulation and mixing and to estimate the uptake of anthropogenic CO_2 in the ocean. Atmospheric SF6 concentrations are ~6,4 ppt, about a hundred times lower than CFC12. In addition, its solubility is much lower, so that surface water concentrations of SF_6 are in the range of 1-2 fmol/kg, a factor of about 1000 lower than those of dissolved CFC12 and CFC11. Therefore the analysis of dissolved SF6 is very challenging.

The initial attempt to measure CFC12 and SF_6 in the same seawater sample could not be realised. Instead parallel samples for CFC12 were measured on a second instrument.

Sampling:

The water samples for SF_6 are the second collected from the 10 l Niskin bottles, right after the syringes for CFC12 and SF_5CF_3 analysis. To minimize contact with air, the samples are flushed directly through the stopcocks into 350 ml glass ampoules equipped with a long tube entry and an outlet at the top. After flushing three times the entire volume through the ampoule, the outlet is tapped with a stainless steel fitting. During filling the ampoule little air bubbles have to be excluded by tapping on the glass. The inlet is left open for pressure regulation in case of warming or cooling. Until the samples are measured, they are stored in a water bath at ~0 °C to minimize the formation of bubbles.

Transfer:

The ampoule is connected to the purgetower and the outlet is opened. After evacuating the purgetower, a small volume of water is filled in, in order to rinse the tubes and get rid of remaining water and air. The water is drained and again the tower gets evacuated. 320 ml of water is filled in by the vacuum and purged for 10 min with a purge flow of ~90 ml/min. All procedures are performed automatically. The gas passes a Nafion dryer (with ~190 ml/min counter flow) and a magnesiumperchlorate dryer.

Trapping:

The first trap (T1) is a 1 m, 1/16" stainless steel tube packed with Haysep D (cleaned in ethanol). It is cooled down to -100/-120 °C with liquid nitrogen. The trap is then electrically heated to 100 °C for two minutes and the gas flows through a precolumn and a 50 cm molsieve (5A 60/80 mesh, 1/8") to pre-seperate the SF_6 from other components. Both columns are located in the GC oven at 35 °C. The precolumn flow is set to ~10 ml/min and the foreflush time to get all SF_6 is 2:30 min. From here the SF_6 is trapped on a second trap, to reduce trap volume and chromatographic peak broadening. The microtrap (T2) is a 1/32" stainless steel tube packed with Carboxen 1000. It is cooled to –70 °C.

Sample injection:

T2 is heated to 150 °C for one minute and the sample is injected into the chromatografic system. The GC oven is held at 35 °C. The sample first passes a 30 m RT-molecular sieve 5A column (0,53 mm ID) and then a 75 m DB 624 column (0,53 mm ID). The gas flow through the columns is ~8 ml/min. SF_6 is detected on an electron capture detector (ECD). The retention time is 4,5 min.

Problems:

A contamination or pressure peak is always found right after SF_6 in the chromatogram, also in standards and blanks. But separation between the two peaks is good enough to integrate the SF6 peak. Nevertheless, in some water samples this peak got very high and integration was not possible. With shortening the foreflush time through the precolumn (to 2:30 min) it was tried to cut off this contamination. The peak disappeared or got smaller but in some samples integration was still not possible.

A second problem was freezing of the first trap, resulting in reduced or no purge flow. By increasing the heating time of T1 (from 1 min to 2 min) it was intended to dry out the trap after each water sample, but still the problem appeared from time to time. Thus, after three or four measured samples, T1 was heated for ~10 min.

5.5 Microstructure Measurements

(Marcus Dengler, Tim Fischer)

General:

The focus of the microstructure measurement program was to identify the dominant mixing processes in the GUTRE and OMZ region, and to investigate spatial and temporal scales of mixing events. It combined the research objectives of three projects: Subproject A3 of Sonderforschungsbereich 754 which aims at quantifying diapycnal fluxes of oxygen in the oxygen minimum zone, the Junior Research Group (DFG Emmy Noether-Nachwuchsgruppe) "Microstructure" focussing on quantifying the impact of upper ocean diapycnal mixing processes on the variability of sea surface temperature, and the BMBF-Verbundvorhaben SOPRAN studying diapycnal fluxes and subsequent outgassing of trace gas N_2O.

Sampling and technical aspects:

During MSM10/1, microstructure data was sampled on 26 stations, usually between narrowly spaced CTD casts in the regions where tracer was found and during GO-FLO stations. At each station 3 to 5 profiles of microstructure shear and temperature fluctuations were recorded from the surface to a depth of about 500 m. A total of 90 profiles were collected on 26 microstructure stations which translates into a total profiling time of about two days.

The tethered microstructure profiling system (manufacturer: Sea and Sun Technology, Trappenkamp, Germany) used during the cruise consisted of a profiler (s/n MSS 26), a winch (s/n 20) and a data interface. The profiler was equipped with two shear probes (airfoil type PNS98, sn 029, and PNS06, sn 6055), a fast-responding temperature sensor (microthermistor FP07), an acceleration sensor and conductivity, temperature, depth sensors that sample at a lower frequency (24 Hz). In addition, two tilt sensors were mounted to the profiler. The loosely-tethered profiler was optimized to sink at a rate of 0.55 m/s. Shear fluctuations recorded due to vibration of the profiler while sinking are recorded by the acceleration sensor and can be removed from the shear data during post-processing. With this set up, the noise level of the instrument is $2x10^{-10}$W/kg for turbulent kinetic energy and $1x10^{-11}$ °K^2s^{-1} for temperature variance. All sensors are mounted to the measuring head of the profiler, with the exception of the tilt sensors that is placed inside the pressure housing.

All components of the system worked extremely well throughout the cruise. No microstructure sensor had to be replaced and data transmission problems did not occur. The cable close to the profiler had to be repaired once due to a broken isolation.

Preliminary results:

During the tracer injection cruise (R/V Maria S. Merian MSM08/1) in April 2008, microstructure measurements during a 48 hour station revealed a pronounced correlation between small scale velocity shear as observed by the vessel-mounted ADCP and enhanced dissipation rates of turbulent kinetic energy and temperature variance in the water column below 150 m. The average eddy diffusivity of temperature derived from the 48h station during MSM08/1 was

$2x10^{-5}$ m^2s^{-1}. The picture from our spatially scattered observations obtained during this cruise was drastically different. Most of the observations show very little mixing to occur in the deeper water column and only sporadic patches of turbulence were found. In fact, most of the microstructure sensors did not measure any significant turbulence throughout most parts of the deeper water column. However, during station 17 at 6.5°N, 22.5°W, we were able to capture a strong mixing event between 300 m and 360 m depth. During station occupation, the VMADCP data revealed a moderate energetic but highly baroclinic internal wave field (Fig. 5.8) that created a region of elevated vertical shear at about 330m depth. Measured dissipation rates in this layer were strongly elevated and reached levels above $1x10^{-8}$ Wm^{-2} (Fig. 5.8). Station average eddy diffusivities here reached values above $2x10^{-4}$ m^2s^{-1}. As was indicated by the vertical shear of the VMADCP velocities, this intense mixing event was however short-lived and lasted for about one hour only. Despite this event, the average eddy diffusivities in the deeper water column calculated from all profiles collected during MSM10/1 are below $1x10^{-5}m^2s^{-1}$.

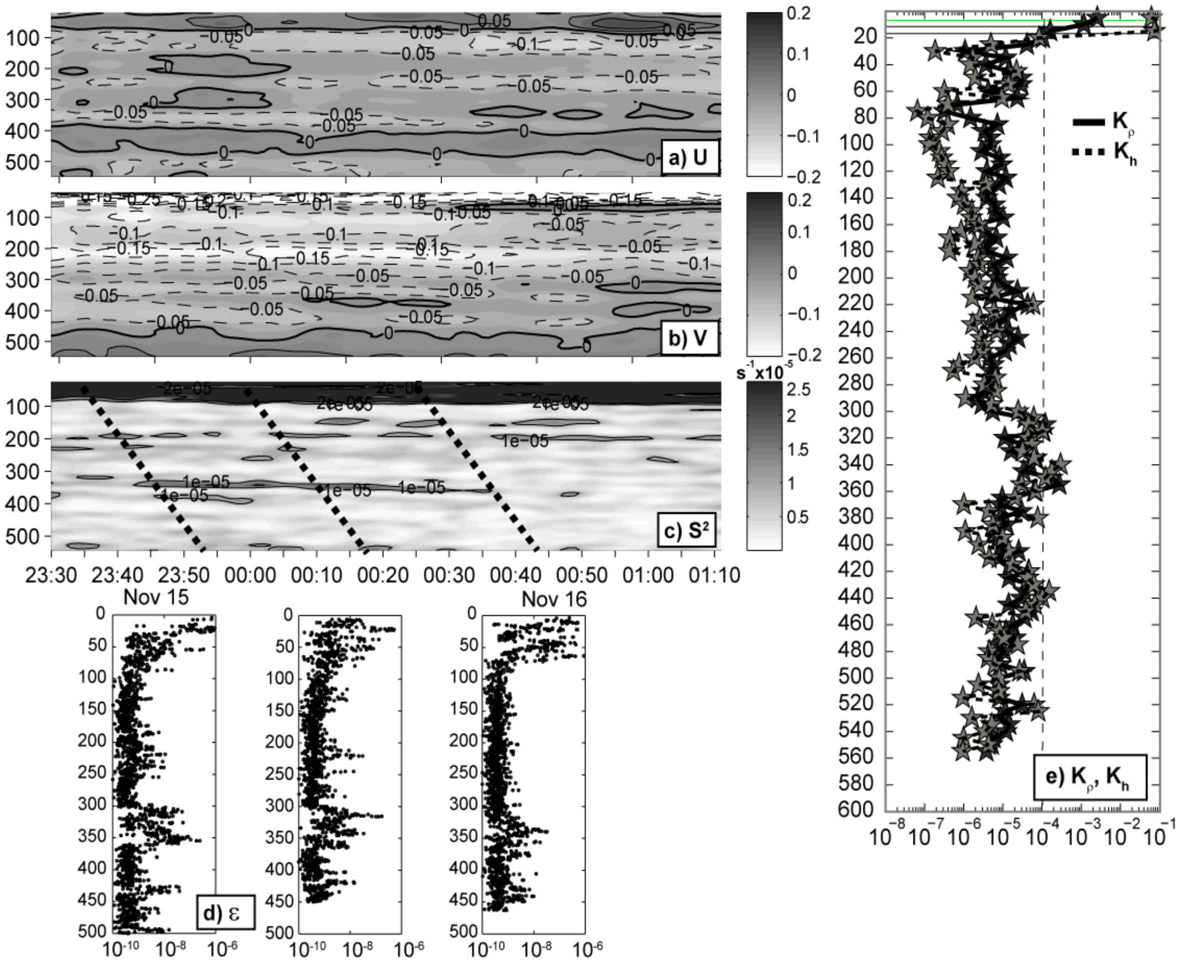

Fig. 5.8 a) zonal velocity and b) meridional velocity from the VMADCP during a microstructure station at 6.5°N, 22.5°W showing enhanced small-scale internal waves, which cause elevated c) vertical shear variance ($S^2 = (dU/dz)^2 + (dV/dz)^2$). Lines in c) indicate downcasts of the microstructure profiler. d) Turbulent dissipation rate of eddy kinetic energy in W kg^{-1} calculated from the two shear sensors of the profiler for each of the three casts, e) average eddy diffusivities of density (black, in m^2s^{-1}) and temperature (grey, in $°K^2s^{-1}$) determined from three MSS casts, dashed black line indicates diffusivities above $1x10^{-4}$

5.6 Sampling of Nitrous Oxide (N_2O)

(Tim Fischer)

At three stations during the cruise, N_2O was sampled. Two stations lay in the Oxygen Minimum Zone and had a high vertical sampling resolution where the oxygen gradient was high (about 300 to 350m). The third station was 'TENATSO', the time series station off Cape Verde, with fine depth resolution in the thermocline.

The aim of the sampling is to measure the flux of the potent greenhouse gas N_2O from the ocean to the atmosphere, and to connect that flux to external parameters. Therefore as many additional measurements as possible were performed in parallel to the N_2O sampling: CTD, microstructure profiles, ADCP, oxygen, F12, nutrients.

N_2O samples were taken as triples in 25ml vials, crimped airtight and conserved. In the meantime they have been measured in Kiel by headspace gaschromatography.

5.7 Trace Metal Sampling and Trace Metal Specification Measurements

(Christian Schlosser, Oliver Baars, Peter Croot)

Introduction:

While it is established now that iron (Fe) and other trace metals (zinc (Zd), cadmium (Cd), etc.) can be (co)limiting nutrients for phytoplankton in High Nutrient Low Chlorophyll (HNLC) regions of the world (Boyd et al., 2000; Coale et al., 2004; Coale et al., 1998; Croot et al., 2001; Croot et al., 2005; Tsuda et al., 2003), we still know little about the processes by which these trace metals are supplied to the ocean (Saharan dust, resuspension of continental shelf sediments, etc.) and how processes in the ocean scavenge/uptake, solubility or remineralize dissolved trace metals. By examining trace metal chemistry in oxygen minimum zones (OMZ) in the Tropical Atlantic such as encountered on MSM10/01 we can try to complete the overview of the key processes controlling biogeochemistry of trace metals in seawater. From this basis we can start to quantify the fluxes involved in each individual process.

Sampling:

At five stations (Fig. 5.9), seawater for trace metal analysis was sampled by four trace metal clean GO-FLO samplers (10 and 12 L). The samplers were deployed at the ship's own Kevlar wire (Standard winch, Serienwinde) and collected seawater samples in 50, 100, 150, 200, 300, 400, 600 and 800 m water depth (euphotic zone, OMZ, and underlying water masses). The collected seawater for graphite furnace - atomic absorption spectroscopy (GF-AAS) and seawater for onboard speciation measurements was filtered through a 0.2 µm filter. For colloidal and soluble size fractionation, cross-flow filtration (with a 10 kDa membrane filter) was performed on seawater from station -0155 from seven different depths. Filtered seawater samples for GF-AAS measurements were filled in 1 L low density polyethylene (LDPE) bottles and acidified with quartz distilled HCl (Q-HCl), below pH 2 to prevent wall sorption effects of the sample bottle. Samples for trace metal speciation measurements were filled in 0.5 L high density polyethylene (HDPE) bottles and stored in a freezer at -20°C. Important, Zn and Cd speciation measurements were performed on seawater of three GO-FLO casts (-0004, -0021, and -0155).

Sampling, sample treatment and speciation measurements were performed in a class 1000 clean container, rented from the University of Bremen.

Analysis:

The collected seawater samples for GF-AAS analysis were shipped to the IFM-GEOMAR, Kiel and analyzed under clean air conditions.

For Fe speciation measurements, competitive ligand equilibration / adsorptive cathodic stripping voltammetry (CLE/ACSV), was used. The voltammetric apparatus consisted of a voltammeter with a static mercury drop electrode (Metrohm 757 VA Computrace), a double-junction Ag / saturated AgCl reference electrode with a salt-bridge filled with 3M KCl and a glass rod as a counter electrode. For zinc and cadmium speciation measurements the static mercury drop electrode was replaced by a rotating disc electrode (RDE). All standard solutions were prepared with Q-HCl and 18 MΩ water.

Preliminary results:

The preliminary data set of Fe ligand measurements (Fig. 5.9) shows a slight higher excess ligand concentration in the surface (50m) for three stations (-0004, -0021, and -0155). The two other stations show a slight decrease at this depth. The reason for this is not clear. Below the euphotice zone, four of five stations, show a slight maximum of excess Fe binding ligands in the maximum of the MOZ. This can be caused by a higher decomposition rate of organic matter and the release of organic ligands in this depth. For more detailed understanding of these results the total dissolved Fe concentrations, which will be measured by GF-AAS in Kiel, are necessary.

Fe ligand measurement performed on cross-flow filtrated seawater samples from station -0155 showed a linear relationship (R^2=0.980) with Fe ligand measurements performed on the same seawater, but 0.2 µm filtered (Fig. 5.9). The existence of a colloidal ligand fraction (sice fraction between 0.2 µm and 10 kDa) was first introduced by Boye et al. (2005). Our measurements support this hypothesis and show a linear relationship of both, soluble and colloidal excess Fe ligands. This relationship, with an average ratio of approximately 1:1 and an increasing amount of soluble ligands from the surface to 200 m water depth, is also valid for samples taken in the MOZ and oxygen rich underlying water masses. However, final results will be available after GF-AAS analysis in Kiel.

As described in the sampling section, seawater samples from three locations, and eight different depths, were used to measure Zn and Cd speciation differences in the water column. Final results are not available, since total dissolved concentrations of Zn and Cd are necessary for speciation calculations. These data will be available after GF-AAS analysis.

Collaborations:

Aerosol Optical Thickness - For a better understanding of Fe and trace metal sources, aerosol optical thickness (AOT) measurements were performed during MSM10/1. For these measurements a multi-band sunphotometer (Microtops II®) with five accurately aligned optical collimators was used. With this instrument, received from Alexander Smirnov, NASA/Goddard Space Flight Center, Greenbelt, USA, it is possible to calculate the amount of dust transported by the atmosphere. The calculations will be done in Kiel.

Si Isotopes – Seawater samples from five different locations (Station -0550, -0002, -0003, -0004 and -0021) and 9 different depths (20, 50, 100, 200, 400, 700, 1000, 1500, and 2000 m) were obtained from the CTD rosette and filtered by a 0.6 µm polycarbonate filter for Si isotope measurements. The filtration equipment and 0.5L sample bottles were received from Prof. Dr. Christina De La Rocha, Institut Universitaire Européen de la Mer (IUEM), Brest, France. The sampled seawater will be first shipped to the IFM-GEOMAR, Kiel and than transported to France were the measurements for paleoclimate research will be performed.

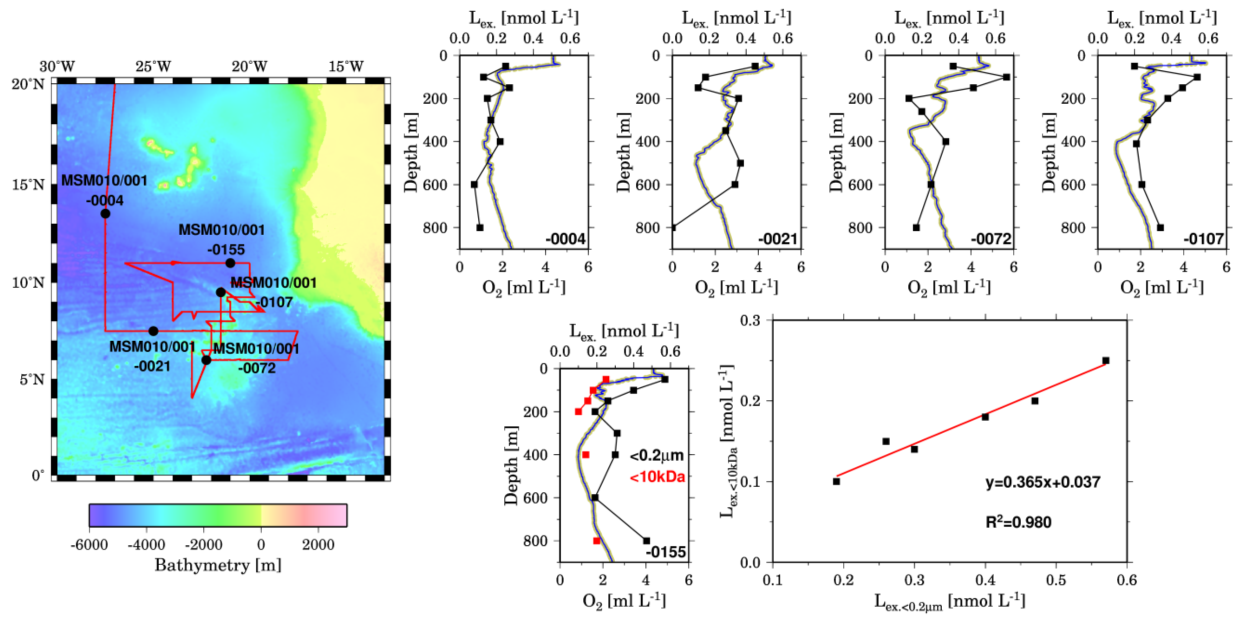

Fig. 5.9 The left picture shows the bathymetric data set, the cruise track during MSM10/1 (red line), and the positions of the performed GO-FLO casts. The diagrams on the right hand site show preliminary results of excess Fe ligand measurements performed onboard. The excess Fe ligand concentration (black squares - <0.2µm; red squares - <10kDa) and the oxygen concentration (solid blue line) are plotted versus depth. The measured data set of cross-flow filtered and 0.2µm filtered samples from station -0155, are shown together in a ligand-ligand diagram. Both ligand fractions show a linear relationship with an increasing ratio of $L_{ex.<0.2\mu m}$ vs. $L_{ex.<10kDa}$ from surface to 200 m. Below 200 m, this ratio decreases again with increasing depth

5.8 Studying the Diazotrophic Diversity in Oxygen Minimum Zones (OMZs) of the Tropical Atlantic Ocean

(Sandra Fehsenfeld, Carolin Löscher)

DNA / RNA sampling:

Dinitrogen (N_2) fixation is a biological process carried out by prokaryotic organisms, known as diazotrophs. This process plays a key role for maintaining biological productivity in the oceans

(Capone, 2008; Deutsch et al., 2007). As an assimilatory pathway, it generates ammonium which is incorporated into cell material, mainly. As a balance to the loss processes of the nitrogen cycle such as denitrification or anammox it constitutes the input into the nitrogen cycle.

In the eastern tropical North Atlantic Ocean (ETNA), denitrification and anammox are not directly responsible for a nitrogen deficiency. However, a nitrogen limitation of primary productivity is a possible niche for diazotrophs (Mills et al., 2004), there.

On this cruise, DNA/RNA samples were taken by filtering 2L of seawater through 0.22 µm mesh sized membranes (Millipore, Isopore membrane filters). To get information about the community structure of organisms involved in the nitrogen cycle, a total of 45 stations with 140 samples were taken. For every station, at least water from surface (10 m) and depth of the O2 minimum (~300-400 m) was sampled. Additional sample depths were at 100 m, 200 m, and 700 m and of the depth with a tracer density of 26.85 kg/m^3. Analysis takes place by Carolin Löscher in the lab of Prof. Ruth Schmitz-Streit at Christian-Albrechts-University Kiel and by Dr. Falguni Joshi in the lab of Prof. Julie LaRoche at IFM-GEOMAR Kiel. Hereby, the phylogenetic diversity of 16S rDNA and the nifH gene were studied by PCR amplification, cloning and sequencing and quantitative analysis takes place via real time PCR. The main interest is the composition of the bacterial community in the OMZ which shows a high level of diversity (Fig.5.10) and in the water masses marked by the SF_5CF_3- tracer brought out in spring 2008 (cruise MSM 8/1) to be able to follow changes in microbial communities over time.

The distribution of nifH along a North to South section shows highest abundances in the surface down to about 150m (Fig.5.11), which might potentially be ascribed to phototrophic diazotrophs. But still, nifH is present in the depth of the OMZ indicating the possibility of nitrogen fixation.

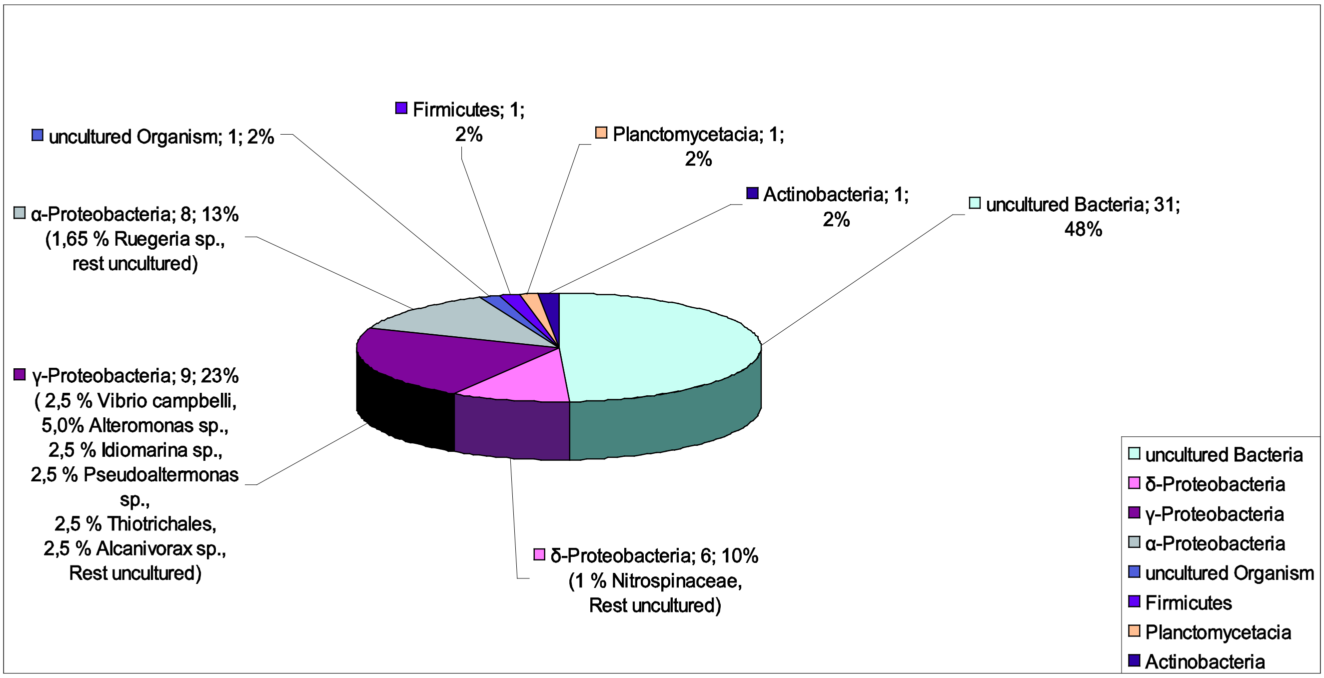

Fig. 5.10 Bacterial diversity in the OMZ

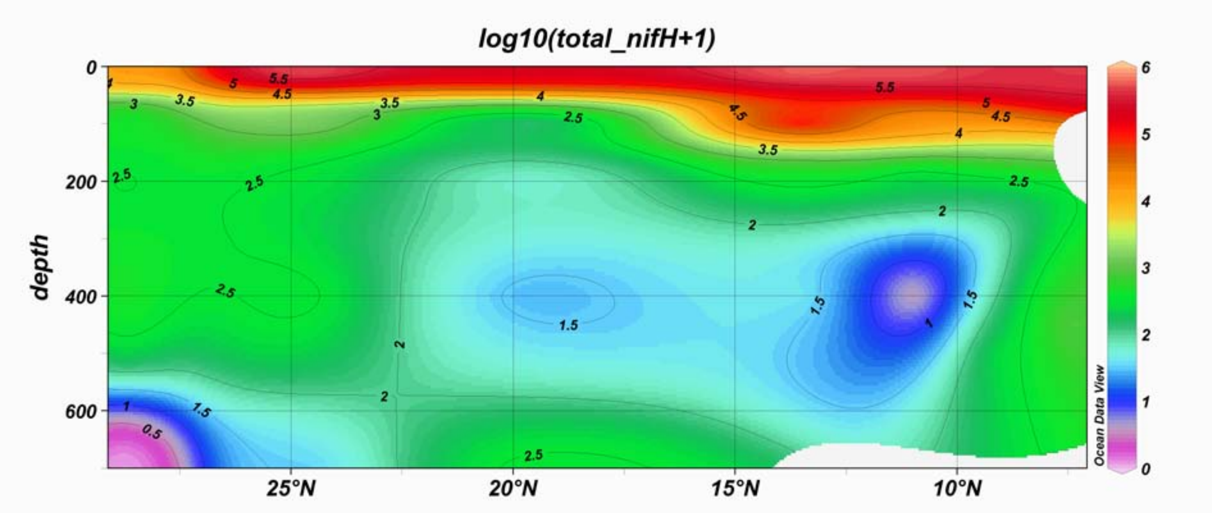

Fig. 5.11 Distribution of total *nifH* along a North- South transect

5.9 Calibration of Aanderaa Oxygen Optodes

(Martin Visbeck, Sara Wilcken)

During this cruise we performed a series of experiments to improve the calibration of 11 AANDERAA optodes (Oxygen Optode 3830) that are used by autonomous observation systems such as moorings, floats and gliders by comparing its readings to the CTD sensor in situ as part of the Bachelor thesis from Sara Wilcken (Wilcken, 2009).

Firstly we followed the recommended steps by the manufacturer, however, there were some potential issues already with the sensor response time, that was then determined in the lab. The settling time was determined for 7 sensors at two temperatures of about 22°C and 5°C (cooled room). By switching from an unsaturated glass of water to one that was saturated with oxygen by an air pump and an air stone. This was done 3 times for each optode at 5°C and at 22°C. The results show some systematic differences, for example optode 1067 is much slower than the others, especially at 5°C. Because of that the results of this optode at 5°C were not used for further statistics. The median response time of 15s at 22°C and 26s at 5°C correspond to the manufacturers' specified value of < 25s.

Secondly several different test were conducted to establish a 'best practice' calibration procedure for optodes that could be applied for the pre- and post deployment sensor calibration. At different times and stations during the cruise several optodes were attached to the CTD rosette and lowered down to a depth of 1000m. At each cast three data loggers were used simultaneously. The experiments focussed on two issues. One to possibly better determine the pressure dependence of the optodes, where several investigators have reported issues with the manufacturers correction value of 3.2% low bias per 1000dbar. Secondly to demonstrate that continuously comparing to the bottle calibrated CTD sensor gave better results compared to time consuming optode calibration at bottle stops (because of the slow adjustment time of the optode long bottle stops would be needed).

To directly check the pressure dependence independently an optode was deployed inside a Niskin bottle (Fig. 5.12). Several different experiments were done and some strange behaviour was found. The most consistent results were obtained by closing the bottle at depth and measuring the pressure induced oxygen bias during the upcast. But in the end these experiments did not yield very satisfactory results.

In the end we concluded that a multiparameter linear fit to the oxygen calibration points obtained during CTD casts without bottle stops with a linear dependence on oxygen and pressure*oxygen allowed for a satisfactory optode calibration with a residuals rms of better than 1 µmol/l . The key to make this comparison of high accuracy was to 'slow' the well calibrated CTD oxygen sensors down by one sided averaging to meet the slow response time of the optode. Furthermore regions of rapid oxygen changes in the vertical profile were avoided.

The results of these experiments were published in the Bachelor Thesis of Sara Wilcken: "In situ Kalibrierung von Optoden zur Messung des Sauerstoffgehaltes im marinen Umfeld" Studienfach Maritime Technologien der Hochschule Bremerhaven.

Fig. 5.12
Optode with datalogger deployed inside of a Niskin bottle

6 Ship's Meteorological Station

No participant from the Deutsche Wetterdienst on RV Merian.

7 Station List MSM10/1

P# signifies 'number of profiles at station' for MSS. SF5 as short version of SF_5CF_3.

Ship Station	P#	Date	Time	Latitude	Longitude	Gear	Comment
1	1	02-Nov-2008	18:10	28° 41.71' N	26° 19.37' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
MSS 1	1/1	02-Nov-2008	19:56	28° 42.13' N	26° 19.92' W	MSS	
ARGOFL 1	1	02-Nov-2008	20:23	28° 42.32' N	26° 19.66' W	ARGOFL	
2	2	03-Nov-2008	16:08	24° 37.12' N	26° 39.42' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
MSS 2	2/3	03-Nov-2008	17:38	24° 37.50' N	26° 39.69' W	MSS	
ARGOFL 2	1	03-Nov-2008	18:56	24° 38.68' N	26° 38.89' W	ARGOFL	
3	3	04-Nov-2008	19:36	19° 33.70' N	27° 1.66' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
GO-FLO 3	1	04-Nov-2008	21:01	19° 34.12' N	27° 1.86' W	GO-FLO	
ARGOFL 3	1	04-Nov-2008	21:46	19° 34.39' N	27° 2.01' W	ARGOFL	
GO-FLO 4	1	06-Nov-2008	02:41	13° 30.00' N	27° 30.00' W	GO-FLO	
4	4	06-Nov-2008	03:39	13° 30.00' N	27° 30.00' W	CTD/RO	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
GO-FLO 4	2	06-Nov-2008	05:07	13° 30.00' N	27° 30.00' W	GO-FLO	
ARGOFL 4	1	06-Nov-2008	06:03	13° 30.01' N	27° 30.00' W	ARGOFL	
5	5	06-Nov-2008	08:51	13° 0.00' N	27° 30.00' W	CTD/RO	Oxygen, Salinity, SF5, CFC-12
6	6	06-Nov-2008	12:25	12° 29.96' N	27° 30.00' W	CTD/RO	Oxygen, SF5, CFC-12
7	7	06-Nov-2008	15:54	12° 0.10' N	27° 30.06' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
8	8	06-Nov-2008	19:22	11° 30.00' N	27° 30.00' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
9	9	06-Nov-2008	22:47	10° 59.98' N	27° 30.02' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
10	10	07-Nov-2008	02:06	10° 30.03' N	27° 29.97' W	CTD/RO/lADCP	Salinity, SF5, CFC-12
11	11	07-Nov-2008	06:00	9° 59.97' N	27° 29.97' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
12	12	07-Nov-2008	09:34	9° 29.97' N	27° 30.05' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
13	13	07-Nov-2008	13:13	9° 0.01' N	27° 30.01' W	CTD/RO/lADCP	Oxygen, RNA/DNA, SF5, CFC-12
14	14	07-Nov-2008	16:49	8° 30.00' N	27° 30.01' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
15	15	07-Nov-2008	20:24	8° 0.01' N	27° 30.00' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
16	16	08-Nov-2008	00:03	7° 29.99' N	27° 30.05' W	CTD/RO/lADCP	Oxygen, Salinity, Nutrients, RNA/DNA, SF5, CFC-12
17	17	08-Nov-2008	03:45	7° 30.00' N	27° 0.01' W	CTD/RO/lADCP	Oxygen, Salinity, Nutrients, SF5, CFC-12
18	18	08-Nov-2008	07:30	7° 29.98' N	26° 30.01' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
19	19	08-Nov-2008	11:13	7° 29.98' N	26° 0.04' W	CTD/RO/lADCP	Oxygen, Nutrients, SF5, CFC-12
20	20	08-Nov-2008	14:51	7° 30.00' N	25° 30.01' W	CTD/RO/lADCP	Oxygen, Salinity, Nutrients, SF5, CFC-12
GO-FLO 21	1	08-Nov-2008	18:33	7° 30.03' N	25° 0.01' W	GO-FLO	
21	21	08-Nov-2008	19:09	7° 30.03' N	25° 0.01' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
MSS 21	3/3	08-Nov-2008	20:39	7° 30.05' N	24° 59.99' W	MSS	
GO-FLO 21	2	08-Nov-2008	21:48	7° 30.03' N	24° 59.99' W	GO-FLO	
22	22	09-Nov-2008	01:29	7° 30.00' N	24° 30.01' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
23	23	09-Nov-2008	03:04	7° 30.00' N	24° 26.75' W	CTD/RO/lADCP	Nutrients, SF5, CFC-12

24	24	09-Nov-2008	04:33	7° 29.99' N	24° 23.82' W	CTD/RO	SF5, CFC-12
25	25	09-Nov-2008	06:09	7° 30.00' N	24° 15.01' W	CTD/RO/lADCP	SF5, CFC-12
26	26	09-Nov-2008	07:37	7° 30.01' N	24° 11.66' W	CTD/RO	SF5, CFC-12
27	27	09-Nov-2008	08:54	7° 29.99' N	24° 8.55' W	CTD/RO	SF5, CFC-12
28	28	09-Nov-2008	10:24	7° 30.00' N	23° 59.98' W	CTD/RO/lADCP	Oxygen, Salinity, Nutrients, SF5, CFC-12
29	29	09-Nov-2008	13:53	7° 30.00' N	23° 30.01' W	CTD/RO/lADCP	Oxygen, Salinity, Nutrients, SF5, CFC-12
30	30	09-Nov-2008	17:28	7° 29.98' N	23° 0.00' W	CTD/RO/lADCP	Oxygen, Nutrients, RNA/DNA, SF5, CFC-12
MSS 31	4/3	09-Nov-2008	18:54	7° 30.08' N	22° 57.76' W	MSS	
31	31	09-Nov-2008	20:12	7° 31.54' N	22° 57.58' W	CTD/RO	SF5, CFC-12
32	32	09-Nov-2008	23:18	7° 30.02' N	22° 30.01' W	CTD/RO/lADCP	Oxygen, Salinity, Nutrients, SF5, CFC-12
33	33	10-Nov-2008	00:57	7° 30.02' N	22° 28.08' W	CTD/RO	SF5, CFC-12
MSS 33	5/3	10-Nov-2008	01:43	7° 30.07' N	22° 28.08' W	MSS	
34	34	10-Nov-2008	03:34	7° 29.99' N	22° 24.89' W	CTD/RO	SF5, CFC-12
MSS 34	6/3	10-Nov-2008	04:12	7° 29.98' N	22° 24.89' W	MSS	
35	35	10-Nov-2008	06:38	7° 29.99' N	22° 15.01' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
MSS 35	7/3	10-Nov-2008	07:37	7° 30.02' N	22° 14.99' W	MSS	
36	36	10-Nov-2008	09:39	7° 29.98' N	22° 10.00' W	CTD/RO/lADCP	SF5, CFC-12
37	37	10-Nov-2008	11:23	7° 29.99' N	21° 59.99' W	CTD/RO/lADCP	Oxygen, Salinity, Nutrients, RNA/DNA, SF5, CFC-12
38	38	10-Nov-2008	12:54	7° 30.02' N	21° 57.99' W	CTD/RO	RNA/DNA, SF5, CFC-12
MSS 38	8/3	10-Nov-2008	13:35	7° 30.07' N	21° 57.98' W	MSS	
39	39	10-Nov-2008	14:59	7° 31.62' N	21° 57.87' W	CTD/RO	SF5, CFC-12
40	40	10-Nov-2008	16:26	7° 29.99' N	21° 52.01' W	CTD/RO	SF5, CFC-12
MSS 40	9/3	10-Nov-2008	17:10	7° 30.02' N	21° 52.00' W	MSS	
41	41	10-Nov-2008	19:16	7° 29.99' N	21° 45.00' W	CTD/RO/lADCP	Oxygen, Salinity, Nutrients, RNA/DNA, SF5, CFC-12
42	42	10-Nov-2008	20:54	7° 29.99' N	21° 39.99' W	CTD/RO	SF5, CFC-12
43	43	10-Nov-2008	22:29	7° 29.99' N	21° 35.05' W	CTD/RO	SF5, CFC-12
44	44	10-Nov-2008	23:54	7° 29.99' N	21° 30.03' W	CTD/RO/lADCP	Oxygen, Salinity, N2O, Nutrients, SF5, CFC-12
MSS 44	10/3	11-Nov-2008	00:58	7° 30.02' N	21° 30.03' W	MSS	
45	45	11-Nov-2008	02:47	7° 30.00' N	21° 25.01' W	CTD/RO	SF5, CFC-12
MSS 45	11/3	11-Nov-2008	03:32	7° 30.03' N	21° 25.00' W	MSS	
46	46	11-Nov-2008	05:25	7° 29.99' N	21° 20.00' W	CTD/RO	SF5, CFC-12
47	47	11-Nov-2008	06:42	7° 29.99' N	21° 15.00' W	CTD/RO/lADCP	Oxygen, Salinity, Nutrients, SF5, CFC-12
MSS 47	12/1	11-Nov-2008	07:45	7° 30.15' N	21° 14.99' W	MSS	Aborted. Problems with cable
48	48	11-Nov-2008	09:36	7° 29.99' N	21° 0.01' W	CTD/RO/lADCP	Oxygen, Salinity, Nutrients, RNA/DNA, SF5, CFC-12
49	49	11-Nov-2008	11:09	7° 29.99' N	20° 55.03' W	CTD/RO	SF5, CFC-12
50	50	11-Nov-2008	12:26	7° 29.98' N	20° 50.02' W	CTD/RO	SF5, CFC-12
51	51	11-Nov-2008	13:47	7° 30.00' N	20° 45.01' W	CTD/RO/lADCP	SF5, CFC-12
52	52	11-Nov-2008	16:19	7° 29.99' N	20° 30.01' W	CTD/RO/lADCP	Oxygen, Salinity, Nutrients, SF5, CFC-12
53	53	11-Nov-2008	20:14	7° 29.98' N	19° 59.99' W	CTD/RO/lADCP	Oxygen, Salinity, Nutrients, RNA/DNA, SF5, CFC-12
54	54	11-Nov-2008	23:45	7° 29.99' N	19° 30.01' W	CTD/RO/lADCP	Oxygen, Salinity, Nutrients, SF5, CFC-12
55	55	12-Nov-2008	03:15	7° 29.99' N	19° 0.01' W	CTD/RO	Oxygen, Salinity, Nutrients, SF5, CFC-12
56	56	12-Nov-2008	06:58	7° 29.99' N	18° 30.02' W	CTD/RO/lADCP	Oxygen, Salinity, Nutrients, SF5, CFC-12
57	57	12-Nov-2008	10:43	7° 30.00' N	18° 0.02' W	CTD/RO/lADCP	Salinity, SF5, CFC-12
58	58	12-Nov-2008	14:21	7° 30.01' N	17° 30.00' W	CTD/RO/lADCP	Salinity, RNA/DNA, SF5,

							CFC-12
59	59	12-Nov-2008	22:40	6° 0.03' N	18° 0.02' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
60	60	13-Nov-2008	02:20	5° 59.99' N	18° 30.00' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
61	61	13-Nov-2008	05:58	6° 0.00' N	19° 0.00' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
62	62	13-Nov-2008	09:33	6° 0.01' N	19° 30.03' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
63	63	13-Nov-2008	13:05	5° 59.98' N	20° 0.01' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
64	64	13-Nov-2008	15:38	5° 59.99' N	20° 15.00' W	CTD/RO	Oxygen, SF5, CFC-12
65	65	13-Nov-2008	18:09	6° 0.01' N	20° 29.96' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
MSS 65	13/3	13-Nov-2008	19:11	6° 0.09' N	20° 29.96' W	MSS	
66	66	13-Nov-2008	22:01	5° 59.99' N	20° 45.00' W	CTD/RO/lADCP	Salinity, SF5, CFC-12
67	67	14-Nov-2008	00:32	6° 0.01' N	20° 59.95' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
68	68	14-Nov-2008	03:01	6° 0.00' N	21° 14.95' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
69	69	14-Nov-2008	05:35	6° 0.01' N	21° 29.96' W	CTD/RO/lADCP	Oxygen, SF5, CFC-12
70	70	14-Nov-2008	08:06	6° 0.02' N	21° 44.97' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
71	71	14-Nov-2008	10:38	6° 0.01' N	22° 0.01' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
GO-FLO 72	1	14-Nov-2008	13:17	6° 0.01' N	22° 15.00' W	GO-FLO	
72	72	14-Nov-2008	13:59	6° 0.01' N	22° 15.00' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
GO-FLO 72	2	14-Nov-2008	15:50	6° 0.01' N	22° 15.00' W	GO-FLO	
73	73	14-Nov-2008	19:50	6° 30.00' N	22° 30.03' W	CTD/RO/lADCP	Oxygen, RNA/DNA, SF5, CFC-12
74	74	14-Nov-2008	22:10	6° 30.07' N	22° 14.98' W	CTD/RO/lADCP	Oxygen, SF5, CFC-12
75	75	15-Nov-2008	00:28	6° 30.08' N	22° 0.02' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
76	76	15-Nov-2008	02:05	6° 30.02' N	21° 55.00' W	CTD/RO	SF5, CFC-12
77	77	15-Nov-2008	03:24	6° 30.01' N	21° 49.95' W	CTD/RO	SF5, CFC-12
78	78	15-Nov-2008	04:50	6° 30.01' N	21° 44.99' W	CTD/RO	SF5, CFC-12
79	79	15-Nov-2008	06:13	6° 30.02' N	21° 40.00' W	CTD/RO	SF5, CFC-12
MSS 79	14/3	15-Nov-2008	06:55	6° 30.02' N	21° 39.97' W	MSS	
80	80	15-Nov-2008	09:13	6° 30.02' N	21° 30.02' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
81	81	15-Nov-2008	12:16	6° 45.12' N	21° 30.00' W	CTD/RO	Salinity, RNA/DNA, SF5, CFC-12
82	82	15-Nov-2008	13:43	6° 50.01' N	21° 30.00' W	CTD/RO	RNA/DNA, SF5, CFC-12
83	83	15-Nov-2008	14:56	6° 55.08' N	21° 29.99' W	CTD/RO	RNA/DNA, SF5, CFC-12
MSS 84	15/3	15-Nov-2008	16:19	7° 0.68' N	21° 31.11' W	MSS	
84	84	15-Nov-2008	17:44	6° 59.83' N	21° 29.71' W	CTD/RO/lADCP	Salinity, SF5, CFC-12
85	85	15-Nov-2008	19:23	7° 5.01' N	21° 30.00' W	CTD/RO	SF5, CFC-12
MSS 86	16/3	15-Nov-2008	20:44	7° 11.32' N	21° 30.87' W	MSS	
86	86	15-Nov-2008	22:09	7° 10.22' N	21° 30.14' W	CTD/RO	SF5, CFC-12
MSS 87	17/3	15-Nov-2008	23:33	7° 15.96' N	21° 30.80' W	MSS	
87	87	16-Nov-2008	01:00	7° 15.01' N	21° 30.00' W	CTD/RO	Oxygen, Salinity, SF5, CFC-12
88	88	16-Nov-2008	03:13	7° 30.01' N	21° 29.99' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
89	89	16-Nov-2008	04:55	7° 35.01' N	21° 30.00' W	CTD/RO	SF5, CFC-12
90	90	16-Nov-2008	06:13	7° 40.01' N	21° 30.00' W	CTD/RO	SF5, CFC-12
91	91	16-Nov-2008	07:32	7° 44.99' N	21° 30.01' W	CTD/RO	SF5, CFC-12
92	92	16-Nov-2008	08:53	7° 50.00' N	21° 30.01' W	CTD/RO	Oxygen, SF5, CFC-12
93	93	16-Nov-2008	10:15	7° 54.99' N	21° 30.04' W	CTD/RO	RNA/DNA, SF5, CFC-12

MSS 94	18/3	16-Nov-2008	14:06	8° 1.34' N	21° 32.10' W	MSS	
94	94	16-Nov-2008	15:40	8° 0.00' N	21° 30.00' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
95	95	16-Nov-2008	18:09	8° 15.00' N	21° 30.01' W	CTD/RO	SF5, CFC-12
96	96	16-Nov-2008	20:13	8° 30.02' N	21° 29.99' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
97	97	16-Nov-2008	22:20	8° 25.03' N	21° 30.03' W	CTD/RO	SF5, CFC-12
98	98	17-Nov-2008	00:10	8° 34.95' N	21° 30.04' W	CTD/RO	Oxygen, SF5, CFC-12
99	99	17-Nov-2008	01:29	8° 40.01' N	21° 30.00' W	CTD/RO	Oxygen, SF5, CFC-12
100	100	17-Nov-2008	02:50	8° 45.01' N	21° 30.00' W	CTD/RO	Salinity, SF5, CFC-12
101	101	17-Nov-2008	04:08	8° 50.01' N	21° 30.00' W	CTD/RO	SF5, CFC-12
102	102	17-Nov-2008	05:33	8° 54.98' N	21° 30.00' W	CTD/RO	SF5, CFC-12
103	103	17-Nov-2008	06:49	8° 59.99' N	21° 30.01' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
104	104	17-Nov-2008	08:24	9° 4.99' N	21° 30.00' W	CTD/RO/lADCP	RNA/DNA, SF5, CFC-12
105	105	17-Nov-2008	10:02	9° 15.00' N	21° 30.03' W	CTD/RO	Salinity, SF5, CFC-12
106	106	17-Nov-2008	11:34	9° 22.48' N	21° 29.98' W	CTD/RO	SF5, CFC-12
GO-FLO 107	1	17-Nov-2008	12:58	9° 29.96' N	21° 30.02' W	GO-FLO	
107	107	17-Nov-2008	13:35	9° 29.95' N	21° 30.02' W	CTD/RO	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
GO-FLO 107	2	17-Nov-2008	15:11	9° 29.96' N	21° 30.02' W	GO-FLO	
108	108	17-Nov-2008	17:32	9° 44.99' N	21° 30.00' W	CTD/RO/lADCP	SF6, SF5, CFC-12
109	109	17-Nov-2008	23:52	9° 0.00' N	20° 30.03' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
110	110	18-Nov-2008	03:16	9° 0.01' N	20° 0.00' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
111	111	18-Nov-2008	06:01	8° 45.01' N	19° 45.00' W	CTD/RO	SF5, CFC-12
112	112	19-Nov-2008	05:09	8° 30.01' N	19° 15.02' W	CTD/RO	SF5, CFC-12
113	113	19-Nov-2008	07:16	8° 30.00' N	19° 30.01' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
114	114	19-Nov-2008	09:37	8° 29.97' N	19° 45.00' W	CTD/RO/lADCP	SF5, CFC-12
115	115	19-Nov-2008	11:40	8° 30.00' N	19° 59.95' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
116	116	19-Nov-2008	14:06	8° 30.00' N	20° 14.99' W	CTD/RO	Oxygen, SF5, CFC-12
117	117	19-Nov-2008	16:26	8° 30.00' N	20° 30.00' W	CTD/RO/lADCP	Oxygen, Salinity, SF6, SF5, CFC-12
118	118	19-Nov-2008	18:48	8° 29.98' N	20° 44.98' W	CTD/RO	RNA/DNA, SF5, CFC-12
119	119	19-Nov-2008	20:14	8° 29.99' N	20° 52.50' W	CTD/RO	SF6, SF5, CFC-12
120	120	19-Nov-2008	21:36	8° 30.00' N	20° 59.98' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
121	121	19-Nov-2008	23:22	8° 30.02' N	21° 7.50' W	CTD/RO	SF5, CFC-12
122	122	20-Nov-2008	00:52	8° 30.03' N	21° 14.95' W	CTD/RO	Oxygen, Salinity, SF5, CFC-12
123	123	20-Nov-2008	02:24	8° 29.99' N	21° 22.50' W	CTD/RO	Salinity, SF5, CFC-12
124	124	20-Nov-2008	03:53	8° 29.99' N	21° 30.01' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
125	125	20-Nov-2008	05:42	8° 30.00' N	21° 37.48' W	CTD/RO	SF5, CFC-12
126	126	20-Nov-2008	07:11	8° 30.00' N	21° 44.99' W	CTD/RO	SF5, CFC-12
127	127	20-Nov-2008	09:19	8° 29.96' N	21° 59.98' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
128	128	20-Nov-2008	11:49	8° 29.94' N	22° 14.99' W	CTD/RO	SF5, CFC-12
129	129	20-Nov-2008	13:57	8° 29.99' N	22° 29.97' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
130	130	20-Nov-2008	16:23	8° 29.99' N	22° 45.00' W	CTD/RO	SF5, CFC-12
MSS 131	19/3	20-Nov-2008	19:18	8° 6.54' N	22° 53.57' W	MSS	
131	131	20-Nov-2008	20:41	8° 7.80' N	22° 53.95' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
132	132	21-Nov-2008	01:34	8° 30.00' N	23° 0.01' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12

133	133	21-Nov-2008	05:12	8° 29.99' N	23° 30.00' W	CTD/RO/lADCP	Oxygen, Salinity, SF6, SF5, CFC-12
134	134	21-Nov-2008	09:50	7° 59.98' N	23° 59.96' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
135	135	21-Nov-2008	13:27	8° 30.00' N	24° 0.01' W	CTD/RO/lADCP	Salinity, SF5, CFC-12
136	136	21-Nov-2008	17:05	9° 0.00' N	23° 59.98' W	CTD/RO/lADCP	Salinity, SF6, SF5, CFC-12
MSS 136	20/5	21-Nov-2008	18:00	9° 0.05' N	23° 59.99' W	MSS	
137	137	21-Nov-2008	22:37	9° 29.96' N	24° 0.02' W	CTD/RO/lADCP	Salinity, RNA/DNA, SF5, CFC-12
138	138	22-Nov-2008	02:04	9° 59.99' N	24° 0.02' W	CTD/RO/lADCP	Salinity, SF5, CFC-12
139	139	22-Nov-2008	15:41	11° 0.00' N	26° 30.01' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
140	140	22-Nov-2008	19:15	10° 59.99' N	25° 59.99' W	CTD/RO/lADCP	Oxygen, Salinity, SF6, SF5, CFC-12
141	141	22-Nov-2008	22:46	10° 59.99' N	25° 30.05' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
142	142	23-Nov-2008	02:18	11° 0.01' N	25° 0.00' W	CTD/RO/lADCP	Salinity, SF6, SF5, CFC-12
143	143	23-Nov-2008	05:49	11° 0.00' N	24° 30.00' W	CTD/RO/lADCP	Oxygen, Salinity, SF6, SF5, CFC-12
144	144	23-Nov-2008	09:16	11° 0.01' N	24° 0.02' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
145	145	23-Nov-2008	11:31	11° 0.00' N	23° 45.01' W	CTD/RO	Salinity, SF5, CFC-12
146	146	23-Nov-2008	14:08	10° 59.98' N	23° 52.53' W	CTD/RO	SF5, CFC-12
147	147	23-Nov-2008	15:49	10° 55.01' N	24° 0.01' W	CTD/RO	SF5, CFC-12
148	148	23-Nov-2008	17:17	10° 59.99' N	24° 5.02' W	CTD/RO	SF5, CFC-12
149	149	23-Nov-2008	18:39	11° 5.00' N	23° 59.99' W	CTD/RO	SF5, CFC-12
150	150	23-Nov-2008	21:57	10° 59.97' N	23° 30.01' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
151	151	24-Nov-2008	01:39	10° 59.99' N	23° 0.04' W	CTD/RO/lADCP	Salinity, SF5, CFC-12
152	152	24-Nov-2008	05:26	11° 0.00' N	22° 30.03' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
153	153	24-Nov-2008	09:07	11° 0.00' N	22° 0.01' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
154	154	24-Nov-2008	12:47	10° 59.99' N	21° 30.01' W	CTD/RO/lADCP	Salinity, SF5, CFC-12
GO-FLO 155	1	24-Nov-2008	16:51	11° 0.00' N	21° 0.01' W	GO-FLO	
155	155	24-Nov-2008	17:27	11° 0.00' N	21° 0.01' W	CTD/RO/lADCP	Oxygen, Salinity, N2O, Nutrients, RNA/DNA, SF6, SF5, CFC-12
MSS 155	21/4	24-Nov-2008	19:01	11° 0.04' N	21° 0.02' W	MSS	
GO-FLO 155	2	24-Nov-2008	20:56	11° 1.64' N	21° 0.19' W	GO-FLO	
156	156	25-Nov-2008	00:52	10° 59.99' N	20° 30.02' W	CTD/RO/lADCP	Salinity, SF5, CFC-12
157	157	25-Nov-2008	04:41	11° 0.00' N	20° 0.01' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
158	158	25-Nov-2008	08:35	10° 29.98' N	20° 0.03' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
159	159	25-Nov-2008	11:05	10° 14.98' N	20° 0.02' W	CTD/RO	SF5, CFC-12
160	160	25-Nov-2008	13:49	10° 0.00' N	19° 45.01' W	CTD/RO	Salinity, SF5, CFC-12
161	161	25-Nov-2008	16:00	10° 0.00' N	20° 0.01' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
162	162	25-Nov-2008	18:30	9° 59.99' N	20° 15.00' W	CTD/RO	SF5, CFC-12
163	163	25-Nov-2008	20:45	10° 0.00' N	20° 30.01' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
164	164	25-Nov-2008	22:31	9° 59.99' N	20° 37.50' W	CTD/RO	SF5, CFC-12
165	165	26-Nov-2008	00:03	9° 59.99' N	20° 45.01' W	CTD/RO	Salinity, SF5, CFC-12
166	166	26-Nov-2008	02:12	10° 0.00' N	21° 0.01' W	CTD/RO/lADCP	Salinity, SF5, CFC-12
167	167	26-Nov-2008	08:22	9° 44.98' N	20° 0.01' W	CTD/RO	RNA/DNA, SF5, CFC-12
168	168	26-Nov-2008	10:28	9° 29.98' N	20° 0.00' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
MSS 168	22/3	26-Nov-2008	12:12	9° 30.05' N	19° 59.99' W	MSS	
169	169	26-Nov-2008	15:40	9° 15.00' N	19° 45.01' W	CTD/RO	Salinity, SF5, CFC-12

170	170	26-Nov-2008	17:52	9° 15.00' N	20° 0.01' W	CTD/RO/lADCP	Oxygen, Salinity, SF6, SF5, CFC-12
171	171	26-Nov-2008	20:11	9° 14.99' N	20° 15.00' W	CTD/RO	SF5, CFC-12
172	172	26-Nov-2008	22:17	9° 14.98' N	20° 30.02' W	CTD/RO/lADCP	Oxygen, SF5, CFC-12
173	173	27-Nov-2008	00:37	9° 14.99' N	20° 45.01' W	CTD/RO	Salinity, SF5, CFC-12
174	174	27-Nov-2008	02:38	9° 15.00' N	21° 0.01' W	CTD/RO/lADCP	Salinity, SF5, CFC-12
175	175	27-Nov-2008	04:33	9° 15.00' N	21° 10.01' W	CTD/RO	SF6, SF5, CFC-12
MSS 176	23/3	27-Nov-2008	06:29	9° 2.98' N	21° 9.92' W	MSS	
177	176	27-Nov-2008	09:19	8° 59.98' N	21° 0.02' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
178	177	27-Nov-2008	11:31	8° 44.96' N	21° 0.03' W	CTD/RO	SF5, CFC-12
179	178	27-Nov-2008	13:40	8° 30.00' N	21° 0.01' W	CTD/RO	SF5, CFC-12
179	179	27-Nov-2008	13:56	8° 30.00' N	21° 0.01' W	CTD/RO	Salinity, RNA/DNA, SF5, CFC-12
180	180	27-Nov-2008	16:15	8° 15.00' N	21° 0.01' W	CTD/RO	Salinity, SF6, SF5, CFC-12
181	181	27-Nov-2008	18:53	7° 59.98' N	20° 45.00' W	CTD/RO	SF5, CFC-12
182	182	27-Nov-2008	20:59	8° 0.00' N	20° 59.99' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
183	183	27-Nov-2008	23:28	7° 59.97' N	21° 15.01' W	CTD/RO	SF5, CFC-12
184	184	28-Nov-2008	01:03	7° 59.99' N	21° 22.67' W	CTD/RO	SF5, CFC-12
185	185	28-Nov-2008	02:39	8° 0.00' N	21° 30.01' W	CTD/RO/lADCP	Salinity, SF5, CFC-12
186	186	28-Nov-2008	05:01	8° 0.00' N	21° 45.01' W	CTD/RO	SF6, SF5, CFC-12
187	187	28-Nov-2008	07:07	7° 59.98' N	22° 0.03' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
188	188	28-Nov-2008	09:30	7° 59.99' N	22° 15.02' W	CTD/RO	SF5, CFC-12
189	189	28-Nov-2008	12:06	7° 44.98' N	22° 0.02' W	CTD/RO	Oxygen, RNA/DNA, SF5, CFC-12
190	190	28-Nov-2008	14:10	7° 30.00' N	22° 0.01' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
191	191	28-Nov-2008	16:27	7° 15.00' N	22° 0.01' W	CTD/RO	SF5, CFC-12
192	192	28-Nov-2008	18:38	7° 0.00' N	22° 0.02' W	CTD/RO/lADCP	Oxygen, SF6, SF5, CFC-12
193	193	28-Nov-2008	21:01	6° 44.98' N	22° 0.00' W	CTD/RO	Oxygen, Salinity, SF5, CFC-12
194	194	28-Nov-2008	23:07	6° 29.97' N	22° 0.00' W	CTD/RO	SF5, CFC-12
195	195	29-Nov-2008	14:00	4° 0.01' N	23° 0.00' W	CTD/RO/lADCP	Oxygen, Salinity, RNA/DNA, SF5, CFC-12
196		29-Nov-2008	16:05	4° 5.44' N	23° 0.46' W	MOR	Check PIRATA Mooring
ARGOFL 197	5/1	29-Nov-2008	19:03	4° 5.49' N	23° 1.07' W	ARGOFL	
198	196	29-Nov-2008	21:15	4° 30.01' N	23° 0.00' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
199	197	29-Nov-2008	23:45	4° 45.00' N	23° 0.01' W	CTD/RO	SF5, CFC-12
200	198	30-Nov-2008	01:43	4° 58.01' N	22° 59.99' W	CTD/RO/lADCP	Salinity, SF5, CFC-12
201	199	30-Nov-2008	05:32	5° 30.01' N	22° 59.99' W	CTD/RO/lADCP	Oxygen, Salinity, SF6, SF5, CFC-12
202	200	30-Nov-2008	09:05	6° 0.01' N	23° 0.00' W	CTD/RO/lADCP	Oxygen, Salinity, SF5, CFC-12
203	201	30-Nov-2008	12:43	6° 29.99' N	23° 0.00' W	CTD/RO/lADCP	Salinity, SF5, CFC-12
ARGOFL 203	6/1	30-Nov-2008	13:47	6° 30.11' N	22° 59.97' W	ARGOFL	
204	202	30-Nov-2008	15:11	6° 45.00' N	23° 0.01' W	CTD/RO	SF5, CFC-12
205	203	30-Nov-2008	17:15	7° 0.00' N	22° 59.99' W	CTD/RO/lADCP	Oxygen, Salinity, SF6, SF5, CFC-12
206	204	30-Nov-2008	19:35	7° 15.00' N	23° 0.00' W	CTD/RO	RNA/DNA, SF5, CFC-12
207	205	30-Nov-2008	21:41	7° 29.97' N	22° 59.99' W	CTD/RO/lADCP	Salinity, SF5, CFC-12
208	206	01-Dec-2008	00:05	7° 44.98' N	23° 0.00' W	CTD/RO	Salinity, SF5, CFC-12
209	207	01-Dec-2008	01:59	7° 57.99' N	23° 0.01' W	CTD/RO/lADCP	Salinity, SF5, CFC-12
210	208	01-Dec-2008	04:28	8° 15.00' N	23° 0.01' W	CTD/RO	SF5, CFC-12
211	209	01-Dec-2008	06:35	8° 30.00' N	23° 0.01' W	CTD/RO/lADCP	Oxygen, Salinity, SF6, SF5, CFC-12

212	210	01-Dec-2008	08:57	8° 45.00' N	23° 0.02' W	CTD/RO	SF5, CFC-12
213	211	01-Dec-2008	11:07	9° 0.00' N	23° 0.01' W	CTD/RO/LADCP	Oxygen, Salinity, SF5, CFC-12
214	212	01-Dec-2008	13:25	9° 15.00' N	23° 0.01' W	CTD/RO	SF5, CFC-12
215	213	01-Dec-2008	15:32	9° 30.00' N	23° 0.01' W	CTD/RO/LADCP	Salinity, RNA/DNA, SF5, CFC-12
216	214	01-Dec-2008	18:00	9° 30.01' N	22° 45.02' W	CTD/RO	SF6, SF5, CFC-12
217	215	01-Dec-2008	20:06	9° 29.99' N	22° 30.01' W	CTD/RO	SF5, CFC-12
218	216	01-Dec-2008	22:16	9° 30.00' N	22° 15.01' W	CTD/RO/LADCP	Oxygen, Salinity, SF5, CFC-12
ARGOFL 218	7/1	01-Dec-2008	23:20	9° 30.06' N	22° 15.02' W	ARGOFL	
219	217	02-Dec-2008	03:57	10° 0.00' N	23° 0.01' W	CTD/RO/LADCP	Salinity, SF6, SF5, CFC-12
220	218	02-Dec-2008	06:15	10° 15.00' N	23° 0.00' W	CTD/RO	SF5, CFC-12
221	219	02-Dec-2008	08:18	10° 29.99' N	23° 0.01' W	CTD/RO/LADCP	Oxygen, Salinity, SF5, CFC-12
222	220	02-Dec-2008	10:35	10° 44.99' N	23° 0.02' W	CTD/RO	SF5, CFC-12
223	221	02-Dec-2008	12:46	11° 0.00' N	23° 0.01' W	CTD/RO/LADCP	Oxygen, Salinity, SF5, CFC-12
224	222	02-Dec-2008	15:03	11° 15.00' N	23° 0.01' W	CTD/RO	SF5, CFC-12
225		02-Dec-2008	16:55	11° 28.81' N	23° 0.47' W	MOR	Check PIRATA Mooring
226	223	02-Dec-2008	19:43	11° 32.00' N	23° 0.01' W	CTD/RO/LADCP	Oxygen, Salinity, RNA/DNA, SF6, SF5, CFC-12
MSS 226	24/3	02-Dec-2008	20:39	11° 32.04' N	23° 0.03' W	MSS	
227	224	03-Dec-2008	00:40	11° 59.99' N	23° 0.00' W	CTD/RO/LADCP	SF5, CFC-12
228	225	03-Dec-2008	04:15	12° 30.00' N	23° 0.01' W	CTD/RO/LADCP	SF6, SF5, CFC-12
229	226	03-Dec-2008	07:57	13° 0.01' N	23° 0.01' W	CTD/RO	Oxygen, SF5, CFC-12
230	227	03-Dec-2008	11:37	13° 30.00' N	23° 0.00' W	CTD/RO/LADCP	Oxygen, SF5, CFC-12
231	228	03-Dec-2008	16:03	14° 0.00' N	23° 0.01' W	CTD/RO/LADCP	SF5, CFC-12
MSS 231	25/1	03-Dec-2008	17:07	14° 0.04' N	23° 0.05' W	MSS	
232	229	04-Dec-2008	15:38	17° 38.00' N	24° 15.01' W	CTD/RO/LADCP	Oxygen, N2O, Nutrients, RNA/DNA, SF5, CFC-12
MSS 232	26/18	04-Dec-2008	17:59	17° 38.04' N	24° 15.01' W	MSS	

8 Data and Sample Storage Availability

The data were collected within the Kiel Sonderforschungsbereich (SFB) 754. In Kiel a joint Data-management-Team is active, and stores data obtained within the institute in a webbased multi-user-system. In a first phase the data were only available to the user groups. The data are now made publicly available through the World Data Centre Pangea, http://doi.pangaea.de/10.1594/PANGAEA.775062 (Schlosser, 2012), http://doi.pangaea.de/10.1594/PANGAEA.774713 (Krahmann, 2012), and http://doi.pangaea.de/10.1594/PANGAEA.775074 (Tanhua et al, 2012).

9 Acknowledgements

We very much appreciated the professionalism and seamanship of crew, officers and Captain of F.S. MERIAN which made this work a success. Financial support came from the Deutsche Forschungsgemeinschaft for the Sonderforschungsbereich 754 “Climate-Biogeochemistry Interactions in the tropical Ocean”.

10 References

Boyd, P.W., et al., 2000. Mesoscale iron fertilisation elevates phytoplankton stocks in the polar Southern Ocean. Nature 407, 695-702.

Boye, M., et al., 2005. Major deviations of iron complexation during 22 days of a mesoscale iron enrichment in the open Southern Ocean. Marine Chemistry 96(3-4), 257-271.

Bullister, J.L., Weiss, R.F., 1988. Determination of CCl_3F and CCl_2F_2 in seawater and air. Deep-Sea Research 35, 839-853.

Capone, D., 2008. The marine nitrogen cycle. Microbe 3(4), 186-192.

Coale, K.H., et al., 2004. Southern Ocean Iron Enrichment Experiment: Carbon Cycling in High- and Low-Si Waters. Science 304(5669), 408-414.

Coale, K.H., et al., 1998. IronEx-I, an insitu iron-enrichment experiment: Experimental design, implementation and results. Deep-Sea Research II 45, 919-945.

Croot, P.L., et al., 2001. Retention of dissolved iron and FeII in an iron induced Southern Ocean phytoplankton bloom. Geophysical Research Letters 28, 3425-3428.

Croot, P.L., et al., 2005. Spatial and Temporal distribution of Fe(II) and H2O2 during EISENEX, an open ocean mesoscale iron enrichment. Marine Chemistry 95, 65-88.

Deutsch, C., Sarmiento, J.L., Sigman, D.M., Gruber, N., Dunne, J.P., 2007. Spatial coupling of nitrogen inputs and losses in the ocean. Nature 445, 163-167.

Krahmann, G., 2012. Physical oceanography during Maria S. Merian cruise MSM10/1. IFM-GEOMAR Leibniz-Institute of Marine Sciences, Kiel University, Dataset #774713, doi.pangaea.de/10.1594/PANGAEA.775074 (DOI registration in progress).

Mills, M.M., Ridame, C., Davey, M., Roche, J.L., Geider, R.J., 2004. Iron and phosphorous co-limit nitrogen fixation in the eastern tropical north atlantic. Nature 429, 292-294.

Schlosser, C., 2012. Trace metal concentration from water samples during Maria S. Merian cruise MSM10/1. IFM-GEOMAR Leibniz-Institute of Marine Sciences, Kiel University, Unpublished dataset #775062, doi.pangaea.de/10.1594/PANGAEA.775062 (DOI registration in progress)

Stramma, L., Johnson, G.C., Sprintall, J., Mohrholz, V., 2008. Expanding oxygen-minimum zones in the tropical oceans. Science 320, 655-658.

Stramma, L., Visbeck, M., Brandt, P., Tanhua, T., Wallace, D., 2009. Deoxygenation in the oxygen minimum zone of the eastern tropical North Atlanic. Geophysical Research Letters 36, L20607, doi:10.1029/2009GL039593.

Tanhua, T., Stramma, L., Desai, F., Löscher, C., 2012. Hydrochemistry and molecular biology during Maria S. Merian cruise MSM10/1. IFM-GEOMAR Leibniz-Institute of Marine Sciences, Kiel University, Dataset #775074, doi.pangaea.de/10.1594/PANGAEA.775074 (DOI registration in progress)

Tsuda, A., et al., 2003. A Mesoscale Iron Enrichment in the Western Subarctic Pacific Induces a Large Centric Diatom Bloom. Science 300(5621), 958-961.

Wilcken, S., 2009. In situ Kalibrierung von Optoden zur Messung des Sauerstoffgehalts im marinen Umfeld. Bachelorarbeit, Hochschule Bremerhaven, 59 pp.