SFB 754

METEOR-Berichte

Oxygen in the Tropical Atlantic
OSTRE Third Tracer Survey

Cruise No. M116/1

May 1 – June 3, 2015,
Pointe-a-Pitre (Guadeloupe) – Mindelo (Cape Verde)

OSTRE IV

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1 Summary

Cruise M116/1 is a contribution to the DFG Collaborative Research Project (SFB) 754: "Climate-Biogeochemistry Interactions in the Tropical Ocean" with the main goal to better understand the supply of oxygen to the oxygen minimum zone (OMZ) of the Tropical Atlantic with a particular focus on the role of regional advection, mesoscale and sub-mesoscale processes for lateral and vertical oxygen fluxes. A key method is the "Oxygen Supply Tracer Release Experiment" (OSTRE), where during M116/1 the third mapping of the tracer CF_3SF_5 using 82 CTD stations was done. Mapping of the water mass properties, including the distributions of oxygen, transient tracers, nutrients and the carbonate system were done mostly along 11°N. A brief detour allowed for the measurements from a 1980's cruise (TTO) to be repeated. A snapshot of the synoptic ocean circulation and mixing was accomplished by shipboard ADCP observations. Ten Argo floats were deployed. One ocean-glider and one wave-glider were recovered. Finally, additional components of the cruise were dedicated to zooplankton studies, nitrogen fixation experiments and underway sampling of a broad range of biogeochemical parameters. The cruise was very successful; most systems on METEOR worked well and all planned objectives were mostly reached.

Zusammenfassung

Die Reise M116/1 ist ein Beitrag zum DFG Sonderforschungsbereich 754: „Klima-Biogeochemische Wechselwirkungen im Tropischen Ozean". Es geht darum die Belüftung der Sauerstoffminimumzone (OMZ) des Tropischen Atlantiks besser zu verstehen und dabei die Rollen der regionalen Zirkulation sowie mesoskalige und submesoskalige Prozesse zu vermessen, die die horizontalen und vertikalen Sauerstofftransport ermöglichen. Eines der Schlüsselexperimente ist das "Oxygen Supply Tracer Release Experiment" (OSTRE) wo auf dieser Reise die dritte Vermessung durch 82 CTD Stationen erfolgte. Ein hydrographischer Schnitt entlang von 11°N und einige kurze Abstecher in Nord-Süd Richtung erlaubten es Stationen aus den 1980ier Jahren (TTO) zu wiederholen und die Veränderungen der Wassermasseneigenschaften inklusive Sauerstoff, Nährstoffe, transiente Tracer und dem Kohlenstoffsystem zu dokumentieren. Die synoptische Zirkulation konnte mit dem Schiffs ADCP erfasst werden. Es wurden 10 Argo floats ausgesetzt und ein Ozean- und ein Wellen-Gleiter aufgenommen. Weiterhin wurden diverse Zooplankton Experimente durchgeführt und Nährstofffixierungsraten durch Inkubationsexperimente bestimmt. Es wurde eine Vielzahl von biogeochemischen Parametern an der Meeresoberfläche durch permanente Unterwegsmessungen bestimmt. Die Reise wahr sehr erfolgreich, die meisten Systeme der METEOR liefen gut und fast alle geplanten Ziele konnten erreicht werden.

2 Participants

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18. Fessler, Sebastian	CO2	GEOMAR
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20. Lohmann, Martina	O2, Nutrients	GEOMAR
21. Nachtigall, Kerstin	Nutrients	GEOMAR
22. Browning, Tom	Phytoplankton	GEOMAR
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MPI-HH Max Plank Institute for Meteorology, Hamburg, Germany

U-HD Heidelberg University, Germany

INDP Instituto Nacional do Desenvolvimento das Pescas, Rua: Cova de Inglesa, Mindelo, São Vicente, C.P: 132, Cabo Verde.

DAL Dalhousie University, PO Box 15000, Halifax, NS B3H 4R2, Canada

Scientific party of M116

3 Research Program

Cruise M116/1 is a contribution to the DFG Collaborative Research Project (SFB) 754: "Climate-Biogeochemistry Interactions in the Tropical Ocean". The main goal of the project is to quantify and better understand the supply of oxygen to the oxygen minimum zone (OMZ) of the Tropical Atlantic with a particular focus on the role of regional advection, mesoscale and sub-mesoscale processes for lateral and vertical oxygen fluxes and thus a critical aspect of the ventilation of this region. One of the methods to derive oxygen transports is the "Oxygen Supply Tracer Release Experiment" (OSTRE), which will allow for quantification of the time averaged diapycnal and lateral mixing rates in the region.

The main objectives of the cruise were to:

a) perform the third mapping of the tracer CF_3SF_5 that was injected in late 2012 (MSM23) near the OMZ at around 10°N 21°W and about 500 meters depth;
b) map the water mass, oxygen and transient tracer distribution by CTDs;
c) determine the synoptic ocean circulation and mixing by S-ADCP observations;
d) determine biogeochemical rates of oxygen consumption and nutrient cycling by zooplankton studies and nitrogen fixation experiments.
e) document the long term changes of water mass properties at repeat stations along the 11°N transects and several short dog legs with a focus on transient tracers, carbonate system, oxygen and nutrients;
f) deploy 10 Argo floats sponsored by the German BSH and recover gliders.

These objectives were addressed by a multi-disciplinary research program during M116/1 encompassing 82 CTD stations, 27 zooplankton surface nets, underway ship-based measurements, Argo deployments and a glider recovery. Many biogeochemical analysis and experiments were carried out during the cruise, whereas samples were collected and transported back to the laboratories for other more complex analysis. It was decided to drop the proposed microstructure profiler measurements in favor of more ship time for an extensive tracer sampling. The shipboard ADCP data are able to provide a reasonable proxy for microstructure measurements in conjunction with the previously done MSS profiles in the region.

In summary, the cruise was very successful; all planned objectives were reached and almost all measurements were carried out as planned.

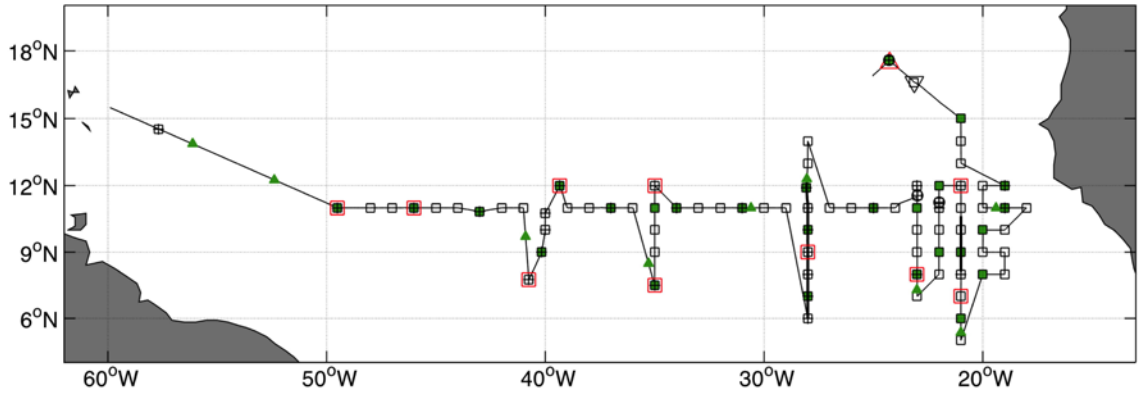

Fig. 3.1 Cruise track of METEOR cruise M116/1 with locations of CTD stations (small black dots), Bio-CTD (small black circle), WP2-Net (large black circle), Multi-Net (black square), drifting sediment trap (red crosses with circle) and glider operations (yellow triangle).

4 Narrative of the Cruise

R/V METEOR departed from Pointe-a-Pitre on May 1, 2015 at 9:00 UTC and transited towards 11°S. Underway sampling began on May 2, 0:00. We reached the first CTD station on May 5, 0:00 at 11°N 49°30'W, deployed the first Argo float and began the 11°N transect with a station every full degree. Between May 8 and May 10, we revisited five stations from the TTO cruise roughly along a 40°W south to north transect between 7° 45' N and 12°N. We ventured east mostly along 11°N with two more dog legs at 35°W and 28°W. During the 28°W section on May 18, the W2 winch showed increasing spooling delay and station depths had to be limited to 4000m water depths. On May 21, we reached the northwestern corner of the tracer control volume box at 12°N and 23°W and sampled along 23°W, 22°W and an extended southward leg along 21°W. On May 29, we reached the easternmost station at 11°N and 18°W. On May 31, we completed the survey at 15°N and 21°W. An ocean glider was recovered on June 1 southwest of the island Sal. On June 2, we completed the last sampling at Cape Verde Ocean Observatory (CVOO) 60nm north of Mindelo and recovered a wave glider.

METEOR arrived in Mindelo in the evening of June 2, 2015.

5 Preliminary Results

In the following report, a detailed account of the types of observations, the methods and instruments used as well as some of the early results are given.

5.1 CTD system and calibration

(PI: Sunke Schmidtko, Rudolf Link, Henrike Schmidt, Anja Witt, Nuno Vieira)

5.1.1 CTD-Rosette system

During M116/1 a total of 82 CTD-profiles and 1774 water samples were collected. The rosette system was installed in a Seabird Rosette System frame for 24 bottles. See table below for sensor details. Depth profiles were performed up to a maximum pressure of 5760 dbar. Deeper profiles were not possible due to limited length of the installed wire on METEOR; for the majority of stations only the top 1200m of the water column was sampled. Data acquisition was done using Seabird Seasave software version 7.23.2; preprocessing was done with SBE Data Processing 7.23.2.

The first CTD profile was collected at instrument test station #473. It was determined that the conductivity of sensor pair 2 looked suspicious. The conductivity cell of sensor pair 2 was replaced after profile 2, station #475, since it showed a significant offset. The cause could not be determined. After profile 3, station #476, the temperature sensor of sensor pair 2 had to replace after a significant amount of spikes in the data rendered the data of that probe dubious.

For profiles 33-36, the wrong configuration was loaded in the deck unit for the secondary sensor pair. The raw data files were reprocessed after editing of the configuration xml-files.

The oxygen probes were shipped via airfreight and did not accompany the CTD System in the container for safety reasons, after the bad experiences with extreme temperature exposures in a previous cruise. The oxygen sensors provided high quality reliable data throughout the cruise. From the current experience, it is suggested to continue the practice of shipping the oxygen sensors separate from the CTD system via airfreight.

During the up-cast in 120dbar depth of profile 10, station #483, there was a blackout of the Seabird Rosette System. The cast was canceled and no further water samples were taken above 120dbar since contact to the CTD was lost. The cause was determined to be the seawater in a corroded cable connection to the altimeter. After cable replacement, the connection to the CTD system was reestablished and no further problems were encountered.

During cast 72 and 73, rosette sampling failed due to a leak in the connector between the CTD wire and the CTD unit; the casts were completed with only two deep samples taken.

No further problems were recorded with the sensors or sampling system of the CTD system. The CTD system worked without problems for the final profiles.

The exact configuration of the CTD system can be found in Table 5.1.1. Additionally a self-recording, self-powered Underwater Video Plankton recorder, UVP, was attached to the water sampler. It is described separately in section 5.13.

Processed preliminary CTD data, 5-dbar binned, was sent in near real time to the Coriolis Data Centre in Brest, France, (via email: codata@ifremer.fr) for integration in the databases to be used for operational oceanography applications and the WMO supported GTS/TESAC system.

Tab. 5.1.1: Summary of CTD system SBE #5 configuration used during M116/1.

	CTD system SBE#5 (cast 1-2)	CTD system SBE#5 (cast 3)	CTD system SBE#5 (cast 4-XX)
Pressure sensor	# 61184	# 61184	# 61184
T primary	# 4875	# 4875	# 4875
T secondary	# 4547	# 4547	# 4051
C primary	# 3425	# 3425	# 3425
C secondary	# 2515	# 3959	# 3959
O2 primary	SBE 43 # 1302	SBE 43 # 1302	SBE 43 # 1302
O2 secondary	SBE 43 # 2686	SBE 43 # 2686	SBE 43 # 2686
Altimeter	# 41840	# 41840	# 41840
WET Labs ECO-AFL/FL	# 2928	# 2928	# 2928

5.1.2 CTD-conductivity calibration

Overall, 298 calibration points were obtained by sampling for salinity. Salinity samples were taken by the CTD watch in 'Flensburger' bottles, which proved to be ideal for storing salt samples over a prolonged time. The limited amount of bottles required the washing and reusing of bottles. Reused bottles were used for salt samples from cast 33 onwards. The results and description of the salt measurements are found in section 5.1.4. An unfortunate recalibration of the salinometer limited the salt samples used to calibrate the CTD to samples taken after profile 24, day 12. A calibration using just the first period of 24 profiles and 12 days resulted in similar stable and good results. The second sampling period was chosen since it did cover a larger amount of time and better vertical spread of samples taken. Due to the large amount of samples, a simple outlier removal method was applied that discharged the largest 30% deviations between CTD and bottle samples prior to calibration. The projection from the bottle stop of the up- to the downcast was done by searching for similar potential temperatures within 50dbar pressure internal around similar pressure horizons between up- and downcast. For the critical loop edit velocity, 0.01m/s were used. The final CTD data set is composed from the primary set of sensors for all profiles, though the differences between sensor pairs were marginal. The conductivity calibration of the downcast data was performed using a first order linear fit with respect to temperature, pressure and conductivity.

The calibration results in a salinity RMS-misfit for the downcast of order 0.00165 psu for the primary and 0.00174 psu for the secondary sensor. The up-cast calibration succeeds these very good values with and RMS-misfit of 0.00156 for the primary and 0.00166 for the secondary sensor.

	CTD system SBE#5 (profile 1 to 82)	CTD system SBE#5 (profile 4 to 82)
Sensor pair	primary	secondary
RMS misfit after calibration - salinity	0.001657	0.001737
Polynomial coefficients - conductivity	Offset: -0.000707 P1: -2.1608e-8 T1: -6.559e-6 C1: -0.000456	Offset: -0.001029 P1: -5.6816e-8 T1: 6.8611e-6 C1: -3.4763e-5
Pressure sensor correction (decks-offset)	1.17	1.17

Table 5.1.2: End of cruise salinity and pressure summary of downcast calibration information for the two CTD systems used during M116/1.

5.1.3 Oxygen calibration:

The CTD oxygen downcast for CTD systems was calibrated by using the best 60 % of the joint data pairs between downcast CTD sensor value and titrated oxygen on samples taken during the upcast (Section 5.2). For the calibration, a linear correction polynomial depending on pressure, temperature and the actual oxygen value was fitted. Due to the very accurate titration and stable oxygen data, a marginal temporal drift was also detected. A total of 1219 oxygen data points for CTD system SBE#5 were recorded, which results in an RMS-misfit for the downcast on the order of 0.79 µmol kg^{-1} for the primary SBE43 and 0.78 µmol kg^{-1} for the secondary SBE43. The up-cast calibration matched these very good values with and RMS-misfit of 0.78 µmol kg^{-1} for the primary SBE43 and 0.85 µmol kg^{-1} for the secondary SBE43.

	Oxygen Sensor #1302	Oxygen Sensor #2686
Sensor pair	primary	secondary
RMS misfit after calibration - oxygen	0.7869	0.78217
Polynomial coefficients - oxygen	Offset: 0.63577 P1: 0.004285 T1: 0.052401 O1: 0.018705	Offset: 0.61719 P1: 0.0052719 T1: 0.037848 O1: 0.029453

Table 5.1.3: End of cruise downcast oxygen summary of calibration information for the CTD system SBE#5 used during M116/1.

5.1.4 Salinometer measurements:

On board were two GEOMAR instruments: Guildline Autosal salinometer, #7 (Model 8400B, AS7) and Guildline Autosal salinometer, #5 (Model 8400A, AS5). Throughout the cruise, only the Guildline Autosal salinometer #7 was used.

The instrument has a manufacturer given absolute accuracy in salinity of ±0.002 psu. In total, a number of 298 samples were measured from *69* CTD stations.

The bath temperature of AS7 was constant throughout the cruise with 24°C in a temperated room of 22°C. A standardisation of the instrument was performed at the beginning on 5th May using IAPSO standard seawater (batch: P155, K15: 0.99981) with a respective salinity of 34.9926. That value was set by adjusting a resistance to get the required conductivity measurement (potentiometer). Furthermore, a large volume of water with constant salinity was used as a substandard to track the stability of the instrument. The substandard was obtained from CTD cast 1, station #473, from 2000 m depth. An unfortunate readjustment of the calibration resistance after the measurements of samples taken from cast 24 rendered the data prior to and after this measurement not comparable. Successive standard measurements with IAPSO standard seawater (batch: P155, K15: 0.99981) indicated stable behavior of the instrument.

The substandard showed little spread and slight salinification trend over the first measurement period. The second measurement period showed significant spread in the substandard measurements. The cause of this spread could not be determined. Plausible origins are unsuitable storage of the substandard, contamination from sample bottles that were not properly rinsed but re-used for substandard measurements, and operator differences. Calibration was done using the second part of the measurements after readjustment of the autosal potentiometer. The reasons for using the second period, despite spread in substandard measurements are the stable standard measurements. Furthermore, the majority of measurements were taken during this period, including samples for other groups and the thermosalinograph.

Salinity samples from the CTD and underway METOR TS recorder were analyzed and the calibration procedures are described in section 5.1.2.

5.1.5 Exemplary results

The sampling strategy of M116/1 data allowed the analysis of water mass distributions along one cross-Atlantic section. The 11°N shows the west to east evolution across the mid Atlantic ridge and Guinea Dome with the lowest dissolved oxygen concentration in the eastern part of the section (Figure 5.1.2).

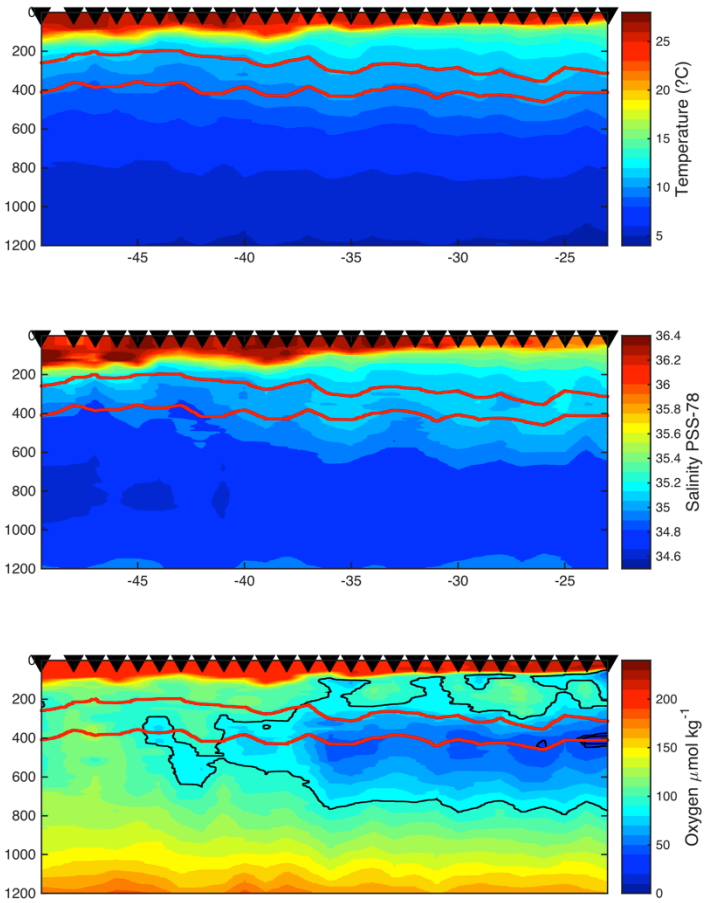

Fig. 5.1.1: Top 1200dbar temperature, salinity and oxygen section along 11°N across the Atlantic. Isopycnals of two tracer release experiments, OSTRE (1027.03 kg m^{-3}) and GUTRE (1026.88 kg m^{-3}), are highlighted (red contours).

5.2 Measurements of Dissolved Oxygen

(Josefine Maas, Martina Lohmann, PI: Toste Tanhua)

Observing and understanding the concentration of dissolved oxygen in the ocean is one of the key objectives of the SFB754. While the CTD system is capable of measuring dissolved oxygen in the ocean at high vertical resolution, the sensors need to be carefully calibrated. Thus high quality reference observations are essential.

During the whole cruise samples for the determination of dissolved oxygen were taken from a total of 74 CTD casts with 100 mL WOCE bottles with well-defined volumes (calibrated flask-stopper combinations) to calibrate the oxygen sensors (SBE 43) and to support chemical and biological CTD data (Langdon, 2010). Oxygen samples were taken immediately after tracer sampling. It was ensured that the sample bottles were flushed with at least 3 times their volume and the samples were free of air-bubbles. On a regular CTD cast, 22 depths between the surface and 1200 m were sampled for dissolved oxygen. Additionally, dissolved oxygen samples were collected on 29 casts deeper than 1200 m (deepest cast down to 5794 m), yielding a total of 1824 samples from 76 casts for the entire cruise. Additional 57 water samples were analyzed from the underway system (see chapter 5.9 for further details) to calibrate and verify the underway oxygen sensors.

The precision of the oxygen concentration measurements determined by Winkler titration was 0,42 µmol/L (arithmetical average of all standard deviations) based on 169 replicate measurements with 3 replicates each.

Standard measurements for the determination of the thiosulfate factor were carried out on a daily basis. In addition to that once a week a standard solution of Potassium Iodate from Wako (034-10251 CSK Standard Solution) was measured to support the quality of the own standard solution.

The following reagents were used during this cruise:

- sulfuric acid (50 %)
- zinc iodide starch solution (500 mL, Merck KGaA)
- stock solution: sodium thiosulfate pentahydrate (49.5 $g \cdot L^{-1}$); stock solution was diluted by a factor of 10 to create the working solution (0.02 $mol \cdot L^{-1}$)
- fixation solution: manganese(II)chloride (600 $g \cdot L^{-1}$), sodium iodide (600 $g \cdot L^{-1}$) and sodium hydroxide (320 $g \cdot L^{-1}$)
- standard solutions: potassium hydrogen diiodate (0.325 $g \cdot L^{-1}$, homemade) and potassium iodate (CSK Standard Solution, 0.01 N, 300 mL, Wako Pure Chemical Industries, Ltd., Japan)

Titrations were performed within the WOCE bottles using a 20 mL Piston Burette (Nr. M 006989) TITRONIC universal from Schott Instruments. Dosing accuracy reported by the company is 0.15 %, referred to the nominal volume, indicated as a measurement uncertainty with a confidence level of 95 %. The iodate standard was added with a 50 mL Piston Burette (Nr. M 003550) TITRONIC universal from Schott Instruments. 1 mL of the fixation solutions (NaI/NaOH and $MnCl_2$) were dispensed with a high precision bottle-top dispenser (0.4-2.0 mL, Ceramus classic, Hirschmann).

Note: Possible sampling, storing (air bubbles) or measuring failures were recorded. Results derived from those measurements were not considered in the data evaluation.

5.3 Measurements of Dissolved Inorganic Carbon (DIC) and Total Alkalinity (TA)

(Hanna Campen, Sebastian Fessler and Tobias Hahn; PI: Arne Körtzinger)

As part of the Repeat Hydrography Program, measurements of Dissolved Inorganic Carbon (DIC) and Total Alkalinity (TA) were performed with the aim of sustaining the high standards set by the international repeat hydrography program GO-SHIP. All measurements were made according to the highest international standards and the standard operating procedures as described in the "Guide to Best Practices for Ocean CO_2 Measurements" (Dickson et al., 2007). Regular measurements of Certified Reference Material (CRM) provided by the Dickson Lab at Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, USA (Dickson, 2010) were used to estimate the uncertainty of DIC and TA measurements.

The CO_2 lab at GEOMAR participated in an inter-laboratory comparison that was undertaken to help evaluate and understand the current reliability of seawater CO_2 measurements (Brockmon and Dickson, 2015). Out of the ~60 participating laboratories (15 countries, 5 continents), we

scored among the 25 % (20 %) of the labs that achieved the most stringent accuracy goals of 2 µmol kg^{-1} for DIC (TA). This highest accuracy goal is defined for measurements of quality sufficient to assess long-term trends with a defined level of confidence, supporting detection of the long-term anthropogenically driven changes in hydrographic conditions and carbon chemistry over multi-decadal time scales (ibid.).

5.3.1 Sampling procedures for DIC/TA

Samples for DIC/TA were drawn directly from Niskin samplers into 500 mL DURAN glass bottles with glass stopper. A drawing tube was used to fill the bottles from the bottom. It was assured that the bottle was overflown by at least 250 mL of water. A headspace of about 1 % was achieved by clamping and removing the tubing. After closing the bottles, the thoroughly greased stoppers were held down firmly with a rubber band. All samples were analyzed within 24 h after being collected. The sampling procedure followed the recommendations (SOP 1) of Dickson et al. (2007).

5.3.2 Measurements of DIC

The analysis of DIC was performed by the SOMMA (single operator multi-parameter metabolic analyzer) system, which is based on coulometric titration of the CO_2 evolved from the seawater sample upon acidification with phosphoric acid (Johnson et al., 1993). The SOMMA collects and dispenses an accurately known volume of seawater to a stripping chamber, acidifies it, purges the CO_2 from the solution, dries the gas, and delivers it to a coulometer cell, where the CO_2 reacts with the solution and produces an acid that is titrated with OH^- ions produced in-situ electrochemically.

The coulometer cell reagents were typically replaced once a TCT (total carbon titrated, in mg C) of about 30-35 was reached (equivalent to approx. 50 individual measurements). In some cases, a maximum of 40 TCT could be achieved as long as the performance of the coulometer cell was acceptable. A newly filled coulometer cell was always pre-conditioned with three “junk samples” followed by one blank measurement before it was calibrated with certified reference material (CRM). A gas calibration with known amounts of CO_2 could not be performed throughout the cruise, however, the CRM was used to correct and calibrate the SOMMA.

DIC was determined from 1246 samples at 66 stations. A total amount of 107 duplicates (σ = 1.30 µmol · kg^{-1}) and 8 triplicates (σ = 0.65 µmol · kg^{-1}) were taken and 105 CRMs were measured in order to determine accuracy and precision.

Measurement setup:

The following reagents and devices were used during this cruise:

- Coulometer CM0512-02, SN# 945012001 and SN# 945012004
- Phosphoric acid (8.5 %)
- ORBO™ - 53 Adsorbent Tubes filled with 200 mg silicate gel
- Magnesium perchlorate hydrate (about 83 % GR for analysis, Merck KGaA)
- Coulometer cell solutions according to Dickson, Sabine & Christian, 2007
- Certified reference material (CRM; Dickson standards for oceanic CO_2 measurements) from batch 142 and 143

Note: Coulometer CM0512-02 SN# 945012001 was used for most samples of profile 16, 17 and 18. Those results are considered invalid due to technical issues with the device caused by a cable failure on the electrode and a non-stable light source. Hence, those results as well as results with measurement errors (e.g. gas leakage from olive, liquid level sensor error and insufficient acid addition) are flagged accordingly and not considered in the data evaluation.

5.3.3 Measurements of TA

TA was determined by open cell two-stage titration of seawater with a strong acid, following the EMF of a proton sensitive electrode. The sample is first acidified to a pH between 3.5 and 4.0 with a single aliquot of titrant. The solution is then stirred for a period of time to allow for the escape of CO_2 that has evolved. The titration is then continued until a pH of 3.0 has been reached. The determination was carried out by a semi-automatic analyzer called VINDTA (Versatile Instrument for the Determination of Titration Alkalinity).

The acid pathway (hydrochloric acid reservoir, burette, tubes) was regularly flushed in order to avoid or get rid of any trapped air bubbles. The acid factor of hydrochloric acid was determined with every new batch being used.

TA was determined from 1246 samples at 66 stations. A total amount of 108 duplicates (σ = 2.73 µmol · kg^{-1})and 9 triplicates (σ = 2.02 µmol · kg^{-1}) were taken and 122 CRM's were measured in order to determine accuracy and precision.

Measurement setup:
The following reagents and devices were used during this cruise:

- VINDTA SN# 054
- Hydrochloric acid (0.1 mol · L^{-1}) in 0.6 mol · L^{-1} NaCl
- 642 mL saturated NaCl solution / 5 L
- Certified reference material (CRM; Dickson standards for oceanic CO_2 measurements) from batch 142 and 143

Note: Results derived from measurement errors (e.g. pipette sensor error and insufficient sample volume) are not considered in the data evaluation. A few results are flagged as outliers because their alkalinity was too low even though measurement errors could not be detected.

5.4 Measurements of Nutrients

(Martina Lohmann, Kerstin Nachtigall, PI: Toste Tanhua)

Nutrients were measured on-board with a QuAAtro auto-analyzer from SEAL Analytical, (Serial number: 8003836) and a SEAL XY-2 Autosampler (Serial number: 5002A15014). The following methods from SEAL Analytical were used:

Nitrite and Nitrate – Q-068-05 Rev 7; the nitrate is determined as nitrite after reduction on a cadmium coil. The nitrite is determined with a colorimetric metric method where sulphanilamide is forming a diazo compound.

Phosphate – Q-064-05 Rev 4; this is the colorimetric method based on reaction with molybdate and antimony ions.

Silicate – Q-066-05 Rev 3; this is the colorimetric method where a silico-molybdate complex is reduced to molybdenum blue.

All together 2755 nutrient samples from 68 CTD casts were sampled during the cruise, of which 169 samples were taken as triplicates. The 14 mL polyethylene sampling tubes and the respective caps were rinsed at least three times with the sampling water before the final sample was taken. In most cases, the samples were measured directly after sampling with a delay of one hour or less. If the start of measurement was delayed for more than one hour, the samples were stored meanwhile in the fridge.

The precisions of the nutrient measurements were calculated from the triplicate samples taken at a selection of stations and determined to be: 0.18 µmol/L for nitrate, 0.01 µmol/L for phosphate and 0.18 µmol/L for silicate.

In addition to the CTD samples, 34 bottles of Reference Material for Nutrients in Seawater (RMNS) from the General Environmental Technos (KANSO) Co., Ltd., Osaka/Japan, were measured as triplicates at least once a day and preferentially at the deep stations. All CRMs were from lot BW with the following concentrations: NO_3 – 24.45 ± 0.26; NO_2 – 0.051 ± 0.048; Si – 59.10 ± 0.58; PO_4 – 1.556 ± 0.030, all units in µmol kg^{-1}. Multiplicative (gain) adjustments were applied to the measured nutrient values on a station-by-station basis based on the deviations between stated and measured nutrient concentrations of the CRMs. For phosphate, these corrections were centred around zero and always within 1%, for nitrate the adjustments were mostly a positive adjustment of up to 2% whereas for silicate a positive adjustment of up to 4% was applied. The standard deviation of the measured replicates was determined to be 0.12 µmol/L for nitrate, 0.01 µmol/L for phosphate and 0.25 µmol/L for silicate.

5.5 Measurements of CFC-12, SF_6 and CF_3SF_5

(Boie Bogner, Manuela Köllner, PI: Toste Tanhua)

5.5.1 Analysis System Setup:

During the cruise, two GAS CHROMATOGRAPH / PURGE-AND-TRAP (GC/PT) systems (PT3 and PT4) were used for the measurements of the transient tracers CFC-12, SF_6 and the deliberately released tracer CF_3SF_5. The systems are modified versions of the set-up normally used for the analysis of CFCs (Bullister and Weiss, 1988). The PT3 instrument was used for measuring the transient tracers SF_6 and CFC-12 as well as the released tracer CF_3SF_5 on all depths, whereas the PT4 instrument was used primarily to measure CF_3SF_5 in high volume ampoules from samples around the target density (i.e. the density at which the tracer was released).

The traps for both systems consisted of 100 cm 1/16” tubing packed with 70cm Heysep D kept at temperatures between -60 and -68°C during trapping. The traps were desorbed by heating to 130°C and passed onto the pre-columnn. For PT3, the pre-column consisted of 20 cm Porasil C followed by 20 cm Molsieve 5A in a 1/8” stainless steel column. For PT4, the pre-column

consisted of 30 cm Porasil C and 30cm Molsieve 5A in a 1/8" stainless steel column. Both systems used a 1/8" packed main column consisting of 180 cm Carbograph 1AC (60-80 mesh) and a 50 cm Molsieve 5A post-column. All columns were kept isothermal at 50°C. Detection was performed on an Electron Capture Detector (ECD). This set-up allowed efficient analysis of CF_3SF_5 on the PT4 system (the CFC-12 is well separated from CF_3SF_5 but the large volume prevents us from quantification of the peak). On PT3, this setup allowed for measurements of all three species.

The transient tracer samples were collected in 250 mL ground glass syringes, of which an aliquot about 200 mL was injected to the purge-and-trap system. The SF_5CF_3 samples were collected in ~1300 mL ampoules, of which an aliquot of ~990 mL was injected to the vacuum-sparge system by evacuating the purge chamber and then sucking in the water through an orifice.

Standardization was performed by injecting small volumes of gaseous standard containing SF_6, SF_5 and CFC-12. This working standard was prepared by the company Dueste-Steiniger (Germany). The CFC-12 and SF_6 concentrations 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. Calibration curves were measured roughly once a week in order to characterize the non-linearity of the system, depending on workload and system performance. Point calibrations were always performed between stations to determine the short-term drift in the detector. Replicate measurements were only taken on a few stations due to high workload. The determined values for precision and limit of detection are listed in Table 5.5.1.

Compound	**System PT3 precision**	**Intersystem precision**	**Detection limit**
SF_6	0.1 fmol L^{-1}	-	0.01 fmol L^{-1}
CF_3SF_5	0.03 fmol L^{-1}	0.03 fmol L^{-1}	0.01 fmol L^{-1}
CFC-12	0.008 pmol L^{-1}	-	0.06 fmol L^{-1}

Table 5.5.1: Precision of tracer measurements determined from replicate measurements and approximate limit of detection. Note that no duplicates could be run on the large volume ampoules, but comparison between measurements on PT3 and PT4 of the same sample could be used to quantify the uncertainty.

At the CVOO station NW from the Cape Verde Islands, water samples for determination of transient tracers were flame-sealed in ~350 mL ampoules for analysis onshore at GEOMAR.

5.5.2 Preliminary results:

Transient tracers:

Along the 11°N section, every 3rd station (every 3rd degree) was sampled to the bottom. This allows for a zonal view of ventilation across the Atlantic at this latitude, Figure 5.5.1. The CFC-12 concentration is a measure of the ventilation of the water masses, where a low CFC-12 concentration indicates slow ventilation. The section clearly shows the slowly ventilated Antarctic Intermediate Water (AAIW) at around 1000 m depth, and how this water mass is better ventilated in the western basin. The tracer maximum below the AAIW at around 1500 m depths

is a tell-tale of the better ventilated Labrador Sea Water (LSW) that is forming an east-flowing jet centered at about 9°N, and where the ventilation is considerable better in the western basin. In general one can see a slower ventilation of the eastern basin as compared to the western basin. This information helps us to determine ventilation time-scales of interior ocean waters. These data will be compared to historic transient tracer measurements in the area with the purpose of quantifying temporal changes in ventilation, if any.

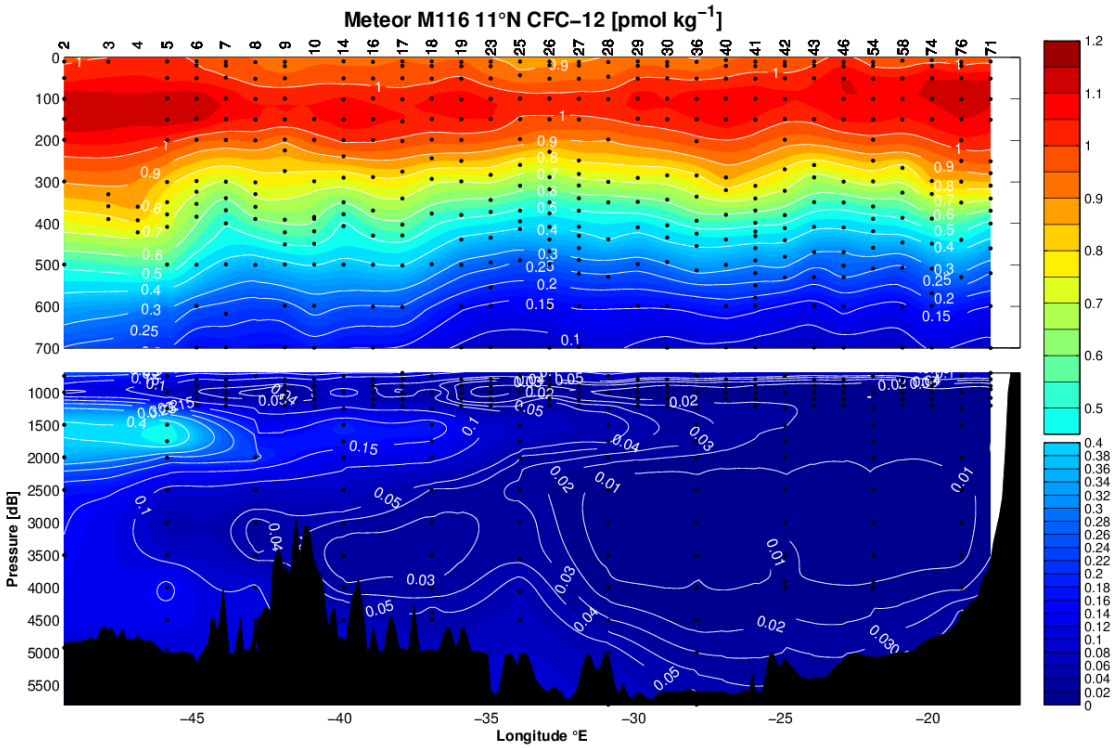

Fig. 5.5.1: Section of CFC-12 concentrations along the 11°N section. Note the non-linear color scale.

Deliberately released tracer (CF_3SF_5)

The concentration of CF_3SF_5, the tracer that was deliberately released at density anomaly 27.04 kg m^{-3} in 2012 and on 26.88 kg m^{-3} in 2008, was measured with large volume samples on samples around these two densities with high vertical resolution (typically 30 m). In general the vertical tracer distribution can be fitted by a Gaussian curve, where the second moment (the "width") of the curve provides information of the vertical dispersion rates. Figure 5.5.2 shows the concentration of the tracer along 11°W, plotted in density coordinates.

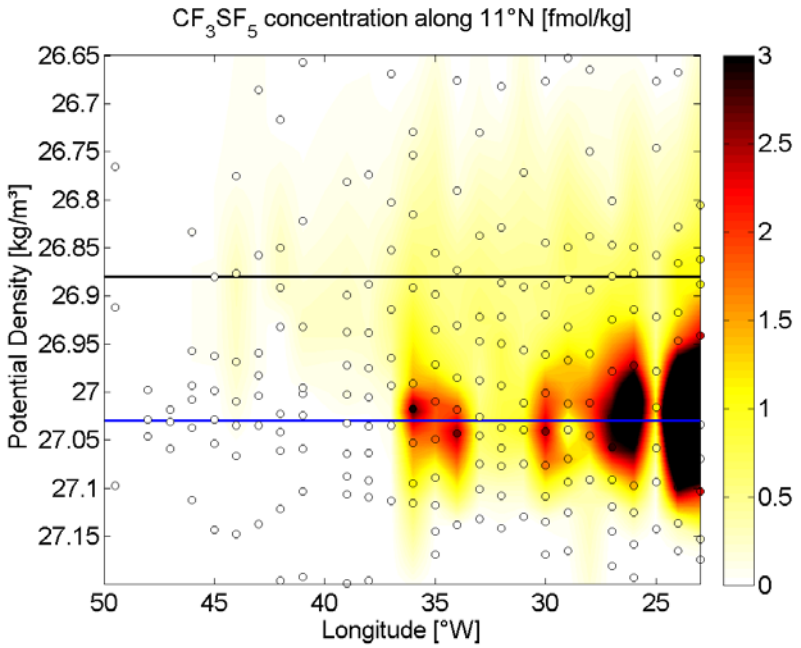

Fig. 5.5.2: The objectively mapped distribution of the deliberately released tracer CF_3SF_5 along the 11°N section. The release densities of the GUTRE (in 2008) and OSTRE (in 2012) releases are marked with a black and blue line, respectively. The units are fmol kg^{-1}.

A primary focus of this cruise was the horizontal dispersion of the tracer that will provide information on horizontal mixing rates. We have therefore calculated the column integral of the tracer along the cruise track, Figure 5.5.3. We can see that the tracer that was injected on 21°W has spread to around 39°W in the zonal direction, but is fairly well focused around latitudes of 10-11°N, with concentrations decaying to zero already at 14°N and 6°N along the 28°W section, and 6°N and 14°N along the 21°W section. The tracer is also relatively homogenous distributed within the control volume area (i.e. the area with borders of 8°N, 12°N, 23°W and 19°W) but with significant gradients. The control volume has been measured already during the two previous tracer survey cruises (M97 and M105).

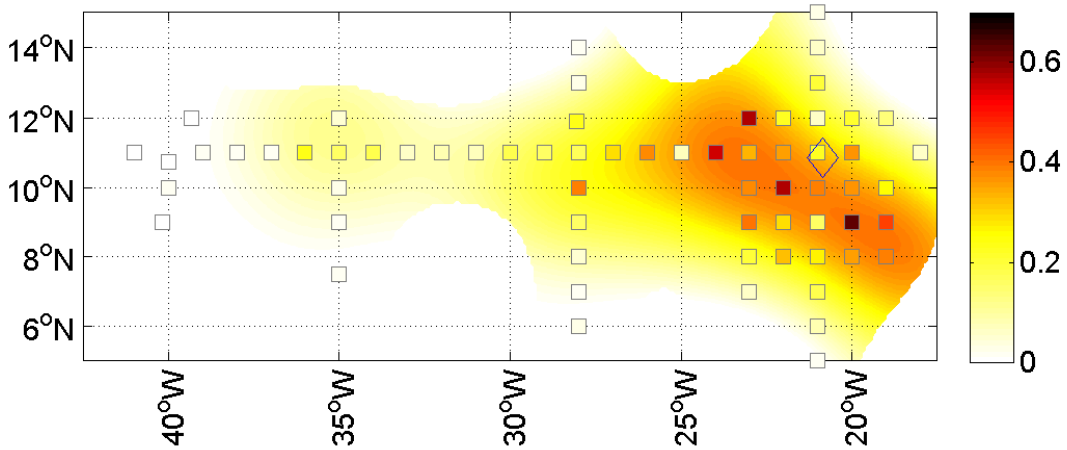

Fig. 5.5.3: The objectively mapped horizontal distribution of the column integral of the deliberately released tracer CF3SF5 from the OSTRE experiment. The squares show the values for the individual stations. The units are nmol m-2. The open diamond indicates the position of the tracer release in 2012.

5.6 Underway Measurements Vessel Mounted ADCP

(Patricia Handmann, PI: Martin Visbeck)

Underway-current measurements were performed continuously throughout the whole cruise using two vessel mounted Acoustic Doppler Current Profilers (VMADCP).

5.6.1 System Setup

The METEOR 75 kHz RDI Ocean Surveyor (OS75) mounted in the ship's hull, and a 38 kHz RDI Ocean Surveyor (OS38) placed in the moon pool were used. VmDas Version 1.46 was collecting the data. The 75 kHz ADCP was turned on 2nd May 2015, whereas the 38 kHz ADCP was turned on on May 15th. Both instruments then worked well and the 75 kHz produced good data for the duration of the cruise. The 38 kHz ADCP had sometimes no data in the velocity; the source of those data dropouts could not readily be detected and will be investiaged during the analysis. The OS38 was aligned to zero degrees (relative to the ship's center line) in order to reduce interference with the OS75 that is aligned to 45 degrees.

The 75 kHz ADCP was run in the more precise but less robust broadband (BB) mode, whereas the 38 kHz ADCP was run in the more robust and less resolving narrowband (NB) mode. The configurations of the two instruments are: OS38 using 55 bins of 32 m, pinging at 60 per minute and OS75 using 100 bins of 8 m, pinging at 60 per minute.

Depending on the region and sea state, the ranges covered by the instruments are around 600 m for the OS75 and around 100 0m for the OS38. During the entire cruise the SEAPATH navigation data was of high quality. Most shipboard acoustic devises were switched of during the cruise to avoid acoustic interference. However the 12 kHz echosounder EM122 was in use during the whole cruise and delivered high quality bathymetry data without noticeable interference. Logging for the EM122 data started on 4th of May 2015. One strong source of noise, which affected or even destroyed especial the OS75 data, due to the position in the ship hull, was the bow thruster during stations. VMDAS software was used to configure the VMADCPs and to record the VMADCP data as well as the ships navigational data. The data were processed on board and a preliminary data set was used for a number of near real time velocity products.

5.6.2 Exemplary Results

ADCP preliminary data processing is showing a turbulent and eddy rich flow through out the whole cruise. The map in figure 5.6.1 shows the mean velocity between 200 m and 500 m, which corresponds to the depth range of the OSTRE and GUTRE tracer injections.

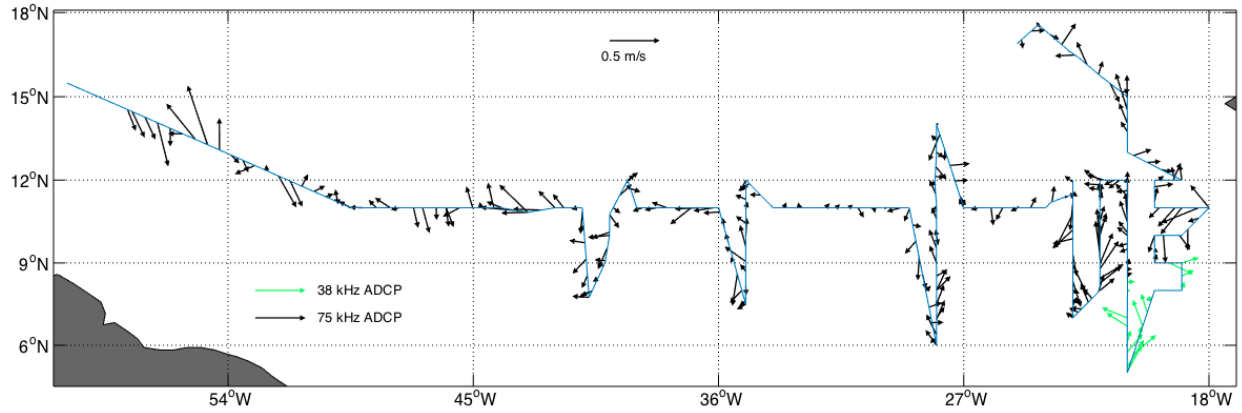

Fig. 5.6.1: Horizontal velocity from 75 kHz ADCP averaged between 200-500 m depth. During times when the 75 kHz ADCP did not work the 38 kHz ADCP data are shown as green arrows.

5.7 Underway CTD System

(PI: Sunke Schmitdko, Rudolph Link)

An Oceanscience UCTD 10-400 system was used during the cruise to make measurements of upper ocean temperature and salinity while underway. The system consists of a CTD probe with a tail spool, on which the desired length of line is spooled on using a rewinder. The probe free falls through the water column, sampling temperature, conductivity and pressure at about 23.9 Hz during a pre-set time interval. Deployment and recovery of the probe are done using a winch and small davit that form part of the UCTD system. Data are recorded internally and uploaded via Bluetooth connection.

Two probes, SN 157 (probe-1) and SN 155 (probe-2), were used alternatingly on the UCTD transects, each a few hours at a time; while one probe was in use, the other had its memory read and battery re-charged. Probe 1 was lost during cast 17 as too much line was spooled of the winch during a late night watch. It could not be reconstructed how the end of the line was attached to the winch; it is supposed that it was taped to the winch with Duct-Tape. The new line spooled onto the winch was attached with a ring-splice, to mitigate the possibility of losing the second probe by spooling too much line of the winch.

A total of 117 UCTD casts were completed during the cruise. Most of the profiles (111 casts) were done to a target depth of 435 m (435 m line spooled on, free-fall time of 100 s). The depth reached by the probe varied but was generally within about 15 m of the target depth.

Initial processing of UCTD data was done using SBE Data Processing, Version 7.21 k, following a procedure used during an earlier METEOR cruise (M99). This basic processing included adjusting for sensor delay between temperature (T) and conductivity (C) sensors relative to pressure (P). The value by which to advance T or C in order to align parameters in time was explored experimentally and an adjustment of +0.08 s for T was selected (based on one cast). Salinity, potential temperature and density were then derived from the measured variables. Data were then averaged into 1 dbar bins. Only data from the down casts were included. Further processing, done in Matlab, involved matching the time stamp of the start of the cast, as recorded by the instrument, with the DAVIS Ship-data record to get the position of the cast.

A calibration cast was performed with the uCTD probes attached to the rosette during a regular CTD cast to 1200 m depth and the data will be used to obtain a final calibration of the system. Probe 157 did not record any data during the calibration cast for unknown, not reproducible, reasons. Since probe 157 was lost prior a second calibration cast was made, calibration of probe 157 was made with two uCTD casts at the location of CTD casts in succession to the CTD cast 48, station 521.

During the course of the third uCTD transect, we noticed that conductivity data of probe 155 were bad, with an offset and significant jumps during each cast. The probe was inspected and it was found to have sustained some serious damage, with visible bending of the probe conductivity cell, which was linked to damage of the conductivity cell. The broken probe was not taken out of service, since probe 157 was lost. The complete conductivity record from probe 155 must be discarded. Data analysis showed that probe 155 was broken prior the first cast. The temperature record from probe 155 is not affected. From probe 157, both temperature and conductivity measurements appear to be of good quality. A total of 16 casts were completed with probe 157 and 100 with probe 155.

Other problems with the UCTD system encountered during the cruise included a technical fault in the clutch controller, which was not reproducible after a cool down of the system. Finally, the overheating of the winch motor led to a total failure of the winch system during a 5 hour-long overnight non-stop 400 m uCTD at 12 knots ship speed transit. It seems that the construction of the uCTD winch is not designed to perform non-stop measurements at greater depth and higher speed despite the claims of the manufacturer. These conditions came with a high workload for the winch working 15-19 min with only a short 4-5 min break during the rewinding and drop.

5.8 Underway Measurements Thermosalinograph

(Henrike Schmidt, PI: Sunke Schmidtko, Martin Visbeck)

Underway temperature and salinity measurements were made with a two SEABIRD Thermosalinographs SBE21 (Serial Number: 3388 & 3394, see also METEOR Handbuch) installed in the ship's port well about 4 to 4.5 m below sea surface. The instrument measures seawater conductivity and temperature continuously. From those salinity is calculated. For calibration purposes of the conductivity sensor, salinity samples were taken every day during the entire duration of the cruise. Due to reconstructions in the bow of the ship, the sampling point was no longer near the main flow pipes of the Thermosalinograph (TSG). The sampling point was located about 10m of pipe of the main pipe. To mitigate the effect of old water residues in the pipe, we had to wait about half an hour from turning on the water until taking the salinity sample. This time was estimated by a flow speed of 1l in 2.5 minute and a volume of about 4l within the pipe system. A 24 minute-long sampling test indicated that the water sampled still had not completely flushed the pipe after that period. We took 27 samples from the TSG. Furthermore, the TSG data were compared to the results of the conductivity-temperature-depth (CTD) profiles.

5.8.1 M116/1 performance

During cruise M116/1 (May 1st to June 1st), CTD measurements were performed in the tropical Atlantic. We expected elevated surface temperatures and salinity, which were confirmed by the TSG measurement. However in these months the coldest waters were encountered in these regions, ranging from sea surface temperatures (SST) 22.8°C to 29.6°C and typical sea surface salinity (SSS) characteristics ranging from 33.6 to 36.5 (Fig 5.8.1.).

Good agreement was found between the reference measurements and the themosalinograph (TSG) data shown in Fig. 5.8.1. Solid lines indicate measurements from the ship's TSG, red diamonds denote preliminary calibrated CTD-data that was averaged over 4 to 5 dbar of the profiles and blue crosses denote the salinometer measurements. SST measurements showed a constant offset of 0.14°C. After removing the mean, the remaining variance between TSG-data and CTD-data is small (0.014°C). The offset of SSS measurements is 0.033 and a variance of 0.006 (Table 5.8.1).

In both time series from the TSG, a slightly decreasing trend of the values compared to CTD stations values is visible over the whole time series. The variation between TSG and CTD temperature and salinity values is low, so it is reasonable to apply a linear fit to the time series. The linear fit for the salinity data has a slope of -0.0018 of practical salinity per CTD station and an intersection of -0.009. A linear fit for the temperature data has a slope of -0.0028°C and an intersection of 0.1798.

Comparison of these two quantities shows that practical TSG-salinity is on average a little lower relative to CTD-measurements by 0.033 psu. TSG-temperature is on average higher than CTD-surface temperatures by 0.138°C (Table 5.8.1)

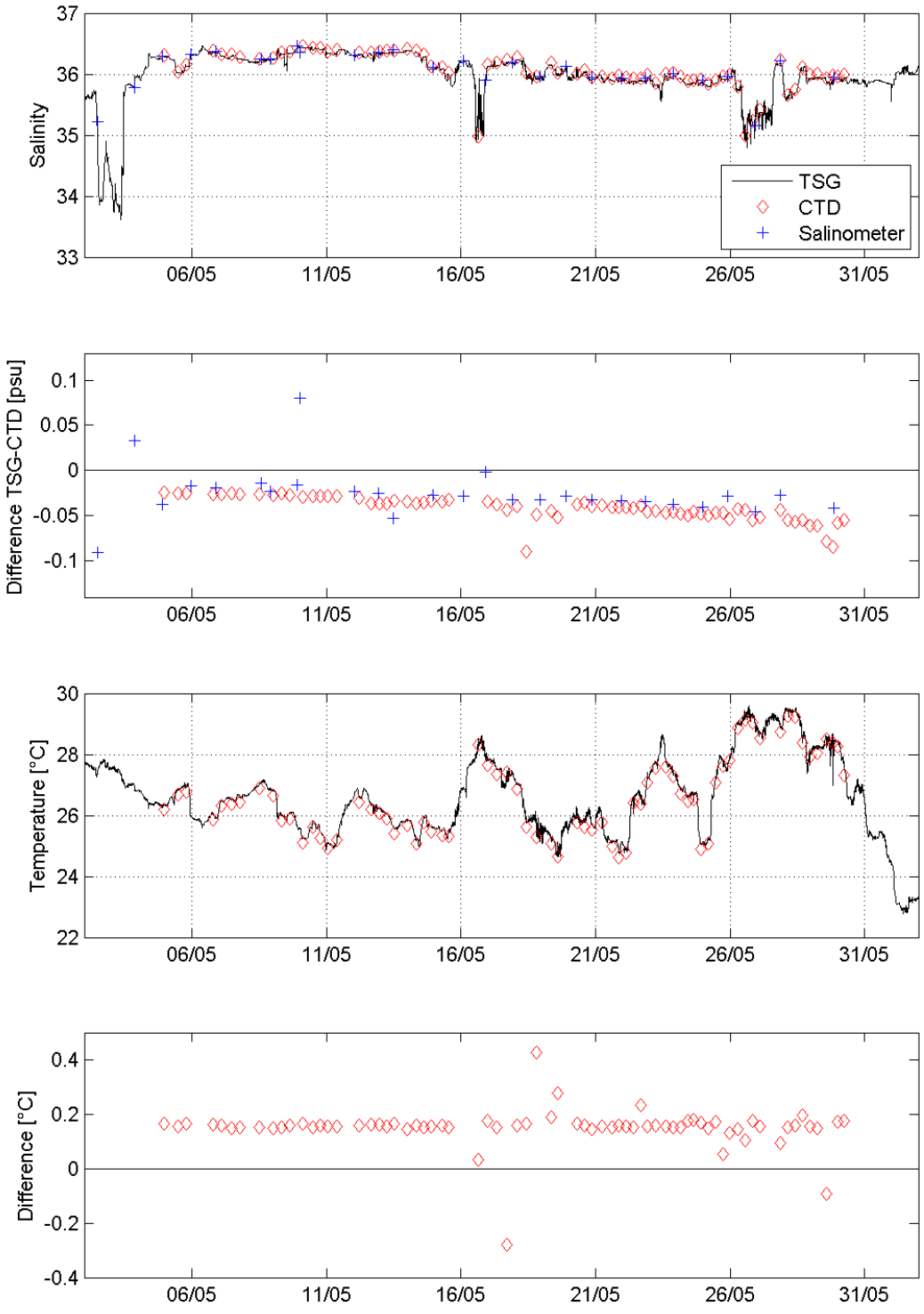

Fig. 5.8.1: Sea Surface Salinity (top), salinity difference between TSG minus CTD and salinometer measurements, Sea Surface Temperature and temperature difference between TSG minus CTD (bottom). SSSs and SSTs from the ships Thermosalinograph (TSG) were compared to surface measurements of the CTD preliminary profiles (average between 4 and 5 dbar) and also to continuous salinometer measurements. TSG-measurements are denoted by solid lines, CTD-measurements by red diamonds and salinometer measurements by blue crosses.

	SST (°C)	SSS
Mean Offset	0.14	-0.033
Variance	0.014	0.0057

Table 5.8.1: Surface temperature and salinity offsets and standard deviation calibrated against high accurate CTD data.

5.8.2 Experience from previous cruises

Furthermore, we measured the salinity of TSG samples from earlier cruises, starting with samples from 16th September 2014. Those samples were taken with helpful support of the captain and previous cruise participants. Most of the sample bottles were missing the airtight plastic cap and were only closed with a simple plastic lid. This led to significant evaporation of the sample and thus not comparable results between the TSG measurements and the calibration samples measured during M116/1. All TSG samples that had the plastic cap and lid were sampled. The data was recorded and stored. Due to the issues with the sampling point described above, the quality of the calibration has to be questioned. Despite good samples, the setup of the pipes with flushing times significantly less than 30min, does lead to salinity calibration measurements that do not show any relation to the TSG data taken within several hours of the time of sampling. A better system should be established at METEOR.

5.9 Underway O_2 and GTD Measurements

Tobias Hahn, PI: A. Körtzinger)

Underway (UW) measurements of dissolved oxygen (O_2), total gas tension (GTD), temperature and salinity were carried out on pumped surface waters in a flow-through box. A submersible pump and a MicroCAT sensor (SBE37-IM, SN# 37IM60039-7957, Sea-Bird Electronics Inc., Bellevue, USA) were installed in the ship's moon pool at approximately 5 m depth. The pump supplied a continuous flow of surface water to the underway instruments in the through-flow box as well as a bypass for discrete water sampling.

The following sensors were implemented: oxygen optodes (model 4330, SN# 1082, Aanderaa Data Instruments AS, Bergen, Norway; model HydroFlash™ O2, SN# DO-1014-005, CONTROS GmbH, Kiel, Germany), GTD Pro gas tension device (SN# 22-019-06, Pro Oceanus Inc., Bridgewater, Canada) and conductivity sensor (model 4319, SN# 772, Aanderaa Data Instruments AS, Bergen, Norway). Temperature was obtained from the optodes as well as the MicroCAT sensor.

Duplicates (67 discrete oxygen and 35 salinity samples) were taken from the bypass to validate and partly calibrate these UW measurements. Both types of samples were measured onboard using Winkler titration and the salinometer, respectively (see chapter 5.2 and 5.1.4, respectively, for further details).

The UW measurements in the flow-through box were started on Mai 2nd at 12:00 am and stopped on Jun 1st, 2015, at 9:33 pm (both UTC).

5.10 Underway Measurements H_2 and DNA&RNA

(Imke Grefe, Jacqueline Zorz, PIs: Robert Moore, Julie LaRoche)

5.10.1 Underway measurements H_2

As part of a study on the relationship between hydrogen supersaturations in the surface ocean and the production of this gas during nitrogen fixation, dissolved hydrogen was measured continuously in surface waters between 3 May 14:00 and 2 June 4:00 UTC during M116/1.

A Peak Performer 1 (PP1) reducing gas analyser (Peak Laboratories, LLC, serial # 145) was connected to a glass coil equilibrator (Xie et al. 2001) for continuous hydrogen (H_2) measurement. Seawater was supplied from the rotary pump and overflowed into a glass reservoir with the seawater tap fully opened. Seawater was pumped to the equilibrator using a peristaltic pump (Ismatec). The pump rate was set to ~14 mL min^{-1} and was controlled regularly. Carrier gas bubbles were inserted into the water stream at a rate of 2 mL min^{-1} using a mass flow controller (MFC, MKS Instruments, Inc.). After equilibration, the carrier gas bubbles were separated from the seawater and fed into the sample loop of the PP1 analyser. An air standard was measured every 70 minutes to correct for analyser drift. Liquid standards were prepared daily by purging seawater with carrier gas. Furthermore, a liquid standard was measured to address the efficiency of the equilibrator. Samples from just downstream of the bow inlet of the pumped seawater supply were measured and compared to H_2 data from the seawater tap in the laboratory to check on build-up of biofilms in the seawater pipes. The system worked well and the H_2 saturation along the cruise track shows some interesting patched and structure (Fig. 5.10.1).

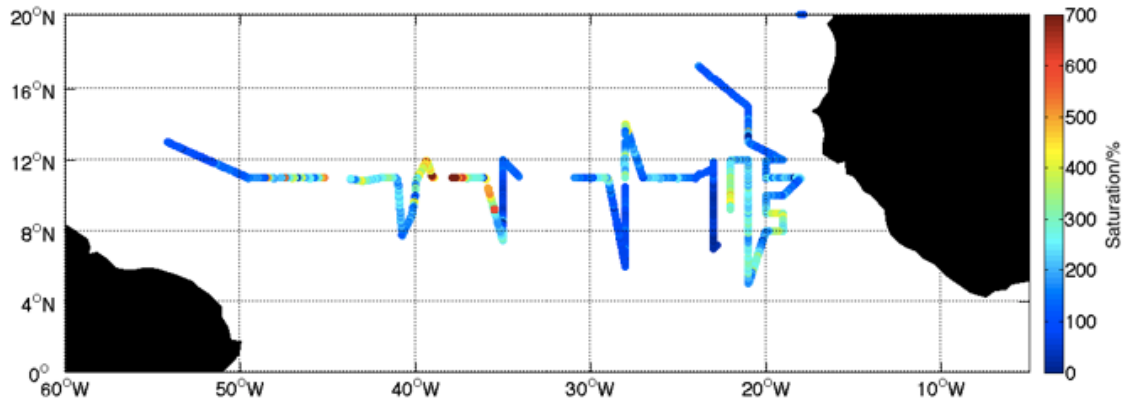

Fig. 5.10.1: H_2 saturation along M116/1 cruise track (preliminary, uncalibrated).

5.10.2. Underway sampling DNA and RNA

Water samples were taken from the underway system approximately every six hours while in transit. Around 3 L of seawater were taken in duplicate for RNA filter samples. These samples were filtered immediately using a peristaltic pump (FH100 Peristaltic Variable Pump System) at 30 rpm. All seawater samples were first filtered through a 3 µm filter (Millipore), followed by a 0.2 µm filter (Millipore). Filtration was stopped after 20 minutes to reduce bottle effects on the samples and to prevent sample loss through decomposition by RNAses. Filters were then placed

in cryotubes, flash frozen in liquid nitrogen, and stored at -80°C. In addition to the duplicate RNA samples, about 4 L of water was taken for DNA filter samples. This sample was filtered after the RNA samples as there is less concern regarding bottle effects for DNA samples. The DNA filter samples were flash frozen and kept at -80°C. For flow cytometry, 2 mL samples were taken during each sampling event and paraformaldehyde was added as a fixative to a final concentration of 1 %. These samples were flash frozen and kept at -80°C. In addition to these routine samples, occasional samples of 50 and 5 mL seawater were collected for fluorescence activated cell sorting (FACS) and microscopy respectively. The 50 mL FACS sample was fixed with a GlyTE buffer solution and stored at -80°C. The 5 mL microscopy sample was fixed with paraformaldehyde to a final concentration of 2 % and stored at 4°C in the fridge. These additional samples were usually taken at sampling events when hydrogen measurements were high. All underway samples collected during the cruise will be sent back to Dalhousie University in Halifax, Canada and analyzed using various molecular biology techniques in the lab of Prof. Julie LaRoche. The exact procedures for analysis of these samples has yet to be determined but will likely include qPCR, RT-qPCR, flow cytometry, and high throughput sequencing of marker genes. The distribution of samples taken over the cruise is shown in Figure 5.10.2. In total, 107 underway samples were taken.

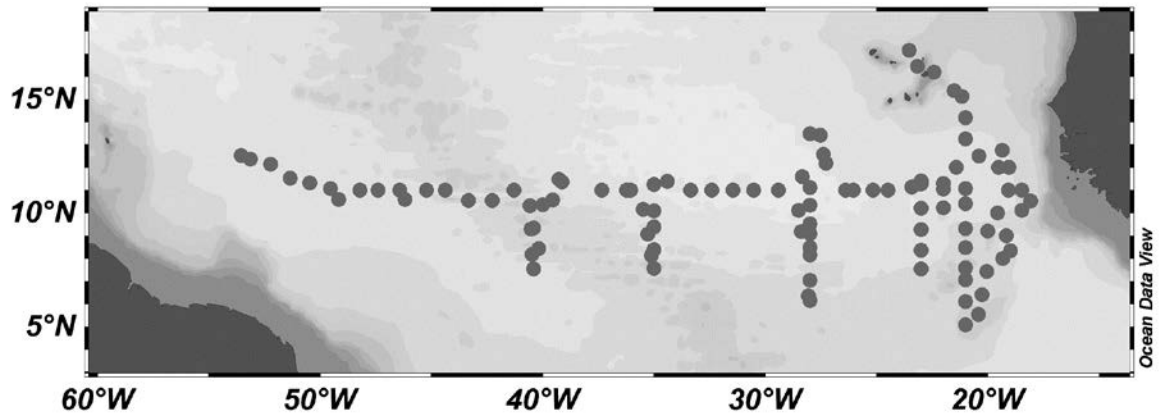

Fig. 5.10.2: Distribution of underway samples taken over the course of the METEOR M116/1 cruise.

5.10.3 Biological CTD Samples

At select CTD stations large volume samples (~3-4 L) were collected to determine the presence of diazotrophs at certain key regions in the water column. The depths of interest were both the deep and shallow oxygen minimums and the chlorophyll maximum. These seawater samples were filtered as detailed above for RNA and/or DNA depending on how much seawater was collected. Furthermore, samples for microscopy, flow cytometry and FACS were collected. These samples will be brought back to Dalhousie University in Halifax, Canada for biological analysis. In total, 32 CTD samples were taken from 16 CTD stations.

5.10.4 Nitrate Isotope CTD Samples

(Imke Grefe, Jacqueline Zorz, PI: Doug Wallace)

Samples for nitrate isotope measurements were taken from a total of 30 CTD stations. Approximately 50 mL of water was collected from 4 depths at each CTD cast sampled. The seawater was filtered through a 0.2 µm GFF filter to remove biological matter before the samples were frozen at -80°C. The depths sampled varied from station to station, but generally consisted of the two shallowest depths, the tracer depth in the OMZ, and a deep sample at 1000m. Sometimes if there was a strong shallow OMZ a sample was collected there instead of at 1000m depth. These samples will be shipped back to Dalhousie University in Halifax, Canada and analyzed using mass spectrometry in the lab of Prof. Doug Wallace.

5.11 Underway Tow Fish Measurements

(Tom Browning, Caroline Utermann, PI: Eric Achterberg)

Surface (~2-3 m depth) seawater was sampled from a custom-built towed-fish via acid washed 1cm diameter tubing with suction provided by a Teflon bellows pump. Water was pumped directly into a purpose-built clean air laboratory container. Positive air pressure was maintained in the container via a continuous inward air flow, with dust particles in this air flow removed by a HEPA filter.

Samples collected were for dissolved macronutrient (nitrate and phosphate) concentrations, trace element concentrations, and phytoplankton samples. Further details for each of these are outlined below. Sample collection for this suite of measurements was carried out every ~3 hours of steaming time with a preference for sampling just before (~10-15 minutes) a CTD station. The total number of sampling points was 150.

5.11.1 Trace elements:

Samples were collected in acid washed 125 mL LDPE sample bottles for dissolved (0.2 µm filter capsule) and total (no filtration) trace metal concentrations (metals: Fe, Zn, Mn, Mg, Cu, Co, Cd, Al). Samples were acidified with 140 µL concentrated (10M) Optima grade hydrochloric acid, in batches and under a laminar flow hood, within a few days of collection. These samples will be measured on return to GEOMAR via pre-concentration on a SeaFAST system (Thermo scientific) and subsequent analysis on an Element 2 ICP-MS following the method of Milne et al. (2010).

5.11.2 Major nutrients:

Samples were collected for dissolved nitrate, phosphate, and dissolved organic phosphate (DOP) concentration analyses at nano-molar level. 50 mL samples were collected in acid washed Falcon tubes for nitrate and phosphate concentrations. 15 mL samples for DOP analysis were collected separately in acid washed Falcon tubes. Both were frozen immediately in a -30°C freezer before subsequent transfer to a -20°C freezer. These samples will be analysed on return to GEOMAR using a custom-built analyser following the method of Patey et al. (2008).

5.11.2 Phytoplankton measurements:

Chlorophyll-a concentrations: triplicate 500 mL samples were filtered onto Macherey-Nagel MN 85/70 GFF filter pads and extracted for 12-24 hours in 10 mL 90 % acetone in a -20°C

freezer in the dark before measurement on a Turner Designs trilogy fluorometer following the method of Welschmeyer (1994).

High Performance Liquid Chromatography (HPLC): 2-4 L seawater was filtered onto Macherey-Nagel MN 85/70 GFF filter pads and placed directly into a -80°C freezer. These will be analysed on return to GEOMAR following the method of e.g. Gibb et al. (2000).

Phytoplankton light absorption: 1-2L seawater were filtered onto Whatman GF6 GFF filter pads inserted into a cryovial without folding and placed directly into a -80°C freezer. These will be measured for spectrally-resolved light absorption (350-750 nm range) relative to a reference filter on a spectrophotometer before and after pigment extraction with hot methanol following the protocol of Kishino (1985).

Analytical flow cytometry: 1.87 mL of seawater was mixed with 0.125 mL 16 % paraformaldehyde yielding a final paraformaldehyde concentration of 1 %. Mixing was carried out using vortex, after which samples were left for 10 minutes at room temperature in the dark before direct transfer to a -80°C freezer. Samples will be analysed on a FACSort flow cytometer (Beckton-Dickinson, UK) following the method of e.g. Davey et al. (2008), with the intention of analysing for nanophytoplankton, picophytoplankton, *Synechococcus*, *Prochlorococcus* and total bacterial cell counts.

Fast Repetition Rate fluorometry (FRRf): A FASTOcean fluorometer (Sensor ID: 14-9740-003) with integrated FASTact laboratory system (both Chelsea Technologies LTD., UK) was used to measure in vitro variable fluorescence of phytoplankton samples after a 30 minute dark acclimation period (with temperature maintained by submersion in continuously flowing water from the ships underway system). Fluorescence light curves were also run following a protocol of progressively increasing light intensities between 20 and 2000 µmol photons m^{-2} s^{-1} (as described in Browning et al., 2014). Blank filtrates (0.2 µm filtrates) were measured for virtually all samples. All FRRf data will be blank-corrected and fluorescence parameters recalculated upon return to GEOMAR.

5.12 Biological Incubation Experiments

(Tom Browning, Caroline Utermann, PI: Eric Achterberg)

48 hour duration on-deck incubation experiments were carried out in 1 or 4 L trace-metal-clean polycarbonate bottles. Seawater was collected at nighttime using the trace-metal-clean towed-fish described previously. Filling times were approximately ~40 minutes for 1 L bottle experiments (total volume = 27 L) and ~2 hours for 4 L bottle experiments (108-120 L depending on experiment). Bottled seawater was spiked with the one of the following combinations of nutrients/trace metals:

1) N, P, Fe, NP, NFe, PFe, NPFe (1 L bottle experiments)
2) N, NP, NFe, NZn, NPFe, NPZn, NFeZn, NPFeZn (4 L bottle experiments)
3) P, Fe, Zn, PFe, PZn, FeZn, PFeZn (4 L bottle experiments)

For all experiments initial conditions were assessed via samples collected in 1 or 4 L bottles at 3 time points throughout the bottle filling procedure. Triplicate control bottles (1 or 4 L) - where no nutrients were added - were also collected and incubated alongside all treatment experiments. Treated bottles were spiked to the following nutrient/trace metal concentrations:

N: 10 µM nitrate and 10 µM ammonium
P: 2 µM phosphate
Fe: 2 nM Fe
Zn: 2 nM Zn

Bottles were placed in on-deck incubators connected to the ships underway flow-through system to continuously maintain temperatures at that of sea surface waters. Incubators were screened with Blue Lagoon screening (Lee Filters), which maintained irradiance at ~30 % of that of the surface. After 48 hours incubation, experiments were taken down and measurements made for:

1L experiments: chlorophyll-a concentrations (1 replicate per treatment bottle), FRRf (single acquisitions only), analytical flow cytometry, a time course analysis of alkaline phosphatase activity using MUF-P (Sigma) as the organic phosphate substrate and directly following the method of Ammerman (1993) with fluorescence measured on a Turner designs Trilogy fluorometer equipped with a custom-built 355/10 nm (excitation) – 460/10 nm (emission detection) snap-in module manufactured by Turner Designs.

4L experiments: as for 1L experiments, and in addition water from 2 experiments was also filtered for RNA analysis onto 0.2 µm pore diameter Durapore (Millipore) filters. Filtration for RNA analysis was always <20 minutes and followed by immediate flash-freezing in liquid nitrogen before transfer to a -80°C freezer. RNA samples will subsequently be shipped from GEOMAR to Dalhousie University (Canada) for analysis via RT-qPCR in the group of J. LaRoche. The exact protocol to be followed for this analysis has yet to be determined at the time of writing.

Water for incubation experiments was collected at the following locations:

Longitude (°W)	Latitude (°N)
56.13	13.87
52.39	12.25
40.90	9.71
35.28	8.48
30.60	10.99
28.03	12.28
23.00	7.30
21.00	5.53

5.13 Ecological Studies

(Svenja Christiansen, PIs: Helena Hauss, Stefanie Ismar, Henk-Jan Hoving)

The ecological investigations focused on three aspects. First, fine-scale vertical profiles of particle and zooplankton distribution were obtained by an Underwater Vision profiler (UVP). Second, surface zooplankton was sampled with a driftnet during the night. Individuals of the calanoid copepod genus *Pontella* and of the chaetognath genus *Sagitta* picked out for stable isotope analysis. In order to identify trophical relationships and food ecology, samples for stable isotope analysis were also taken from storm petrels (*Oceanodroma leucorhoa*) that landed on

deck during the night and from squid that were caught during CTD night stations. Third, daily seabird observations were done.

5.13.1 Particle and Zooplankton observations with the Underwater Vision Profiler

An Underwater Vision Profiler 5 (UVP), serial number 10, was mounted on the CTD-rosette. The UVP consists of one down facing HD camera in a pressure-proof case and two red LED light arrays, which illuminate a defined water volume. During the downcast of a CTD-deployment, the UVP takes 3 to 11 pictures of the illuminated field per second. For each picture, particles larger than 60 µm are sized and counted. Furthermore, images of particles with a size > 500 µm are saved as separate "vignettes" - small cut-outs of the original picture – which allow for later, computer assisted identification of these particles and e.g. their grouping into different particle, phyto- and zooplankton classes.

In total 82 UVP profiles were taken on 82 CTD-stations during M116/1; 29 of them to the bottom depth (between 5797 db and 2340 db) and 48 to a depth of 1200 db. 3 casts went to a depth of 2200 db, 1 to 2000 db and 1 to 1000 db. The UVP was run autonomously and a specific depth routine was carried out to start it: the CTD was lowered to 22 db to enable the power up of the UVP and to start image acquisition; the actual downcast began as the CTD was heaved to the surface.

All measurements were taken with the same configuration settings of the UVP; the most important ones are shown in Table 5.13.1. A well-defined distance of 36 cm was set between the camera and the lights.

Lens_model	Tamron
Lens_focal	8
Fovx	188
Fovy	141
Pixel	151
Focal_distance	375
Aa_calib	32
Exp_calib	13.603
Img_Vol	93

Table 5.13.1: Main parameter setting for the UVP 5 system.

5.13.2 Zooplankton, Seabird and Squid sampling

In order to detect foraging patterns and the influence of oxygen minimum zones (OMZ) on the distribution and food ecology of storm petrels in the tropical North Atlantic, zooplankton and seabird samplings were done. During every night with CTD station, a WP2 Net was used as a driftnet to sample surface zooplankton. Each net haul took 10 minutes, during which the net was hung down right next to the ship directly beneath the surface. Water was dragged in only by the low currents alongside the ship. After the haul, the zooplankton was rinsed into a bucket of filtered seawater, a photo was taken to document the approximate abundance (the net hauls were not quantitative) and then 5 individuals of the calanoid copepod genus Pontella and 1-2 (depending on their size) chaetognaths (Sagitta lyra) were picked out with a pasteur pipette.

These samples were put into pre-weighed tin cups and dried at 55°C for later stable isotope (SI) analysis ashore. In the net samples, high abundances of the diazotroph Cyanobacterium Trichodesmium were found at several stations. Since no quantitative counting was possible, abundances were set into a scale from 0 to 10 for a semi-quantitative estimate.

The zooplankton SI data are supposed to be compared with seabird SI data, so whenever a storm petrel landed on deck, it was caught for sampling. The birds were weighed, beak and wing length measured and then two feather samples were taken for the SI analysis, one from the hind part of the head and one from the breast of the bird. After this treatment the birds were released by giving starting aid. Photos were taken if possible.

During CTD casts in the early night, often squids were caught for later analysis of diet and stable isotope signature that can be used to characterize foraging patterns and trophic position. The squids were frozen and taken back to the lab in Kiel. Squids were caught on roughly every second night.

In total, 27 net hauls were done at 26 stations, with 1 repeated haul due to low abundance of *Pontella* in the first haul. 9 birds were caught of which 7 were sampled successfully. One bird escaped before sampling was possible and of one, feathers already plugged out by the bird were taken as sample so the origin of the feather was unsure. Only stormpetrels of the species *Oceanodroma leucorhoa* were caught and sampled.

5.13.3 Seabird observations

Every day of the cruise, one hour was spent on seabird observation which was performed as follows. During one hour in the afternoon, sky and water were surveyed with a binocular from the front of the monkey island in regular (2-5 minutes) time intervals. These surveys covered about 180° of the surrounding of the ship, starting at 90° to the port and ending at 90° to the starboard side. In between the binocular surveys, this area was watched only by naked eye. About every 10 minutes, also the other 180° to the aft of the ship were observed. If the ship was on station during observation time, this interval was shortened and the fact noted in the protocol. Observed seabirds were identified as far as possible and identification, distance to ship, number of individuals and "mode" (eg. foraging, following ship etc.) noted down. If close enough (<100 m distance), photos were taken for further identification and documentation. During the observation time, the abundance of the brown macroalgae Sargassum was noted and sorted into a scale from 0 to 10.

Additionally, seabirds sighted at other times of the day/night were recorded if identification was possible. In total 30.5 hours were spent on regular observation, with 23 identified species, 1 unknown/unidentified species and 174 individuals. In Table 5.13.2 a summary of observed species is given. Sightings were given a quality flag depending on the security of the identification: 0 = 90-100 % security (species sure), 1 = >60 % security (genus sure, but not species), 2 = <60 % security (genus unsure). A complete list of the sightings will be available in the database of the SFB 754 in Kiel. In this database, also a description of the scale for the abundance of Sargassum and Trichodesmium can be found.

Hours of observation	30,5
Total number of observed species	23
Total number of observed individuals	174
Most abundant species	Calonectris diomedea Oceanodroma leucorhoa

Table 5.13.2: A summary of the observed species

5.14 Instrument Test of CONTROS Optodes

(Tobias Hahn; PI: Arne Körtzinger)

Besides the underway performance test of a CONTROS optode (see chapter 5.9), optical oxygen measurements with optodes (model: HydroFlash™ O2, SN# DO-1014-001, DO-1014-003 and DO-1014-004, CONTROS GmbH, Kiel, Germany) were carried out on 14 CTD casts in order to characterize its performance. The CTD profiles between 24 and 38 were used to determine the sensor response during the up- and downcast of the CTD. Therefore, the optodes were attached on the near-bottom of the CTD-Rosette as close as possible to the inlet of the SBE43 for comparison. All data during each CTD cast were logged internally every 1 s with the optode using the power supply of a manufacturer customized battery module. Problems with data logging occurred for optode DO-1014-003 and -004 during the casts between profile 32 and 38 because the cold temperature in the deep ocean decreased the power supply of the battery module below the necessary threshold.

For the determination of the sensor performance during air measurements, these three optodes were also attached on the top deck above the air chemistry lab where simultaneous data logging was ensured. Additionally, measurements were conducted in the flow-through box (see chapter 5.9) in order determine drift and changes in the optodes' signal. Table 5.14.1 provides exact details for each optode during these experiments.

<table>
<tr><th rowspan="2">SN# DO-1014-</th><th rowspan="2">Performance on CTD-Cast, profile #</th><th colspan="2">Measurement times (UTC) in the flow-through box</th><th colspan="2">Air measurements</th></tr>
<tr><th>Start</th><th>End</th><th>Start</th><th>End</th></tr>
<tr><td rowspan="2">001</td><td rowspan="2">24-29, 31-38</td><td>May 2nd, 12:00am</td><td>May 3rd, 4:49pm</td><td rowspan="2">May 3rd, 5:54pm</td><td rowspan="2">May 5th, 7:51pm</td></tr>
<tr><td rowspan="2">May 5th, 8:13pm</td><td rowspan="2">May 12th, 7:09pm</td></tr>
<tr><td>003</td><td>24-29, 31, 34</td><td rowspan="2">May 21st, 9:01am</td><td rowspan="2">May 27th, 1:22pm</td><td rowspan="2">May 27th, 1:59pm</td><td rowspan="2">May 31st, 7:38pm</td></tr>
<tr><td>004</td><td>24-29, 31-36</td></tr>
<tr><td></td><td></td><td>May 31st, 8:12pm</td><td>Jun 1st, 5:47pm</td><td></td><td></td></tr>
</table>

Table 5.14.1: Details about the instrument test of CONTROS optodes

5.15 Sampling of seawater for Argon-39 determination

(Arne Kersting and PI: Toste Tanhua)

The radioactively decaying isotope ^{39}Ar has a half-life of 269 years, so that a few half-lives are similar to the ventilation time-scale of the ocean. Since argon is an inert gas without any chemical reactions, measurements of ^{39}Ar hold great potential for constraining ocean ventilation. However, low concentrations and cumbersome analytical methods have prevented a large scale survey of ^{39}Ar in the ocean. A recently developed technique, Atomic Trap Trace Analysis (ATTA), does open the possibility to perform these measurements on lower volume samples (~20 L) as opposed to the 1000 L required by the Low Level Counting method. This cruise offered the possibility to conduct the first sampling for ^{39}Ar in the ocean for the ATTA method, and will serve as a "proof of concept" study for large scale surveys.

During the cruise, three CTD casts were performed exclusively for argon measurements. Two casts were conducted in the center of the oxygen minimum zone (10°30'N, 22°W and 10°15'N, 23°W), and one station at the CVOO station. At each station we pooled the water from 3 different Niskin bottles to one sample of between 21 and 24 L of water in one sampling container. This led to 8 samples per cast, each from different depths between 4000 m and 10 m.

As sample container, we used 27 L propane gas bottles. These were brand new, never used ones, that were evacuated and flushed with nitrogen three times and refilled with about 1100mbar of nitrogen for the transport to this cruise. Two hours before every sampling station, we evacuated 8 containers to approx. 1mbar and assembled 3-way-valves to the bottles to be able to flush the inlet with the seawater and to get rid of air bubbles while sampling. During the sampling we put the propane gas bottles on scales to control that the amount of water we took from each Niskin never exceeded 8 L.

The sample time for one from 3 Niskin bottles was approximately 10 minutes. The sample containers were shipped to the Institute of Environmental Physics in Heidelberg, where they will be degased and processed to separate out the argon fraction. The pure argon is then transported to the Atom Trap Trace Analysis instrument at the Kirchhoff-institute for Physics for the measurement of the ^{39}Ar concentration.

5.16 Argo Float Deployments

(Sunke Schmidtdko; PI: Birgit Klein BSH)

During the cruise M116/1 ten Argo floats were deployed after deep (>2000 dbar) CTD stations. The Argo floats were deployed for the German Bundesamt für Seeschifffahrt und Hydrographie (BSH) at the positions as recorded in table 5.16.1. The floats were Nova-Iridium floats with serial numbers #217 to #226.

The provided Argo floats were deploy-ready provided. Three protection caps and a magnet were removed prior deployment. Deployment was made by throwing the float bottom first from the back of the ship during slow speed through the water (2 knots) at the location of a CTD station.

WMO number	Serial number	Latitude of deployment	Longitude of deployment
6902607	217	10° 59.94' N	45° 59.82' W
6902610	218	8° 0.09’ N	27° 59.98’ W
6902613	219	12° 0.01' N	39° 20.01' W
6902606	220	11° 0.00' N	49° 29.98' W
6902608	221	7° 44.92' N	40° 44.99' W
6902611	222	8° 0.00’ N	23° 0.00’ W
6902609	223	7° 29.99' N	35° 0.01' W
6902614	224	12° 0.06' N	34° 59.85' W
6902615	225	11° 0.00’ N	21° 0.00’ W
6902612	226	7° 0.00' N	21° 0.00' W

Table 5.16.1: Details about the deployed Nova-Iridium floats

5.17 Glider Recovery

(Sunke Schmidtko; PI: Gerd Krahmann and Arne Körtzinger)

During the cruise M116/1 the SLOCUM ocean glider IFM#12 was recovered at 16° 38’N and 23° 08’W on June 1 at 16:00 UTC. A zodiac operation recovered the glider swiftly despite significant swell (1.7 m hight) and wind (11 m/s). Prior deployment ordinary cosmetic zinc-crème was used to cover most of the glider surface as biofouling protection, this proofed to be a good anti-fouling measure. The glider showed very little biofouling and only a small amount of mussel growth on its surface, despite its record length deployment period of 89 days. The glider was rinsed with freshwater and dissembled. Visual inspection of the oxygen optode showed scratches on the foil. The oxygen optode of the glider was immediately removed and attached with a logger to the CTD within 45 minutes of glider recovery. A 1000dbar oxygen optode calibration cast with the CTD was performed (Station #553, cast #80), 7 stops with 5 minute wait times were made during the up-cast to allow a better CTD-sensor – optode comparison, paying tribute to the slow response time of the optical oxygen sensor. Finally the glider memory card was secured and copied. For glider transport the instrument was reassembled with a new silicate pack inside and all sensors mounted.

A wave glider GEOMAR-1 was recovered at 17° 33.4’W and 24° 16.1’N on June 2 at 09:30 UTC. A zodiac operation tied a line to the wave glider and it was taken on board with the aft crane. The wave glider seemed in good shape but a tube connection in the science bay had come loose and interrupted some of the measurements. The glider was cleaned and prepared for shipment back to Kiel.

5.18 Aerosol Optical Depth (AOD) Measurements

(Astrid Eichhorn, PI: Stefan Kinne MPI-MET)

In collaboration with the National Aeronautics and Space Administration Goddard Space Flight Center (NASA-GSFC) and the Max Planck Institute for Meteorology, MICROTOPS-II hand-held sun photometer measurements have been conducted as part of the Maritime Aerosol Network (MAN), which has been developed as a component of the Aerosol Robotic Network (AERONET). Measurements offer required ocean reference data for satellite remote sensing and simulated aerosol properties in global models. Smirnov et al. (2009) describe details about the AERONET-MAN program.

RV METEOR's research transit-voyage M116/1 across the tropical North Atlantic region allowed the survey of atmospheric properties associated with Saharan dust events. Especially during spring enhanced Saharan dust transport across the Atlantic is expected. Measurements have been undertaken with a hand-held MICROTOPS-II sun-photometer (#19746), calibrated unit of NASA-GSFC, in combination with a GPS unit. The monitoring device was manually operated on the ship's upper deck to have an unobstructed view to the sun disk.

At assured cloud-free conditions AOD was measured daily by pointing the instrument's solar sensors directly into the sun. Therefore, a continuous monitoring of the sky as well as a correct pointing to the sun while scanning was required. If possible, we measured in 15 minutes intervals. Each measurement consisted of 10 consecutive direct radiation scans (samples) lasting for about 2 minutes in total.

The MICROTOPS-II data has been sent to a NASA-GSFC archive where the preliminary aerosol measurements become visible and accessible via web. After a past-voyage re-calibration of the data at NASA, additionally, higher quality data version will be offered: http://aeronet.gsfc.nasa.gov/new_web/maritime_aerosol_network.html

6 Weather conditions during M116/1

(Christian Rohleder, Meteorological Office RV METEOR)

On Friday, 01.05.2015 at about 09:00 local time, RV METEOR left the harbor of Pointe-a–Pitre (Guadeloupe) for research trip M116/1-1 to Mindelo/Kap Verde.

After leaving the harbour FS METEOR was within the transition zone of the subtropical high and the tropical Depression belt in the NE-trade zone. Easterly winds were experienced with no precipitation. In the first week fair conditions persisted with winds of 4 to 6 Bft within a dry and stable airmass. Towards the second weekend the risk for showers slightly increased. The route of the expedition occasionally approached the tropical Convergence zone with its showers and thunderstorms. During the second week of the journey an extensive low pressure complex developed over the north Atlantic. This caused for a short time a higher swell of RV METEOR. From the 16th/17th of May a small low moved from Mauretania to Cap Verde. The NE- trade wind was disturbed with the result of changeable wind directions.

With the start of the third week a thermal trough extended from western Africa into the working area. This stable airmass was accompanied by dust from the Sahara. It was particular evident in the morning and evening hours. In the night to 23.05., RV METEOR reached the inner

tropical convergence zone (07N). In the morning and night hours showers and some lightning were experienced. Later RV METEOR navigated on a more northerly course (08N) into a more stable airmass, the shower activity decreased within a low pressure gradient. In the night to 27.05, RV METEOR moved again southwards (05N), showers and some lighting were experienced. The maximum of the shower activity was in the morning hours while RV METEOR was already on a northerly course. A heavy thunderstorm brought up to 12mm of precipitation. During the course of the morning some local showers were experienced, however while passing 08N RV METEOR reached again the stable airmass to the north of the ITC. In the last days RV METEOR was located close to the African continent with the surface trade winds backing (due to coastal effects). From the last weekend the wind increased a little.

In the last part of the cruise the SLOCOM ocean glider and the Wave Glider were successfully taken with a rubber dinghy despite northerly winds about 5 Bft and a sea/swell about 2m from the NNE.

On the 2nd of June 2015, RV METEOR reached the port of Mindelo/Cap Verde.

7 Station List M116/1

Station List: of R/V METEOR cruise M116/1.

Station METEOR	CTD Profile	Date	Time UTC	Latitude	Longitude	max. p [dbar]	Comment/measurements
M116/1_473	1	02/05/2015	14:05	14°31.86'	-58°19.51'	2003	O_2,Nutrients, NO_2, NO_3, PO_4, Si
M116/1_474		02/05/2015	16:14	14° 31.86'	-57° 40.49'	0	TMC Fish deployment
M116/1_475	2	04/05/2015	23:05	11°00.00'	-50°29.98'	5026	Argo deployment, O_2, Nutrients, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si, Plankton Net haul
M116/1_476	3	05/05/2015	11:05	11°00.00'	-48°00.03'	1203	O_2, Nutrients, Nitrogen, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_477	4	05/05/2015	18:05	11°00.02'	-48°59.98'	1210	O_2, Nutrients, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_478	5	06/05/2015	02:05	10°59.91'	-46°00.02'	5047	Argo deployment, O_2, Nutrients, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si, Plankton Net haul
M116/1_479	6	06/05/2015	11:05	10°59.97'	-46°59.94'	1202	O_2, Nutrients, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_480	7	06/05/2015	19:05	11°00.01'	-45°59.89'	1208	O_2, Nutrients, Nitrogen, DNA, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_481	8	07/05/2015	02:05	10°50.01'	-44°59.98'	5265	O_2, Nutrients, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si, Plankton Net haul
M116/1_482	9	07/05/2015	11:05	11°00.00'	-43°59.96'	1203	O_2, Nutrients, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_483	10	07/05/2015	18:05	10°59.97'	-42°59.96'	1217	O_2, Nutrients, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_484	11	08/05/2015	12:05	7°44.96'	-41°14.99'	4772	Argo deployment, O_2, Nutrients, Nitrogen, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4,TA, Si
M116/1_485	12	09/05/2015	00:05	9°00.01'	-41°49.96'	2340	O_2, Nutrients,SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si, Plankton Net haul
M116/1_486	13	09/05/2015	08:05	9°59.99'	-41°59.97'	4205	O_2, Nutrients, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_487	14	09/05/2015	15:05	10°44.97'	-41°59.96'	5386	O_2, Nutrients, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4,TA, Si
M116/1_488	15	10/05/2015	03:05	11°59.95'	-40°39.98'	5480	Argo deployment, O_2, Nutrients, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si, Plankton Net haul
M116/1_489	16	10/05/2015	12:05	11°00.02'	-40°59.98'	1200	O_2, Nutrients, Nitrogen,DNA, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_490	17	10/05/2015	18:05	11°00.03'	-39°59.96'	1208	O_2, Nutrients, SF_6, SF_5, CFC, NO_2, NO_3, PO_4 ,TA, Si
M116/1_491	18	11/05/2015	01:05	10°59.99'	-37°00.00'	4479	O_2 ,Nutrients, SF6, SF5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si, Plankton Net haul
M116/1_492	19	11/05/2015	09:05	10°59.98'	-37°59.97'	1207	O_2, Nutrients, Nitrogen, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_493	20	12/05/2015	05:05	7°29.92'	-36°59.93'	3910	Argo deployment, O_2, Nutrients, Nitrogen, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4 ,TA, Si, Plankton Net haul
M116/1_494	21	12/05/2015	16:05	8°59.93'	-36°59.97'	1204	O_2, Nutrients, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_495	22	12/05/2015	22:05	10°00.00'	-36°59.99'	1203	O_2, Nutrients, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si

Station METEOR	CTD Profile	Date	Time UTC	Latitude	Longitude	max. p [dbar]	Comment/measurements
M116/1_496	23	13/05/2015	05:05	10°59.96'	-36°59.98'	1210	O_2, Nutrients, SF_6, SF_5, CFC, NO_2, NO_3, PO_4, TA, Si, Plankton Net haul
M116/1_497	24	13/05/2015	12:05	12°00.00'	-35°00.01'	5713	Argo deployment, O_2, Nutrients, SF_6, SF_5, CFC, NO2, NO3, PO4, TA, Si
M116/1_498	25	13/05/2015	23:05	10°59.99'	-34°00.00'	5346	O_2, Nutrients, Nitrogen, DNA, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si, Plankton Net haul
M116/1_499	26	14/05/2015	08:05	10°59.99'	-33°00.01'	1203	O_2, Nutrients, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA ,Si
M116/1_500	27	14/05/2015	14:05	10°59.98'	-33°59.96'	1202	O_2, Nutrients, Nitrogen, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_501	28	14/05/2015	21:05	10°59.98'	-31°00.00'	5797	O_2, Nutrients, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4,TA ,Si ,Plankton Net haul
M116/1_502	29	15/05/2015	06:05	10°59.98'	-31°59.99'	1203	O_2, Nutrients ,Nitrogen, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_503	30	15/05/2015	13:05	11°00.00'	-30°59.95'	1203	O_2, Nutrients, DNA, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4,TA, Si
M116/1_504	31	16/05/2015	15:05	5°59.97'	-29°59.97'	4049	O_2, Nutrients, Nitrogen, SF_6, SF_5, CFC, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_505	32	16/05/2015	23:05	7°00.00'	-28°00.00'	4409	O_2, Nutrients, SF6, SF5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si,Plankton Net haul
M116/1_506	33	17/05/2015	08:05	7°59.97'	-28°00.01'	5195	O_2, Nutrients, Nitrogen, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA ,Si
M116/1_507	34	17/05/2015	17:05	8°59.99'	-28°00.03'	5300	Argo deployment, O_2, Nutrients, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_508	35	18/05/2015	01:05	9°59.98'	-29°59.99'	5332	O_2, Nutrients ,SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA ,Si, Plankton Net haul
M116/1_509	36	18/05/2015	10:05	10°59.98'	-28°00.00'	5796	O_2, Nutrients, Nitrogen, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_510	37	18/05/2015	19:05	11°53.96'	-29°56.39'	5760	O_2, Nutrients, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si, Plankton Net haul
M116/1_511	38	19/05/2015	08:05	13°00.01'	-28°00.00'	1216	O_2, Nutrients, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_512	39	19/05/2015	14:05	13°59.95'	-29°59.98'	1220	O_2, Nutrients, Nitrogen, DNA, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_513	40	20/05/2015	07:05	10°59.95'	-27°00.01'	1203	O_2, Nutrients, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA,Si
M116/1_514	41	20/05/2015	14:05	10°59.95'	-27°59.92'	1213	O_2, Nutrients, Nitrogen, DNA, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_515	42	20/05/2015	20:05	10°59.96'	-26°59.97'	4004	O_2, Nutrients, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si, Plankton Net haul
M116/1_516	43	21/05/2015	05:05	10°59.95'	-25°59.97'	1203	O_2, Nutrients, Nitrogen,DNA, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si

Station METEOR	CTD Profile	Date	Time UTC	Latitude	Longitude	max. p [dbar]	Comment/measurements
M116/1_517	44	21/05/2015	15:05	11°32.93'	-23°00.47'	4014	Argon sample
M116/1_518	45	21/05/2015	20:05	11°59.97'	-24°59.96'	1263	O_2, Nutrients, Nitrogen, DNA, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_519	46	22/05/2015	03:05	10°59.94'	-24°59.93'	1201	O_2, Nutrients, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si, Plankton Net haul
M116/1_520	47	22/05/2015	09:05	10°00.04'	-23°00.01'	1202	O_2, Nutrients, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_521	48	22/05/2015	16:05	8°59.89'	-23°00.04'	1203	O_2, Nutrients, Nitrogen, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_522	49	22/05/2015	22:05	8°00.01'	-24°59.97'	2210	Argo deployment, O_2, Nutrients, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si, Plankton Net haul
M116/1_523	50	23/05/2015	05:05	6°59.99'	-23°00.00'	1208	O_2, Nutrients, Nitrogen, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_524	51	23/05/2015	14:05	7°59.98'	-23°59.99'	1204	O_2, SF_6, SF_5, CFC, Salinity
M116/1_525	52	23/05/2015	21:05	8°59.98'	-23°59.98'	1201	O_2, SF_6, SF_5, CFC, Salinity, Plankton Net haul
M116/1_526	53	24/05/2015	04:05	9°59.98'	-22°00.07'	1202	SF_6, SF_5, CFC, Salinity
M116/1_527	54	24/05/2015	10:05	11°00.01'	-22°00.00'	4002	O_2, Nutrients, Nitrogen, DNA, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO4, TA, Si
M116/1_528	55	24/05/2015	14:05	11°14.97'	-23°59.98'	4006	Argon sample
M116/1_529	56	24/05/2015	22:05	11°59.95'	-23°59.98'	1202	O_2, SF_6, SF_5, CFC, Salinity, Plankton Net haul
M116/1_530	57	25/05/2015	04:05	11°59.95'	-21°00.00'	2193	Argo deployment, O_2, Nutrients, Nitrogen, DNA, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_531	58	25/05/2015	11:05	11°00.00'	-22°59.98'	1201	O_2, Nutrients, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_532	59	25/05/2015	17:05	9°59.95'	-21°00.02'	1208	O_2, Nutrients, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_533	60	25/05/2015	23:05	8°59.98'	-21°00.00'	1202	O_2, Nutrients, Nitrogen, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si, Plankton Net haul
M116/1_534	61	26/05/2015	06:05	7°59.99'	-21°00.02'	2204	O_2, Nutrients, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_535	62	26/05/2015	13:05	6°59.93'	-22°59.99'	1211	Argo deployment, O_2, Nutrients, Nitrogen, SF_6, SF_5, CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si
M116/1_536	63	26/05/2015	20:05	5°59.97'	-21°00.00'	1210	O_2, Nutrients, SF_6, SF_5,CFC, Salinity, DIC, NO_2, NO_3, PO_4, TA, Si, Plankton Net haul
M116/1_537	64	27/05/2015	02:05	5°00.08'	-21°00.28'	1201	O_2, Nutrients, Nitrogen, SF_6, SF_5, CFC, Salinity, DIC, TA
M116/1_538	65	27/05/2015	21:05	7°59.98'	-21°59.97'	1202	O_2, Nitrogen, SF_6, SF_5, CFC, Salinity, Plankton Net haul

Station METEOR	CTD Profile	Date	Time UTC	Latitude	Longitude	max. p [dbar]	Comment/measurements
M116/1_539	66	28/05/2015	03:05	7°59.94'	-19°00.01'	1203	O_2, SF_6, SF_5, CFC, Salinity
M116/1_540	67	28/05/2015	09:05	9°00.00'	-19°00.06'	1217	O_2, Nitrogen, SF_6, SF_5, CFC, Salinity
M116/1_541	68	28/05/2015	16:05	8°59.92'	-20°00.04'	1202	O_2, SF_6, SF_5, CFC, Salinity
M116/1_542	69	28/05/2015	23:05	9°59.93'	-20°00.00'	1203	O_2, Nitrogen, SF_6, SF_5, CFC, Salinity, Plankton Net haul
M116/1_543	70	29/05/2015	05:05	9°59.97'	-19°00.05'	1206	O_2, SF_6, SF_5, CFC, Salinity
M116/1_544	71	29/05/2015	14:05	10°59.97'	-18°00.02'	1202	O_2, Nitrogen, DNA, SF_6, SF_5, CFC, Salinity, DIC, TA
M116/1_545	72	29/05/2015	20:05	10°59.93'	-19°00.01'	4548	O_2, SF_6, SF_5, CFC, DIC, TA, Plankton Net haul
M116/1_546	73	29/05/2015	23:05	10°59.97'	-20°59.97'	1201	
M116/1_547	74	30/05/2015	05:05	10°59.97'	-20°00.01'	1204	O_2, Nitrogen, DNA, SF_6, SF_5, CFC, DIC, TA
M116/1_548	75	30/05/2015	12:05	11°59.96'	-20°00.06'	1203	O_2, SF_6, SF_5, CFC, Salinity
M116/1_549	76	30/05/2015	18:05	11°59.96'	-19°00.01'	4492	O_2, Nitrogen, DNA, SF_6, SF_5, CFC, Salinity, DIC, TA, Plankton Net haul
M116/1_550	77	31/05/2015	09:05	12°59.99'	-21°00.01'	1203	O_2, DNA, SF_6, SF_5, CFC, DIC, TA
M116/1_551	78	31/05/2015	16:05	13°59.93'	-22°59.95'	1203	O_2, Nitrogen, SF_6, SF_5, CFC, DIC, TA
M116/1_552	79	01/06/2015	00:06	14°59.95'	-21°00.00'	1204	O_2, DNA, SF_6, SF_5, CFC, DIC, TA, Plankton Net haul
M116/1_553	80	01/06/2015	17:06	16°36.51'	-24°51.54'	1004	Glider IFM#12 recovery
M116/1_554	81	02/06/2015	02:06	17°34.89'	-25°42.94'	3642	O_2, DNA, SF_6, SF_5, CFC, Plankton Net haul
M116/1_555	82	02/06/2015	06:06	17°34.97'	-25°42.98'	3647	Argon sample
M116/1_556		02/06/2015	09:20	17° 33.29'	-24°16.04'	0	Wave glider recovery

8 Data and Sample Storage and Availability

In Kiel a joint Data-management-Team is active, which stores the data from various projects and cruises in a web-based multi-user-system. Data gathered during M116/1 are stored at the Kiel data portal, and is proprietary for the PIs of the cruise and for members of SFB754. All data will be submitted to PANGAEA within 3 years, i.e. by June 2018. Preliminary CTD data were submitted to CORIOLIS during the cruise for real time oceanographic analysis and Argo calibration. The chemistry data from the water sampling will be submitted to CDIAC for inclusion in the GLODAP data product on interior ocean carbon data.

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10 References

During the cruise we followed the guidelines recently developed by the GO-SHIP group, particularly did we consider the guides for best practices:

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