METEOR-Berichte

Eastern boundary circulation and upwelling off Angola, tropical Atlantic overturning circulation

Cruise No. M148/1

May 24 – June 29, 2018

Belem (Brazil) – Walvis Bay (Namibia)

Angola Circ and AMOC

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2024

Table of Contents

1 Cruise Summary

1.1 Summary in English

During the research cruise M148/1 of the R/V METEOR, a physical-oceanographic and biogeochemical study was successfully completed in the tropical South Atlantic and in the eastern upwelling region off Angola. The major goals of the cruise were to (1) quantify the variability of eastern boundary current transports in conjunction with wave propagation along the coastal wave guides; (2) carry out a 4-day process study to elucidate the mechanism sustaining upwelling off Angola during the austral winter season; and (3) to determine deep water mass variability and the strength of the Atlantic meridional overturning circulation at 12°S.

The working programme involved a full-depth transatlantic hydrographic/lowered acoustic Doppler profiler section along 12°S and eastern boundary sections along 6°S, 15°S and from 18°S to 24°S. Moorings and pressure inverted echo sounders at the eastern boundary at 12°S were recovered and redeployment. During the 4-day process study, a short-term velocity mooring array was installed at 12°S and autonomous hydrographic and turbulence measurements by ocean gliders very collected. Additionally, vessel-mounted microstructure measurements and CTD/O_2 measurements were taken. Water samples were analysed for oxygen, nutrients, N_2O, stable isotopes $\delta^{15}N$ and $\delta^{18}O$ and salinity. Continuous measurements of dissolved N_2O, its isotopic composition, CO_2 and CO were carried out.

The cruise included a capacity strengthening component for scientists and graduate students from our African project partners and from different countries in South America.

1.2 Zusammenfassung

Während der FS METEOR M148/1 Reise wurden physikalisch-ozeanographische und biogeochemische Messungen im tropischen Südatlantik bei 12°S und im östlichen Auftriebsgebiet vor Angola erfolgreich durchgeführt. Die Hauptziele der Forschungsreise waren (1) die Quantifizierung der Variabilität der Randstromzirkulation in Verbindung mit der Ausbreitung von Küstenkelvinwellen; (2) die Durchführung einer viertägigen Prozessstudie zur Erforschung der Mechanismen, der den Auftrieb vor Angola während der australischen Wintersaison aufrechterhalten, und (3) Bestimmung der Variabilität der Tiefenwassermassen und der Stärke der meridionalen Umwälzzirkulation im Atlantik bei 12°S.

Das Arbeitsprogramm umfasste einen transatlantischen hydrographischen Schnitt entlang von 12°S mit direkten Strömungsmessungen und zusätzliche hydrographische Schnitte entlang 6°S, 15°S und von 18°S bis 24°S in der östlichen Randstromregion vor Angola. Langzeitverankerungen und Bodendrucksensoren mit Laufzeitmessungen am Kontinentalabhang vor Angola wurden geborgen und wieder ausgesetzt. Während der 4-tägigen Prozessstudie wurden Kurzzeitströmungsverankerungen auf dem angolanischen Schelf bei 12°S installiert und autonome Turbulenzmessungen mit Gleitern durchgeführt. Zusätzlich wurden schiffsgebundene Turbulenzmessungen sowie CTD/O_2-Messungen genommen. Wasserproben von den CTD Stationen wurden auf den Gehalt von Sauerstoff, Nährstoffe, N_2O, stabile Isotope $\delta^{15}N$ und $\delta^{18}O$ sowie Salzgehalt analysiert. Kontinuierliche Messungen von gelöstem N_2O, seiner isotopischen Zusammensetzung, CO_2 und CO wurden durchgeführt.

Die Fahrt beinhaltete auch eine Ausbildungskomponente für Wissenschaftler und Studierende von unseren afrikanischen Projektpartnern sowie aus unterschiedlichen Ländern Südamerikas.

2 Participants

2.1 Principal Investigators

Name	Institution
Dengler, Marcus, Dr.	GEOMAR
Arévalo-Martínez, Damian, Dr.	GEOMAR
Sanders, Tina, Dr.	HZG

2.2 Scientific Party

Name	Discipline	Institution
Dengler, Marcus, Dr.	PO, Chief scientist	GEOMAR
Arévalo-Martínez, Damian, Dr.	Chemical Oceanography	GEOMAR
Sanders, Tina, Dr.	Chemical Oceanography	HZG
Assunção, Ramilla Vieira	Physical Oceanography Trainee	UFPE
Bastian, Daniel	Chemical Oceanography	GEOMAR
Branco, Felipe Lopes	Physical Oceanography Trainee	UFPA
Burmeister, Kristin	Physical Oceanography	GEOMAR
Campen, Hanna	Chemical Oceanography Technician	GEOMAR
Carreres Calabuig, Joan	Chemical Oceanography	SDU
Coelho, Paulo	Physical Oceanography Trainee	INIP
Dias, Anderson	Observer	Brazilian Navy
Francisco, José Amaro	Physical Oceanography Trainee	INIP
Herrford, Josefine	Physical Oceanography	GEOMAR
Heukamp, Finn	Physical Oceanography Student	GEOMAR
Houndegnonto, Odilon Joel	Physical Oceanography Trainee	UAC
Kahilo, Emanuel Muhongo	Physical Oceanography Trainee	INIP
Krusenbaum, Moritz	Physical Oceanography Student	GEOMAR
Link, Rudolf	Physical Oceanography Technician	GEOMAR
Lüdke, Jan	Physical Oceanography	GEOMAR
Matos, Fernanda	Physical Oceanography Trainee	UFPA
Mette, Jonathan	Physical Oceanography, Student	GEOMAR
Müller, Mario	Physical Oceanography Technician	GEOMAR
Nielsen, Martin	Physical Oceanography Technician	GEOMAR
Risaro, Daniela Belén	Physical Oceanography Trainee	UBA
Sandoval Belmar, Marco	Physical Oceanography Trainee	UCC
Stelzner, Martin	Meteorology	DWD
Wiskandt, Jonathan	Physical Oceanography	GEOMAR

2.3 Participating Institutions

GEOMAR GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel, Kiel, Germany.

DWD	Deutscher Wetterdienst, Hamburg, Germany.
HZG	Helmholtz-Zentrum Geesthacht, Geesthacht, Germany.
INIP	Instituto National de Investigacao Pesqueira, Luanda, Angola.
SDU	University of Southern Denmark, Odense, Denmark.
UAC	University of Abomey, Cotonou, Republic of Benin.
UBA	University of Buenos Aires, Buenos Aires, Argentina
UCC	University of Conceptión, Concepción, Chile
UFBA	Universidade Federal de Bahia, Ondina, Brazil
UFPA	Universidade Federal do Pará, Belém, Brazil
UFPE	Universidade Federal de Pernambuco, Recife, Brazil.

3 Research Program

3.1 Description of the Work Area

The research program of R/V METEOR cruise M148/1 covered two main areas, a transatlantic section in the tropical South Atlantic along 11°S and surveys in the eastern boundary upwelling region of Angola and Namibia (Figs 3.1 and 3.2). The circulation system in the Atlantic transports large amounts of heat as part of the Atlantic meridional overturning circulation (AMOC) and is to a large extent responsible for the mean climate state in the Atlantic sector. Currently, the strength of the AMOC is continuously observed at selected latitudes, including the AMOC observing system (RAPID-MOCHA array) at 26°N, the OSNAP array in the subpolar gyre, measurements of the DWBC at 16°N and the SAMBA/SAMOC array at 34°S (e.g. McCarthy et al., 2015; Meinen et al., 2013). For climate research, it is particularly important to understand the meridional coherence of AMOC signals, propagating from the South Atlantic toward the subpolar North Atlantic with a tropical observing system at 11°S representing a link between North and South Atlantic MOC variability. Since 2013, GEOMAR is maintaining mooring arrays combined with bottom pressure sensors at 300m and 500m depth along the western and eastern boundary at 11°S. This data is and will be used to estimate the variability of the AMOC in the tropics at 11°S.

Situated between the Benguela upwelling region and the eastern equatorial Atlantic, the eastern boundary region of Angola (~ 6°S - 17°S) represents a highly-productive but seasonally varying ecosystem (Ostrowski et al., 2009). Maximum productivity here occurs between July to September. It is generally accepted that the coastal upwelling of cold and nutrient-rich waters in the four major Eastern Boundary Upwelling Systems (Benguela, Canaries, Humboldt, California) is driven by the along-shore component of the trade winds and by the negative wind stress curl (e.g. Carr and Kearns, 2003; Chavez and Messie, 2009). However, since the availability of satellite retrievals of wind, sea surface temperature and chlorophyll, it became evident that this explanation cannot hold for many tropical seasonal varying upwelling regions.

Off Angola, alongshore wind stress and wind stress curl are at a seasonal minimum when maximum productivity occurs during austral winter. Thus, processes other than offshore Ekman transport must be the dominant drivers of productivity. Physical factors discussed in this context are the equatorial current system, surface heat fluxes, remote forcing along the equatorial waveguide and the mixed layer depth (Echevin et al., 2008; Tchipalanga et al., 2018). Along with understanding the drivers of the tropical upwelling system, it is of great socio-economic interest to predict their variability. However, state-of-the-art climate models have difficulties to realistically represent eastern boundary upwelling regions and their variability (e.g. Richter, 2015). Large warm biases in sea surface temperature (SST) are still present in the tropical eastern-boundary upwelling systems, suggesting that the physical processes driving these systems are not fully captured in these models. It is crucial to advance process understanding and improve prediction skills to assess possible future changes within these systems e.g., due to anthropogenic influences.

Production and emissions of marine-derived greenhouse gases (GHG) is crucial for the Earth's atmosphere. Hence the investigation of their distribution and sea-air fluxes is pivotal for better understanding potential responses of the ocean and the overlying atmosphere to environmental changes such as warming and deoxygenation. Measurements in unexplored depths of remote (undisturbed) locations in the open ocean might provide hints on slight changes which on larger time scales could result in altered budgets of atmospheric gases like nitrous oxide (N_2O). Among the eastern boundary upwelling systems, the Benguela upwelling region has the highest primary production rates (Messié et al., 2009). Elevated oxygen consumption due to the degradation of organic matter further reduces oxygen concentrations of the Central Waters as they move poleward along the eastern boundary, leading to occasional anoxic and anoxic-sulfidic conditions in the thermocline (Mohrholz et al., 2008). These conditions favor elevated production of trace gases such as N_2O.

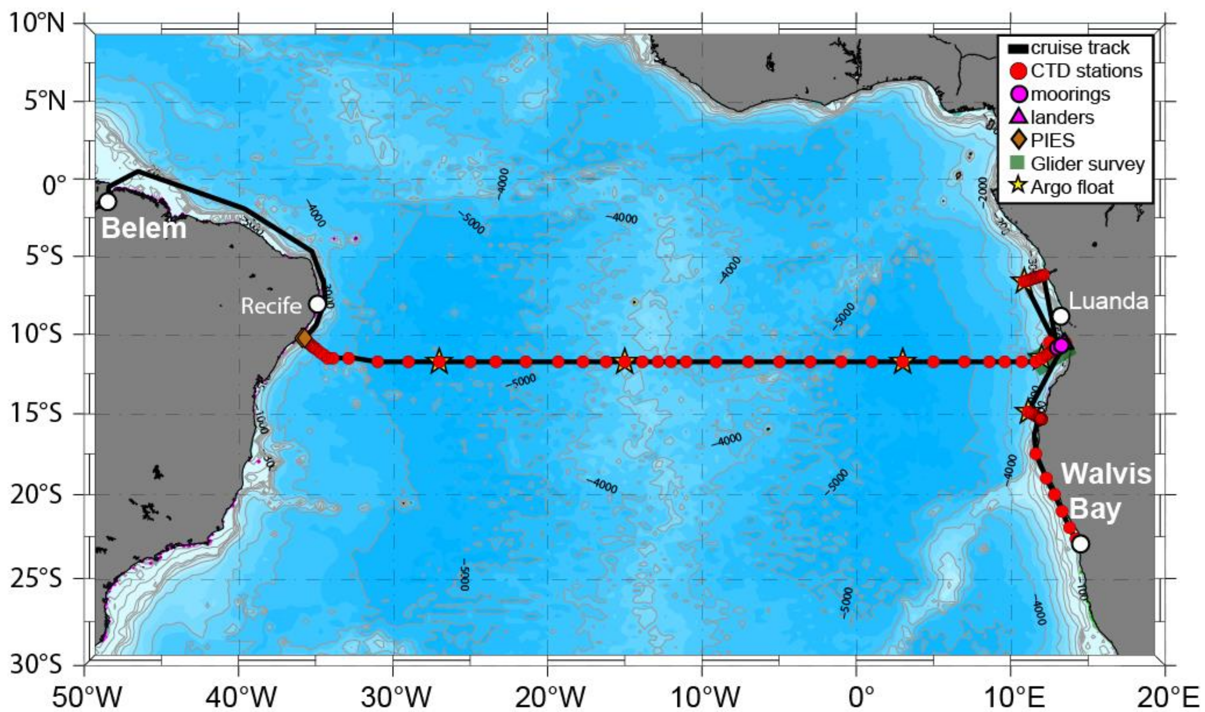

Fig. 3.1 Cruise track of R/V METEOR cruise M148/1 (black solid line) including locations of conductivity-temperature-depths (CTD) stations, positions of pressure inverted echo sounder (PIES) deployments, mooring and lander deployments and recoveries, glider operations and positions of Argo float releases. Bathymetric map with

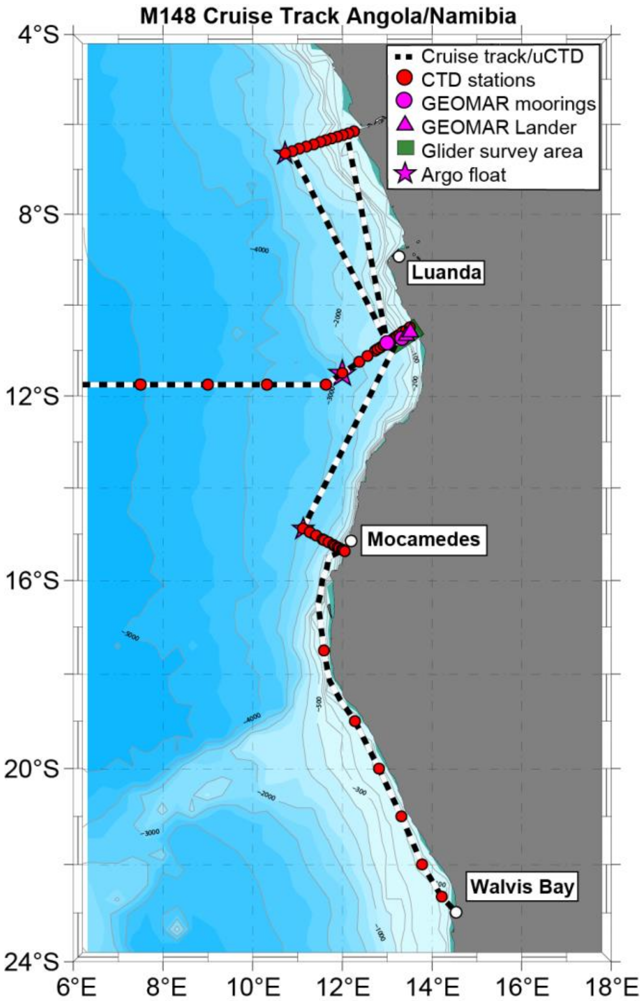

Fig. 3.2 Detailed cruise track and stations of the survey area along the eastern boundary.

3.2 Aims of the Cruise

During R/V METEOR cruise M148/1, a physical oceanography and biogeochemical study was carried out in the tropical South Atlantic at 11°S and in the eastern boundary upwelling region off Angola. The cruise combined the foci of the BMBF collaborative projects "Southwest African Coastal Upwelling System and Benguela Niños II (SPACES-SACUS II)" and "Regional Atlantic Circulation and Global Change (RACE II)". The major objectives related to physical oceanography were to

1) quantify the variability of the eastern boundary current circulation off Angola and Namibia and to investigate the variability of anomalous water masses advection in conjunction with coastal wave propagation and interannual climate variability;
2) elucidate the mechanisms sustaining upwelling off Angola during austral winter by carrying out a 4-day upwelling process study;
3) determine the strength of the tropical Atlantic meridional overturning circulation and long-term variability of deep water masses by collecting a full-depth hydrographic transect across the Atlantic at 11°S.

Related to biogeochemistry, our main objectives were to

1) assess the surface distribution of dissolved N_2O, CO_2 and the indirect GHG carbon monoxide (CO), as well as the spatial variability of their sea-to-air fluxes. This survey builds upon data collected by GEOMAR during the R/V METEOR cruises M98-M100/1

and complements those observations with data in areas yet uncovered in the southern east Atlantic.

2) assess the deep (< 1000 m depth) distribution of N_2O across the tropical Atlantic and relate it to the large-scale circulation. In addition to the deep water samples, the west-east gradient of N_2O within the OMZ was studied by sampling within low-oxygen waters along the 11°45'S section.
3) decipher the vertical structure and production/consumption pathways of N_2O across the south east Atlantic between the Angola Tropical Zone and the northern Benguela Upwelling System.

In addition to the scientific program, a capacity strengthening program for students and scientists from African and South American countries was carried out. Altogether, nine students from Angola, Benin, Brazil, Argentina and Chile received training during the cruise. The training program was supported by the Nippon Foundation and POGO Ship-board Training Fellowship program and the BMBF-SACUS project.

3.3 Agenda of the Cruise

The work program included ship-board hydrographic and velocity sections, servicing of moorings, deployment and retrieval of autonomous observatories and underway sampling. Hydrographic and velocity measurements were taken during the transatlantic section at 11.5°S and during sections at the eastern boundary at 6°S, 11°S and 15°S. Additionally, CTD stations were taken along the Namibian shelf. A long-term oceanographic mooring measuring the variability of the eastern boundary circulation and hydrography at 11°S in a water depth of 1500m was retrieved and reinstalled at the same position. During the upwelling process study, high-resolution sampling of hydrography (underway and on station), turbulence, biogeochemical parameters and autonomous measurements by ocean gliders (Fig. 3.2) were carried out.

For the biogeochemical component, we measurement program consisted of a combination of along-track (surface) and discrete measurements of trace gases, extensive measurements of inorganic nutrient concentrations (NO_{3-}, NO_{2-}, PO^{3}_{4-}, SiO_2), sampling for molecular analysis of markers of nitrogen cycle processes and sampling for isotopic signature measurements. In addition, we performed the first continuous measurements of surface isotopic signatures of N_2O for this area.

The cruise was carried out in accordance with the declarations on responsible marine research (Appendices 1 to 3 of the GPF Cruise Proposal Preparation Instructions). In particular, hydroacoustic sources with pulsed sound emissions was limited to multibeam echosounder and acoustic Doppler current profiling that were strictly necessary for scientific purposes. All other hydroacoustic pulsed instruments, such as Parasound and Posidonia remained unused during the cruise.

4 Narrative of the Cruise

On Thursday, May 24 2018, R/V METEOR departed from the harbour of Belém, Brazil at 6:30 am local time. Following the Rio Para downstream, we reached the Atlantic at 2:30 pm on the same day. Sampling by the underway systems that included trace gas concentration measurements in the surface waters, particularly nitrous oxide (N_2O) and carbon monoxide and dioxide (CO and CO_2), sea surface temperature and salinity measurements and upper ocean velocity measurements was started at 23:00 UTC.

The working program on the Brazilian shelf began on May 30 at 21:00 UTC, about 36 hours later than expected. Strong southeastern trade winds of 5 to 6 Beaufort during the first 4 days and strong westward surface flow within the Brazil Current significantly reduced the speed of our vessel. During the next two days, we completed a conductivity-temperature-depth-oxygen (CTD/O_2) section that was complemented by lowered acoustic Doppler current profiles (LADCP) and nutrient sampling running perpendicular to the coastline at about 11°S. Additionally, two bottom-pressure inverted echo sounders were deployed along the continental slope at 300m and 500m depth.

R/V METEOR left the exclusive economic zone of Brazil just before midnight local time on May 31 to start full-depth CTD/O_2 measurements along a transatlantic section at 11°45'S. Again, water samples for nutrient and nutrient isotope concentrations measurements were collected at most of the CTD/O_2 stations. Station spacing along this transect was 120 nm which reduced to about 60 nm when crossing the Mid-Atlantic Ridge to avoid data gaps due to bottom triangles. In between stations, underway CTD measurements were carried out every 2 hours to obtain a high-resolution hydrographic section in the upper 400m of the water column. Additionally, as a service to the Bundesanstalt für Schifffahrt und Hydrographie (BSH), four Argo floats were deployed along the section. Fortunately, we encountered favourable weather conditions while crossing the Atlantic Ocean that allowed us to make up some of the lost time. The transatlantic section was completed on June 16 at 18:00 UTC.

During the next three days, R/V METEOR headed towards the Angolan coast while taking hydrographic and velocity profiles, water samples for nutrient, nutrient isotope and microplastics concentration analysis, and microstructure profiles along a section perpendicular to the Angolan coastline at about 11°S. On this section, a mooring array was installed in June 2013 during R/V METEOR cruise M98. It was serviced in October 2015 (M120) and November 2016 (M131). The array consisted of a bottom shield at 500m depth and a mooring at 1200m depth mooring, both equipped with an acoustic Doppler current profiler (ADCP) to measure the variability of the eastern boundary current transport. In the afternoon of June 17, we tried to establish communication to the releaser mounted to the bottom shield using underwater acoustics. However, we did not receive any response from the instrument.

As part of the upwelling process study, we successfully deployed two ocean gliders using R/V METEOR's rubber boat and a mooring measuring velocity profiles with two ADCPs at 200m water depth in the morning and afternoon of June 16, respectively. The 11°S section was finalized in the early morning of June 19. Prior to departing to 6°S, two landers equipped with ADCPs were deployed in 50m and 100m water depth and the mooring that had been deployed at 1200m water depth during M131 was successfully recovered.

In the evening of June 20, we headed north to work on a cross-slope section just south of the Congo River inflow at 6°S. During the 22-hour transit, uCTD profiles were taken. The position of the first CTD/O_2 station was reached on June 21 at 16:30 UTC. Sampling along the 6°S section included 12 CTD/O_2 and LADCP profiles as well as 7 MSS stations on which 3 to 5 profiles were collected. Additionally, water samples from the CTD rosette were collected to determine nutrient, nutrient isotope, salinity and oxygen concentrations. Furthermore, water samples for microplastics continued. After deploying another Argo float for the BSH, R/V METEOR started the transit back to the 11°S section on June 21 at 14:00 UTC.

Up on arrival at 11°S, the 1200m mooring as part of the eastern boundary mooring array was redeployed and additional CTD/O_2 and microstructure profiles were taken along the 11°S section. A dredging operation was carried out in the morning of June 23 in an attempt to recover a catch line of the bottom shield moored at 500m depth. However, the attempt proved to be unsuccessful leading to the conclusion that the bottom shield was no longer in its place. An elaborate analysis of fish trawler operation in that area showed that the 500m isobaths is heavily occupied by the vessels. It is thus likely that the bottom shield was relocated or destroyed due to bottom fishing gear. In the afternoon, we successfully recovered the two gliders. During the night, a high-resolution hydrographic section of the upper 100m of the water column was taken on the shelf at 11°S using the Rapid-Cast system. With these measurements, we intend to study non-linear internal wave trains that are generated due to tide-topography interaction on the continental slope. For the same reason, we took two microstructure profiles transects between 200m and 50m bottom depth. During the next morning, the two landers and the mooring deployed on the shelf were recovered before R/V METEOR left the 11°S section heading toward 15°S.

Underway CTD profiles were collected during transit and we reached the position of the first station of the 15°S section at noon on June 25. Altogether, 13 CTD/O_2 profiles were collected along that section, which was completed at 10:00 UTC the next day. Two hours later, while heading towards 11°E, strong northerly winds of 7 to 8 Beaufort and elevated swell of up to 4m from the south forced us to refrain from taking CTD/O_2 profiles along the 11°E section. Instead, underway CTD data were collected. However, in the afternoon, when the winds again increased, these measurements were omitted as well. Winds weakened around midnight when station work was continued along the 100m isobaths as planned. Data sampling from all underway systems was discontinued on June 28 at 18:00 UTC. Having received permission for early docking from the Leitstelle, R/V M ETEOR the port of Walvis Bay two hours later.

5 Preliminary Results

5.1 CTD System, Salinity and Oxygen Measurements and Calibration

(J. Herrford, J. Wiskandt, J. Herrford, F. Heukamp, O. J. Houndegnonto, M. Krusenbaum, F. Branco, M. Dengler)

A total number of 103 CTD/O_2 profiles were collected, in most cases to full ocean depth. The CTD stations cover the northeastern Brazilian shelf, a full-depth transatlantic section along 11.45°S (Fig. 5.1), as well as several sections off the coast of Angola and Namibia. During the entire cruise, the GEOMAR SBE#7 with a Seabird SBE 911plus CTD rosette system was used.

The CTD was equipped with one Digiquartz pressure sensor (s/n 1162), as well as double sensor packages (temperature-1 = s/n 4823, temperature-2 = s/n 2120, conductivity-1 = s/n 4062, conductivity-2 = s/n 3381, oxygen-1 = s/n 2588, oxygen-2 = s/n 2686). All sensors worked flawlessly during the entire cruise. Data acquisition was done using Seabird Seasave software version 7.26.6.26. The CTD was mounted on a rosette frame with a 24-bottle rosette sampling system with 10 l bottles. 22 bottles were attached to the rosette, with the lowered ADCP installed in the remaining 2 spots.

During CTD/O_2 casts shallower than 2000 m depth, a Satlantic SUNA sensor (SN 0761), measuring the water's Nitrate (NO_3) concentration, and a PAR sensor measuring the intensity of photosynthetically active radiation (PAR) were attached to the top of the rosette frame. Additionally, a fluorescence and a turbidity sensor from WET labs were attached to the carousel and data was recorded, but not calibrated in post-processing. An altimeter was used to monitor the CTD's distance to the bottom.

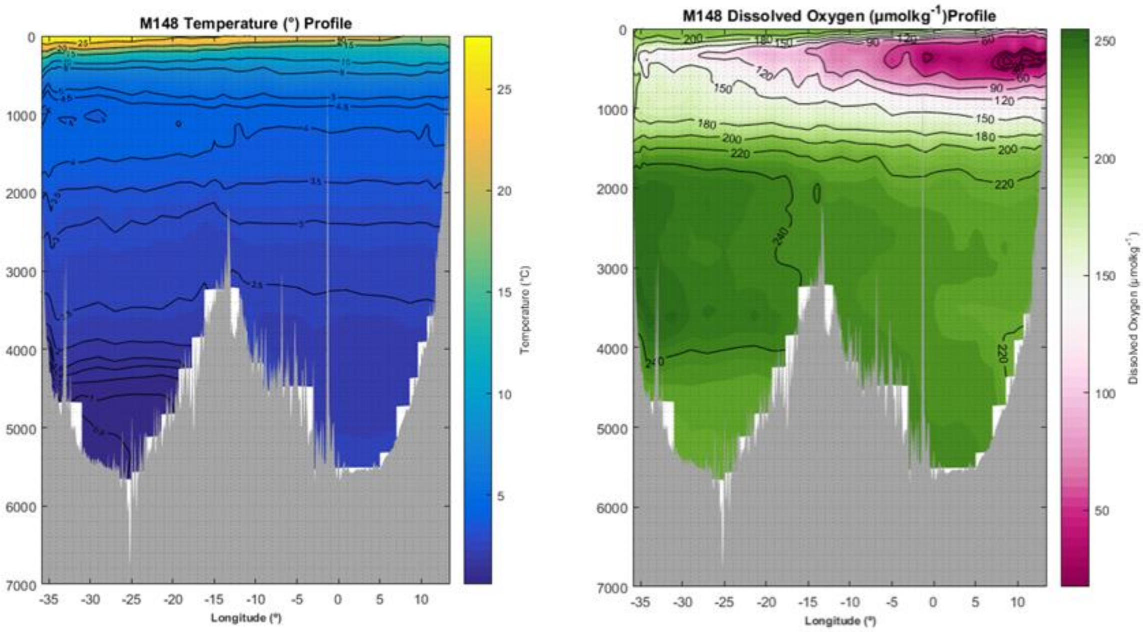

Fig. 5.1 Preliminarily calibrated CTD/O_2 measurements of temperature and dissolved oxygen along the full-depth transatlantic section at 11.45°S.

5.1.1. Conductivity Sensor Calibration

Conductivity sensor data were calibrated against conductivity values measured from water samples collected by the Niskin bottles of the CTD. In total, conductivity of 304 water samples were determined. The first 176 water samples were analyzed with a Guildline Autosal 4 salinometer (see below). The conductivity of the remaining water samples was measured using an Optimare Precision Salinometer. Conductivity sensor calibration was performed using linear dependencies in pressure, temperature, and conductivity. The calibration resulted in a root-mean-square salinity misfit of 0.0022178 PSU after removal of 33% of bottle values. In addition to the CTD samples, 205 water samples for the calibration of the conductivity cell of the Thermosalinograph from the cruises M146, M147 and M148/1 were analyzed during the cruise.

Unfortunately, there were several problems with the salinometer: Right after setting up the Autosal 4, one of the two integrated water pumps stopped working and had to be replaced. During the second half of the cruise, the vessels air conditioning system malfunctioned for 4-5 hours. Conductivity measurements of two water samples analyzed during this period had to be discarded because of rising temperatures within the water tank. Furthermore, there were several problems with the serial interface between the data log off the salinometer and the connected computer. Rebooting the computer helped for a couple of days, but did not solve the problem for good. On the May 24, the replaced pump of the Autosal 4 also malfunctioned. Therefore, the remaining salinity sampled were measured with the Optimare Precision salinometer.

5.1.2 Oxygen Sensor Calibration

The CTD oxygen sensor data were calibrated against oxygen values determined from water sample taken from the Niskin bottles of the CTD system. In total, 513 samples were taken on 101 of the 103 CTD stations. For most of the stations, one triplicate sample was taken at varying depths. Oxygen content of the sea water was determined by Winkler titration. The final oxygen calibration of the downcast data was done using a linear fit in respect to oxygen concentration, temperature and a linear and square fit in respect to pressure. After removing the worst 33% of the oxygen values derived from Winkler titration, a root-mean-square misfit of 0.9175 µmol/kg was obtained for the published oxygen sensor data.

Oxygen titration standards were calibrated against WAKO standard to make sure that our standard was correct. However, it should be noted, that the WAKO standard had expired in 2013. Also, we took duplicates on one station to compare two different titration solutions to one another. In the end we were pleased with the results and continued measuring the samples as before. To correct the measured oxygen concentrations, we measured a blanc-factor on several occasions to calculate onto the titrated volume in order to make up for an offset in the titrated volume that could be induced by the chemicals used. Here, the procedures suggested in “Methods of Seawater Analysis” (3^{rd}), Chapter 4.6.5 were followed.

5.1.3 Underway CTD Measurements

The underway CTD (uCTD) system allows sampling of conductivity, temperature, and pressure while the vessel is steaming at full speed. During the cruise, two different uCTD systems were used. A system manufactured by OceanSciences that was mounted to starboard stern of the vessel and a Teledyne RapidCast system for autonomous and continuous underway measurements. The two systems use the same uCTD probes, but differ in winch and spooling techniques.

Altogether, 253 uCTD profiles were collected. Data using the Oceansciences system were taken along the transatlantic transect (120 profiles) in between CTD/O_2 stations and while steaming between eastern boundary transects, i.e. from 11°S to 6°S (13 profiles), from 6°S to 11°S (12 profiles) and from 11°S to 15°S (13 profiles). Additionally, uCTD data were collected across the Angola-Benguela front along 11°E (40 profiles) when CTD/O_2 measurements were not possible due to strong winds and elevated surface waves. A conservative sampling program was conducted along these sections to preserve the functionality of the underway system. Every 2-hours, a profile was taken. At the beginning of the cruise, a depth of 280m was frequently reached when the vessel was steaming at 10 knots. However, max depth range reduced with time due to wearing of the Oceansciences winch system. RapidCast transects were collected along 11°S during the upwelling process study. Altogether, 75 profiles were taken during two transects in water depths between 50m and 200m. Unfortunately, the line that is attached to the probe got entangled during the second transect and autonomous profiling had to be stopped.

For calibration of the uCTD sensors, uCTD profiles were collected just before and shortly after CTD stations. Additionally, the probes were attached to the CTD/O_2 rosette to identify possible pressure offsets. Ongoing calibration includes thermal lag calculation, pressure offsets from CTD/O_2 comparison and temporal sensor drifts determined from nearby CTD/O_2 profiles and from surface temperature and salinity measurements from the thermosalinograph.

5.1.4 Thermosalinograph

Sea surface temperature (SST) and sea surface salinity (SSS) were continuously measured by the ship's dual thermosalinograph (TSG). The system consists of two devices, one with an inlet at the starboard side (TSG1) and the second with an inlet at the portside (TSG2). The two external temperature sensors, $T1_{sec}$ from TSG1 and $T2_{sec}$ from TSG2, and both conductivity sensors (S1, S2) were calibrated against samples measured with a salinometer and the 5dbar values from the CTD profiles conducted during the cruise. High offsets between the CTD values and the conductivity sensors occurred close to the Congo River while we were passing through the freshwater lens which only exists close to the surface and is not captured by the CTD data. The TSG pumps were switched off in the port of Luanda. Both conductivity sensors showed a nonlinear time dependence of salinities during the cruise, stronger for S1, which was corrected by a quadratic fit in time. The corrections and resulting uncertainties for each sensor are listed in Tab. 5.1.

Table 5.1 Corrections terms (offset and quadratic in time, t, for salinity) and resulting uncertainties of TSG sensors.

Sensor name	Correction	Uncertainty
$T1_{sec}$	-0.0079682	±0.023391
$T2_{sec}$	-0.0047955	±0.018813
S1	$-0.036251+0.0024953*t+8.6926e-05*t^2$	±0.0049417
S2	$-0.049201-0.00013868*t+5.5207e-05*t^2$	±0.0024399

Figure 5.2 shows the temperature and salinity measurements near the African coast. In general, higher temperatures were found in the northern area off Angola with temperatures of up to 26.3°C, which drops rapidly across the Angola-Benguela front near 17°S to well below 16°C. Highest salinities above 35.5 psu were found between 18°S and 10°S. Off Angola north of 10°S, small scale low salinity intrusions were present, associated with the Congo River outflow with lowest salinities measured down to 26 psu.

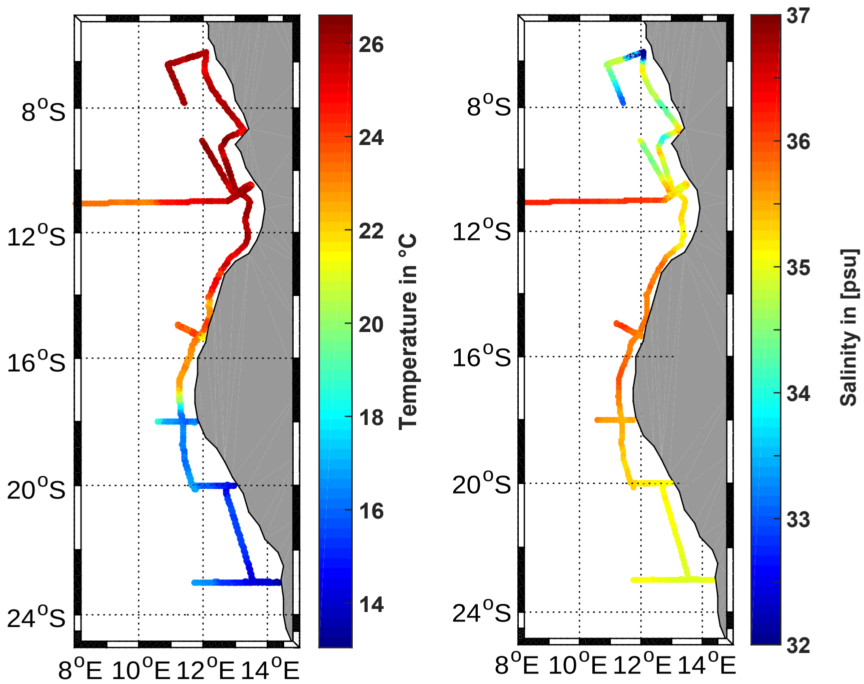

Fig. 5.2 Temperature (left) and salinity (right) as measured with the TSG off Angola and Namibia during M148/1.

5.2 Current Observations

(R. V. Assunção, K. Burmeister, M. Dengler, J. Lüdke)

5.2.1 Vessel-Mounted Acoustic Doppler Current Profiler

During the whole cruise we recorded upper ocean velocities with R/V METEOR’s two vessel mounted Acoustic Doppler Current Profilers (VMADCP), the Ocean Surveyor (OS) 75 operating at a frequency of 75 kHz and the OS38 at 38 kHz, respectively. Both systems continuously recorded data without any system failures. However, due to replacement of a malfunctioning water pump, the OS38 had to be taken out of the moon pool on June 5 requiring a recalibration of the data after this date. Additionally, in the night from June 26 to 27 the steel plate mount in the moon pool loosened, adding to uncertainty of the measurements collected during that time.

The OS38 was operated in narrow-band mode – recording 55 bins of 32 m bin length and with a blanking distance of 16 m for the whole cruise. To maximize the sampling depth range, the OS75 was operated in narrow-band mode during most of the cruise, recording 100 bins of 8 m bin length and a blanking distance of 4 m. However, during the upwelling process study off Angola, the OS75 was switched to broadband mode from June 22 UTC 18:40 till June 24 UTC 10:43. In this period, the OS75 configuration included 128 bins of 4 m length and a blanking distance of 2 m. The two systems were operated from May 24, 2018 20:50 UTC to June 28, 2018 16:00 UTC.

Water track calibration of the OS38 for the period before June 5 was done using data from May 29 UTC 20:27 to June 5 UTC 14:00. The limitation is due to lack of station work prior to May 29. Due to the loose steal plate mount, all OS38 data recorded after June 26 UTC 09:43 are considered unreliable and will thus not be used for scientific purposes. An interesting result from the OS38 calibration it the large difference in the misalignment angle before and after June 5 (table 5.2). As an erroneous misalignment angle of 0.1° causes a velocity bias of about 1 cm/s while the vessel is steaming at 10 knots, carful calibration of the OS38 is required every time the moonpool mount is released.

Table 5.2 Results from the water track calibration of the two Ocean Surveyors. The uncertainty represents one standard deviation of individual water track calibrations.

Ocean Surveyor	Misalignment angle ± std	Amplitude factor ± std
OS75 (NB mode, 8m bins)	-1.1095 ± 0.4899	1.0027 ± 0.0077
OS38 (before June 5)	0.5529 ± 0.5952	1.0032 ± 0.0093
OS38 (after June 5)	0.1499 ± 0.5614	1.0024 ± 0.0084

5.2.2 Lowered Acoustic Doppler Current Profiler

During the whole cruise the CTD/Rosette system was equipped with a lowered ADCP setup based on two Teledyne RDI ADCPs. The setup consisted of an upward-looking and a downward-looking 300-kHz instrument. These two instruments were mounted to the CTD rosette with a GEOMAR manufactured rack protecting the instruments and allowing no obstruction of the acoustic beams. A battery pack was mounted below the up-looking slave. Both ADCPs were connected to the battery case, which was also the connection point for the data interface cable.

The LADCP system was equipped with SN #20508 as down-looking master instrument and #20507 as up-looking slave (#20507 actually was already a hybrid combining the internal boards of #11436, the housing of #839 and the transducer head of #20507 on previous cruises). A new power supply for the LADCP system was tested on profile 1 and 2. It contained rechargeable batteries which are directly charged by the single-conductor cable at which the CTD system is attached. The advantage of the new power system is that there is no need to change the batteries when the CTD is on deck. Unfortunately, in this setup, the up-looking slave did not work. This is why the traditional battery pack were reinstalled. For profiles 3-103 the LADCP system worked without trouble exceptionally for profile 9 (table 5.3). Due to a badly connected cable the LADCP system was not properly started and did not record during that CTD profile.

During the cruise we used a simple software with which the start, stop, download, and erase cycles of the two LADCP systems can be controlled (ladcp_tool_1.8 developed at GEOMAR). Data processing was done during the cruise using the GEOMAR LADCP processing software V11 beta, which includes both shear and inversion methods to derive an absolute velocity profile. As additional data are necessary for the processing, the corresponding pre-processed CTD files containing pressure, temperature and salinity profiles as well as time and navigation data were used. Profile 67 and 68 could not be processed by this routine, as they were too short. The processing routine needs a certain amount of data points to work properly.

Overall, Teledyne RDI instruments resulted in reasonable to good deep-ocean velocity profiles when processed in conjunction with the observations of the VMADCP and when coming close enough to the seafloor to obtain TRDI bottom track data. Nevertheless, the generally adverse conditions for LADCP in the open tropical South Atlantic Ocean (too few scatterers) lead to a several profiles with high uncertainties in particular along the 6°S and 11°S transects. For profile 22, 27 and 37-39 no Bottom information is available due to water depth above 6000m, which leads to high uncertainties and partly unrealistic velocity estimates in the onboard processing. The bottom information improves the data quality of LADCP measurement distinctly, as the LADCP gets correct information about its own motion.

Table 5.3 LADCP instrument configuration during CTD stations.

ADCP Serial number / **CTD Profile No.**	**20508 (DOWN)**	**20507 (UP)**
1 - 2	X	-
3-8	X	X
9	-	-
10-103	X	X

5.3 Mooring Operations

(K. Burmeister, M. Dengler)

We deployed 2 PIES off the Brazilian coast at 11°S. The PIES are part of a long-term mooring array perpendicular to the Brazilian coast at 10°S. They had been recovered during METEOR cruise M145 in March 2018 and were subsequently serviced.

Additional mooring operations were carried out along the Angolan continental slope. A mooring and a bottom shield had been deployed at 1200 m and 500 m water depth along a section perpendicular to the coastline at 11°S during METEOR cruise M131 in November 2016, about 1.5 years before M148/1. The mooring and the bottom shield were equipped with 75 kHz Longranger ADCPs to observe variability of the eastern boundary circulation and to determine intraseasonal to interannual variability of the transport of the Angola Current. Additionally, the offshore mooring carried oxygen (optode), temperature and salinity (MicroCat) loggers just below the ADCP to analyse water mass variability. During M148/1, only the mooring placed at 1200m water depth could be recovered. We were not able to receive any response from the acoustic releaser installed in the bottom shield at 500 m water depth. Both alternative ways to recover the shield, an underwater camera system and the vessel’s dredge were not successful. Thus, it was concluded that the mooring was no longer in its place. Although the fate of the bottom shield remains unknown, an elaborate analysis of fish trawler operation in that area (data from https://www.marinetraffic.com/) showed that the 500m isobaths is heavily occupied by the vessels. It is thus likely that the bottom shield was relocated or destroyed due to bottom fishing gear. As this was already the third loss of a bottom shield in this area.

Nevertheless, we now obtained a 5-year long velocity time series at the continental slope from the mooring deployed at 1200m depth (Fig. 5.3). The alongshore velocity component shows elevated variability on intraseasonal time scales that originate from poleward propagating coastally trapped waves. These waves are predominately remotely forced by wind fluctuations within the western equatorial Atlantic. The extended velocity time series will allow to advance understanding of these intraseasonal fluctuations and their impact on climate extremes in the Benguela region such as Benguela Ninos (e.g. Imbol Koungue et al. 2017).

During a 4-day upwelling process study conducted at the upper continental slope and the shelf region at 11°S, a mooring array was deployed on a short term. It consisted of a mooring located at 200 m water depth and two landers deployed at 100 m and 50 m depth. The mooring at 200 m was equipped with an upward-looking 300 kHz and a downward-looking 1200 kHz Workhorse ADCP at 170 m depth as well as with oxygen (optode), temperature and salinity loggers (MicroCATs). The two landers were each equipped with an upward-looking 300 kHz Workhorse ADCP and an optode. The lander at 100 m depth was additionally equipped with CTD loggers (MicroCAT).

CTD/O_2 calibration casts were performed for all MicroCATs and optodes. The pre-deployment calibrations were already done during METEOR cruise M145. The post-deployment calibration cast was CTD cast 80. During this CTD profile, 6 calibration stops were performed with a duration of at least 3.5 min in order to ensure an equilibrium of the internal sensor temperatures of the optodes at each calibration point.

Additionally, onboard laboratory calibrations were conducted for all optodes in water-filled beakers of 0% and 100% O_2-saturated water at two different temperatures (~9°C and ~22°C) following the Aanderaa optode manual.

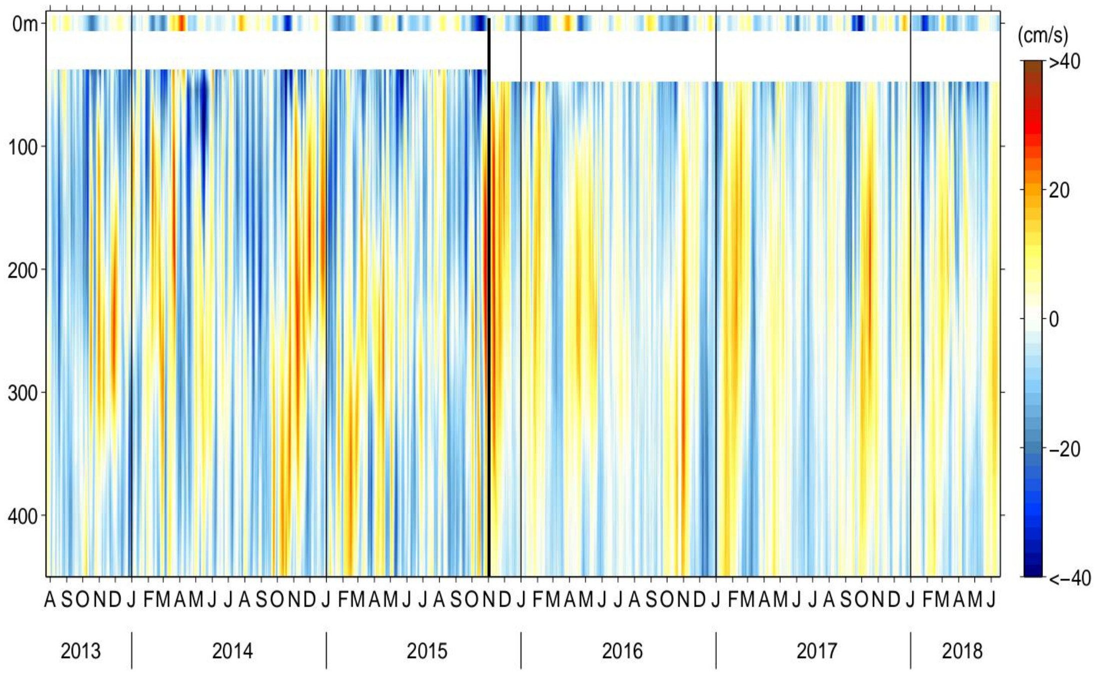

Fig. 5.3 Time series of alongshore velocity (-34°) as measured by the ADCP in the offshore mooring. Positive values indicate northward and negative values indicate southward flow. At the surface corresponding AVISO geostrophic alongshore velocities are plotted (update from Kopte et al. 2017).

5.4 Shipboard Ocean Turbulence Measurements

(M. Dengler, J. Lüdke, M. Sandoval Belmar)

Ship-based microstructure measurements were performed using a loosely-tethered MSS 90-D (S/N 073) microstructure profiler and a winch mounted to the gunwale portside of METEOR's stern. The MSS profiler was equipped with 3 fast-responding shear sensors for turbulence measurements, a microstructure temperature sensor, standard CTD sensors for precision measurements, and oxygen, turbidity, and acceleration sensors. All sensors were mounted to the head of the profiler and sampled at 1024 Hertz. The profiler was ballasted with negative buoyancy to adjust the sinking velocity to 0.6 m/s.

In total, 165 microstructure profiles were taken. All CTD stations along the 6°S and 11°S sections were followed by microstructure stations. At each of those stations, 3 to 5 microstructure profiles were collected. Additionally, measurements were performed along a cross-shelf transect at 11°S during June 23 to 24, where 67 profiles were taken. Preliminary data processing suggested high-quality data, except for profiles 10 through 12, when measurements were performed without prior removal of the shear sensors' protection caps. The data will be used to investigate mixing processes along the continental slope and shelf off Angola and to quantify upper ocean heat loss due to turbulent mixing processes.

5.5 Ocean Glider Measurements

(M. Dengler, G. Krahmann, M. Müller)

Two Teledyne Webb Research Slocum gliders (ifm09 and ifm13) were deployed and retrieved during M148/1. Both gliders were equipped with temperature, conductivity, pressure, oxygen, chlorophyll and turbidity sensors. In addition, a microstructure probes (MicroRider, manufactured by Rockland Scientific) was mounted to the glider ifm09 and an optical nitrate sensor (SUNA, manufactured by Satlantic) was mounted to glider ifm13 (table 5.3). The microstructure probe carried two microstructure shear and two microstructure temperature sensors as well as fast-responding accelerometers and tilt sensors.

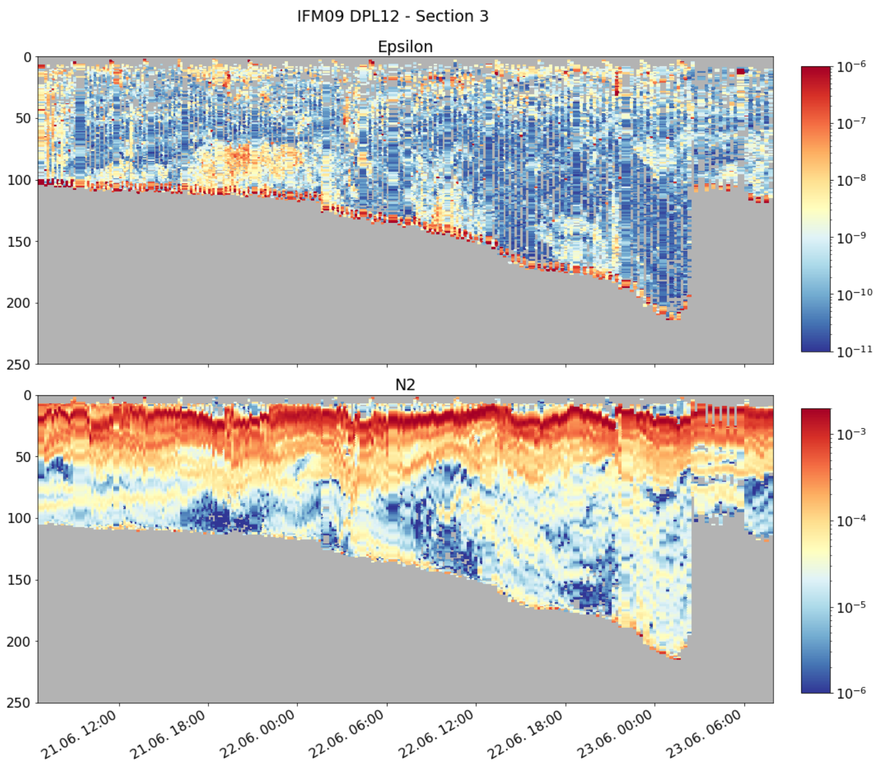

Fig. 5.4 Preliminary processed microstructure and hydrographic data collected by glider ifm09 (depl. 6). Upper panel shows the dissipation rate of turbulent kinetic energy in watts per kilogram while the glider was moving offshore along the shelf. The lower panel exhibits stratification (N^2) in s^{-2} during the same gilder path. Please not that both plots use logarithmic colour scales.

Glider ifm13 and ifm09 were deployed using the vessel's rubber boat on June 18 at 10:00 UTC and 13:00 UTC respectively. Both gliders sampled along the 11°S section before they were retrieved on June 23. Their missions were configured to sample as close to the bottom as possible. This was achieved by setting the dive termination threshold to 10m above the bottom detection of the glider's altimeter readings. To avoid early dive determinations due to false altimeter readings in the turbid near-surface waters, the dive determination threshold was activated at depth below 100m only. Unfortunately, when ifm09 progressed in shallow waters below 100m, the depth threshold for activating the altimeter was not adjusted in time. The glider thus did not receive a dive determination signal and remained at the bottom on the shelf for more than 6h until an emergency ascent command was activated. Fortunately, the visit to the ocean's floor did not damage any sensors. Ifm09 collected 408 profiles of hydrographic, oxygen, chlorophyll and turbulence data and excellently captured the turbulence variability and staining of hydrography of internal tides along the continental slope (figure 5.4). Ifm13 worked well throughout the 5-day mission and collected 435 profiles of hydrographic, oxygen, chlorophyll and nitrate (NO_3) concentration data. A summary of the glider deployments and mission-specific sensors are listed in the table 5.3. Details of the missions and plots of the satellite-transmitted data can be retrieved from https://gliderweb.geomar.de/html/swarm10.html.

Table 5.4 Summary of glider missions.

	Ifm09	**Ifm13**
Mission	Depl12	Depl06
Survey area	11°S section	11°S section
Deployment date	June 18, 2018, 13:00	June 18, 2018, 10:00
Recovery date	June 23, 2018, 13:30	June 23, 2018, 14:00
Sensors	p, T, S, O_2, chl-a, turbidity	p, T, S, O_2, chl-a, turbidity
Mounted probes	Microstructure	Nitrate (SUNA)
Number of profiles	408	435
Max. depth [dbar]	831	903

5.6 Biogeochemistry of Trace Gases

(D. L. Arévalo-Martínez, T. Sanders, J. Carreres)

The trace gas measurement program consisted of continuous along-track surface concentrations measurements and discrete sampling in the upper ocean.

5.6.1 Continuous Trace Gas Surface Measurements

Continuous measurements of dissolved N_2O, N_2O isotopes, CO_2 and CO in seawater were carried out by means of an autonomous equilibrator headspace setup (GO-System; General Oceanics, Inc.) coupled to two off-axis integrated cavity output spectroscopy analyzers. The combined setup is shown in Figure 5.5. Water was drawn into the system at ~ 3 L min^{-1} by a LOWARA submersible pump installed in the ship's moon pool (~6 m depth). Ambient air measurements were carried out every six hours by drawing air into the system from a suction point located at the ship's mast at about 30 m high. Control measurements and calibration procedures were performed every ~6 and 24 h respectively, by means of 3 standard gas mixtures (Deuste Steininger GmbH) bracketing the expected concentrations in this area.

Fig. 5.5 Setup for UW measurements of N_2O concentration, N_2O isotopes, CO_2, and CO during M148/1. (A) Equilibration system and gas analyzers, (B) inlet for ambient air measurements, (C) reference gases, (D) submersible pump installed at the "moon pool".

In addition to the trace gas measurements we conducted continuous measurements of dissolved oxygen and chlorophyll concentration by equipping a flow-through box with an Anderaa 4330 optode and a Wetlabs Fluorescence/Turbidity sensor (ECO). This data will provide additional information on the physical and biological controls of the distribution and gas exchange of trace gases during the cruise.

Figure 5.6 shows the distribution of dissolved N_2O, CO_2 and CO as well as the concentrations of oxygen and chlorophyll during the transit along 11° 45' S. Although for most of the cruise surface waters were in equilibrium with the corresponding atmospheric mixing ratios (grey dashed lines; values from the NOAA global air cooperative sampling station network), overall the open ocean along the section acted as a source for these three gases. Decreasing temperatures and increased levels of primary production (PP) were reflected in the changes between the west and the east side of the section: on the one hand decreasing temperatures increase N_2O and CO_2 solubility leading to higher values in the water; on the other, increasing PP towards the east results in CO_2 drawdown driving its levels slightly below atmospheric equilibrium. N_2O remained affected only by its solubility since it is not consumed nor produced in surface waters. Dissolved CO featured the typical diel cycles which result from photochemical decomposition of organic material in the euphotic zone during the day, followed by consumption during the night. This can be seen when comparing the distribution of CO and the ship's underway global radiation measurements.

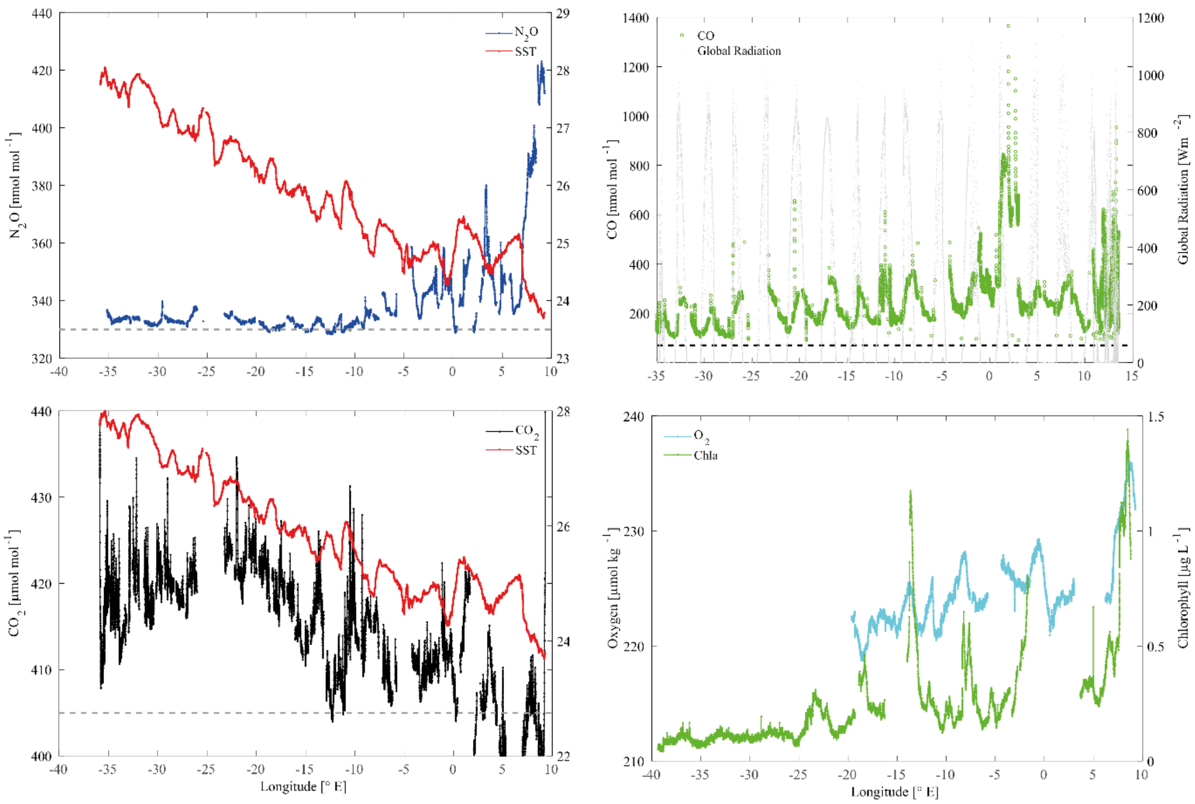

Fig. 5.6 Surface distribution of trace gases along 11°45'S. Upper (lower) left panel shows dissolved N_2O (CO_2) concentrations and sea surface temperature (SST). The upper right panel shows dissolved CO concentrations as well as global radiation values as measured by the METEOR's meteorological sensors. Lower right panel depicts the surface distribution of oxygen concentrations and chlorophyll concentrations (estimated from fluorescence data). Note that oxygen data is only available for locations east of ~20°W due to technical problems.

Stronger divergence from equilibrium conditions (N_2O ~ 330 nmol mol^{-1} and CO_2 ~ 410 µmol mol^{-1}) were observed within the ATZ, across the Angola-Benguela Front and the northern Benguela upwelling system (Figure 5.7). As we proceeded southward from the 6°S section a sharp increase in N_2O and CO_2 was observed with values that surpassed atmospheric mixing ratios for about 10 and 3 times respectively. The elevated values for these two gases point out towards strong mixing events which transported the shelf mid-water maxima towards the near-surface. While for N_2O the southward increasing trend was steady, for CO_2 larger variability was observed due to the counteracting effects of low solubility and elevated primary production, as reflected by the underway chlorophyll measurements. Underway surface oxygen measurements (not shown) support these observations since anomalously low saturations (down to 50%) could be measured at the near-surface. Further analysis of the continuous N_2O concentration and isotopic signatures data, together with the water column information on N_2O, molecular markers and inorganic nutrients will allow us to obtain a better understanding of the nitrogen pathways influencing N_2O distribution in this region as well as to assess the potential effects of extreme mixing events due to e.g. storms during winter time in the distribution and emissions of trace gases.

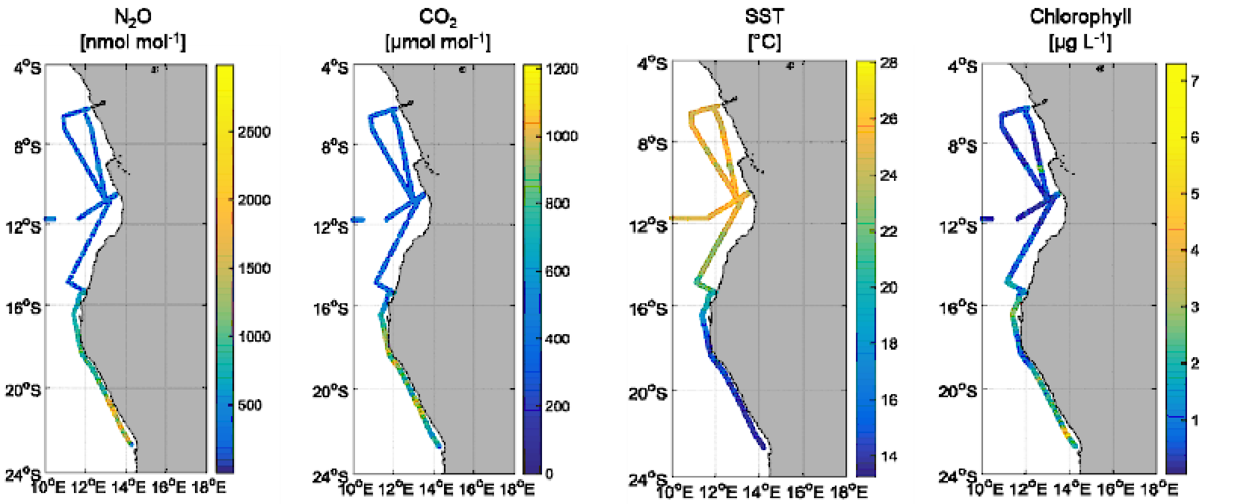

Fig. 5.7 Preliminary results of continuous measurements of dissolved N_2O and CO_2 off Angola and Namibia. Along-track SST (as measured by the ship's thermosalinograph) and estimated chlorophyll concentration are also shown.

5.6.2 Discrete N_2O and DNA Sampling

Discrete samples for N_2O measurements and DNA analysis were collected daily (N_2O) or in 6 h intervals (DNA) by sampling from the same water stream that fed the continuous setup (see above). For N_2O, bubble-free triplicate samples were collected and immediately sealed by means of butyl stoppers and aluminum crimps. Subsequently 50 µL of a saturated mercuric chloride ($HgCl_2$) solution were added. The samples will be analyzed by means of a gas chromatographic setup at the chemical oceanography department of GEOMAR. Samples for DNA analysis were obtained by filtering water from selected depths into Durapore® membrane filters (0.22 µm). Upon filtration, the filters were preserved and immediately frozen at -80°C. The DNA analysis will be carried out by Carolin Löscher at the department of biology of the University of Southern Denmark. Additionally, comparison samples for N_2O isotopic signatures were collected off Angola and Namibia and will be measured by Claudia Frey (University of Basel).

5.6.3 Depth Profiles of N_2O and Molecular Markers of N-Cycling

The sampling for N_2O measurements was carried out in conjunction with nutrient concentrations, nutrient isotopes and microstructure measurements. Samples were drawn directly from 10 L Niskin bottles mounted on a standard CTD/Rosette. Glass vials of 20 were used and the samples were treated as explained above and will be analyzed at the chemical oceanography department of GEOMAR. The sampling scheme varied according with the location during the cruise, such that during the west-east transit along 11°45'S only deep (<1000 m) waters and the mid-water oxygen minimum were sampled, whereas during the cross-shore transects within the ATZ and the nBUS full water column profiles were obtained. Samples for the determination of presence and abundance of the molecular markers *amoA*, *nirS*, *norB*, *nosZ*, *nifH* and *amx* were collected at selected depths in stations in which also N_2O, nutrients and flow cytometry samples were taken (only west of 10°E after completion of the 11°45'S section). Sample processing was done as described above and the measurements will be performed at the department of biology of the University of Southern Denmark. Table 7.3 summarizes of the sampling locations and depths.

5.7 Nutrients and Nitrogen Stable Isotopes

(T. Sanders, H. Campen, D. Bastian, D. Arévalo-Martínez)

During the cruise nutrients samples were taken at 73 CTD stations. The majorty of samples were analyzed onboard for nutrients such as nitrite (NO_2), nitrate (NO_3), phosphate (PO_4) and silicate ($Si(OH)_4$). This was realized by an autoanalyzer (Quaatro, SEAL Analytics) using photometric methods to measure nutrient concentrations. The last samples taken were frozen and will be analyzed in the home laboratory. The underlying chemical reactions of the measurements of all nutrients follow the procedures as described in Grasshoff et al. (2009).

Varying nutrient concentrations were found, which can be used to distinguish individual water masses. We found relatively high concentrations in the bottom water of the Brazilian Basin, likely associated with the Antarctic Bottom Water (figure 5.8). In general, nitrate had its maximum above 1000 m depths and concentrations steadily increased from west to east.

Additional water samples from more than 60 CTD stations were taken for further analysis of stabile isotopes and determination of DON (dissolved organic nitrogen) concentrations. Samples were filtered through precombusted, rinsed GF/F filters, were aliquoted into PE bottles and stored at -18°C. To measure the DON concentration, the total dissolved nitrogen will be oxidized to nitrate with persulfate in a microwave. The stable isotopes of nitrate ($\delta^{15}N$ and $\delta^{18}O$) will be determined with the denitrifier-method (Casciotti et al., 2002; Sigman et al., 2001), which is based on the isotopic analysis of nitrous oxide (N_2O) produced by the denitrifying bacterium *Pseudomonas aureofaciens* (ATCC#13985). For the analysis an isotope ratio mass spectrometer (Delta V of Thermo) will be used, coupled to a pre-concentration unit and GC column. The data will be available in Coast Map, a geodatabase of HZG.

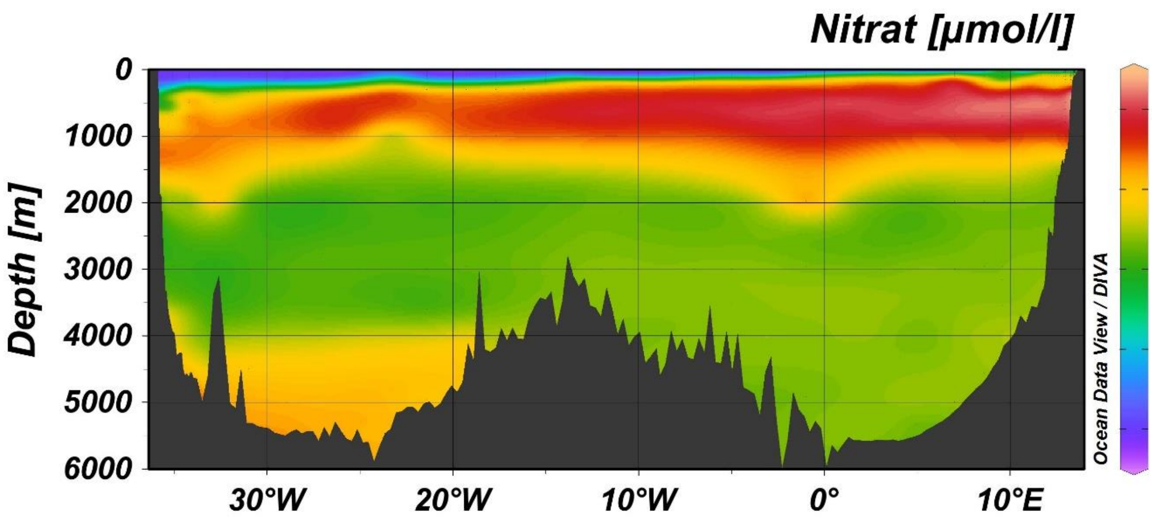

Fig. 5.8 Concentration of nitrate along the 11°S transect.

5.8 Sampling of Micro Plastics

(J. Carreres)

During the cruise, a measurement program focused on investigating the contamination of micro plastics in the tropical South Atlantic and the upwelling off Angola. To accomplish the objective, samples was collected from a total of 33 CTD stations along the 11° transect and the 6ºS section.

At each station, 2 liters of water was taken from CTD Niskin bottles at three different depths: surface (at 10 dbar depth in the majority of the stations), chlorophyll maximum and bottom. The water was immediately filtered using 0.7µm (pre-combusted glass fibre of 47 mm diameter) and 0.22 µm (cellulose membrane 47mm diameter) filters and stored at -20ºC for further analyses at the University of Southern Denmark and University of Copenhagen. Once the samples arrive at our laboratory, micro plastic concentrations will be quantified using Raman spectroscopy.

5.9 Argo Float Deployments

(F. Matos, M. Dengler)

Altogether, 6 Argo floats were deployed during the cruise. The Arvor floats (manufacturer: NKE) were provided by the Bundesanstalt für Schifffahrt und Hydographie as part of the German Argo program. Deployment schedule and positions are detailed in table 5.4. Upon arrival of the floats at the vessel, it was noticed that the shock indicators on three of the six boxes were red, indicating some rough handling during transport from Germany to the ship. Thus, prior to deployment, several test including CTD tests were performed that were evaluated by NKE and Seabird (manufacturer of the floats' CTD). Fortunately, all tests were positive and no malfunctioning was detected. The floats were deployed as scheduled.

Table 5.5 Deployment schedule and position of Argo floats and corresponding CTD profile number.

Float S/N	WMO	Argos ID	Deployment date / time (UTC)	latitude	longitude	CTD profile
AL250018DE001	3901670	55134	21.06.2018 / 13:19	06°36,472'S	10°52,462'E	79
AL250018DE002	3901671	55135	17.06.2018 / 00:55	11°29,985'S	11°59,951'E	47
AL250018DE003	3901672	55137	25.06.2018 / 14:13	14°52,512'S	11°07,521'E	85
AL250018DE004	3901673	55141	04.06.2018 / 13:28	11°45,032'S	26°59,958'W	21
AL250018DE005	3901674	55142	08.06.2018 / 06:03	11°45,200'S	15°00,150'W	28
AL250018DE006	3901675	55143	14.06.2018 / 01:59	11°44,909'S	03°00,115'E	39

6 Ship's Meteorological Station

(M. Stelzner)

The research vessel METEOR left the port of Belém on 24.05.2018 at about 06 o'clock. At the beginning of the journey, the inner-tropical convergence zone stretched along the Amazon estuary not far north of Belem. This caused heavy clouds in Belém and in the initial sailing area heavy rain showers with weak northeasterly winds. In the vicinity of the Rio Pará, the swell did not yet play a role. In the late afternoon the R/V METEOR moved from the Amazon estuary to the Atlantic Ocean. The water cleared and a slow developing northeasterly swell of 1m set in. The transit to the south was particular difficult. On the 27th and 28th strong east to southeast winds with 6 to 7 Bft set in with the wind sea up to 1.5m. With the decrease of the wind and the decline of the wind sea an increase of a southeasterly swell to 2.5m was accompanied. In addition, R/V METEOR struggled with a very strong countercurrent. All these factors contributed that the R/V METEOR arrived at the first CTD station 1.5 days later than planned. On the evening of the 30th the first CTD was launched. At that time, R/V METEOR was at the northeastern edge of a high-pressure area at 31°S 28°W. As a consequence, southeasterly winds of 4 to 5 Bft set in with a southeasterly swell of 1.5 to 2m. The weather was fine with only a few Cumuli clouds around. On the night from May to June thicker clouds developed in the cruising area, with intermittent rain to follow from the early morning hours into the rest of the day. On the morning of June 2, the sky slowly cleared with only some cumulus clouds left over. Wind and swell were not affected.

On the same evening, R/V METEOR reached position 11°45'S / 31°W and the journey to the east along this latitude began. In the following 9 days the weather remained largely the same. With bright weather and only shallow cumulus clouds, the sun was shining many hours a day. The wind blew constantly from the SE with mostly 4 to 5 Bft resulting in a low wind sea. The southeasterly swell showed 1.5m. However, on June 8 and 9, this continuity was disturbed by a 2m high swell area coming from the SW with a period of 14 seconds. On June 12, R/V METEOR moved from the west to the east hemisphere, with the Passat cloudiness setting in, covering the sun until the end of the journey. At the same time, the high southwest of R/V METEOR shifted eastward and later southeast until it finally was over South Africa. The wind rose to 5, at times to 6 Bft and shifted, just like the 1m high swell, from southeast to south. On the night 14th/15th of June the next swell area reached the sailing region from the southwest. The now prevailing cross swell rose up to 3m and persisted for the next 2 days. On the evening of the 16th R/V METEOR reached the endpoint of the CTD profile along 11°45'S. While travelling further to the east, the so far prevailing high pressure weather situation weakened.

The tropical low pressure zone extended a low pressure trough along the coast of Angola into the northwest of Namibia dominating the local weather. The wind shifted to the southwest and dropped to 2-3 Bft while the prevailing southwesterly swell decreasing to 1m. On the afternoon of 17th R/V METEOR experienced almost a smooth sea. The wind and sea conditions hardly changed until the 23th.In the early afternoon of the 24th the one-day transit to the CTD profile at 15°S/11°E began. On a SW'ly course R/V METEOR headed directly into a new swell area with the result of a gradually increasing. Finally, on Monday afternoon, at the first CTD station, the swell reached a maximum of 3-3.5m with a period of 12 seconds. With the CTD profile very close to the coast, the swell temporarily dropped to 1.5m on Tuesday morning. During the transit and the following station works the wind was blowing with 2-3 Bft. On Tuesday afternoon the mostly southwestern wind, at times from variable directions, increased to 4-5 Bft. After completion of CTD work on Tuesday noon, the last transit section to Walvis Bay finally began. While travelling further to the south the wind freshened and rose on Wednesday the 27th to 7-8 Bft from the south. Although the swell area from the past days had subsided, the 3m swell persisted due to the rising wind sea. On Wednesday evening, the swell calmed down again. However, at the same time another strong swell field moved up from the southwest, the significant wave height remained unchanged at 3m and increased to 3.5-4m on Thursday. Due to a long period of 13-15 seconds the situation was not as bad.

Shaken by the wind and swell of the past days, R/V METEOR finally reached the saving bay off Walvis Bay on Thursday evening and moored at the pier early that same evening.

7 Station List M148/1

7.1 Overall Station List

Station No.		Date	Gear	Time	Latitude	Longitude	Water Depth	Remarks
METEOR (M148-)	GEOMAR	2018		[UTC]	[°]	[°]	[m]	
1-1	CTD 1	30.05.	CTD	21:03	10°14.566'S	035°53.610'W	223	CTD to bottom
2-1	CTD 2	30.05.	CTD	22:17	10°15.275'S	035°52.595'W	520	CTD to bottom
3-1	KPO1203	30.05.	Moor	23:22	10°13.625'S	035°52.400'W	320	PIES deployment
4-1	KPO1204	30.05.	Moor	23:41	10°13.965'S	035°51.684'W	517	PIES deployment
5-1	CTD 3	31.05.	CTD	00:20	10°15.994'S	035°51.687'W	902	CTD to bottom
6-1	CTD 4	31.05.	CTD	02:03	10°19.488'S	035°46.107'W	1725	CTD to bottom
7-1	CTD 5	31.05.	CTD	04:28	10°22.727'S	035°40.812'W	2322	CTD to bottom
8-1	CTD 6	31.05.	CTD	07:16	10°27.341'S	035°34.886'W	2879	CTD to bottom
9-1	CTD 7	31.05.	CTD	10:08	10°32.005'S	035°29.294'W	3221	CTD to bottom
10-1	CTD 8	31.05.	CTD	13:06	10°36.500'S	035°23.900'W	3519	CTD to bottom
11-1	CTD 9	31.05.	CTD	16:26	10°41.380'S	035°17.597'W	3699	CTD to bottom
12-1	CTD 10	31.05.	CTD	19:52	10°46.399'S	035°11.617'W	3893	CTD to bottom
13-1	CTD 11	31.05.	CTD	23:46	10°51.399'S	035°05.600'W	3979	CTD to bottom
14-1	CTD 12	01.06.	CTD	03:17	10°56.385'S	034°59.590'W	4127	CTD to bottom
15-1	CTD 13	01.06.	CTD	07:57	10°07.582'S	034°43.926'W	4269	CTD to bottom
16-1	CTD 14	01.06.	CTD	13:38	11°18.790'S	034°28.220'W	4669	CTD to bottom
17-1	CTD 15	01.06.	CTD	19:01	11°29.978'S	034°13.007'W	4601	CTD to bottom
18-1	CTD 16	02.06.	CTD	0:28	11°30.000'S	033°53.011'W	4648	CTD to bottom
19-1	CTD 17	02.06.	CTD	10:18	11°30.188'S	032°51.715'W	4450	CTD to bottom
20-1	uCTD 1	02.06.	uCTD	13:15-23:25	11°30.243'S-11°42.987'S	032°51.466'W-031°15.167'W	4597	6 profiles
21-1	CTD 18	03.06.	CTD	01:15	11°44.991'S	031°00.009'W	5360	CTD to bottom
22-1	uCTD 2	03.06.	uCTD	04:42-16:17	11°44.980'S-11°45.000'S	030°59.449'W-029°14.455'W	5248	7 profiles
23-1	CTD 19	03.06.	CTD	17:56	11°45.004'S	029°00.029'W	5537	CTD to 500m
24-1	CTD 20	03.06.	CTD	18:46	11°45.004'S	029°00.026'W	5537	CTD to bottom
25-1	uCTD 3	03.-04.06.	uCTD	22:16-08:25	11°44.981'S-11°44.999'S	028°59.779'W-027°13.737'W	5536	6 profiles
26-1	CTD 21	04.06.	CTD	09:51	11°44.976'S	026°59.999'W	5528	CTD to bottom
27-1	ARGO 1	04.06.	FLOAT	13:28	11°45.032'S	026°59.958'W	5505	Arvor float AL250018DE004
28-1	uCTD 4	04.-05.06.	uCTD	13:38-00:16	11°44.998'S-11°45.158'S	026°59.440'W-025°06.755'W	5556	6 profiles
29-1	CTD 22	05.06.	CTD	01:18	11°44.998'S	024°59.996'W	6370	CTD to 5700m
30-1	uCTD 5	05.06.	uCTD	05:03-13:12	11°44.939'S-11°45.000'S	024°59.437'W-023°30.841'W	6383	5 profiles
31-1	CTD 23	05.06.	CTD	14:14	11°45.006'S	023°21.009'W	5387	CTD to bottom
32-1	uCTD 6	05.-06.06.	uCTD	17:35-03:50	11°45.080'S-11°45.000'S	023°20.508'W-021°28.280'W	5235	6 profiles
33-1	CTD 24	06.06.	CTD	04:27	11°45.000'S	021°24.003'W	4984	CTD to bottom
34-1	uCTD 7	06.06.	uCTD	08:06-18:18	11°44.998'S-11°45.000'S	021°18.174'W-019°26.349'W	5225	6 profiles
35-1	CTD 25	06.06.	CTD	19:14	11°44.998'S	019°18.002'W	4656	CTD to bottom
36-1	uCTD 8	06.-07.06.	uCTD	22:16-06:43	11°44.969'S-11°44.999'S	019°17.508'W-017°43.032'W	4719	7 profiles
37-1	CTD 26	07.06.	CTD	06:59	11°44.970'S	017°42.015'W	4134	CTD to bottom
38-1	uCTD 9	07.06.	uCTD	09:42-18:13	11°44.964'S-11°44.999'S	017°42.022'W-016°12.678'W	4130	8 profiles
39-1	CTD 27	07.06.	CTD	18:24	11°44.995'S	016°12.035'W	3915	CTD to bottom

40-1	uCTD 10	07.-08. 06.	uCTD	20:56-03:01	11°45.102'S-11°44.999'S	016°11.902'W-15°07.149'W	3924	4 profiles
41-1	CTD 28	08.06.	CTD	03:50	11°44.996'S	015°00.015'W	3217	CTD to bottom
42-1	ARGO 2	08.06.	FLOAT	06:03	11°45.200'S	015°00.150'W	3250	Arvor float AL250018DE005
43-1	uCTD 11	08.06.	uCTD	01:58 - 12:08	11°44.997'S-11°45.001'S	015°18.429'W-013°56.480'W	3542	4 profiles
44-1	CTD 29	08.06.	CTD	12:45	11°44.997'S	013°51.620'W	3182	CTD to bottom
45-1	uCTD 12	08.06.	uCTD	15:01-19:16	11°44.902'S-11°45.001'S	013°51.702'W-013°08.304'W	3211	3 profiles
46-1	CTD 30	08.06.	CTD	21:04	11°45.021'S	012°51.683'W	3708	CTD to bottom
47-1	uCTD 13	08.-09.06.	uCTD	23:12 - 03:20	11°44.765'S-11°44.999'S	012°52.429'W-012°09.963'W	3250	3 profiles
48-1	CTD 31	09.06.	CTD	04:30	11°44.975'S	012°00.052'W	3820	CTD to bottom
49-1	uCTD 14	09.06.	uCTD	06:53 - 11:02	11°44.989'S-11°45.000'S	012°00.279'W-011°16.354'W	3824	3 profiles
50-1	CTD 32	09.06.	CTD	12:32	11°45.009'S	011°01.689'W	4060	CTD to bottom
51-1	uCTD 15	09.06.	uCTD	15:14-16:43	11°45.002'S-11°45.000'S	011°01.197'W-010°45.492'W	4081	2 profiles
52-1	uCTD 16	10.06.	uCTD	00:50-07:14	11°44.998'S-11°44.999'S	010°23.472'W-009°14.190'W	3953	4 profiles
53-1	CTD 33	10.06.	CTD	08:30	11°44.975'S	009°04.080'W	4417	CTD to bottom
54-1	uCTD 17	10.06.	uCTD	11:18-21:06	11°45.021'S-11°45.001'S	009°03.948'W-007°15.954'W	4418	6 profiles
55-1	CTD 34	10.06.	CTD	23:06	11°45.007'S	007°00.013'W	4701	CTD to bottom
56-1	uCTD 18	11.06.	uCTD	02:11	11°44.997'S-11°45.001'S	006°59.786'W-005°04.090'W	4713	6 profiles
57-1	CTD 35	11.06.	CTD	12:56-	11°44.986'S	005°00.012'W	4360	CTD to bottom
58-1	uCTD 19	11.-12.06.	uCTD	15:51-01:49	11°45.033'S-11°45.001'S	004°59.640'W-003°03.868'W	4365	6 profiles
59-1	CTD 36	12.06.	CTD	02:41	11°44.974'S	003°00.020'W	5320	CTD to bottom
60-1	uCTD 20	12.06.	uCTD	06:32-14:38	11°45.057'S-11°44.998'S	002°59.439'W-001°28.084'W	5467	5 profiles
61-1	CTD 37	12.06.	CTD	17:18	11°45.047'S	001°00.034'W	5669	CTD to bottom
62-1	uCTD 21	12.-13.06.	uCTD	22:07-08:09	11°44.990'S-11°44.998'S	000°59.719'W-000°56.981'E	5557	6 profiles
63-1	CTD 38	13.06.	CTD	08:35	11°44.974'S	001°00.060'E	5603	CTD to bottom
64-1	uCTD 22	13.06.	uCTD	14:15-22:06	11°44.998'S-11°44.998'S	001°27.337'E-002°59.086'E	5635	5 profiles
65-1	CTD 39	13.06.	CTD	22:18	11°44.983'S	003°00.011'E	5605	CTD to bottom
66-1	ARGO 3	14.06.	FLOAT	01:59	11°44.909'S	003°00.115'E	5603	Avor float AL250018DE006
67-1	uCTD 23	14.06.	uCTD	02:03-12:08	11°44.874'S-11°44.999'S	003°00.516'E-004°55.202'E	5604	6 profiles
68-1	CTD 40	14.06.	CTD	12:42	11°44.985'S	004°59.970'E	5497	CTD to 500m
69-1	CTD 41	14.06.	CTD	13:14	11°44.978'S	005°00.015'E	5498	CTD to bottom
70-1	uCTD 24	14.-15.06.	uCTD	17:07-03:06	11°44.818'S-11°44.999'S	005°00.022'E-006°46.511'E	5500	6 profiles
71-1	CTD 42	15.06.	CTD	04:31	11°44.963'S	007°00.017'E	5209	CTD to bottom
72-1	uCTD 25	15.06.	uCTD	07:55-16:15	11°44.865'S-11°44.998'S	006°59.847'E-008°29.013'E	5217	5 profiles
73-1	CTD 43	15.06.	CTD	17:07	11°44.978'S	008°35.986'E	4614	CTD to bottom
74-1	uCTD 26	15.-16.06.	uCTD	20:15-01:44	11°45.074'S-11°44.998'S	008°36.021'E-009°19.714'E	4611	3 profiles
75-1	CTD 44	16.06.	CTD	01:44	11°44.972'S	009°35.991'E	4239	CTD to bottom
76-1	uCTD 27	16.06.	uCTD	04:38-09:06	11°45.204'S-11°44.996'S	009°36.323'E-010°27.836'E	4218	3 profiles

77-1	CTD 45	16.06.	CTD	10:30	11°44.999'S	010°41.986'E	3787	CTD to bottom
78-1	uCTD 28	16.06.	uCTD	13:12-17:33	11°45.477'S-11°44.998'S	010°42.389'E-011°33.164'E	3779	3 profiles
79-1	CTD 46	16.06.	CTD	18:05	11°44.984'S	011°38.021'E	3461	CTD to bottom
80-1	CTD 47	16.06.	CTD	22:58	11°29.998'S	012°00.000'E	2586	CTD to bottom
81-1	ARGO 4	17.06.	FLOAT	00:55	11°30.017'S	011°59.951'E	2593	Arvor float AL250018DE002
82-1	CTD 48	17.06.	CTD	02:36	11°19.989'S	012°15.026'E	2282	CTD to bottom
83-1	CTD 49	17.06.	CTD	05:11	11°15.003'S	012°22.499'E	1878	CTD to bottom
84-1	CTD 50	17.06.	CTD	07:31	11°10.008'S	012°29.991'E	1616	CTD to bottom
85-1	CTD 51	17.06.	CTD	09:41	11°05.004'S	012°37.495'E	1533	CTD to bottom
86-1	KPO 1074 - 1	17.06.	MOOR	14:35-15:45	10°41.889'S	013°11.603'E	458	bottom shield KPO 1074 recover (unsuccessful)
87-1	MSS 1	17.06.	MSS	19:19-20:20	10°58.781'S	012°43.885'E	1472	MSS to 250m, 3 profiles
88-1	CTD 52	17.06.	CTD	20:45	10°59.989'S	012°44.003'E	1432	CTD to bottom
89-1	MSS 2	17.-18. 06	MSS	23:15-00:13	10°54.282'S	012°53.184'E	1352	MSS to 250m, 3 profiles
90-1	CTD 53	18.06.	CTD	00:20	10°54.755'S	012°52.341'E	1368	CTD to bottom
91-1	MSS 3	18.06.	MSS	02:17-03:13	10°50.182'S	012°59.710'E	1233	MSS to 250m, 3 profiles
92-1	CTD 54	18.06.	CTD	03:25	10°50.677'S	012°58.722'E	1243	CTD to bottom
93-1	MSS 4	18.06.	MSS	05:21-05:34	10°47.395'S	013°04.192'E	1055	MSS (malfunctioned)
94-1	CTD 55	18.06.	CTD	05:58	10°47.905'S	013°02.976'E	1162	CTD to bottom
95-1	CTD 56	18.06.	CTD	07:24	10°45.998'S	013°06.007'E	946	CTD to bottom
96-1	IFM13	18.06.	GLIDER	09:11-10:40	10°45.999'S	013°06.010'E	946	IFM13 deployment
97-1	CTD 57	18.06.	CTD	11:14	10°44.018'S	013°09.001'E	705	CTD to bottom
98-1	IFM09	18.06.	GLIDER	12:23-13:30	10°44.021'S	013°09.004'E	705	IFM09 deployment
99-1	MSS 5	18.06.	MSS	14:06-15:11	10°43.322'S	013°10.112'E	588	MSS to 250m, 3 profiles
100-1	CTD 58	18.06.	CTD	15:35	10°41.988'S	013°11.867'E	445	CTD to bottom
101-1	KPO 1207	18.06.	MOOR	16:31-16:52	10°41.529'S	013°15.654'E	296	KPO 1207 deployment
102-1	CTD 59	18.06.	CTD	17:24	10°40.554'S	013°14.232'E	261	CTD to bottom
103-1	MSS 6	18.06.	MSS	17:58-18:54	10°40.603'S	013°14.177'E	299	MSS to 250m, 3 profiles
104-1	CTD 60	18.06.	CTD	19:26	10°39.220'S	013°16.204'E	174	CTD to bottom
105-1	MSS 7	18.06.	MSS	19:54-20:34	10°39.259'S	013°16.161'E	175	MSS to bottom, 3 profiles
106-1	CTD 61	18.06.	CTD	21:29	10°37.891'S	013°18.202'E	128	CTD to bottom
107-1	MSS 8	18.06.	MSS	21:53-22:39	10°37.915'S	013°18.163'E	128	MSS to bottom, 4 profiles
108-1	CTD 62	18.06.	CTD	23:05	10°36.591'S	013°20.206'E	117	CTD to bottom
109-1	MSS 9	18.-19. 06.	MSS	23:28-00:14	10°36.615'S	013°20.177'E	117	MSS to bottom, 5 profiles
110-1	CTD 63	19.06.	CTD	00:43	10°35.256'S	013°22.212'E	105	CTD to bottom
111-1	MSS 10	19.06.	MSS	00:59-01:33	10°35.284'S	013°22.193'E	106	MSS to bottom, 5 profiles
112-1	CTD 64	19.06.	CTD	02:05	10°34.204'S	013°23.692'E	96	CTD to bottom
113-1	MSS 11	19.06.	MSS	02:22-02:57	10°34.213'S	013°23.629'E	98	MSS to bottom, 5 profiles
114-1	CTD 65	19.06.	CTD	03:32	10°32.883'S	013°25.706'E	83	CTD to bottom

115-1	MSS 12	19.06.	MSS	03:52-04:28	10°32.903'S	013°25.675'E	84	MSS to bottom, 5 profiles
116-1	CTD 66	19.06.	CTD	04:58	10°31.561'S	013°27.703'E	62	CTD to bottom
117-1	MSS 13	19.06.	MSS	05:19-05:51	10°31.598'S	013°27.682'E	62	MSS to bottom, 5 profiles
118-1	CTD 67	19.06.	CTD	06:21	10°30.299'S	013°29.695'E	52	CTD to bottom
119-1	MSS 14	19.06.	MSS	06:38-07:02	10°30.312'S	013°29.680'E	53	MSS to bottom, 5 profiles
120-1	KPO 1208	19.06.	LANDER	07:53-08:08	10°33.366'S	013°29.199'E	60	SML1 deployment
121-1	KPO 1209	19.06.	LANDER	09:05-09:17	10°37.170'S	013°23.495'E	96	SML2 deployment
122-1	KPO 1174-2	19.06.	MOOR	10:57-12:15	10°42.727'S	013°11.363'E	490	search for bottom shield using
123-1	KPO 1175	19.06.	MOOR	15:06-16:00	10°49.845'S	013°00.192'E	1223	KPO 1175 recovery
124-1	uCTD 28	19.-20. 06.	uCTD	17:21-15:04	10°35.058'S-06°23.379'S	012°56.957'E-011°57.043'E	962	12 profiles
125-1	CTD 68	20.06.	CTD	16:25	06°12.601'S	012°05.982'E	42	CTD to bottom
126-1	CTD 69	20.06.	CTD	17:37	06°14.904'S	011°59.981'E	69	CTD to bottom
127-1	MSS 15	20.06.	MSS	18:08-18:45	06°14.978'S	011°59.916'E	70	MSS to bottom, 5 profiles
128-1	CTD 70	20.06.	CTD	19:16	06°16.758'S	011°53.979'E	86	CTD to bottom
129-1	MSS 16	20.06.	MSS	19:39-20:12	06°16.771'S	011°53.920'E	87	MSS to bottom, 4 profiles
130-1	CTD 71	20.06.	CTD	20:51	06°18.595'S	011°48.005'E	111	CTD to bottom
131-1	MSS 17	20.06.	MSS	21:11-21:35	06°18.636'S	011°47.927'E	110	MSS to bottom, 3 profiles
132-1	CTD 72	20.06.	CTD	22:16	06°20.394'S	011°42.012'E	124	CTD to bottom
133-1	MSS 18	20.06.	MSS	22:36-23:12	06°20.426'S	011°41.989'E	124	MSS to bottom, 3 profiles
134-1	CTD 73	20.06.	CTD	23:45	06°22.262'S	011°36.013'E	213	CTD to bottom
135-1	MSS 19	21.06.	MSS	00:04-00:43	06°22.302'S	011°35.974'E	208	MSS to bottom, 3 profiles
136-1	CTD 74	21.06.	CTD	01:39	06°24.166'S	011°29.992'E	354	CTD to bottom
137-1	CTD 75	21.06.	CTD	03:14	06°26.593'S	011°22.484'E	537	CTD to bottom
138-1	MSS 20	21.06.	MSS	03:52-04:41	06°26.593'S	011°22.432'E	538	MSS to bottom, 3 profiles
139-1	CTD 76	21.06.	CTD	05:37	06°29.010'S	011°15.038'E	838	CTD to bottom
140-1	CTD 77	21.06.	CTD	07:36	06°31.519'S	011°07.426'E	1134	CTD to bottom
141-1	MSS 21	21.06.	MSS	08:30-09:17	06°31.545'S	011°07.421'E	1137	MSS to bottom, 3 profiles
142-1	CTD 78	21.06.	CTD	10:06	06°33.938'S	010°59.998'E	1450	CTD to bottom
143-1	CTD 79	21.06.	CTD	12:04	06°36.372'S	010°52.502'E	1666	CTD to bottom
144-1	ARGO 5	21.06.	FLOAT	13:19	06°36.472'S	010°52.462'E	1673	Avor float AL250018DE001
145-1	uCTD 29	21.-22. 06.	uCTD	14:02-14:14	06°44.001'S-10°42.063'S	010°53.130'E-012°55.416'E	1682	13 profiles
146-1	KPO 1200	22.06.	MOOR	15:07-16:48	10°50.025'S	012°59.974'E	1226	deployment of KPO 1200
147-1	MSS 22	22.06.	MSS	17:58-18:52	10°46.056'S	013°05.974'E	949	MSS to 250m, 3 profiles
148-1	CTD 80	22.06.	CTD	19:42	10°44.056'S	013°08.998'E	704	CTD to bottom
149-1	MSS 23	22.06.	MSS	20:50-21:44	10°44.109'S	013°08.955'E	712	MSS to 250m, 3 profiles
150-1	CTD 81	22.06.	CTD	22:43	10°39.240'S	013°16.236'E	169	CTD to bottom

151-1	MSS 24	22.06.	MSS	23:06-00:35	10°39.309'S	013°16.271'E	168	MSS to bottom, 5 profiles
152-1	CTD 82	23.06.	CTD	01:16	10°34.202'S	013°23.704'E	96	CTD to bottom
153-1	MSS 25	23.06.	MSS	01:35-02:19	10°34.221'S	013°23.684'E	96	MSS to bottom, 5 profiles
154-1	CTD 83	23.06.	CTD	03:08	10°31.598'S	013°27.696'E	62	CTD to bottom
155-1	MSS 26	23.06.	MSS	03:28-04:17	10°31.619'S	013°27.677'E	61	MSS to bottom, 5 profiles
156-1	KPO 1074-3	23.06.	MOOR	06:13-12:33	10°42.584'S	013°11.700'E	469	dredging for bottom shield
158-1	IFM09	23.06.	GLIDER	13:26	10°40.934'S	013°17.031'E	190	ifm09 recovery
159-1	IFM13	23.06.	GLIDER	14:16	10°43.336'S	013°16.618'E	275	ifm13 recovery
160-1	uCTD 30	23.06.	uCTD	15:18-18:24	10°41.638'S-10°33.345'S	013°15.625'E-013°29.240'E	266	Rapid-Cast transect 11°S
161-1	MSS 27	23.-24.06.	MSS	20:30-03:34	10°38.868'S-10°32.590'S	013°21.179'E-013°27.496'E	120	MSS transect 67 profiles
162-1	uCTD 31	24.06.	uCTD	03:44-05:14	10°32.884'S-10°37.919'S	013°27.487'E-013°21.754'E	66	Rapid-Cast transect 11°S
163-1	KPO 1208	24.06.	LANDER	05:32-05:59	10°37.042'S	013°23.683'E	104	SLM2 recovery
164-1	KPO 1209	24.06.	LANDER	07:02-07:23	10°33.255'S	013°29.327'E	60	SLM1 recovery
165-1	KPO 1207	24.06.	MOOR	09:36-10:09	10°41.583'S	013°16.931'E	211	KPO 1207 recovery
166-1	CTD 84	24.06.	CTD	10:26	10°41.705'S	013°16.779'E	220	CTD to bottom
167-1	uCTD 32	24.-25.06.	uCTD	11:16-10:20	10°46.379'S	013°14.654'E	97	13 profiles
168-1	CTD 85	25.06.	CTD	12:40	14°52.510'S	011°07.523'E	3024	CTD to bottom
169-1	ARGO 6	25.06.	FLOAT	14:13	14°52.512'S	011°07.521'E	3025	Avor float AL250018DE003
170-1	CTD 86	25.06.	CTD	15:37	14°58.292'S	011°18.350'E	2787	CTD to bottom
171-1	CTD 87	25.06.	CTD	17:48	15°01.965'S	011°25.196'E	2584	CTD to bottom
172-1	CTD 88	25.06.	CTD	20:13	15°05.644'S	011°32.049'E	1838	CTD to bottom
173-1	CTD 89	25.06.	CTD	22:29	15°09.303'S	011°38.847'E	1778	CTD to bottom
174-1	CTD 90	26.06.	CTD	00:28	15°11.734'S	011°43.411'E	1474	CTD to bottom
175-1	CTD 91	26.06.	CTD	02:36	15°14.186'S	011°48.010'E	1084	CTD to bottom
176-1	CTD 92	26.06.	CTD	04:25	15°15.399'S	011°50.264'E	835	CTD to bottom
177-1	CTD 93	26.06.	CTD	05:38	15°16.615'S	011°52.563'E	603	CTD to bottom
178-1	CTD 94	26.06.	CTD	06:45	15°17.857'S	011°54.796'E	621	CTD to bottom
179-1	CTD 95	26.06.	CTD	07:52	15°19.096'S	011°57.103'E	478	CTD to bottom
180-1	CTD 96	26.06.	CTD	08:52	15°20.335'S	011°59.440'E	89	CTD to bottom
181-1	CTD 97	26.06.	CTD	09:36	15°20.941'S	012°00.553'E	50	CTD to bottom
182-1	uCTD 33	26.06.	uCTD	10:08-16:10	15°21.472'S-16°13.694'S	011°59.440'E-011°27.698'E	46	3 profiles
183-1	CTD 98	27.06.	CTD	02:30	17°29.975'S	011°36.981'E	121	CTD to bottom
184-1	CTD 99	27.06.	CTD	14:28	18°59.987'S	012°17.016'E	111	CTD to bottom
185-1	CTD 100	27.06.	CTD	21:37	19°59.999'S	012°48.980'E	114	CTD to bottom
186-1	CTD 101	28.06.	CTD	04:25	20°59.989'S	013°18.982'E	104	CTD to bottom
187-1	CTD 102	28.06.	CTD	10:52	21°59.974'S	013°46.978'E	108	CTD to bottom
188-1	CTD 103	28.06.	CTD	15:46	22°39.915'S	014°12.973'E	104	CTD to bottom

7.2 List of Mooring Deployments and Recoveries

7.2.1. Mooring Work Summary Table

M148/1 Mooring Recoveries off Brasil and Angola				
Mooring	**Latitude**	**Longitude**	**Deployment Date**	**Recovery Date**
KPO_1175	10°S 49:99’	12°E 59.98’	27-Oct-2016	19-June-2018
KPO_1174	10°S 42.73’	13°E 11.34’	27-Oct-2016	Could not be recovered
KPO_1207	10°S 41,70’	13°E 16.74’	18-Jun-2018	24-Jun-2018
KPO_1208	10°S 33.37’	13°E 29.20’	19-Jun-2018	24-Jun-2018
KPO_1209	10°S 37.17’	13°E 23.94’	19-Jun-2018	24-Jun-2018

M131 Mooring Deployments off Brasil and Angola				
Mooring	**Latitude**	**Longitude**	**Deployment Date**	**Recovery Date**
KPO_1203	10°S 13.63’	35°W 52.40’	30-May-2018	
KPO_1204	10°S 13.97’	35°W 51.68’	30-May-2018	
KPO_1207	10°S 42.70’	13°E 16.74’	18-Jun-2018	24-Jun-2018
KPO_1208	10°S 33.37’	13°E 29.20’	19-Jun-2018	24-Jun-2018
KPO_1209	10°S 37.17’	13°E 23.94’	19-Jun-2018	24-Jun-2018
KPO_1200	10°S 50,03’	12°E 59.98’	22-June-2018	

7.2.2. Mooring deployments and recoveries

Mooring Recovery SACUS Angola Array mooring (ADCP)					**Notes:**	**KPO 1175**	
Vessel:	Meteor	M131					
Deployed:	27-Oct	2016					
Vessel:	Meteor	M148/1					
Recovered:	19-Jun	2018					
Latitude:	10	50.000	S				
Longitude:	13	0.000	E				
Water depth:	1221		Mag Var:	-5,5			
ID	**Depth**	**Instr. type**	**s/n**	**Startup**			
		Argos	9243				
KPO_1175_01	491	ADCP LR 75 kHz up	2395	**x**	Fl45: PO13		
KPO_1175_02	491	O2 Logger	379	**x**			
KPO_1175_03	492	Microcat	6860	**x**			
	1208						
	1125	Release AR661	642	Code:	**M: A**	**E: 4A83**	**R: 4A84**

Mooring Deployment/Recovery Angola short-term mooring					**Notes:**	**KPO_1207**	
Vessel:	Meteor	M148/1					
Deployed:	18-Jun	2018					
Vessel:	Meteor	M148/1					
Recovered:	24-Jun	2018					
Latitude:	10°	41.70	S				
Longitude:	13°	16.74	E				
Water depth:	200		Mag Var:	-4,2			
ID	**Depth**	**Instr. type**	**s/n**	**Startup**			
		Argos	2267				
KPO_1200_01	170	ADCP WH 300 kHz up	1522	**x**	Fl45: PO11		
KPO_1200_02	170	ADCP WH 1200 kHz dn	7279	**x**			
KPO_1200_03	170	Optode	1141	**x**			
KPO_1200_04	170	Microcat	3754	**x**			
KPO_1200_05	1261	Release AR661	821		**M: A**	**E: A447**	**R: A448**

KPO_1200_06	1261	Release AR861	1104	Code:	**M: B**	**E: 0804**	**R: 0855-**

Mooring Deployment/Recovery Lander SLM 1 Angola					**Notes:**	**KPO_1208**
Vessel:	Meteor	M148/1				
Deployed:	19-Jun	2018				
Vessel:	Meteor	M148/1				
Recovered:	24-Jun	2018				
Latitude:	10°	33.37	S			
Longitude:	13°	29.20	E			
Water depth:	50.5		Mag Var:	-4,2		
ID	**Depth**	**Instr. type**	**s/n**	**Startup**		
KPO_1208_01	50	ADCP WH 300 kHz up	14495	**x**		
KPO_1208_03	50	Optode	381	**x**		

Mooring Deployment/Recovery Lander SLM 2 Angola					**Notes:**	**KPO_1209**
Vessel:	Meteor	M148/1				
Deployed:	19-Jun	2018				
Vessel:	Meteor	M148/1				
Recovered:	24-Jun	2018				
Latitude:	10°	37.17	S			
Longitude:	13°	23.94	E			
Water depth:	106.2		Mag Var:	-4,1		
ID	**Depth**	**Instr. type**	**s/n**	**Startup**		
KPO_1209_01	106	ADCP WH 300 kHz up	14623	**x**		
KPO_1209_02	106	Optode	432	**x**		
KPO_1209_03	106	SBE16plus	01606606	**x**		

Mooring Deployment/Recovery Angola short-term mooring					**Notes:**	**KPO_1207**	
Vessel:	Meteor	M148/1					
Deployed:	18-Jun	2018					
Vessel:	Meteor	M148/1					
Recovered:	24-Jun	2018					
Latitude:	10°	41.70	S				
Longitude:	13°	16.74	E				
Water depth:	200		Mag Var:	-4,2			
ID	**Depth**	**Instr. type**	**s/n**	**Startup**			
		Argos	2267				
KPO_1200_01	170	ADCP WH 300 kHz up	1522	**x**	Fl45: PO11		
KPO_1200_02	170	ADCP WH 1200 kHz dn	7279	**x**			
KPO_1200_03	170	Optode	1141	**x**			
KPO_1200_04	170	Microcat	3754	**x**			
KPO_1200_05	1261	Release AR661	821		**M: A**	**E: A447**	**R: A448**
KPO_1200_06	1261	Release AR861	1104	Code:	**M: B**	**E: 0804**	**R: 0855-**

Mooring Deployment PIES Brasil 300m					**Notes:**	**KPO_1203**
Vessel:	Meteor	M148/1				
Deployed:	30-May	2018		23:22		
Vessel:						
Recovered:						
Latitude:	10°	13.625’	S			
Longitude:	35°	51.400’	W			
Water depth:	320,4	Mag Var:		-22.8		

ID	Depth	Instr. type	s/n	Startup	Remarks
KPO_1203_01	320	PIES	320	x	Telem:66, XPND:70, BEACON:74, RELEASE:0
KPO_1203_02	320	Develogic Modem	3070	x	Adress: 0x0031

Mooring Deployment PIES Brasil 500m					**Notes: KPO_1203**
Vessel:	Meteor		M148/1		
Deployed:	30-May		2018	23:41	
Vessel:					
Recovered:					
Latitude:	10°		13.625' S		
Longitude:	35°		51.400' W		
Water depth:	320,4		Mag Var:	-22.8	
ID	**Depth**	**Instr. type**	**s/n**	**Startup**	**Remarks**
KPO_1203_01	320	PIES	320	x	Telem:66, XPND:70, BEACON:74, RELEASE:0
KPO_1203_02	320	Develogic Modem	3070	x	Adress: 0x0031

Mooring Deployment PREFACE/SACUS Angola Array mooring (ADCP)					**Notes: KPO_1200**		
Vessel:	Meteor	M148/1					
Deployed:	22-Jun	2018					
Vessel:							
Recovered:							
Latitude:	10°	50,00	S				
Longitude:	13°	00.00	E				
Water depth:	1221		Mag Var:	-4.4			
ID	**Depth**	**Instr. type**	**s/n**	**Startup**			
		Argos	2255				
KPO_1200_01	499	ADCP LR 75 kHz up	2395	x	Fl45: PO10		
KPO_1200_02	503	Optode	1133	x			
KPO_1200_03	503	Microcat	1717	x			
KPO_1200_04	1261	Release AR861	1644		**M:B**	**E: 0A89**	**R:0A55**
KPO_1200_05	1261	Release AR861	1646	Code:	**M: B**	**E: 0A8B**	**R: 0A55**

7.3 N_2O Water Column Sampling

Sampling locations for N_2O during M148/1. Deep water (<1000 m) sampling took place in stations marked with an asterisk.

Station	Cast	Date	Time (UTC)	Bottom depth (m)	Latitude °N	Longitude °E
M148_17*	15	2018/06/01	19:00:00	4610	-11.4997	-34.2168
M148_19*	17	2018/06/02	07:00:00	4566	-11.5031	-32.8619
M148_24*	20	2018/06/03	17:00:00	5492	-11.7500	-29.0000
M148_26*	21	2018/06/04	08:00:00	5522	-11.7500	-27.0000
M148_29*	22	2018/06/05	23:30:00	6320	-11.7500	-25.0000
M148_31*	23	2018/06/05	13:00:00	5371	-11.7500	-23.3500
M148_33*	24	2018/06/06	04:00:00	4895	-11.7500	-21.4000
M148_35*	25	2018/06/06	19:00:00	4500	-11.7500	-19.3000
M148_37*	26	2018/06/07	06:00:00	4080	-11.7500	-17.7000
M148_41*	28	2018/06/08	02:00:00	3479	-11.7500	-15.0000

M148_46*	30	2018/06/08	20:00:00	3320	-11.7500	-12.8600
M148_50*	32	2018/06/09	12:30:00	3990	-11.7500	-10.7000
M148_53*	33	2018/06/10	08:00:00	4410	-11.7500	-9.0000
M148_55*	34	2018/06/11	23:00:00	4695	-11.7500	-7.0000
M148_57*	35	2018/06/11	17:00:00	4580	-11.7500	-5.0000
M148_59*	36	2018/06/12	03:00:00	5465	-11.7500	-3.0000
M148_61*	37	2018/06/12	17:00:00	5260	-11.7500	-1.0000
M148_63*	38	2018/06/13	08:30:00	5200	-11.7500	1.0000
M148_65*	39	2018/06/14	19:00:00	5262	-11.7500	3.0000
M148_69*	40	2018/06/14	12:39:00	5490	-11.7500	5.0000
M148_71*	42	2018/06/15	05:00:00	5132	-11.7500	7.0000
M148_75*	44	2018/06/16	03:00:00	4270	-11.7500	9.6000
M148_79*	46	2018/06/16	18:00:00	3410	-11.7500	11.6333
M148_84	50	2018/06/17	08:30:00	1600	-11.1667	12.5000
M148_118	66	2019/06/18	06:00:00	50	-10.5267	13.4617
M148_120	67	2019/06/19	07:00:00	45	-10.5050	13.4950
M148_124	68	2019/06/20	18:30:00	45	-6.2100	12.1000
M148_129	70	2019/06/20	19:30:00	80	-6.2792	11.9000
M148_133	72	2019/06/21	00:00:00	120	-6.3403	11.7000
M148_137	74	2019/06/21	03:30:00	345	-6.4028	11.5000
M148_140	76	2019/06/21	07:30:00	840	-6.4842	11.2500
M148_148	80	2019/06/22	21:30:00	696	-10.7342	13.1500
M148_151	81	2019/06/23	00:30:00	150	-10.6538	13.2700
M148_153	82	2019/06/23	03:00:00	90	-10.5700	13.3950
M148_155	83	2019/06/23	05:00:00	50	-10.5267	13.4617
M148_171	87	2019/06/25	06:00:00	1997	-15.0324	11.4200
M148_174	90	2019/06/26	01:00:00	1441	-15.1946	11.7240
M148_176	92	2019/06/26	04:30:00	1000	-15.2564	11.8379
M148_179	95	2019/06/26	07:30:00	500	-15.3179	11.9518
M148_180	96	2019/06/26	08:30:00	90	-15.3389	11.9911
M148_181	97	2019/06/26	09:30:00	50	-15.3488	12.0094
M148_183	98	2019/06/27	10:30:00	110	-17.4993	11.6163
M148_184	99	2019/06/27	14:00:00	110	-18.9995	12.2836
M148_185	100	2019/06/27	21:00:00	110	-19.9997	12.8164
M148_186	101	2019/06/28	04:00:00	110	-20.9996	13.3137
M148_187	102	2019/06/28	10:00:00	110	-21.9993	13.7831
M148_188	103	2019/06/28	15:00:00	110	-22.6654	14.2164

8 Data and Sample Storage and Availability

A joint data management team in Kiel is set up to store the data from various projects and cruises in a web-based multi-user-system. Data gathered during M148/1 are stored at the Kiel data portal OSIS, and remain proprietary for the PIs of the cruise and for members of BMBF-BANINO project. All data will be submitted to PANGAEA within 3 years after the cruise, i.e. latest by June 2021. Some of the data sets collected during M148/1 have already been made publicly available. Digital object identifiers (DOIs) are automatically assigned to data sets archived in the PANGAEA Open Access library making them publicly retrievable, citable and reusable for the future. The list of files submitted to the OSIS data base and all metadata are publicly available via the following link: https://portal.geomar.de/metadata/leg/show/344913.

Table 8.1 Overview of data availability

Data Type	Database	Available	Free Access Link	Contact Person (E-mail address)
CTD/O_2 profiles	PANGAEA	2021	PANGAEA.928997	G. Krahmann, GEOMAR, (gkrahmann@geomar.de)
Underway – CTD profiles	OSIS	02/2019	OSIS.344913	G. Krahmann, GEOMAR, (gkrahmann@geomar.de)
Underway Thermosalinograph data	OSIS	12/2020	OSIS.344913	G. Krahmann, GEOMAR, (gkrahmann@geomar.de)
ADCP (38kHz and 75kHz)	PANGAEA	2021	PANGAEA.937657	M. Dengler, GEOMAR, (mdengler@geomar.de)
lADCP	PANGAEA	2022	PANGAEA.939883	G. Krahmann, GEOMAR, (gkrahmann@geomar.de)
Microstructure shear and temperature profiles	PANGAEA	2023	PANGAEA.953871	M. Dengler, GEOMAR, (mdengler@geomar.de)
Glider data (T, S, P, O_2, chl-*a*, turb., NO_3, microstructure)	OSIS	12/2020	OSIS.344913	G. Krahmann, GEOMAR, (gkrahmann@geomar.de)
Microstructure data from glider ifm09 survey	OSIS	12/2020	OSIS.344913	M. Dengler, GEOMAR, (mdengler@geomar.de)
Mooring data from KPO 1200	PANGAEA	2021	PANGAEA.931374	R. Imbol Koungue, GEOMAR (rimbol@geomar.de)
Mooring data from KPO 1215	PANGAEA	2021	PANGAEA.939249	R. Hummels, GEOMAR, (rhummels@geomar.de)
Hydrochemistry of water samples (nutrients, O_2, nutrient isotopes)	OSIS	06/2019	OSIS.344913	D. L. Arévalo-Martínez, GEOMAR (darevalo@geomar.de)
Water column N_2O concentration measurements	OSIS	12/2020	OSIS.344913	D. L. Arévalo-Martínez, GEOMAR (darevalo@geomar.de)
Underway measurements of dissolved N_2O and CO in surface waters and atmosphere	OSIS	12/2020	OSIS.344913	D. L. Arévalo-Martínez, GEOMAR (darevalo@geomar.de)
Raw multibeam EM122 Echosounder data	PANGAEA	11/2019	PANGAEA.963171	A.-C. Wölfl, GEOMAR (cwoelfl@geomar.de)
Samples of micro plastic	Please contact PI			C. R. Löscher, SDU (cloescher@biology.sdu.dk)

9 Acknowledgements

We are grateful to Rainer Hammacher and his crew for the excellent collaboration and the pleasant working atmosphere during the cruise. The crew of R/V METEOR greatly contributed to the success of the cruise. The ship time of METEOR was provided by the German Science Foundation (DFG) within the core program METEOR / MERIAN. Financial support was provided German Federal Ministry of Education and Research (BMBF) as part of the cooperative projects “Southwest African Coastal Upwelling System and Benguela Niños II” (SACUS) and “Regional Atlantic Circulation and Global Change“ (RACE II).

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11 Abbreviations

ABFZ	Angola Benguela Frontal Zone
ADCP	Acoustic Doppler Current Profiler
BMBF	Federal Ministry of Education and Research
BSH	Bundesanstalt für Schifffahrt und Hydrographie

CTD/O_2	conductivity, temperature, depth and oxygen probe
CO	carbon monoxide
CO_2	carbon dioxide
GHG	greenhouse gas
LADCP	lowered acoustic Doppler current profiles
MSS	microstructure system
N_2O	nitrous oxide
NatMIRC	National Marine Information and Research Center
NH_4^+	Ammonium
NO_3^-	Nitrate
NO_2^-	Nitrite
OMZ	oxygen minimum zone
OS	Ocean Surveyor
PAR	photosynthetically active radiation
PO_4^{3-}	Phosphate
POGO	Partnership for Observation of the Global Ocean
PP	primary production
RACE	Regional Atlantic Circulation and Global Change
SACUS	Southwest African Coastal Upwelling System and Benguela Niños
SSS	sea surface salinity
SST	sea surface temperature
TKE	turbulent kinetic energy
TSG	thermosalinograph
uCTD	underway conductivity, temperature, and depth probe
UVP	underwater vision profiler
VMADCP	vessel-mounted acoustic Doppler current profiler

12 Appendices

12.1 Selected pictures of shipboard operations

Fig. 12.1 M148/1 activities at 11°S off Angola during the upwelling process study. Upper right picture shows the deployment of a lander measuring ocean currents. Upper left shows the retrieval of the top buoy of the mooring deployed at 11°S in 1200m water depth. Lower right picture shows the retrieval of buoyancy elements of the same mooring. Lower right picture shows the deployment of an ocean glider from a rubber boat.