IFM-GEOMAR REPORT

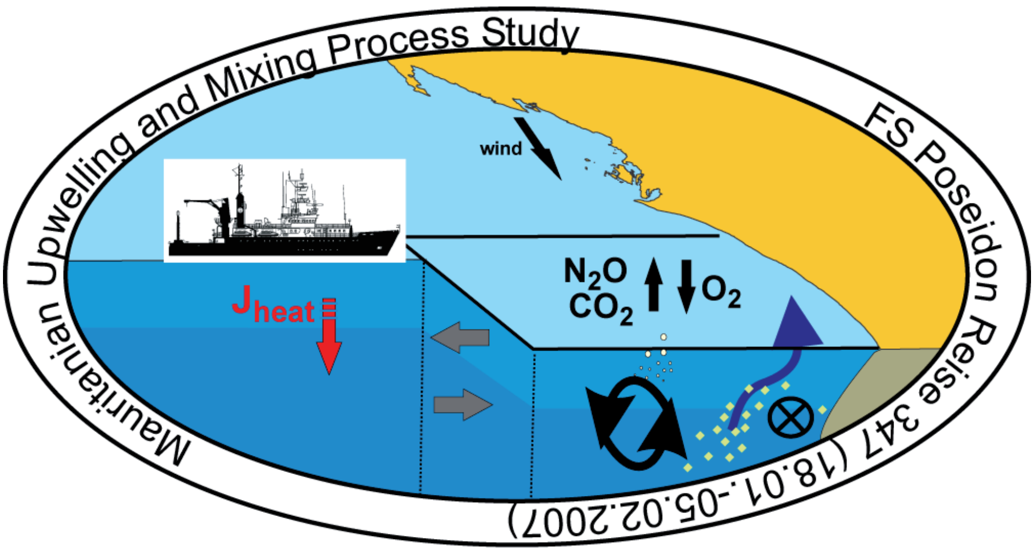
IFM-GEOMAR

Leibniz-Institut für Meereswissenschaften
an der Universität Kiel

FS Poseidon
Fahrtbericht / Cruise Report P347

Mauritanian Upwelling and Mixing Process Study (MUMP)

Las-Palmas - Las Palmas
18.01. - 05.02.2007



Berichte aus dem Leibniz-Institut
für Meereswissenschaften an der
Christian-Albrechts-Universität zu Kiel

Nr. 16
Juli 2008

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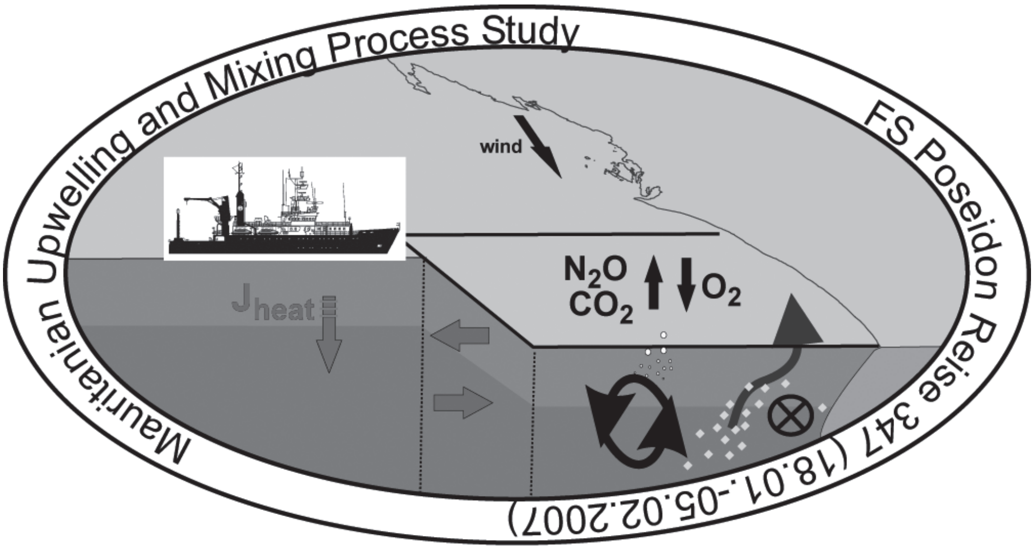

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Cruise Report

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R/V Poseidon Cruise No.: 347

Cruise Schedule: 18 January – 5 February 2007

Research Topics: Physical Oceanography, Marine Biogeochemistry

Oceanic Region: Upwelling regime off Mauritania in the northern tropical Atlantic

Ports of Call: Las Palmas (Canary Islands, Spain)

Institute: IFM-GEOMAR. Kiel, Germany

Chief Scientist: Dr. Marcus Dengler, IFM-GEOMAR, Kiel, Germany

Number of Participants: 10 Scientists/Technicians

Projects: Mauritanian Upwelling and Mixing Process Study (DFG), Junior Research Group "Microstructure" (DFG), Surface Ocean Processes in the Anthropocene (BMBF)

Contents

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J. Toole – Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, USA
J. Ould – Institut Mauritanie des Recherches Océanographic et de Pêches, Mauritania

2 Research program

2.1 Research objectives

The overall goal of R/V Poseidon's cruise P347 was to quantify physical and biogeochemical processes in the upwelling region off Mauritania during the period of maximum upwelling. It combined the research objectives of the DFG Emmy Noether Junior Research Group "Microstructure" and sub-project theme 3 of the BMBF joint project SOPRAN (Surface Ocean Process in the Anthropocene). The main goal of the Junior Research Group, which was established at IFM-GEOMAR beginning of 2006, is to quantify the impact of diapycnal mixing processes on the variability of sea surface temperature within the equatorial cold tongue and eastern upwelling regions of the tropical Atlantic. SOPRAN Theme 3 addresses the within-ocean processes that control the sea-to-air flux of a range of trace gases that have major impacts on the Earth System: both through direct impacts on the radiation balance, and through more indirect impacts via alteration of atmospheric chemistry.

The research program carried out during Poseidon cruise P347 focused on

- investigating turbulent mixing processes and quantifying diapycnal fluxes of heat, trace gases and nutrients
- investigating the large scale circulation and its variability in the upwelling region
- quantifying lateral exchange between the shelf region and deeper ocean by eddies, filaments and advection
- quantifying the air-sea gas exchange of the greenhouse gases carbon dioxide (CO_2) and nitrous oxide (N_2O)
- estimating vertical advection into the mixed layer using vertical distributions of isotope helium-3 (^3He) and sulphur hexafluoride (SF_6) in combination microstructure measurements
- quantifying the variability of anthropogenic CO_2 in the waters off Mauritania using SF_6 and chlorofluorocarbons (CFC-12).

2.2 Measurement program

The target area of the measurement program was a rectangular region off Mauritania extending from the northwestern position at 18.5°N, 17.5°E to the south-eastern position at 17.5°N, 16.25°E (Fig. 1). This region enclosed parts of the Mauritanian shelf region, the continental slope as well as deeper waters. The measurement program consisted of three components

(i) continuous shipboard measurements of multiple oceanic and atmospheric variables
(ii) CTD-O_2 and microstructure measurements performed during ship stations that included parameters measured from the water samples collected by the CTD rosette system

(iii) observations from moorings that were deployed at the beginning and retrieved near the end of the cruise

Continuously sampled variables included upper ocean velocity (20-600m) from a shipboard acoustic Doppler current profiler (ADCP), sea surface temperature and salinity from a thermosalinograph, water depth, and atmospheric parameters such as wind speed and direction, air temperature, air pressure and humidity. In addition a surface water pump system was installed that allowed a continuous sampling of pCO_2, nitrate, dissolved oxygen (O_2), chromophoric dissolved organic matter (CDOM) and chlorophyll.

On stations, conductivity-temperature-depth-dissolved oxygen (CTD-O_2) profiles were collected. The CTD-O2 system was mounted on a rosette frame with 12 bottles. The water samples were analyzed for O_2, N_2O, SF_6, CFC-12, He^3, nutrients, salinity, total organic matter (TOC) and chlorophyll. Prior or after CTD casts and during two long duration stations (24 hours and 8 hours), microstructure shear and temperature measurements were performed using different microstructure profilers.

Two moorings were deployed and recovered during the cruise. One mooring (MUMP1) was deployed on the continental slope at 18°N in a water depth of 380 m. The mooring was equipped with a moored profiler that performed velocity and CTD measurements in the depth range from 50 m to 380 m every 45 minutes. Additionally, an ADCP. near bottom velocity and temperature-salinity recorders were attached. A second mooring on the shelf (MUMP2) at 18°N, 16.25°W collected high vertical resolution velocity time series using a 1200 kHz ADCP.

The section program completed during the cruise consisted of a zonal section at 18°N, repeated sampling along a box that encompasses the rectangular research area and several short sections perpendicular to the continental slope (Fig. 1).

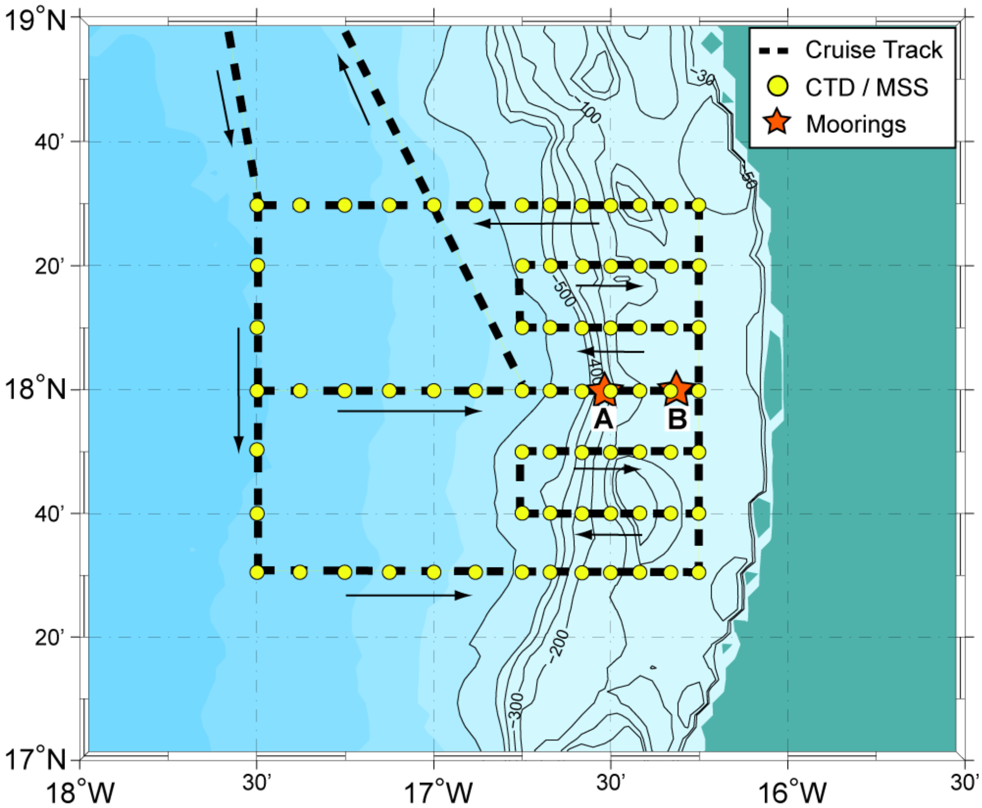

Fig. 1: Cruise track and positions of CTD/MSS stations during P347.

3. Narrative of cruise

R/V Poseidon left Las Palmas, Canary Islands as scheduled at 9:00 on 18 January 2007 for a transit leg towards the Mauritanian upwelling region. A test station was performed on January 20 at 14:00 hours that included testing of the CTD-O_2 rosette and microstructure systems. The oxygen sensor on the CTD-O_2 system was malfunctioning and needed top be replaced. However, all three microstructure profiling systems indicated good performance and required no further modification. Station work began at 8:00 UTC of January 21, with the first station along the 18°N section at 17°30'W. The 18°N section that had been surveyed during previous boreal winter cruises in 2005 and 2006 was repeated to study the variability of currents and hydrography as well as of biogeochemical parameters in the water column. On the third station along the 18°N section, a short circuit damaged the CTD system (IFM-GEOMAR's SBE5). The Seabird 911 plus system could not be repaired and a spare CTD system (IFM-GEOMAR's SBE3) was used from this station onward (Tab. A1). The section was terminated at 18:00 UTC on the 22 January. Altogether, 11 stations were completed on 18°N (Tab. A1). At each station one or two CTD-O_2 casts and three to five microstructure profiles were collected.

Two moorings were deployed along 18°N. One of the moorings (MUMP1) was positioned on the continental slope in a water depth of 380 m to study the variability of the eastern boundary current and to acquire information on barotropic and baroclinic tides on the continental slope. The 380 m isobath was reached at 9:45 UTC on January 22. After a survey of bottom topography, the deployment of MUMP1 began at 10:24 UTC and ended 11:02 UTC at the position 17°59.65'N, 16°32.0'W. The second mooring (MUMP2) was deployed at the eastern end of the 18°N section at 16°16.15' W in a water depth of 38 m. Deployment started at 16:20 UTC in the afternoon of the same day and finished 10 minutes later. The mooring consisted of an upward-looking 1200 kHz ADCP attached close to the anchor to observe the variability of turbulence on the continental shelf in conjunction with tidal bores that are generated at the shelf break and travel towards the shore region of Mauritania. Both deployment operations were successful thanks to a well functioning collaboration between able seaman and scientific staff.

Following the 18°N section, two short zonal sections perpendicular to the continental slope and onto the shelf region along latitudes 18°10'N and 18°20'N were completed using a dense station spacing of 5 nm. On the first station of the 18°10'N section, a water leakage into the microstructure profiler in use (MSS 32) was detected. The profiler was replaced by MSS 26 that was used from there onward. At each station, five microstructure profiles and a CTD profile were collected. The region of strong coastal upwelling off Mauritania is located close to the shelf break in a water depth between 30 m and 100 m. This was not only suggested from the collected data, but could also be inferred from the numerous fishing trawlers that we observed in this region. The measurements from the short sections running perpendicular to the bathymetry will be used to investigate and quantify the physical and biogeochemical processes in the region of maximum upwelling.

Shortly after midnight of January 24, a section along 18°30'W was begun as part of a box that encompasses the rectangular research area. Similar to the 18°N section a suite of additional water samples were collected along this box that included SF6, He^3, N_2O, nutrients and TOC. Attempts will be made to budget the fluxes of these different parameters on different density surface within the box to quantify vertical and diapycnal fluxes associated within the upwelling region. The south-eastern most station of the box was reached at 23:00 UTC of January 26, nearly three days after beginning the box. During the box survey, northerly wind having wind speeds between 14 and 24 knots prevailed.

After completing two additional short zonal sections perpendicular to the continental slope and onto the shelf region along latitudes 17°40'N and 17°50'N, a long-duration microstructure station (30 hours) was conducted on the shelf and continental slope at 18°N from January 27 and 28. The measurements will be used to investigate the temporal variability of diapycnal mixing processes associated with baroclinic tides. Every three hours, a CTD cast was performed. Calm weather conditions with the northeast trade winds blowing at 5 to 14 knots were experienced during the 30 hour station while local upwelling was only little pronounced. Altogether, 192 microstructure profiles were collected during the long-duration station using the MSS26 and MSS28 systems.

At 6:00 in the morning on January 29 a second box encompassing the upwelling region was begun at the northwestern position 18°30'N and 16°20'W. Maximum depth of CTD casts during transects was set to 500 m. The second box was completed at 2:00 in the morning of January 31. During the box survey, winds were stronger than during the previous survey and between 19 and 25 knots. Two short sections along the continental slope and shelf regions of latitudes 17°40'N and 17°50'N followed the box survey. In between the two sections, a six-hour microstructure station was carried out on 17°50'N, 16°20'W starting on January 31st at 22:00 UTC. Altogether, 84 microstructure profiles were collected on that station.

In the morning of February 1st Poseidon returned to 18°N and the shelf mooring (MUMP 2) was recovered at 8:20 UTC. All instruments had performed well. After performing 4 CTD stations along the shelf at 18°N, the position of mooring MUMP1 was reached at 13:15 UTC. The recovery of the mooring again worked well. All instruments except the down-looking ADCP had recorded excellent data. Following the mooring recovery a microstructure profiler calibration casts was performed for which the microstructure profiler was attached to the rosette of the CTD. During the CTD cast, both systems collected data simultaneously and the differences between the CTD and microstructure CTD sensors will be used to calibrate the latter. Two more CTD casts were then performed along 18°N.

Station work was completed on 18°N, 16°40'W at 21:45 UTC. On the way returning to Las Palmas strong northerly winds were encountered. However, R/V Poseidon managed to arrive as scheduled.

4 Technical aspects and preliminary results

4.1 CTD-O_2 measurements

a) Technical aspects

Two different Seabird SBE 9 plus systems were used during the cruise, IFM-GEOMAR's SBE-3 and SBE-5 system. CTD-O_2 measurements on the test station and the first three stations were performed using the SBE-3 system. During the third station along the 18°N section, a short-circuit in one of the connectors to the CTD damaged the electronics in the main housing of the SBE-3 as well as the deck unit when the rosette had just returned on deck. Neither the CTD nor the deck unit could be repaired during the cruise and both devices were replaced. The SBE-5 system which attached to the deep sea winch after the third station worked well throughout the remaining period of the measurement program.

During the cruise a total of 126 CTD-O_2 profiles were collected. CTD casts were usually taken to the bottom, except for the stations during the repeat box survey, where CTD depth was limited to 500 m. Due to a well functioning mechanical bottom detector and advertent operators, the CTD had no ground contact during the cruise. Similarly, the Seabird bottle release unit used with the rosette worked well throughout the cruise. However, some leakages of the bottles did occur occasionally.

Different methodologies were used for the calibration of the CTD sensors. While the CTD temperature and pressure sensors were calibrated in the calibration laboratory of IFM-GEOMAR before and after the cruise, the conductivity and the oxygen sensors were calibrated using water samples collected during the cruise that were analyzed for salinity and oxygen content respectively. Onboard salinity analysis was carried out using a Guildline Autosal salinometer (AS 5, S/N 50387). To ensure high-quality data, salinity analysis with the salinometer were performed during night time only - when air temperatures were

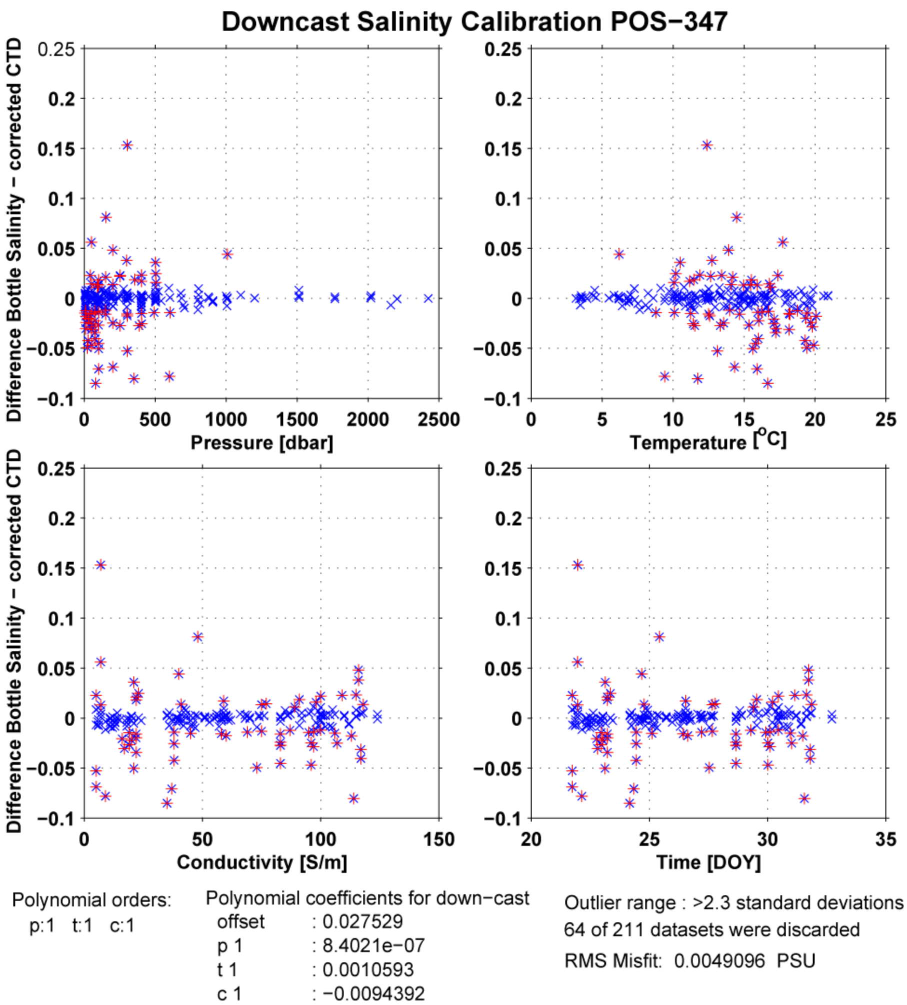

Fig. 2: Calibration of conductivity sensor. Differences between analyzed salinity samples and CTD salinity after calibration against pressure (upper left), temperature (upper right), conductivity (lower left) and time (lower right). Linear coefficients p1, t1 and c1 were used to calibrate CTD conductivity.

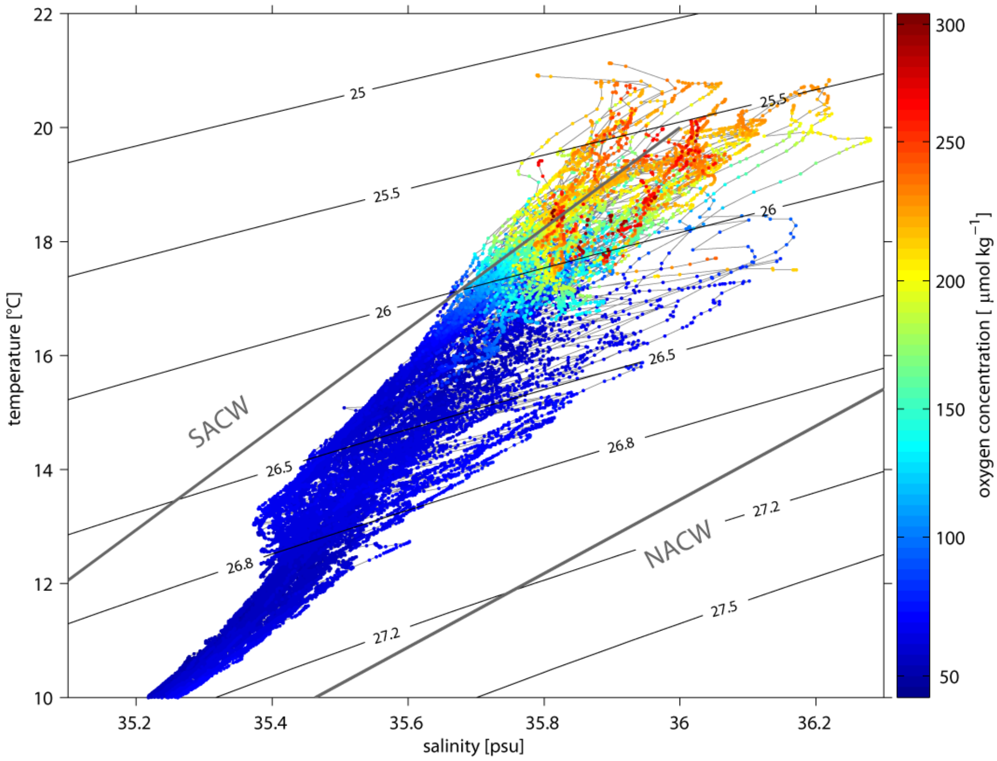

Fig. 3: θ-S diagram of all CTD profiles acquired during P347. Color code of the diagram indicates oxygen content. Grey lines labeled SACW and NACW indicate characteristics of South Atlantic Central Water and North Atlantic Central Water.

fairly constant. The AS 5 worked well throughout the cruise. Altogether, 211 salinity values from the water samples were available. Conductivity sensor calibration was performed using a multi linear fit of temperature, conductivity and pressure. For the fit, only salinity samples that were within a range of 2.3 times the standard deviation of the observed differences were used (Fig. 2). Tests using quadratic fits in some or all of the dependencies did not improve the overall quality in a significant manner. We chose the downcast as final dataset for several reasons:1) Sensor hysteresis starts from a well defined point, 2) the incoming flow is not perturbed by turbulence generated by the CTD-rosette, and 3) long stops during the upcast profiles lead to unsteady profiles over depth. For the downcast conductivity, we got a root mean square (rms) difference of 0.00050 S/m corresponding to a rms salinity of 0.00491 psu (Fig. 2). A comparison of up- and downcast profiles shows that the intrinsic time and space variability are much larger than the uncertainties involved in the calibration processes.

For the oxygen calibration the oxygen content of water samples was determined by the Winkler's titration method. Altogether, 442 oxygen samples were available (for details see section 4.6). Similarly as for conductivity, the downcast oxygen content was calibrated using all samples within 2.8 standard deviations of the observed salinity differences. This included 316 of the samples and led to a rms difference of 0.069 ml/l using a multi-linear correction for temperature (t1=0.005135), pressure (p1=0.000197) and oxygen (o1=0.39106) itself as well as an offset of -0.061587. The CTD data were recorded using Seabird Seasave V7.12 software.

b) Preliminary results
Near surface waters encountered during the cruise in the rather small rectangular survey region off Mauritania were between 16.5°C close to shelf break and 21°C farther offshore (Fig. 3). In general, the central water mass found in the survey region are dominated by South Atlantic Central Water (SACW, Fig. 3) that is formed in the subduction regions of the South Atlantic between 25°S and 40°S. This implies that the Cape Verde Frontal Zone at which SACW and NACW meet, which is usually found between 10°N and 15°N, is located further to the north at the eastern boundary of the tropical North Atlantic. A possible explanation for the dominance of SACW in the survey region is the northward advection of SACW within the eastern boundary current (see section 4.3 and 4.4 for details).

4.2 Microstructure measurements

One of the major objectives of the scientific program was to investigate turbulent mixing processes and to quantify diapycnal fluxes of heat, trace gases and nutrients in the Mauritanian upwelling region. For this reason, an intensive microstructure measuring program was carried out collecting a total of 582 microstructure profiles (MSS) at 100 stations (Fig. 4, Tab. A2).

a) Technical aspects
The three microstructure profiling systems used during the cruise were all manufactured by ISW-Messtechnik in collaboration with Sea and Sun Technology (Trappenkamp, Germany) and consist of profilers (MSS 26, MSS 28 and MSS 32), winches and data interfaces. Each profiler can operate 16 channels with a very high data transmission rate (1024 Hz) that is sufficient to resolve micro-scale gradients (~0.6 mm) of velocity shear and temperature that

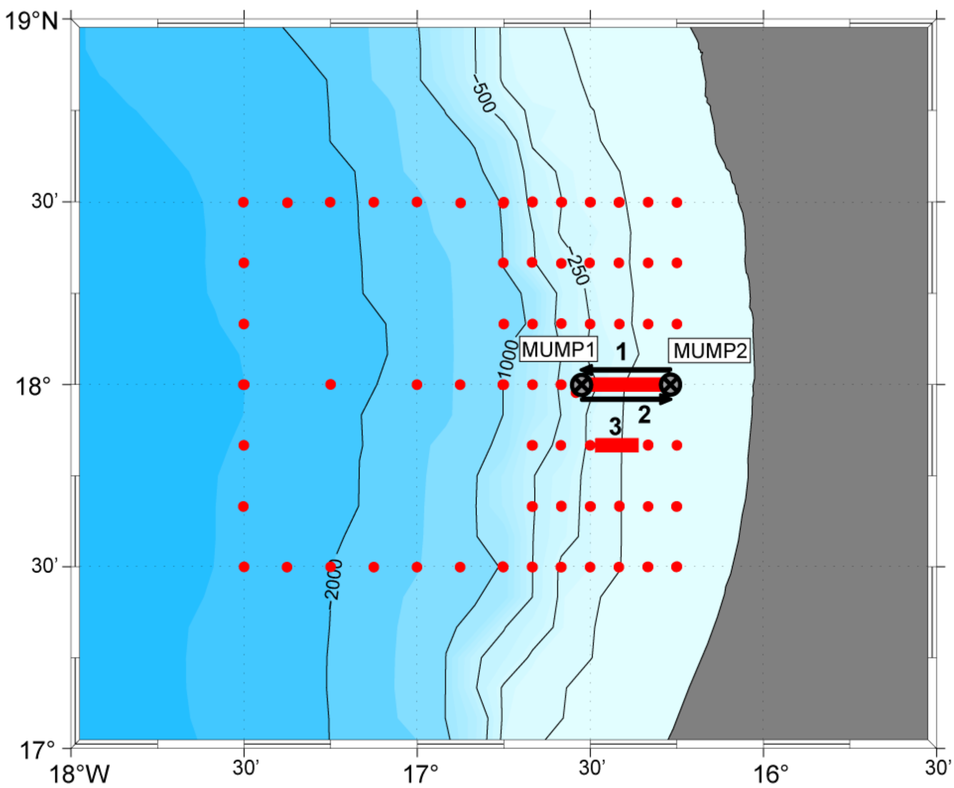

Fig. 4: Map of microstructure measurement positions. Red dots represent positions of repeated microstructure profiles. 1, 2 and 3 mark the positions of long duration stations, while black arrows show direction of associated transects.

can be used to infer turbulent fluctuations in the ocean. Common sensors on all three profilers were two shear probes (airfoil, 4ms response time), a fast-responding temperature sensor (Thermistor FP07, 12 ms response time), an acceleration sensor and conductivity, temperature and pressure sensors that sample at a lower frequency (24 Hz). In addition, some of the profilers were equipped with oxygen, turbidity, tilt and a microstructure conductivity sensor (for details see Tab. 1 to 3). The loosely-tethered profilers were optimized to sink at a rate of about 0.6 m/s and are capable of measuring to a depth of 2000 m (MSS 28 only to 500 m). Shear fluctuations recorded due to vibration of the profiler while sinking can be diagnosed from the spectra of the acceleration sensor time series.

Routinely, MSS casts were made from the surface to a depth of 150-250 m or to a few meters above bottom in shallower waters. At each CTD station, 3 to 5 MSS profiles were collected. Additionally, three long-duration stations near the continental slope and the shelf were conducted during which MSS casts were continuously performed. Two of the long-duration stations were performed near the mooring sites (marked by A, B in Fig.1) MUMP1

Tab. 2: Setup Microstructure Probe MSS 32 (P1)

Sensor	Type	Responds time	Serial No.
Temperature	PT100	40 ms	
Conductivity	ADM	40 ms	
Pressure	PA-50 Progress	40 ms	
Oxygen	Oxyguard		DO4522M18
Acceleration	ACC	4 ms	8023
Turbidity	Seapoint bulkhead		
Tilt X	ADXL 203		
Tilt X	ADXL 203		
Shear	Airfoil	4 ms	6070
Shear	Airfoil	4 ms	6071
Temperature	NTC; FP07	12 ms	

Tab. 3: Setup Microstructure Probe MSS 26 (P2)

Sensor	Type	Responds time	Serial No.
Temperature	PT100	40 ms	
Conductivity	ADM	40 ms	
Pressure	PA-50 Progress	40 ms	
Acceleration	ACC	4 ms	8022
Tilt X	ADXL 203		
Tilt X	ADXL 203		
Shear	Airfoil	4 ms	6055
Shear	Airfoil	4 ms	6058
Shear	Airfoil	4 ms	6057
Shear	Airfoil	4 ms	6075
Shear	Airfoil	4 ms	0603
Temperature	NTC; FP07	12 ms	40

Tab. 4: Setup Microstructure Probe MSS 28 (P3)

Sensor	Type	Responds time	Serial No.
Temperature	PT100	40 ms	
Conductivity	ADM	40 ms	
Pressure	PA-50 Progress	40 ms	
Oxygen	Oxyguard		DO522M18
Acceleration	ACC	4 ms	8023
Shear	Airfoil	4 ms	6064
Shear	Airfoil	4 ms	6054
Shear	Airfoil	4 ms	6074
Shear	Airfoil	4 ms	6019
Temperature	NTC; FP07	12 ms	38
Conductivity	Microstructure C-sensor	4 ms	13

(18°N, 16°31.5'W) and MUMP2 (18°N, 16°16.1'W). A third long duration station of around 7 hours was carried out along the continental slope and the shelf at 17°50'N close to the position of MUMP2 (see Tab. A2 in the appendix for details).

Profiles were collected while the vessel was steaming at about 1.5 kn from the ship's stern. At station 125 our microstructure probe 32 send unrealistic pressure values, so we had to replace the profiler. The reason for this error was some water inside of the housing. Although we found the source of the leakage, from that on we used the MSS 26, which worked well until the end of the cruise, as well as all other parts of our equipment.

b) Preliminary results

As had been suggested by data from previous cruises, turbulence and thus diapycnal mixing away from the continental slope is low (Fig. 5). Below the mixed layer, average dissipation rates of turbulent kinetic energy here are below $1x10^{-9}Wm^{-2}$, although there are occasional events of enhanced mixing due to baroclinic inertial waves. On the shelf and along the continental slope, however, elevated levels of turbulent dissipation rates are observed. Levels are particularly high near the bottom of the continental slope and at the shelf break.

An energy source for enhanced mixing occurring in this region is from breaking of internal tides reflecting at the continental slope. As indicated by the velocity time series from the mooring (see section 4.4), baroclinic tides are very energetic and have amplitudes in the order of 0.2 m s^{-1}. The angle of inclination of the continental slope in this region is near the critical angle for reflecting internal tides. Internal waves preserve their angle to the horizontal upon reflection, so that reflection from slopes near the critical angle given above lead to reflected waves with higher wavenumbers and greater shear. Model studies have shown that such a topographic configuration may lead to the generation of internal bores that propagate up the continental slope at some tens of meters above the bottom. In turn, these tidal bores are responsible for enhanced mixing occurring in this depth interval. As indicated by the vertical distribution of stratification (Fig. 6, upper right panel) during the third long-duration microstructure station, a region of weak stratification is found parallel to the sloping bottom suggesting that similar processes might be at work at the continental slope of Mauritania.

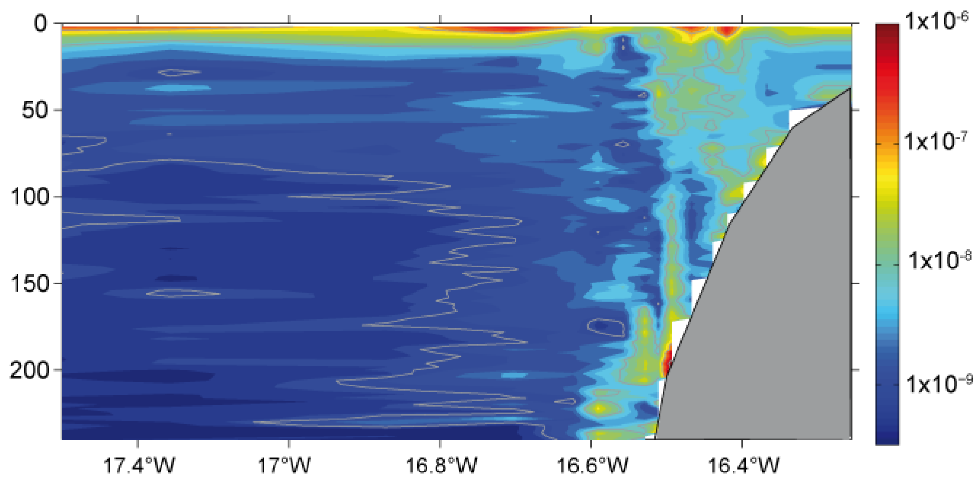

Fig. 5: Average dissipation rate in Wm^{-2} of turbulent kinetic energy from all 582 microstructure profiles sorted in respect to bottom depth.

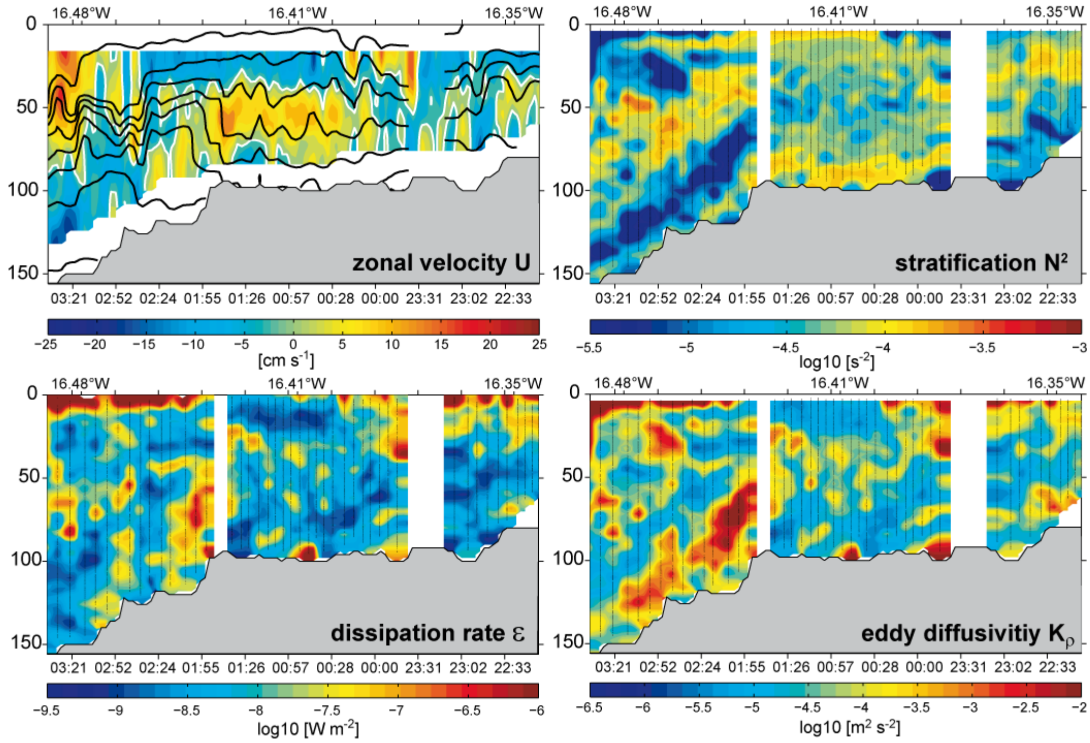

Fig. 6: Zonal (on-shore) velocity and selected isopycnals (black lines), stratification (upper right), dissipation rate of turbulent kinetic energy (lower left) and eddy diffusivities (lower right) against time of measurement and longitude during a long-duration station along the continental slope and onto the shelf.

Internal tidal bores that can be diagnosed by strongly displaced isopycnals and small-scale velocity maxima (Fig. 6, upper right panel) were frequently observed along the continental slope and correlated with enhanced dissipation rates from our microstructure measurements. Baroclinic tides thus appear to be a dominant source of energy for turbulence along the continental slope of Mauritania and are likely responsible for the elevated dissipation rates along the continental slope and at the shelf break (Fig. 5). This process may lead to elevated diapycnal fluxes of trace gases and nutrients from the deeper ocean into the mixed layer at the continental slope.

4.3 ADCP measurements

During P347, continuous upper ocean velocity data were recorded by a vessel-mounted Ocean Surveyor that was installed in R/V Poseidon's moon pool. The Ocean Surveyor (OS) is a newer generation shipboard acoustic Doppler current profiler (ADCP) which uses a phased array transducer consisting of 36 by 36 individual ceramic elements. In contrast to the older narrow band four transducer VMADCP, the OS produces sound pulses at all four beams during the same time and can be operated in either broadband or narrowband mode. R/V Poseidon is equipped with a 75kHz OS that allows to survey velocity in the upper 600 m of the water column.

a) Technical aspects

The systems configuration used during the cruise is briefly described as follows: The OS was controlled by RDI's vessel-mounted data acquisition system (VMDAS, version 1.3). Heading information from a gyrocompass was directly supplied to the electronic chassis via a synchro interface to convert the measured velocities from beam to earth coordinates, which were then recorded by the VMDAS as single ping data. In addition to the velocities, the VMDAS was supplied with real time heading from a 3-D Ashtech GPS receiver and GPS position via two serial interfaces. The VMDAS records these data in separate files ending on N1R and N2R. In post-processing, the erroneous heading from the gyrocompass needs to be corrected using the heading information from the Ashtech ADU2 system to ensure high data quality. The configuration of the 75kHz OS via the VMDAS was not altered during the cruise. We chose to record 100 bins at a sampling rate of about 2.4 s having a bin length of 8 m, a pulse length of 8 m and a blanking interval of 8 m. Considering that the Ocean Surveyor is mounted to the moon pool at 5 m water depth, the uppermost bin is located in a water depth of 21 m.The OS was set to record in narrow band mode, which is the preferable mode for open ocean current measurements.

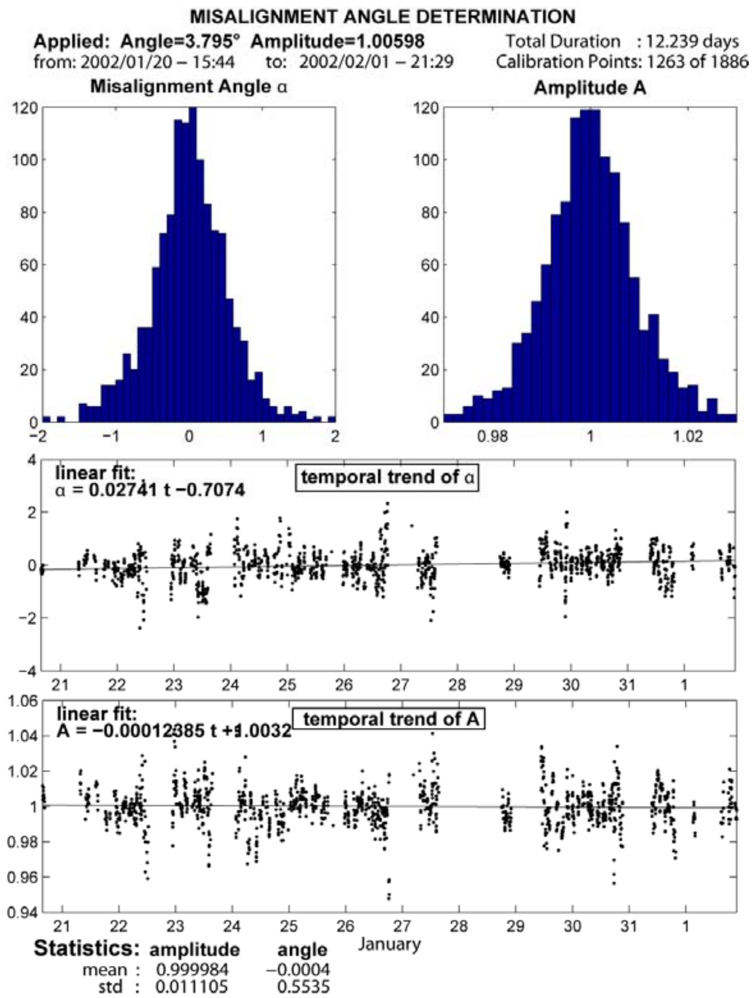

Fig. 7: Water track calibration of misalignment angle and amplitude of the Ocean Surveyor velocity data after applying an angle α=3.795° and an amplitude factor A=1.00598. Upper panels show frequency distribution of calibration points, mid and lower panel show temporal evolution of α and A.

The Ashtec ADU2 system had failed during the previous cruise. For unknown reasons, attempts to fully restore previous setup files before departure failed. It was, however, possible to program the output of all true NMEA strings, which included GPS information and heading information (as $GPHDT), although the ADU2 system continued to refuse sending $GPATT and $GPATT2 strings that are usually used in post-processing of OS velocities. The use of the $GPHDT string does not affect the overall data quality.

Data from the OS was recorded from January 20, 15:45 UTC to February 1, 21:30 UTC. Both the OS and the ADU2 worked well throughout the cruise and a continuous upper ocean velocity data set was obtained. During post-processing, the misalignment angle between the axis of the ADCP and the axis of the ADU2 needs to be determined. This is done by evaluating the rotation of measured velocities during acceleration periods of the vessel. The so called water track calibration resulted in a misalignment angle of 3.795° with a standard deviation σ = 0.554° and an amplitude factor of 1.00598 (σ = 0.011). A temporal dependency to the calibration coefficients was not applied. As indicated by the small standard deviations of the misalignment angle (Fig. 7), ocean surveyor velocity data in combination with the heading data from the Ashetch is of high quality.

b) Preliminary results

As found during a previous boreal winter cruises in 2005, the large scale surface currents off Mauritania exhibited a cyclonic structure (Fig. 8). Northward velocities were dominant close to the shelf break where, as indicated by the chlorophyll distribution (Fig. 8), upwelling was most pronounced. About 100 km offshore, southward velocities appeared dominant. Previous measurement programs in the 1970'ies suggested that during boreal winter and

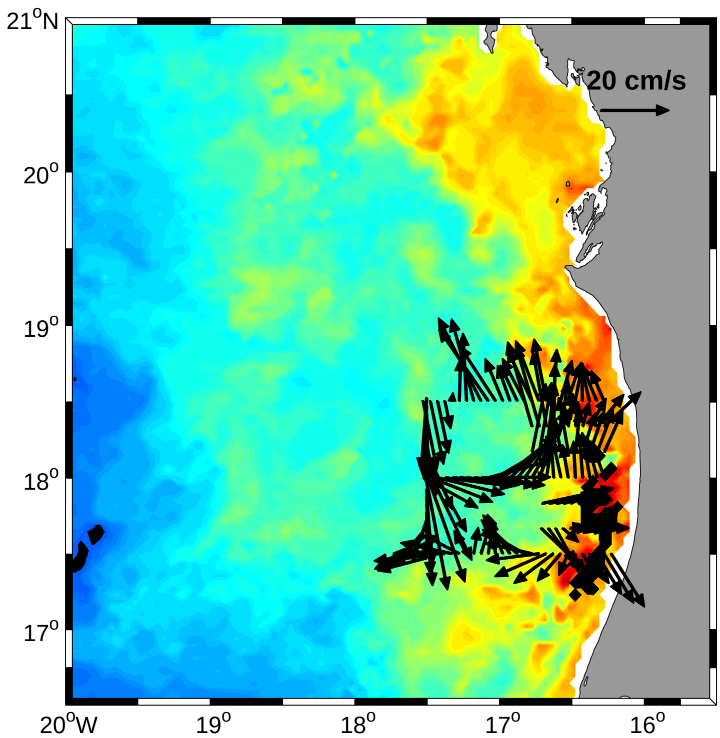

Fig. 8: Average chlorophyll distribution (color contours) and near surface currents (16-24m, black arrows) during the first box survey.

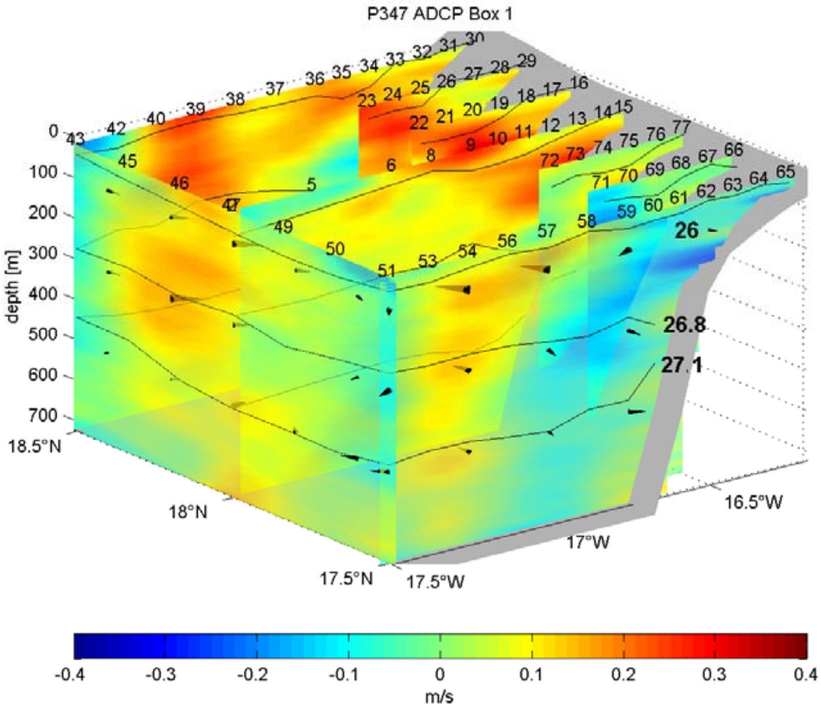

Fig. 9: 3-D distribution of the cross-section velocity component as measured by the ship-board ADCP during the first box survey (January 22 to 27). Black lines indicate isopycnals of σ_θ=26, 26.8 and 27.1 kg m^{-3}. Cone shape features show direction of currents. Upper numbers indicate CTD stations.

spring, a southward flowing current on the continental slope inshore of cylonic gyre is present. This southward current was neither observed during this cruise, nor during a previous cruise in 2005. However, surface currents also show strong variability due to mesoscale eddies and planetary waves.

During most of the sections perpendicular to the continental slope, a northward flowing eastern boundary undercurrent, the Upwelling Undercurrent, could be observed (Fig. 9). The core of the Upwelling Undercurrent was usually located at about 120 m depth and associated velocities were between 0.2 and 0.4 m s^{-1}. However, the Upwelling Undercurrent was absent during some section occupations, particularly during the surveys at 17°30'N and 17°40'N at the end of the first box survey (Fig. 9), indicating strong variability of along-shore velocity in the region of the continental slope on time scales of less than a week.

4.4 Mooring operations

Two moorings were deployed and recovered during the cruise. One mooring (MUMP1) was deployed on the continental slope to determine current and watermass variability of and within the Upwelling Undercurrent as well as to acquire information on barotropic and baroclinic tides on the continental slope. A second mooring (MUMP2) aimed at observing the strength and variability of turbulence on the continental shelf in conjunction with tidal bores that are generated at the shelf break.

a) Technical aspects

Mooring MUMP1 consisted of a down-looking 300 kHz ADCP with a temperature and pressure logger (Mini T), a Moored Profiler (M-CTD), as well as a temperature, pressure, salinity logger (Microcat) and an acoustic current meter (Argonaut) near the bottom of the mooring (Fig. 10, Tab. 5). Prior to the cruise, the density of the Moored Profiler was carefully ballasted to adjust its density to mid-depth conditions at the continental slope. It was programmed to climb up and down the mooring cable in the depth range between 25 m and 370 m, thereby recording three-dimensional velocity data and conductivity, temperature and pressure data. The profiler's descent and ascent velocity is about 0.3 m s^{-1}. To record as much data as possible, we set the profile sampling interval to 45 minutes. The ADCP was configured to use a bin length of 4 m, 50 depth cells, a 60 s sampling interval and 50 pings per ensemble.

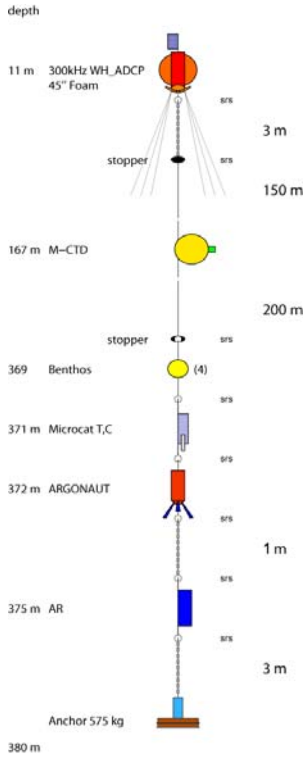

Fig. 10: Instrumental setup of MUMP1.

The second mooring MUMP2 consisted of an upward looking 1200 kHz ADCP mounted close to the bottom that had a temperature and pressure logger (Mini T) attached to it and a temperature, salinity, pressure logger (Microcat) mounted underneath the ADCP (Fig. 11, Tab. 5). The 1200 kHz ADCP is capable of sampling velocity at a very high ping rate and can thus be used to measure turbulent velocity fluctuations in the water column. The following ADCP setup was used: Depth cell was set to 0.5 m, single ping ensemble in beam coordinates were recorded that consisted of 10 internally averaged sub-pings using a Doppler shift averaging technique (Mode 12), the number of depth cells and the ensemble interval was set to 40 and two seconds respectively. Both moorings were deployed at the beginning of the cruise while surveying the 18°N section. Moorings MUMP1 and MUMP2 were deployed in a water depth of 386 m and 41 m respectively (Figs. 11,12, Tab. 5). Deployment duration of both moorings was about 10 days. Except for the 300 kHz ADCP attached to MUMP1, all moored instruments worked well and returned high quality data (Tab. 5). For unknown reasons, the 300 kHz ADCP failed to wake up and start pinging at a specified date after deployment and thus did not record any data. The moored profiler completed its mission correctly and recorded 311 CTD and velocity profiles. However, after about four days, the profiler was unable to climb to the upper stopper at 25 m depth and instead stopped its ascent at depths between 70 m and 90 m. This problem had previously occurred during deployments in deeper waters and may arise from the isolation of the mooring cable that looses track after a certain numbers of passes by the profiler. The data set was post-processed using McLane Moored Profiler data reduction and processing procedures (version: November 2006) made available by John Toole, Woods Hole Oceanographic Institute. Data from temperature-pressure loggers (Mini T) and the Microcats were

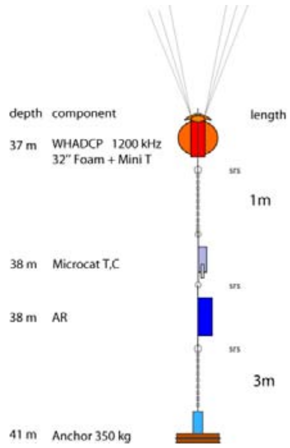

Fig. 11: Instrumental setup of MUMP2.

***Tab. 5:** Obtained moored time series*

MUMP 1	**Lat: 17°59.65'N, Lon: 16°32.00'W°, Water Depth: 386m Start: 2007/22/01 10:26 Stop: 2007/02/01 13:15**			
Instrument	**Serial No.**	**Variables**	**Depth**	**Sampling rate**
Mini T	3388	t,p	25m	300s
Moored Profiler	RO1 (JT)	profiles of u,v,w,p,t,c	40-380m	45 min/profile
Microcat	2249	t,c	385m	180s
Argonaut	179	u,v	386m	180s

MUMP 2	**Lat: 18°00.08'N, Lon: 16°16.15'W°, Water Depth: 41m Start: 2007/22/01 16:28 Stop: 2007/02/01 08:20**			
Instrument	**Serial No.**	**Variables**	**Depth**	**Sampling rate**
ADCP (1200kHz)	001	profiles of u,v,w	17-37m	2s
Mini T	56	t,p	38m	300s
Microcat	2251	t,c	39m	180s

calibrated against CTD measurements that were obtained during a calibration cast at which the loggers were attached to the rosette of the CTD. After calibration, temperature time series were accurate to 0.01°C, salinity to 0.005 and pressure to 1 dbar.

b) Preliminary results

The average velocity profile from the 10-day deployment period of the Moored Profiler indicates northward velocities along the continental slope between 50 m and 250 m depth, indicative for a pronounced Upwelling Undercurrent (Fig. 12). The core of the eastern

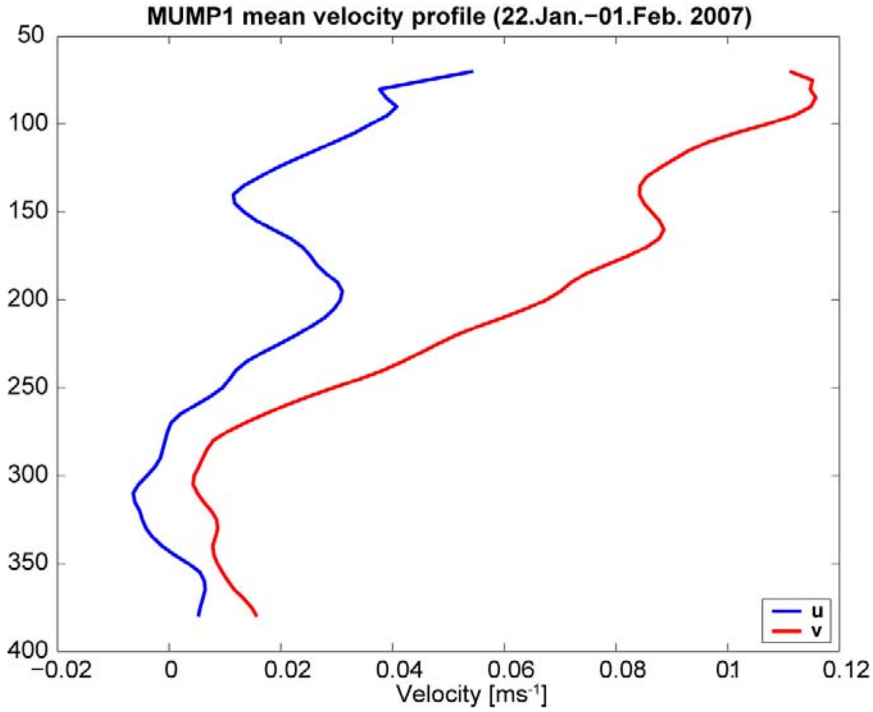

Fig. 12: Mean velocity profile as measured by the Moored Profiler at the continental slope.

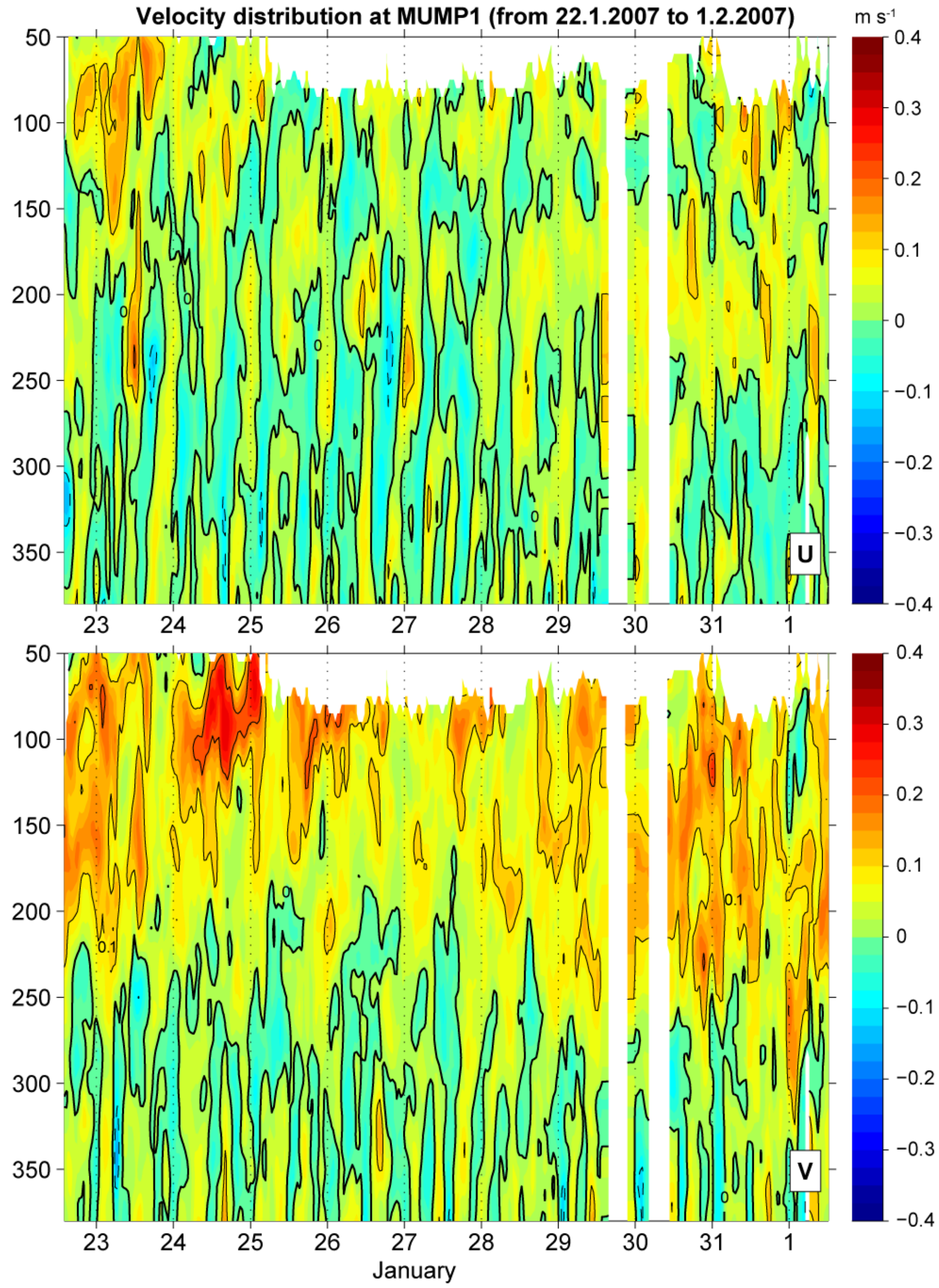

Fig. 13: Time series of zonal (across-shore, upper panel) and meridional (longshore, lower panel) velocity profiles collected by the moored profiler deployed at 386m depth.

boundary current is located between 50 m and 100 m having maximum average velocity of above 0.1 m s^{-1}. Northward velocities in the core persisted during the deployment period, but varied between a few cm s^{-1} to 0.5 m s^{-1} (Fig. 13, lower panel).

The most prominent signal of variability in the velocity profile time series is of tidal origin (Fig. 13). Strong oscillating currents with periods of the M_2 tide (12.4 hours) and amplitudes up to 0.2 m s^{-1} were observed in both velocity components, being somewhat more pronounced in the zonal velocity (i.e. cross-shore velocity). A preliminary analysis of the velocity data showed that most of the tidal signal can be attributed to baroclinic tides as amplitudes of the barotropic tide are only about 0.03 ms^{-1}. During several occasions, e.g. at noon on 23rd and just before midnight on the 26th of January, particularly elevated baroclinic tidal flows having vertical scales of about 50 m were found at about 250 m depth (Fig. 13, upper panel). These features could represent internal tidal bores that are generated when cross-shore tidal currents change directions. As mentioned before, model simulations of tides interacting with the continental slope indicated the generation of tidal bores some tens of meters above the seafloor on the continental slope that subsequently propagate towards the shelf and enhance mixing in the region where they propagate. These observations could thus explain the low stratification regions parallel to the continental slope at a depth of 50 m above the bottom (Fig. 6).

Apart from enhancing current variability, baroclinic tides also significantly displace water parcels in respect to the vertical. Average vertical displacement calculated from the temperature profiles of the Moored Profiler were about 40 m at a depth of 200 m and 60 m at a depth of 350 m. This variability needs to be taken in account when analyzing distribution of oceanic properties on isobars.

4.5 Chemistry observations

One objective during the cruise was to sample the perimeters of a “box” with nutrients and oxygen in order to be able to do a mass-balance in the upwelling region. A second objective was to do repeat sampling of the trace gases N_2O, CFC-12 and CF_6 along the west-east sections. Further were continuous surface samples measured for pCO_2, chlorophyll, oxygen, CDOM, gas tension, nitrate, temperature and salinity. The underway sampling for nitrate were part of a pilot project to evaluate a new instrument for oceanographic applications, therefore surface nitrate concentrations were performed with a wet-chemical method every 3 hours.

a) Technical aspects

Oxygen measurements were performed with Winkler titrations. In all 442 samples were analyzed, and in addition were 26 double samples analyzed, which yielded a standard deviation of the measurements of 0.6 μmol kg^{-1}. These measurements served also to calibrate the oxygen sensor on the CTD. A total of about 350 samples for nutrients were taken and immediately frozen to –30°C. These samples were analyzed during the follow up cruise of R/V Poseidon P348 by Frank Malien. Additionally, 200 water samples were prepared to be analyzed for TOC (Total Organic Carbon) and subsequently stored in the refrigerator at –30°C. Final determination of TOC content from the samples was done at IFM-GEOMAR after the cruise. During the first occupation of sections at 18°30’, 18°00’ and 17°30’, a total of about 260 triple samples drawn for N_20 measurements. The samples were immediately fixed with HgCl and stored dark during the cruise. Final analysis of the samples was performed at IFM-GEOMAR in Kiel by Dr. Hermann Bange. A total of 64 samples for the transient tracers SF_6 and CFC-12 were sampled during the first repeat of the 18°00’ section. The samples were drawn in 300 ml glass ampoules and were flame sealed under a continuous flow of ECD-quality nitrogen-gas immediately after sampling. The samples will be analyzed in the laboratory at Kiel by Dr. Toste Tanhua.

The pCO_2 measurements were performed with an autonomous system that records averaged data each minute. An automatic calibration was performed every 3 hours by using

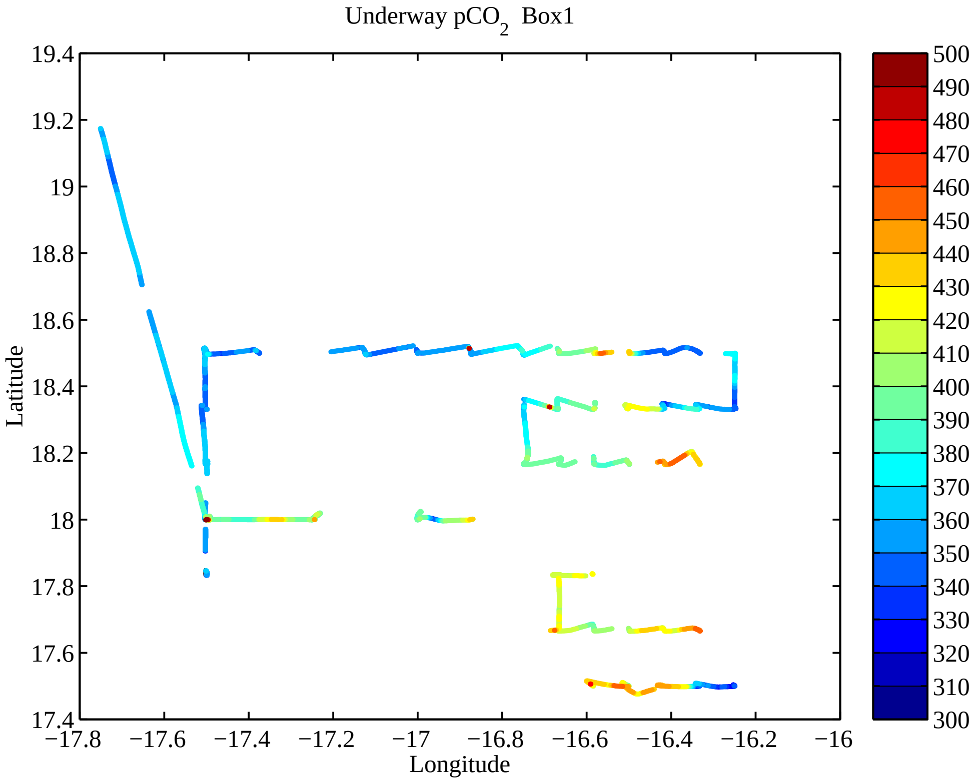

Fig. 14: Surface pCO_2 from the underway system. Note that these are un-calibrated data, never the less, high pCO_2 indicate active upwelling.

3 standard span gases for CO_2. A small error in the electronics, which could be repaired, caused several temporal gaps in the dataset during the first box survey (Fig. 14). Once the electronics were repaired, the pCO_2 system worked flawlessly. Nitrate was measured every 10 minutes with an in situ UV-photometer combined with optical sensors for chlorophyll, CDOM and oxygen-optode. For controlling the quality of this new sampling method, 97 discrete samples of nitrate were taken and analyzed by reducing the nitrate to nitrite and measuring the absorption of an added dye at 542 nm. The mean standard deviation of 16 double samples is 0.05 µmol l^{-1}.

For the purpose of calibration of the underway chlorophyll sensor, one or two samples were filtrated each day. While on board, these samples were frozen and sample analysis was performed by Dr. Ilka Peeken at the laboratory at IFM-GEOMAR.

b) Preliminary results

An analysis of the oxygen content during the first box survey indicated two oxygen minima at about 100 m and 400 m depth, respectively (Fig. 15). The lowest oxygen concentrations encountered were about 50 µmol kg^{-1}. A very sharp gradient in oxygen close to the surface is clearly seen, and on a few locations, low oxygen concentrations extend all the way to the surface, indicating upwelling (Fig. 15). Indeed, also the surface pCO_2 from the same time (Fig. 14) indicate high pCO_2 values where the low oxygen concentrations reach toward the

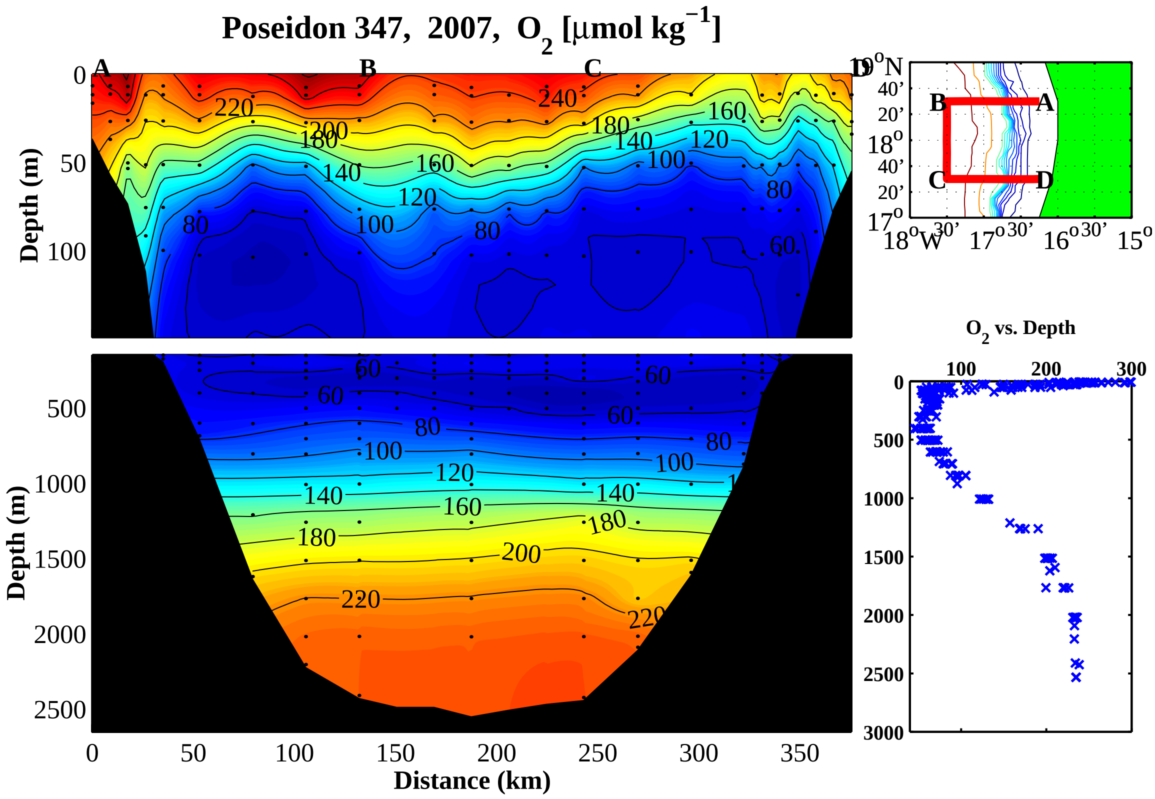

Fig. 15: Oxygen concentrations during the first repeat of the “Box” determined from discrete measurements.

surface. Also the surface nitrate concentrations were high in these areas (up to about 10 µmol kg^{-1}), again a sign of active upwelling.

Appendix

Table A1: *CTD stations and water sampling during P347 (S - salinity, NUTS – nutrients). Asterisks in CTD casts denote profiles collected with the IFM-GEOMAR SBE5 CTD system, all other profiles were collected using IFM-GEOMAR's SBE3 CTD.*

CTD Cast	POS. Station	Date	Time (UTC)	Latitude	Longitude	Water Depth [m]	Profile Depth [dbar]	Water Samples
1*	112	07/01/20	14:22	20°18.0'N	17°60.0'W	1499.0	1502	S/O_2
2*	113	07/01/21	08:00	18°00.0'N	17°30.0'W	2509.0	2520	S/O_2/NUTS/N_2O/He
3*	113	07/01/21	11:01	18°00.0'N	17°30.0'W	2507.0	252	S/O_2/NUTS/N_2O
4	114	07/01/21	15:24	18°00.0'N	17°15.0'W	2145.0	2149	S/N_2O
5	114	07/01/21	17:03	18°00.0'N	17°15.1'W	2153.0	2159	S/O_2/NUTS/N_2O/SF_6
6	115	07/01/21	20:28	18°00.0'N	17°00.1'W	1716.0	1710	S/O_2/NUTS/N_2O/SF_6 CFC/He
7	115	07/01/21	23:08	18°00.0'N	17°00.0'W	1713.0	303	S/O_2/NUTS/N_2O/SF_6 CFC
8	116	07/01/22	00:31	18°00.0'N	16°52.6'W	1403.0	1387	
9	117	07/01/22	03:11	18°00.0'N	16°45.1'W	994.0	991	S/O_2/NUTS/N_2O/SF_6 CFC/He
10	118	07/01/22	05:39	18°00.0'N	16°40.2'W	713.0	712	
11	119	07/01/22	07:43	18°00.0'N	16°35.1'W	457.0	455	S/O_2/NUTS/N_2O/He
12	120	07/01/22	11:29	18°00.0'N	16°30.0'W	189.0	186	S/O_2/NUTS/N_2O/SF_6 CFC/He
13	121	07/01/22	13:15	18°00.0'N	16°25.1'W	104.0	97	S/O_2/NUTS/N_2O/SF_6 CFC/He
14	122	07/01/22	14:52	18°00.0'N	16°20.1'W	75.0	76	S/O_2/NUTS/N_2O/SF_6 CFC/He
15	123	07/01/22	16:38	18°00.1'N	16°16.3'W	35.0	32	S/O_2/NUTS/TOC N_2O/He
16	124	07/01/22	18:20	18°10.0'N	16°15.0'W	33.0	31	S/O_2/NUTS/N_2O/SF_6 CFC/He
17	125	07/01/22	19:25	18°10.0'N	16°20.0'W	51.0	49	S
18	126	07/01/22	21:31	18°10.0'N	16°24.9'W	78.0	72	S/He
19	127	07/01/22	23:02	18°10.0'N	16°30.0'W	148.0	143	S
20	128	07/01/23	00:36	18°10.0'N	16°35.0'W	422.0	413	S/He
21	129	07/01/23	02:59	18°10.0'N	16°40.0'W	838.0	831	S
22	130	07/01/23	05:10	18°10.0'N	16°45.0'W	1102.0	1099	S/He
23	131	07/01/23	08:19	18°20.0'N	16°45.0'W	885.0	881	S/He
24	132	07/01/23	10:35	18°20.0'N	16°40.1'W	549.0	542	S
25	133	07/01/23	12:35	18°19.9'N	16°35.0'W	242.0	233	S/He
26	134	07/01/23	14:30	18°20.0'N	16°30.1'W	164.0	166	S/He
27	135	07/01/23	16:21	18°20.0'N	16°25.0'W	75.0	68	
28	136	07/01/23	17:41	18°20.0'N	16°20.0'W	40.5	39	S/He
29	137	07/01/23	19:07	18°20.0'N	16°15.0'W	21.0	20	S/O_2/NUTS/He
30	138	07/01/23	20:48	18°29.9'N	16°15.0'W	17.0	17	S/O_2/NUTS/N_2O/He
31	139	07/01/23	21:53	18°29.9'N	16°20.0'W	38.0	36	S/O_2/NUTS/TOC/N_2O
32	140	07/01/23	23:11	18°29.9'N	16°24.9'W	52.0	53	S/O_2/NUTS/TOC N_2O/He
33	141	07/01/24	00:30	18°30.0'N	16°30.0'W	92.0	91	S/O_2/NUTS/N_2O/He
34	142	07/01/24	01:57	18°30.0'N	16°34.9'W	178.0	174	S/O_2/NUTS/TOC N_2O/He
35	143	07/01/24	03:54	18°30.0'N	16°40.0'W	371.0	366	S
36	144	07/01/24	05:44	18°29.8'N	16°45.1'W	683.0	687	S/O_2/NUTS/TOC N_2O/He
37	145	07/01/24	08:03	18°29.8'N	16°52.5'W	1134.0	1145	S
38	146	07/01/24	10:32	18°30.0'N	17°00.0'W	1615.0	1621	S/O_2/NUTS/TOC N_2O/He
39	147	07/01/24	13:17	18°29.9'N	17°07.5'W	1987.0	1997	S
40	148	07/01/24	15:57	18°30.0'N	17°15.0'W	2191.0	2202	S/O_2/NUTS/TOC N_2O/He
41	148	07/01/24	18:26	18°32.3'N	17°15.6'W	2242.0	301	S/O_2/NUTS/TOC N_2O
42	149	07/01/24	19:53	18°29.9'N	17°22.5'W	2305.0	502	S
43	150	07/01/24	21:56	18°29.9'N	17°30.1'W	2399.0	2409	S/O_2/NUTS/TOC N_2O/He

Table A1:continued

CTD Cast	POS. Station	Date	Time (UTC)	Latitude	Longitude	Water Depth [m]	Profile Depth [dbar]	Water Samples
44	150	07/01/25	00:46	18°29.9'N	17°30.1'W	2399.0	300	S/O_2/NUTS/TOC N_2O
45	151	07/01/25	02:25	18°20.0'N	17°30.1'W	2488.0	503	S/O_2/NUTS
46	152	07/01/25	04:54	18°10.0'N	17°30.1'W	2430.0	502	S/O_2/NUTS/TOC
47	153	07/01/25	07:20	18°00.0'N	17°30.1'W	2517.0	2531	S/O_2/NUTS/He
48	153	07/01/25	10:01	17°59.9'N	17°30.0'W	2509.0	303	S/ O_2/NUTS
49	154	07/01/25	11:31	17°50.0'N	17°30.0'W	2519.0	504	S/O_2/NUTS/TOC
50	155	07/01/25	14:06	17°40.0'N	17°30.1'W	2450.0	512	S/O_2/NUTS
51	156	07/01/25	16:38	17°30.0'N	17°30.0'W	2415.0	2425	S/O_2/NUTS/N_2O/He
52	156	07/01/25	18:51	17°31.0'N	17°30.2'W	2416.0	504	S/O_2/NUTS/N_2O
53	157	07/01/25	22:00	17°29.9'N	17°22.5'W	2257.0	504	S
54	158	07/01/26	01:25	17°30.0'N	17°15.0'W	2083.0	2089	S/O_2/NUTS/N_2O/He
55	158	07/01/26	03:46	17°30.1'N	17°15.1'W	2092.0	324	S/O_2/NUTS/N_2O
56	159	07/01/26	05:05	17°29.9'N	17°07.5'W	1896.0	504	S
57	160	07/01/26	07:11	17°29.9'N	17°00.0'W	1594	1593	S/O_2/NUTS/N_2O/He
58	161	07/01/26	10:05	17°29.9'N	16°52.5'W	1199	1200	S
59	162	07/01/26	12:39	17°30.0'N	16°45.2'W	878	873	S/O_2/NUTS/N_2O/He
60	163	07/01/26	14:54	17°30.0'N	16°40.1'W	412	401	S/O_2/NUTS/He
61	164	07/01/26	16:46	17°30.0'N	16°35.1'W	186	181	S/O_2/NUTS/N_2O/He
62	165	07/01/26	18:33	17°30.0'N	16°30.0'W	125	124	S/O_2/NUTS/N_2O/He
63	166	07/01/26	20:14	17°29.9'N	16°25.0'W	94	89	S/O_2/NUTS/N_2O/He
64	167	07/01/26	21:54	17°30.0'N	16°20.1'W	62	56	S/O_2/NUTS/N_2O
65	168	07/01/26	23:12	17°30.0'N	16°15.0'W	41	35	S/O_2/NUTS/He
66	169	07/01/27	01:00	17°39.9'N	16°15.0'W	52	49	S/O_2/NUTS/He
67	170	07/01/27	02:17	17°39.9'N	16°20.0'W	75	70	S/He
68	171	07/01/27	03:41	17°40.0'N	16°25.0'W	97	91	S
69	172	07/01/27	04:50	17°39.9'N	16°30.0'W	154	152	S/He
70	173	07/01/27	06:13	17°40.0'N	16°35.0'W	245	238	S/He
71	174	07/01/27	07:57	17°40.0'N	16°40.0'W	496	470	S
72	175	07/01/27	10:47	17°50.0'N	16°40.0'W	501	495	S/He
73	176	07/01/27	12:50	17°50.0'N	16°35.1'W	304	299	S
74	177	07/01/27	14:33	17°50.0'N	16°30.0'W	172	167	S/He
75	178	07/01/27	15:52	17°50.0'N	16°25.1'W	99	98	S/He
76	179	07/01/27	16:59	17°50.0'N	16°20.0'W	77	74	S/O_2/He
77	180	07/01/27	18:28	17°50.0'N	16°15.0'W	55.0	53	S/He
78	181	07/01/27	20:16	18°00.1'N	16°16.6'W	38.0	35	S
79	182	07/01/28	06:18	18°00.0'N	16°23.1'W	88.0	86	
80	182	07/01/28	09:14	18°00.0'N	16°27.7'W	120.0	121	
81	182	07/01/28	12:10	18°00.3'N	16°32.5'W	464.0	460	S
82	182	07/01/28	15:13	18°00.1'N	16°35.9'W	449.0	99	
83	182	07/01/28	15:36	18°00.2'N	16°35.7'W	448.0	455	S/O_2
84	182	07/01/28	18:18	17°59.9'N	16°38.0'W	589.0	583	
85	183	07/01/28	19:42	18°00.0'N	16°45.0'W	988.0	985	S
86	184	07/01/28	21:08	17°59.9'N	16°50.0'W	1281.0	1281	S
87	186	07/01/29	06:53	18°30.0'N	16°20.0'W	37.0	32	S/He
88	187	07/01/29	08:09	18°29.9'N	16°25.1'W	51.0	49	
89	188	07/01/29	09:42	18°30.0'N	16°30.0'W	96.0	93	S
90	189	07/01/29	11:12	18°30.0'N	16°35.0'W	180.0	181	
91	190	07/01/29	12:53	18°29.9'N	16°40.0'W	362.0	354	S
92	191	07/01/29	14:34	18°29.9'N	16°45.0'W	682.0	679	S/O_2
93	192	07/01/29	17:37	18°30.0'N	17°00.0'W	1610.0	505	

Table A1 continued

CTD Cast	POS. Station	Date	Time (UTC)	Latitude	Longitude	Water Depth [m]	Profile Depth [dbar]	Water Samples
94	193	07/01/29	19:50	18°29.9'N	17°15.0'W	2195.0	507	S
95	194	07/01/29	21:59	18°29.9'N	17°29.9'W	2397.0	557	S
96	195	07/01/30	00:13	18°15.0'N	17°30.1'W	2420.0	503	S
97	196	07/01/30	02:27	18°00.0'N	17°30.1'W	2509.0	503	S
98	197	07/01/30	04:37	17°44.9'N	17°30.1'W	2467.0	505	S
99	198	07/01/30	08:13	17°28.9'N	17°30.4'W	2424.0	523	S
100	199	07/01/30	10:49	17°30.0'N	17°15.0'W	2084.0	503	S/O_2
101	200	07/01/30	13:12	17°30.0'N	17°00.1'W	1595.0	500	S
102	201	07/01/30	16:00	17°29.9'N	16°45.1'W	868.0	501	S
103	202	07/01/30	17:55	17°29.9'N	16°40.0'W	406.0	400	
104	203	07/01/30	19:41	17°29.9'N	16°35.0'W	186.0	179	S/O_2
105	204	07/01/30	21:29	17°40.0'N	16°30.0'W	124.0	121	S
106	205	07/01/30	23:02	17°30.0'N	16°25.0'W	99.0	92	S
107	206	07/01/31	00:24	17°30.0'N	16°20.0'W	62.0	55	S/He
108	207	07/01/31	01:52	17°30.0'N	16°15.1'W	42.0	33	S
109	208	07/01/31	03:39	17°40.0'N	16°15.0'W	53.0	43	S
110	209	07/01/31	04:58	17°39.9'N	16°20.0'W	75.0	71	S/He
111	210	07/01/31	08:07	17°40.0'N	16°25.0'W	99.0	96	S/He
112	211	07/01/31	09:56	17°40.0'N	16°30.0'W	151.0	150	S
113	212	07/01/31	11:33	17°40.0'N	16°35.0'W	243.0	243	S
114	213	07/01/31	13:16	17°40.0'N	16°40.0'W	453.0	454	S
115	214	07/01/31	15:27	17°50.0'N	16°40.1'W	500.0	502	S
116	215	07/01/31	17:20	17°50.0'N	16°35.1'W	305.0	298	S
117	216	07/01/31	19:01	17°50.0'N	16°30.0'W	173.0	168	S/He
118	217	07/01/31	20:27	17°50.0'N	16°25.0'W	100.0	96	S/He
119	218	07/01/31	21:49	17°50.0'N	16°20.0'W	76.0	73	S/He
120	220	07/02/01	08:39	18°00.0'N	16°16.2'W	35.3	33	
121	221	07/02/01	09:30	18°00.0'N	16°20.0'W	74.0	72	S/He
122	222	07/02/01	11:16	18°00.0'N	16°25.1'W	103.0	99	S/He
123	223	07/02/01	13:09	18°00.0'N	16°31.5'W	342.0	360	S/He
124	224	07/02/01	16:10	17°59.9'N	16°35.0'W	519.0	401	S/He
125	224	07/02/01	17:30	18°00.0'N	16°35.0'W	384.0	411	
126	225	07/02/01	19:33	18°00.0'N	16°40.0'W	707.0	708	

Table A2: *Microstructure stations during P347. Profilers used on stations are abbreviated as: P1 - MSS32, P2 - MSS 26, and P3 - MSS28. For instrumental setup see section 5.*

MSS Station (Profiles)	Profiler / Profile No.	Date Begin	Time Begin (UTC)	Time End (UTC)	Latitude	Longitude	Water Depth [m]	POS Station	CTD Cast
1 (2)	P1 1-2	07/01/20	15:42	16:31	20°18.0'N	18°00.0'W	1499	112	1
2 (3)	P1 3-5	07/01/21	09:56	10:36	18°00.0'N	17°30.0'W	2509	113	2-3
3 (5)	P1 6-10	07/01/21	13:50	14:51	18°00.0'N	17°15.0'W	2146	114	4-5
4 (3)	P1 11-13	07/01/21	22:03	22:36	18°00.0'N	17°00.1'W	1716	115	6-7
5 (3)	P1 14-16	07/01/22	01:37	02:09	18°00.0'N	16°52.6'W	1403	116	8
6 (3)	P1 17-19	07/01/22	04:15	04:53	18°00.0'N	16°45.1'W	994	117	9
7 (3)	P1 20-22	07/01/22	06:22	06:59	18°00.0'N	16°40.2'W	713	118	10
8 (3)	P1 23-25	07/01/22	08:26	09:12	18°00.0'N	16°35.1'W	457	119	11
9 (3)	P1 26-28	07/01/22	11:58	12:29	18°00.0'N	16°30.0'W	189	120	12
10 (4)	P1 29-32	07/01/22	13:34	14:08	18°00.0'N	16°25.1'W	104	121	13
11 (5)	P1 33-37	07/01/22	15:03	15:32	18°00.0'N	16°20.1'W	75	122	14
12 (5)	P1 38-42	07/01/22	16:53	17:06	18°00.1'N	16°16.3'W	33'	123	15
13 (5)	P1 43-47	07/01/22	18:34	18:47	18°10.0'N	16°15.0'W	33	124	16
14 (5)	P2 1-5	07/01/22	20:10	20:50	18°10.0'N	16°20.0'W	51	125	17
15 (5)	P2 6-10	07/01/22	21:56	22:17	18°10.0'N	16°24.9'W	78	126	18
16 (3)	P2 11-13	07/01/22	23:22	23:54	18°10.0'N	16°30.0'W	148	127	19
17 (3)	P2 14-16	07/01/23	01:15	02:03	18°10.0'N	16°35.0'W	422	128	20
18 (3)	P2 17-19	07/01/23	03:45	04:25	18°10.0'N	16°40.0'W	838	129	21
19 (3)	P2 20-22	07/01/23	06:10	06:45	18°10.0'N	16°45.0'W	1102	130	22
20 (3)	P2 23-25	07/01/23	09:14	09:47	18°20.0'N	16°45.0'W	88	131	23
21 (3)	P2 26-28	07/01/23	11:09	11:40	18°20.0'N	16°40.1'W	528	132	24
22 (3)	P2 29-31	07/01/23	13:07	13:43	18°19.9'N	16°35.0'W	233	133	25
23 (3)	P2 32-34	07/01/23	14:59	15:28	18°20.0'N	16°30.1'W	175	134	26
24 (5)	P2 35-39	07/01/23	16:31	16:58	18°20.0'N	16°25.0'W	75	135	27
25 (8)	P2 40-47	07/01/23	18:00	18:27	18°20.0'N	16°20.0'W	40	136	28
26 (5)	P2 48-52	07/01/23	19:21	19:36	18°20.0'N	16°15.0'W	21	137	29
27 (5)	P2 53-57	07/01/23	21:00	21:21	18°29.9'N	16°15.0'W	18	138	30
28 (5)	P2 58-62	07/01/23	22:11	22:51	18°29.9'N	16°20.0'W	38	139	31
29 (5)	P2 63-67	07/01/23	23:28	23:48	18°29.9'N	16°24.9'W	52	140	32
30 (4)	P2 68-71	07/01/24	00:50	01:12	18°30.0'N	16°30.0'W	93	141	33
31 (3)	P2 72-74	07/01/24	02:36	03:13	18°30.0'N	16°34.9'W	178	142	34
32 (3)	P2 75-77	07/01/24	04:26	05:02	18°30.0'N	16°40.0'W	376	143	35
33 (3)	P2 78-80	07/01/24	06:30	07:12	18°29.8'N	16°45.1'W	683	144	36
34 (3)	P2 81-83	07/01/24	09:00	09:35	18°29.8'N	16°52.5'W	1140	145	37
35 (3)	P2 84-86	07/01/24	11:44	12:17	18°30.0'N	17°00.0'W	1620	146	38
36 (3)	P2 87-89	07/01/24	14:28	15:00	18°29.9'N	17°07.5'W	1982	147	39
37 (3)	P2 90-92	07/01/24	17:45	18:20	18°30.0'N	17°15.0'W	2183	148	40-41
38 (3)	P2 93-95	07/01/24	20:25	20:58	18°32.3'N	17°15.6'W	2327	149	42
39 (3)	P2 96-98	07/01/24	23:38	00:04	18°29.9'N	17°22.5'W	2397	150	43-44
40 (3)	P2 99-101	07/01/25	02:55	03:22	18°20.0'N	17°30.1'W	2485	151	45
41 (3)	P2 102-104	07/01/25	05:30	06:05	18°10.0'N	17°30.1'W	2430	152	46
42 (3)	P2 105-107	07/01/25	09:00	09:36	18°00.0'N	17°30.1'W	2507	153	47-48
43 (3)	P2 108-110	07/01/25	12:04	12:40	17°50.0'N	17°30.0'W	2513	154	49
44 (3)	P2 111-113	07/01/25	14:35	15:10	17°40.0'N	17°30.1'W	2445	155	50
45 (3)	P2 114-116	07/01/25	18:12	18:41	17°30.0'N	17°30.0'W	2413	156	51-52
46 (3)	P2 117-119	07/01/25	23:35	00:06	17°29.9'N	17°22.5'W	2260	157	53
47 (3)	P2 120-122	07/01/26	02:50	03:27	17°30.0'N	17°15.0'W	2078	158	54-55
48 (3)	P2 123-125	07/01/26	05:38	06:12	17°29.9'N	17°07.3'W	1905	159	56
49 (3)	P2 126-128	07/01/26	08:23	08:56	17°29.9'N	17°00.0'W	1588	160	57

Table A2 continued

MSS Station	Profiler / Profile No.	Date Begin	Time Begin	Time End	Latitude	Longitude	Water Depth	POS Station	CTD Station
50 (3)	P2 129-131	07/01/26	11:00	11:31	17°29.9'N	16°52.5'W	1197	161	58
51 (3)	P2 132-134	07/01/26	13:25	14:08	17°30.0'N	16°45.2'W	878	162	59
52 (3)	P2 135-137	07/01/26	15:20	16:05	17°30.0'N	16°40.1'W	410	163	60
53 (3)	P2 138-140	07/01/26	17:08	17:44	17°30.0'N	16°35.1'W	186	164	61
54 (3)	P2 141-143	07/01/26	18:52	19:17	17°30.0'N	16°30.0'W	125	165	62
55 (5)	P2 144-148	07/01/26	20:33	21:00	17°29.9'N	16°25.0'W	93	166	63
56 (4)	P2 149-152	07/01/26	22:05	22:28	17°30.0'N	16°20.1'W	62	167	64
57 (5)	P2 153-157	07/01/26	23:25	23:45	17°30.0'N	16°15.0'W	42	168	65
58 (5)	P2 158-162	07/01/27	01:20	01:40	17°39.9'N	16°15.0'W	52	169	66
59 (4)	P2 163-166	07/01/27	02:47	03:07	17°39.9'N	16°20.0'W	76	170	67
60 (3)	P2 167-169	07/01/27	03:55	04:09	17°40.0'N	16°25.0'W	97	171	68
61 (3)	P2 170-172	07/01/27	05:09	05:34	17°39.9'N	16°30.0'W	153	172	69
62 (3)	P2 173-175	07/01/27	06:35	07:13	17°40.0'N	16°35.0'W	244	173	70
63 (3)	P2 176-178	07/01/27	08:32	09:02	17°40.0'N	16°40.0'W	488	174	71
64 (3)	P2 179-181	07/01/27	11:18	11:56	17°50.0'N	16°40.0'W	498	175	72
65 (3)	P2 182-184	07/01/27	13:10	13:43	17°50.0'N	16°35.1'W	313	176	73
66 (3)	P2 185-187	07/01/27	14:49	15:21	17°50.0'N	16°30.0'W	171	177	74
67 (3)	P2 188-190	07/01/27	16:07	16:28	17°50.0'N	16°25.1'W	98	178	75
68 (5)	P2 191-195	07/01/27	17:22	17:43	17°50.0'N	16°20.0'W	76	179	76
69 (5)	P2 196-200	07/01/27	18:39	18:58	17°50.0'N	16°15.0'W	56	180	77
70 (138)	P2 201-338	07/01/27	20:30	07:45	18°00.1'N	16°16.6'W	38-103	181	78
71 (20)	P2 339-359	07/01/28	09:30	16:59	18°00.0'N	16°23.1'W	140-650	182	79-84
72 (8)	P3 1-8	07/01/28	14:10	18:00	18°00.0'N	16°45.0'W	413-899	183	86
73 (26)	P3 9-34	07/01/29	00:47	03:23	18°00.0'N	16°23.1'W	87-101	185	86
74 (5)	P2 360-364	07/01/29	07:05	07:25	18°30.0'N	16°20.0'W	37	186	87
75 (5)	P3 35-39	07/01/29	08:31	08:49	18°29.9'N	16°25.1'W	50	187	88
76 (4)	P2 365-368	07/01/29	10:01	10:30	18°30.0'N	16°30.0'W	96	188	89
77 (3)	P2 369-371	07/01/29	11:31	12:01	18°30.0'N	16°35.0'W	180	189	90
78 (3)	P2 372-374	07/01/29	13:20	13:50	18°29.9'N	16°40.0'W	360	190	91
79 (3)	P2 375-377	07/01/29	15:12	15:57	18°29.9'N	16°45.0'W	686	191	92
80 (3)	P2 378-380	07/01/30	16:26	17:01	17°29.9'N	16°45.1'W	868	201	102
81 (3)	P2 381-383	07/01/30	18:15	18:46	17°29.9'N	16°40.0'W	415	202	103
82 (3)	P2 384-386	07/01/30	20:03	20:35	17°29.9'N	16°35.0'W	185	203	104
83 (3)	P2 387-389	07/01/30	21:48	22:07	17°40.0'N	16°30.0'W	124	204	105
84 (3)	P2 390-392	07/01/30	23:17	23:35	17°30.0'N	16°25.0'W	99	205	106
85 (4)	P2 393-396	07/01/31	00:50	01:07	17°30.0'N	16°20.0'W	62	206	107
86 (6)	P2 397-402	07/01/31	02:03	02:20	17°30.0'N	16°15.1'W	41	207	108
87 (6)	P2 403-408	07/01/31	03:53	04:18	17°40.0'N	16°15.0'W	52	208	109
88 (4)	P2 409-412	07/01/31	08:40	09:05	17°40.0'N	16°25.0'W	956	210	111
89 (3)	P2 413-415	07/01/31	10:15	10:43	17°40.0'N	16°30.0'W	152	211	112
90 (3)	P2 416-418	07/01/31	11:51	12:35	17°40.0'N	16°35.0'W	239	212	113
91 (3)	P2 419-421	07/01/31	13:41	14:16	17°40.0'N	16°40.0'W	453	213	114
92 (3)	P2 422-424	07/01/31	15:52	16:30	17°50.0'N	16°40.1'W	500	214	115
93 (3)	P2 425-427	07/01/31	17:40	18:11	17°50.0'N	16°35.1'W	302	215	116
94 (3)	P2 428-430	07/01/31	19:19	19:43	17°50.0'N	16°30.0'W	172	216	117
95 (3)	P2 431-433	07/01/31	20:48	21:10	17°50.0'N	16°25.0'W	99	217	118
96 (84)	P2 434-478	07/01/31	22:12	03:40	17°50.0'N	16°20.0'W	76 -156	218	119
97 (5)	P2 479-483	07/02/01	10:13	10:40	18°00.0'N	16°20.0'W	735	221	121
98 (3)	P2 484-486	07/02/01	11:36	11:59	18°00.0'N	16°25.2'W	104	222	122
99 (3)	P2 487-489	07/02/01	16:15	16:47	18°00.0'N	16°35.1'W	419	224	124-125
100 (7)	P2 490-496	07/02/01	20:07	21:34	18°00.0'N	16°40.0'W	710	225	126

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No.	Title
1	RV Sonne Fahrtbericht / Cruise Report SO 176 & 179 MERAMEX I & II (Merapi Amphibious Experiment) 18.05.-01.06.04 & 16.09.-07.10.04. Ed. by Heidrun Kopp & Ernst R. Flueh, 2004, 206 pp. In English
2	RV Sonne Fahrtbericht / Cruise Report SO 181 TIPTEQ (from The Incoming Plate to mega Thrust EarthQuakes) 06.12.2004.-26.02.2005. Ed. by Ernst R. Flueh & Ingo Grevemeyer, 2005, 533 pp. In English
3	RV Poseidon Fahrtbericht / Cruise Report POS 316 Carbonate Mounds and Aphotic Corals in the NE-Atlantic 03.08.–17.08.2004. Ed. by Olaf Pfannkuche & Christine Utecht, 2005, 64 pp. In English
4	RV Sonne Fahrtbericht / Cruise Report SO 177 - (Sino-German Cooperative Project, South China Sea: Distribution, Formation and Effect of Methane & Gas Hydrate on the Environment) 02.06.-20.07.2004. Ed. by Erwin Suess, Yongyang Huang, Nengyou Wu, Xiqiu Han & Xin Su, 2005, 154 pp. In English and Chinese
5	RV Sonne Fahrtbericht / Cruise Report SO 186 – GITEWS (German Indonesian Tsunami Early Warning System 28.10.-13.1.2005 & 15.11.-28.11.2005 & 07.01.-20.01.2006. Ed. by Ernst R. Flueh, Tilo Schoene & Wilhelm Weinrebe, 2006, 169 pp. In English
6	RV Sonne Fahrtbericht / Cruise Report SO 186 -3 – SeaCause II, 26.02.-16.03.2006. Ed. by Heidrun Kopp & Ernst R. Flueh, 2006, 174 pp. In English
7	RV Meteor, Fahrtbericht / Cruise Report M67/1 CHILE-MARGIN-SURVEY 20.02.-13.03.2006. Ed. by Wilhelm Weinrebe und Silke Schenk, 2006, 112 pp. In English
8	RV Sonne Fahrtbericht / Cruise Report SO 190 - SINDBAD (Seismic and Geoacoustic Investigations Along The Sunda-Banda Arc Transition) 10.11.2006 - 24.12.2006. Ed. by Heidrun Kopp & Ernst R. Flueh, 2006, 193 pp. In English
9	RV Sonne Fahrtbericht / Cruise Report SO 191 - New Vents "Puaretanga Hou" 11.01. - 23.03.2007. Ed. by Jörg Bialas, Jens Greinert, Peter Linke, Olaf Pfannkuche, 2007, 190 pp. In English

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