SONNE-Berichte

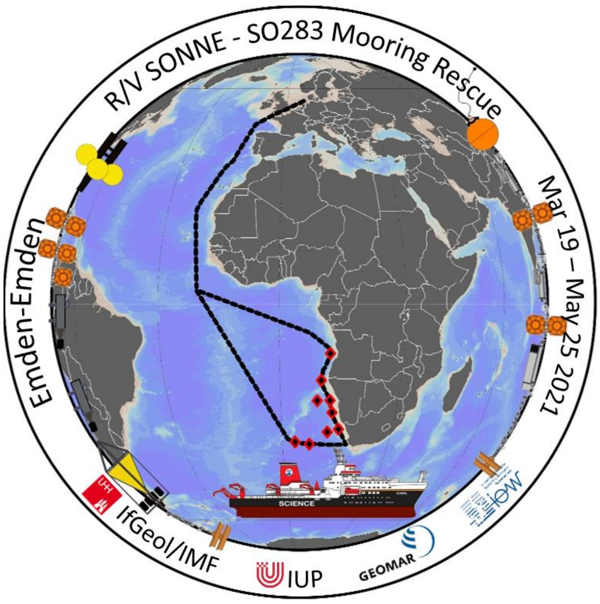
Mooring Rescue

Cruise No. SO283

19 March 2021 – 25 May 2021

Emden (Germany) – Emden (Germany)

TRR181 / TRAFFIC / EVAR / BANINO



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2021

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1 Cruise Summary

1.1 Summary in English

SONNE cruise SO283 is not a classical research cruise based on a single research project, but aims to continue ongoing mooring programs of different projects in the South Atlantic, i.e. to recover existing moorings or to re-deploy them - hence *Mooring Rescue*. *Mooring Rescue* compensates for the research cruises with RV METEOR and RV MARIA S. MERIAN that were cancelled in 2020 and 2021 due to the Corona pandemic. The goal is to recover existing moorings in time before they have to be considered technically lost. In addition to the loss of instruments and equipment, there was also a threat of loss of invaluable data that could not be replaced.

All core objectives of the cruise were achieved. As part of the DFG program TRR181 (Energy Transfers in Atmosphere and Ocean), two moorings were deployed in the open South Atlantic in approximately 5000 m water depth, flanked by *Pressure Inverted Echo Sounders* (PIES). For the TRAFFIC project (Trophic TRAnsfer eFFICiency in the Benguela Current), long-term sediment trap moorings were recovered in the Bengula upwelling area and re-deployed at four locations (two South Africa, two Namibia). In addition, seven short-term drifting sediment trap systems were deployed and successfully recovered during the cruise. In the northern Benguela area off Namibia, three IOW moorings were recovered and one was re-deployed. As part of the BANINO project (Benguela Niños: physical processes and long term variability), an oceanographic mooring system was successfully recovered and re-deployed off the coast of Angola. The remaining time in the working areas was used for oceanographic, biogeochemical and biological work as well as for underway measurements. This included the investigation of the seasonal variability of trace gas (N_2O, CH_4 and CO_2) along three transects perpendicular to the coast of Namibia at about 17.25°S, 23°S and 25°S and underway measurement of e.g. pH, total carbonate and total alkalinity in the entire south Atlantic. Furthermore, five ARGO floats were deployed. The deployment of a total of 282 instruments, gears and systems at 101 stations made the expedition a complete success.

1.2 Zusammenfassung

Die SONNE-Fahrt SO283 ist keine klassische Forschungsfahrt basierend auf einem einzelnen Forschungsprojekt, sondern hat zum Ziel, laufende Verankerungsprogramme unterschiedlicher Projekte im Südatlantik fortzuführen, also bestehende Verankerungen zu bergen oder neu auszulegen - daher *Mooring Rescue*. *Mooring Rescue* kompensiert die wegen der Corona-Pandemie abgesagten Forschungsfahrten mit FS METEOR bzw. FS MARIA S. MERIAN und damit ausgefallenen Verankerungsarbeiten im Südatlantik aus den Jahren 2020 und 2021. Ziel ist es, bestehende Verankerungen rechtzeitig zu bergen, bevor sie technisch als verloren gelten müssen. Neben dem Verlust der Instrumente und Geräte drohte auch ein Verlust an nicht zu ersetzenden Daten.

Alle Kernziele der Reise wurden erreicht. Im Rahmen des DFG-Schwerpunktprogramm TRR181 (*Energy Transfers in Atmosphere and Ocean*), wurden im offenen Südatlantik in ca. 5000 m Wassertiefe zwei Verankerungen gesetzt, flankiert von *Presssure Inverted Echo Sounder* (PIES). Für das TRAFFIC-Projekt (*Trophic TRAnsfer eFFICiency in the Benguela Current*) wurden die Sinkstofffallenverankerungen im Benguela-Auftriebsgebiet geborgen und an vier Positionen (zwei Südafrika, zwei Namibia) wieder ausgesetzt. Zusätzlich wurden während der

Fahrt insgesamt sieben driftende Sinkstofffallensysteme für kurze Zeit ausgebracht und wieder erfolgreich geborgen. Im nördlichen Benguela-Gebiet vor Namibia wurden drei Verankerungen des IOW geborgen und eine davon wieder ausgesetzt. Im Rahmen des BANINO-Projekts (*Benguela Niños: physical processes and long term variability)* wurde vor der Küste Angolas ein ozeanographisches Verankerungssystem erfolgreich geborgen und wieder ausgesetzt. Die verbliebene Zeit in den Arbeitsgebieten wurde für ozeanographische, biogeochemische und biologische Arbeiten sowie für Unterwegsmessungen genutzt. Dies beinhaltete die Untersuchung der saisonalen Variabilität von Spurengasen (N2O, CH4 und CO2) entlang dreier Transekte senkrecht zur Küste Namibias bei ca. 17,25°S, 23°S und 25°S und die Messung von z.B. pH-Wert, Gesamtkarbonat und Gesamtalkalinität im gesamten Südatlantik. Außerdem wurden fünf ARGO-Floats ausgebracht. Der Einsatz von insgesamt 282 Instrumenten, Geräten und Systemen an 101 Stationen machte die Expedition zu einem vollen Erfolg.

2 Participants

2.1 Principal Investigators

Name	Institution
Lahajnar, Niko, Dr.	Universität Hamburg
Mertens, Christian, Dr.	Universität Bremen
Sabbaghzadeh, Bita, Dr.	IOW
Schmidt, Martin, Dr.	IOW

2.2 Scientific Party

Name	Discipline	Institution
Lahajnar, Niko, Dr.	Biogeochemistry / Chief Scientist	UHH
Andrae, Alexandra	Moorings / ARGO Floats	GEOMAR
Beier, Sebastian	Moorings	IOW
Heinatz, Knut	Microplankton	UHH
Hirschmann, Sophia	Microplankton	UHH
Meiritz, Luisa Chiara	Moorings / Drifter	UHH
Mertens, Christian, Dr.	Moorings / Hydrographie	UHB
Rose, Jonathan	Biogeochemistry	UHH
Sabbaghzadeh, Bita, Dr.	Underway-Measurement	IOW
Schmidt, Martin, Dr.	Oceanography	IOW
Stake, Jürgen	Moorings	UHB
Stiehler, Jan Eric	Moorings	UHB
Witting, Paul Jaspar	Moorings	GEOMAR

2.3 Participating Institutions

UHH	Universität Hamburg
UHB	Universität Bremen
GEOMAR	Helmholtz-Zentrum für Ozeanforschung GEOMAR, Kiel
IOW	Leibniz-Institut für Ostseeforschung Warnemünde

3 Research Program

3.1 Description of the Work Area

There was no single work area because of the different foci of the individual research projects. The first area of interest was the open South Atlantic far away from any continental influence. This region at 32-34°S and 4-8°E is characterized by a flat seabed of approximately 5000 m water depth where the variability of the internal wave energy flux south of the Walvis Ridge can be measured. The deployment positions follow the propagation path of internal tides as seen in model simulations and satellite altimetry. Internal tides in the ocean are generated by the interaction of tidal currents with the rough topography on the ocean floor. The lowest modes of these internal tides, that contain a large fraction of the energy of the internal wave field, are capable of propagating basin-wide in the stratified ocean, before they eventually break and generate turbulence. The spatial distribution of the diapycnal mixing related to this internal wave breaking and mixing has been shown to influence the global overturning circulation.

The second major region of interest is the Benguela Upwelling System (BUS) from 18° to 32°S off the coasts of South Africa and Namibia. It belongs to the four major eastern boundary upwelling systems in the world. This upwelling area can be subdivided into a southern (sBUS) and a northern (nBUS) part as the ecosystem functioning is quite different in those two sub-areas. Recent findings from model studies show a poleward shift in subtropical high pressure areas due to global climate change (Garcia-Reyes et al. 2015, Rykaczewski et al., 2015). Hence, food webs seem to differ in the efficiency of nutrient cycling, which leads to different export ratios. Recent findings (Siddiqui et al., in review) suggest that the export ratio influences the uptake of atmospheric CO_2. Also Benguela upwelling fosters the release of the greenhouse gases (GHG) i.e. methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) to the atmosphere. Maxima sedimentary CH_4 release around the southern and northern mud-belt at 23 and 25°S transects were found in the first EVAR expedition (Sabbaghzadeh et al., in prep.). The different subdivision of BUS also found to act differently with respect to CO_2 as nBUS acts as a source for CO_2 whereas the sBUS acts as a CO_2 sink. The BUS has been intensively studied by recent joint research programs (NAMIBGAS, GENUS, SACUS, PREFACE, EVAR, TRAFFIC). As part of the research projects SACUS, EVAR and TRAFFIC, numerous short-term and long-term mooring systems have been deployed in this area. During the last expedition period in 2019, in total seven mooring systems were deployed off the coast of Namibia and South Africa in 2019, respectively. Also, detailed survey of GHG around the three main transects of 17.5°S, 23°S and 25°S in the BUS were conducted as the part of EVAR project.

The last area of interest is the coastal region off Angola. There, the BANINO project aims for a better understanding of the temperature anomalies in the Northern Benguela System, so called

Benguela Niños and Niñas, caused by the variability of poleward propagation of tropical water masses. This variability has high impact on the hydrographic conditions in the ecosystem, specifically on fishery, Gammelsrød et al. (1998). The main physical mechanism behind positive temperature anomalies, i.e., Benguela Niños, is a weakening of trade winds in the equatorial Atlantic, which generates equatorial Kelvin waves related to a thermocline elevation and response in the equatorial undercurrent and finally to a poleward directed pulse of tropical water in the coastal wave guide. The locally observed variability of hydrographic conditions along the Angolan and Namibian coast reveals as elements of a long distance interaction between the equatorial current system and the subtropical ocean mediated by waves in the coastal wave guide, Florenchie et al. (2004), Lübbecke et al. (2010).

3.2 Aims of the Cruise

Mooring Rescue was initiated at relatively short notice because several research cruises in the South Atlantic with RV METEOR and RV MARIA S. MERIAN in 2020 and spring 2021 were cancelled due to the effects of the Corona pandemic. This lack of ship time meant that the associated research projects could not be continued.

However, eight mooring systems had already been deployed in 2019 - prior to the outbreak of the pandemic - as integral components of the respective BMBF research projects off the coasts of South Africa, Namibia and Angola, respectively. In addition, two large mooring systems should have been deployed in 2020 as part of the DFG collaborative research center TRR181 „Energy Transfers in Atmosphere and Ocean", an interdisciplinary project that aims to better understand the energy transfer between waves, eddies and local turbulence in the ocean and the atmosphere to develop energetically consistent models and thus enhance climate analyzes and forecast accuracy. Due to the lack of ship time, there was a risk of total loss of these moorings as they only had a limited battery life and could no longer be actively recovered after a certain deployment period. This would also result in a massive loss of recorded data and samples. For TRR181, the lack of ship time would have meant to cancel major parts of the second phase of the research program.

3.3 Agenda of the Cruise

The following mooring work was the basis for SO-283 (Fig. 3.1):

- Two deployments of oceanographic moorings in the open South Atlantic as part of the TRR181 program.
- Two deployments of sediment trap moorings off South Africa.
- Two recoveries and two re-deployments of sediment trap moorings off Namibia.
- Three recoveries and one re-deployment of oceanographic moorings off Namibia
- One recovery and one re-deployment of an oceanographic mooring off Angola

In addition to the anchored moorings, in total seven short-term drifting sediment traps systems ("drifter") were deployed and recovered in the TRAFFIC working area off the coast of South Africa and Namibia. Apart from the mooring work, CTD profiles in all mooring areas were part of the research program of SO-283. The CTD work was accompanied by APSTEIN- and WP-2 net hauls. Finally, three ARVOR- and two BIO-ARGO-Floats were released between 33° and 10°S. Throughout the cruise (at least south of the EEZ of Cape Verde Islands), underway measurements for water pH, dissolved inorganic carbon (DIC), total alkalinity (TA), temperature and salinity and other parameters including weather data were conducted providing a unique data set for such a long cruise.

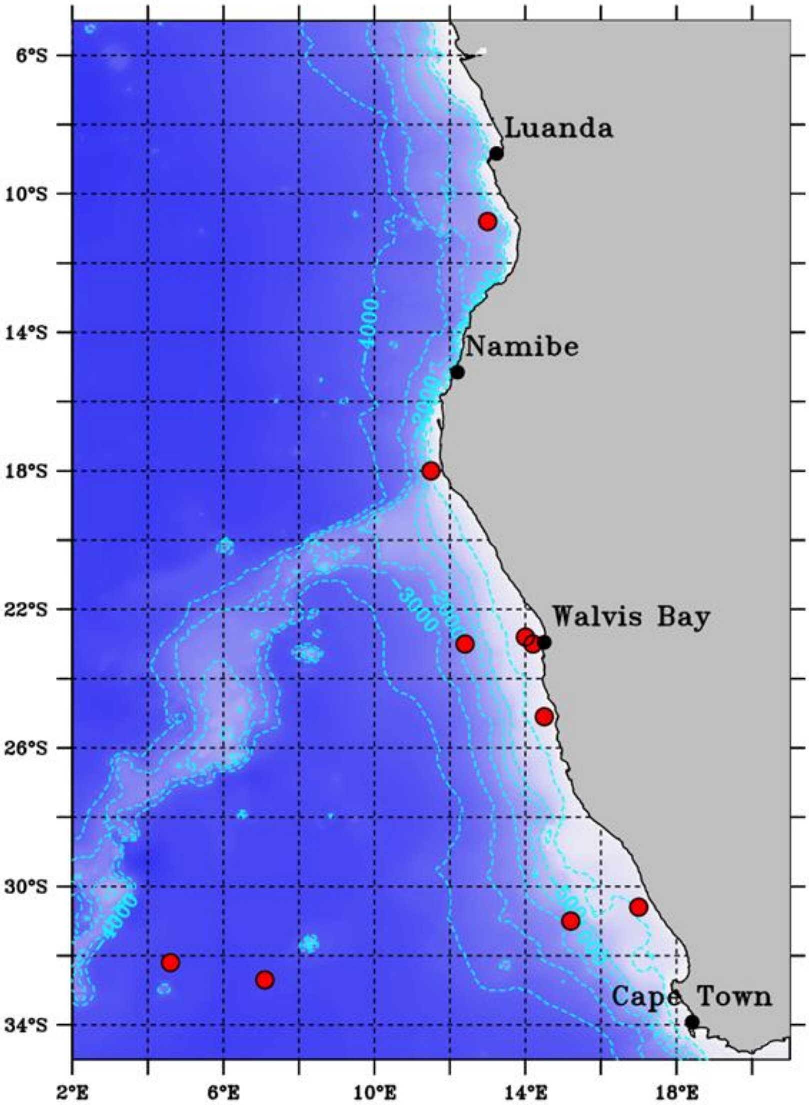

Fig. 3.1 Dedicated mooring positions (red dots) during SO-283.

4 Narrative of the Cruise

The first step of the cruise was our quarantine period at the hotel in Varel. We all checked in on March 9, 2021 and stayed in our hotel rooms for 9 consecutive days without even leaving our rooms. But our stay in the hotel was really well organized and comfortable. The time passed very quickly. On March 18, after we had checked out, we were transferred to RV SONNE in the port of Emden. At 14:30 local time we took our first steps on the ship.

A total of 13 scientists from the Universities of Hamburg and Bremen, GEOMAR in Kiel and the Leibniz Institute for Baltic Sea Research Warnemünde (IOW) started their long journey from Emden to the South Atlantic on Friday, March 19, 2021. Right on time at 12:58 o'clock it was time to cast off! We passed R/V METEOR in the port of Emden. It seemed as if the circle is already closing in the harbor basin of Emden. Because in 2019, during the research voyages with R/V METEOR, we had laid out the moorings in the southern Atlantic, which we now want to recover with R/V SONNE. A total of almost 15,000 nautical miles, i.e. approx. 28,000 km, or 67 days on board R/V SONNE lied ahead of us

The weather conditions at the beginning meant well with us. Whenever there would have been storm or heavy swell on our route, we usually passed the area before it really started. After 10 days at sea, the external conditions were really good and most of the time we could see the sun setting on the horizon in the evening. On the entry into the English Channel we could enjoy the White Cliffs of Dover for a short time and then quickly left the coast of Brittany, the Bay of Biscay and the waters of Madeira and the Canary Islands behind us. On Friday, March 26 we already crossed the Tropic of Cancer and in the course of Saturday evening we reached the westernmost point of our cruise at the latitude of Cape Verde. Here we face locally wind force 7 and waves up to 3 m height, which, however, does not affect RV SONNE very much - the ship lies really impressively calmly in the water. The work under the subtropical sun is now full of contrasts.

The main focus of the work continued to be the preparations for the mooring operations. Wherever you looked, somewhere there is always unpacking and assembling, calibrating and testing, checking and bolting together. It was very impressive what is being unloaded from the containers. The different working groups got to know each other so well that we were able to elect the persons of trust for the scientific party. Bita Sabbaghzadeh from the IOW was elected as the confidant for the female participants, and Sebastian Beier, also from the IOW, represented the male participants.

In three weeks since we had left Emden, we covered more than 6,000 nautical miles and arrived at the first working area with mooring operations after exactly 21 days of sailing. On Thursday, April 8, 2021, the machines were stopped and preparations for the mooring work in the TRR-181 program started. After a careful survey of the bathymetry at the intended mooring position and the physical measurements of the water layers based on a 5000 m CTD profile, the actual deployment of a 5000 m mooring at 32°10’S, 04°36’E for the TRR-181 research program by the Institute of Environmental Physics (IUP) of the University of Bremen started right on time at 07:00 on April 9. 5000 m mooring is a huge challenge for all involved, i.e. for the ship's command, for the deck crew, but of course also for the scientists themselves. The preparation time during the long journey was perfectly used for this, so that after less than 5 hours of deck work, the anchor went overboard at 11:43. and the system disappeared into the depths of the Atlantic.

In the days that followed, so-called PIES (Pressure Inverted Echo Sounders) were then deployed at previously selected positions in the working area. These instruments will also autonomously measure the water layers during the next months and provide important information about the water mass distribution in the South Atlantic. On Sunday, April 11, the second almost 5 km long mooring system of the IUP was already on the station schedule at 32°41’S, 07°05’E. At 06:30 the head buoy went into the water and after that successively about three dozen instruments and sensors in predefined intervals. Shortly before 11:00, the entire system was actually already ready to be deployed, but due to the strong current, the SONNE could only tow the system very slowly to the designated anchor position, so as not to expose the instruments, ropes and shackle connections to too much tension. Safety first. At exactly 14:10. the time had come, the anchor was released and pulled the almost 5 km long mooring system with it into the depths of the Atlantic. Finally, at 14:40, the head buoy also submerged, so that the station could be finished and we left for the next PIES station. An important milestone of this cruise could already be successfully checked off.

In the open Atlantic we deployed the last PIES for the TRR181 program before setting course for Cape Town. On the way there at 33°06'S, 13'53'E, we launched a so-called Bio-ARGO float for a French research institute in a cyclonic ocean eddy on the morning of April 13, 2021. These ARGO floats were equipped with various sensors and autonomously measure physical and chemical parameters in the upper 1000 m of the water column and then send the data via satellite to the home institutes every 10 days for several years.

And then it was time: after almost four weeks on the open ocean, with nothing but the endless blue sea around us, we saw land again. Birds, whales and seals greeted us, butterflies and dragonflies basked on the top deck, the color of the water and the smells in the air changed. On schedule, we arrived at the port of Cape Town at 07:15 in the morning of April 14, 2021. A surprise was waiting for us there: At the neighboring pier lay the famous drilling ship JOIDES Resolution, and greeted the SONNE while going alongside. In Cape Town, fuel was bunkered during the day and fresh provisions were taken on board. After less than 12 hours of stay, we cast off again at 18:50. With our stopover in Cape Town we left the most southern point of our long journey at the same time with the most beautiful sunset. The turning point was reached, from now on we were heading north again.

The winds around the Cape of Good Hope have always been notorious and feared. And we got to feel that clearly right away. Within a few hours the weather conditions changed dramatically, so that on the evening April 15, we were confronted with wind force Beaufort 9 and 4.5 m high waves. What a contrast to the almost unusually calm conditions of the previous weeks. However, we were well prepared so that even under these difficult conditions the research continued - and very successfully. The two mooring systems in the TRAFFIC program could already be deployed again on April 15 at 31°02'S, 15°13'E and April 16 at 30°38'S, 17°01'E, respectively.

The mooring work was flanked by numerous CTD stations and micro- or zooplankton net deployments, which brought an abundance of plankton communities under the microscopes and onto the filtration units of the working groups. In addition, so-called drifter systems were also released, each equipped with five sediment traps at different depths to measure the particle flux and vertical zooplankton migration.

So on Sunday, April 18 shortly before 20:00 shipboard time we conclude the station work in the Exclusive Economic Zone of South Africa and were able to put a big green tick behind the work in the southern Benguela upwelling area. All plans could be fulfilled to 100%. RV SONNE then directly headed to Walvis Bay for another stopover.

RV SONNE had never been in Namibian waters before and had to be cleared in first. So we moored at the pier in Walvis Bay on April 20 at 09:35 ship time. All the necessary formalities were completed during the day so that we could leave the pier again at 15:50 on the same day and started station work in Namibian waters.

There was not enough daylight left for mooring work, so the night hours were used intensively for station work with CTD deployments and net catches. On the way to the western mooring WBST West-02, two drifter systems with various sediment trap bottles were set out before things got really exciting for the first time around noon on 21 April: the recovery of mooring WBST West-02 at 23°00’S, 12°23’E. In the course of the day, the almost 1.7 km long mooring was then recovered and an inventory was made. It turned out that most likely due to fishing activities the top float, a buoyancy module and a CTD sensor had been torn off. In addition, it turned out that the sediment trap had not worked as intended due to motor damage.

After everything had been checked and secured on deck, RV SONNE sailed to the next mooring system overnight. When we arrived at the mooring station (23°01, 14°13’E) on the morning of April 22, we were slowed down by thick clouds of fog. Around 07:30 board time, the fog lifted and the system could be released. It responded immediately and also came to the surface - but with a big surprise. Almost the entire system was completely covered with shells, star fish and other organisms during the more than two years of mooring time. It was a sight no one had expected. Nevertheless, all systems and sensors worked successfully and collected an important set of data and samples for the TRAFFIC project.

After the successful recovery, the first thing to do was to scrub the deck so that work could continue. The next mooring LTMB of the EVAR project was less than an hour away at 23°00’S, 14°03’E. Here, too, the acoustic release responded immediately, but nothing came to the surface, despite multiple pings. Fortunately, the system was equipped with an emergency trigger, which then also brought buoys to the surface. Still, something seemed strange. And it soon turned out what: large parts of the main system had been torn off. A total of 17 instruments and sensors were missing - a great loss of material and data.

On deck, everything was now counted, a general inventory was carried out and it was decided: all systems can be deployed again, which is of great importance for the individual projects. So in the afternoon of April 22. WBST West-03 was re-deployed, before in the morning of April 23. the systems LTMB and WBST East-09 were successfully moored. In the afternoon, the drifters were successfully recovered before the transit towards 18°S began after a very labor-intensive day, in order to recover the next mooring there and to deploy a short-term drifter system.

In the evening we were greeted by wind gusts of up to 8 Bft., but this did not prevent us from continuing our night station work with CTD deployments. The next mooring was already waiting for us on Sunday morning, April 25. At 18°00’S, 11°40’E, the Trawl Resistant Bottom Mount – also called the "turtle", immediately came to the surface and the whole system was on deck in less than an hour. We still collected the drifter in the afternoon, accompanied by a school of pilot whales, and were then heading to 25°S to recover the last mooring in Namibian waters and to collect some more data and samples there on the transect. The transit was also used to conduct the monthly safety drill to keep everyone on board in practice. And then another good three days of research work started, which was to demand everything from the ship, the material and the people on board.

On April 27, a short and a long drifter system were deployed, then one CTD station followed the next, so that all involved worked sleepless through the night. So plenty of data was collected, water samples were filled and net catches were brought on board and further processed virtually every hour.

On April 28. at sunrise shortly after 06:00 ship time it got exciting again: The last mooring in Namibian waters, LTCN-01, was pinged at 25°05’S, 14°32’E. The system responded immediately and was also visible on the water surface a short time later. However, something was visible but only dimly resembled what had been moored in 2019. Similar to WBST East-08, almost the entire system was overgrown with mussels and other benthic organisms. So not only were all the instruments and equipment successfully recovered, but so were hundreds of kilograms of bivalves. Despite intensive scraping and scratching, it took time for the actual instruments to reappear. Most importantly, the system was successfully back on deck.

During April 28, several CTD and net deployments were on the station schedule, before the two drifters were to be recovered again on April 29. During the night the wind increased more and more, so that we had to fight with wind gusts up to 10 Bft. and waves up to 5 m high in the morning of April 29. Under these conditions it was difficult to see the drifters at all in the rough sea. But now the weeks of cooperation on the ship were about to pay off. In excellent cooperation between the bridge, the deck crew and the mooring specialists of the Universität Hamburg, both drifter systems were recovered from heavy seas and secured on deck on the morning of April 29 - including the sample set. RV SONNE then changed on course north towards Walvis Bay in the evening of April 29.

In the gray coastal fog, RV SONNE then docked in Walvis Bay for the second time on this voyage on April 30 at 09:00 shipboard time. On the one hand, this was necessary so that the ship could be cleared out again after completion of the work in Namibian waters; on the other hand, fuel was bunkered once again due to the additional nautical miles and port calls. With full tanks, RV SONNE left Walvis Bay in the afternoon at 15:24 in bright sunshine, set course north along the southwest African coast towards Angola. On the way to the actual working area at 14°48’S, 11°06’E, the first of three BSH ARGO floats was launched on the morning of May 02 at 07:00. On the morning of 03.05.2021 with a few CTD stations before, we then arrived at the last mooring on this cruise at 10°50’S, 13°00’E: KPO-1215 belonging to GEOMAR. All parameters matched, so this system was also cleared for release. Flotation modules were quickly sighted. One by one, the individual modules came to the surface. The ship slowly approached the head buoy and at 07:20 the system was hooked. All modules, all sensors, all instruments were pulled on deck step by step until 08:20. With this it was clear that SO283 Mooring Rescue can be classified as a complete success. All systems, for which we had taken this long and long journey to rescue them, could be recovered.

After recovery, the day was spent overhauling the system. Numerous other CTD stations followed in short intervals until a few nautical miles away from the coast of Angola. Until deep into the night, one profile after the next was taken until we were back in the morning at the same mooring position as the day before. On May 04 we started the re-deployment of the mooring from GEOMAR. At 06:20, under good weather conditions, the modules were successively lowered into the water until the ship was able to pull the system behind it like a string of pearls. After an hour and 20 minutes, the designated position was reached and the anchor dropped. Mooring KPO-1235 was back in almost exactly the same position as KPO-1215.

Still in the morning, a last BIO-ARGO float was deployed at 11°00'S, 12°45'E for a French research institute. The last stop on this voyage was then scheduled for the night of 05.05. In the central part of the so-called Angola Dome close to 10°S and 10°E, whose water masses have a large influence on the northern Benguela upwelling area, CTD data and water samples were taken once again, plankton nets were run and underway data were recorded. Again, everything went well and smoothly.

Then at dawn on May 05, our last station, appropriately station #100 was to conclude this cruise: BSH's last ARGO float was to be launched briefly. And as if it were yet another great reminder that nothing should be taken for granted on research cruises, the ARGO float simply would not connect to the satellite. Countless e-mails were written back and forth with the operators and various attempts were made to restart the float. At first, all attempts were unsuccessful. It was not until new codes were sent directly to the instrument by satellite from the manufacturer the next morning that the float woke up correctly and was ready to measure. Within a few minutes the SONNE reduced her speed and the float was handed over to the Atlantic 08°21’S, 03°21’E. Thus, after exactly #101 stations, the station work ended 100% successful after all.

After the last station it was time to head for home. Ahead of us were now about 5,550 nautical miles or more than 14 days of transit. But this time was used profitably on board. There was enough data and samples that still had to be evaluated and processed. The weather conditions supported mostly a fast cruising speed so that we reached the European continent a bit earlier than initially planned. By leaving the English Channel we faced wind speeds of up to 10 Bft. in the North Sea on May 21.

RV SONNE reached the port of Emden on May 22 at 11:00 h in the morning – after more than 16,970 nautical miles and being 64 days continuously at sea.

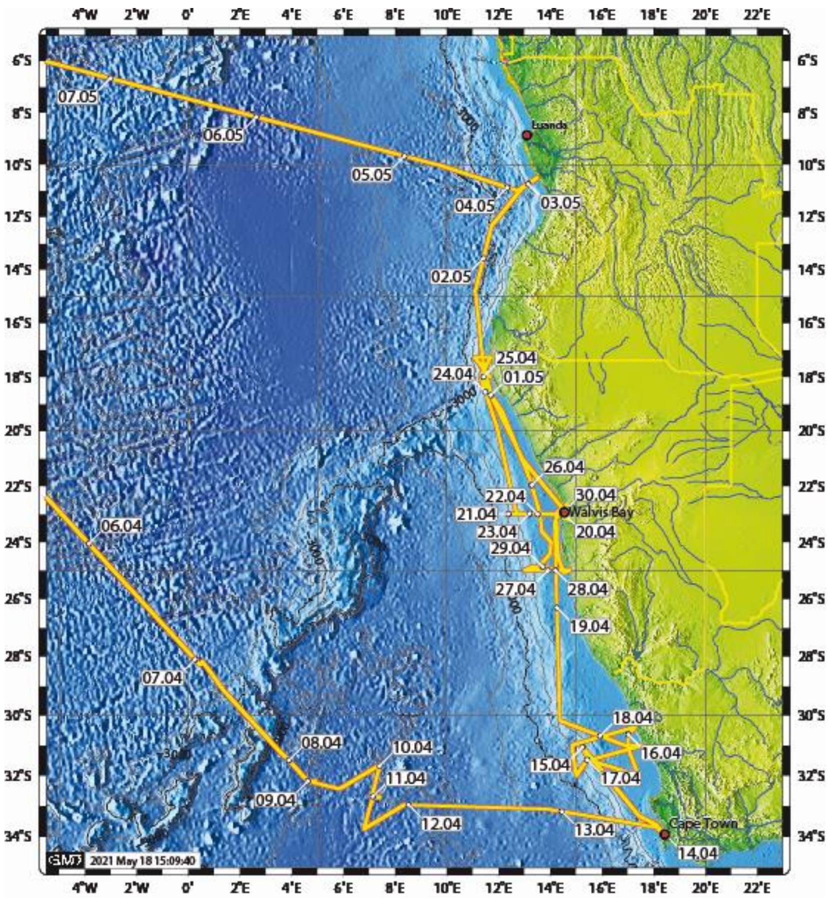

Fig. 4.1 Cruise track SO283 in the South Atlantic.

5 Preliminary Results

5.1 TRR181 Energy Transfers in Atmosphere and Ocean

(Christian Mertens, Jürgen Stake, Jan Stiehler)

Two moorings and five pressure sensor equipped inverted echo sounders (PIES) were deployed by the team of the Institute for Environmental Physics at the University of Bremen to study the scattering and refraction of internal tides in the Cape Basin, southeast of the Walvis Ridge (Fig. 5.1). The interaction of barotropic tidal currents with the rough seafloor generates internal gravity waves that propagate three-dimensionally in the ocean. These so-called internal tides are critical for the ocean's interior energy pathways because their lowest modes, which carry much of their energy, can propagate over long distances before they eventually break and contribute to diapycnal mixing. This experiment is a contribution to the collaborative research center TRR181 „Energy Transfers in Atmosphere and Ocean" (www.trr-energytransfers.de), an interdisciplinary project that aims to better understand the energy transfer between waves, eddies and local turbulence in the ocean and the atmosphere to develop energetically consistent models and thus enhance climate analyzes and forecast accuracy. The original plan was to deploy the moorings and PIES in January 2021 on the MARIA S. MERIAN cruise MSM97 (GPF 19-2-65/Leg 1), but this cruise was cancelled due to the Corona pandemic.

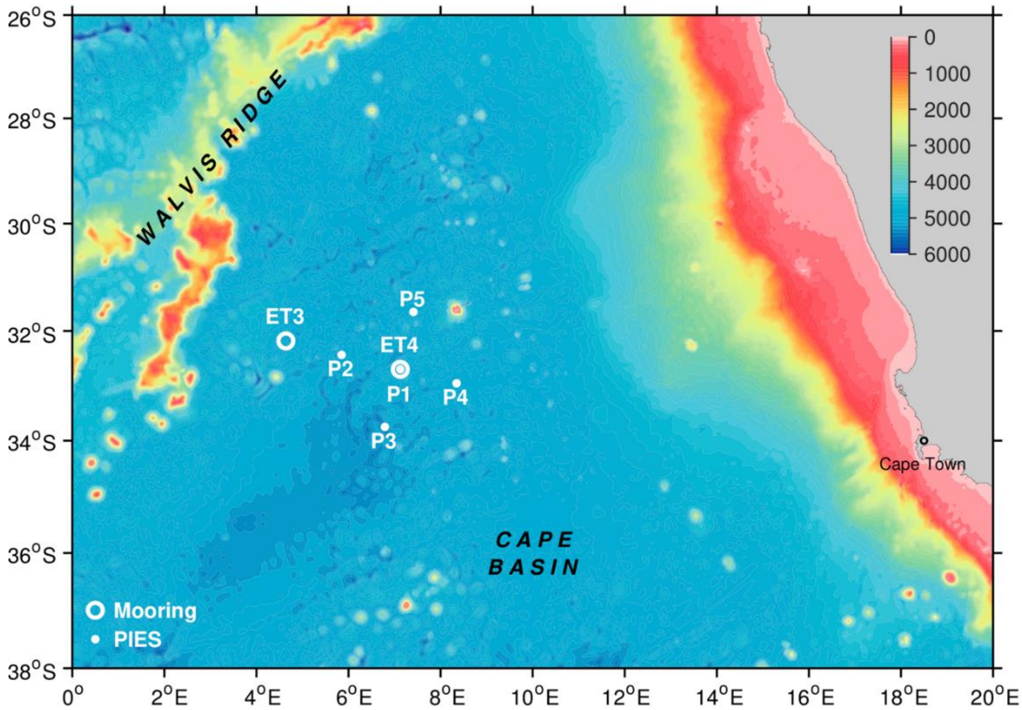

Fig. 5.1 Internal wave array deployed by Institute for Environmental Physics at the University of Breen in the northeastern Cape Basin with mooring (circles) and PIES (dots) positions, bathymetry from ETOPO1.

5.1.1 Moorings

Two moorings were deployed in the propagation direction of energetic internal tides emanating from Walvis Ridge (Fig. 5.1, Tab. 5.1). One mooring, located approx. 200 km to the east of Walvis Ridge, will provide a baseline for the energy flux that leaves the generation site. The second mooring was deployed roughly two internal tide mode-one wavelengths (about 280 km) east of the first mooring, following the propagation path of the low-mode internal tides. The moorings were designed to separate the temporal variability of the energy flux that leaves the generation site from the changes imposed on the internal tides along their propagation path. Both moorings are equipped with ADCPs covering the uppermost 700 meters, current meters, and temperature loggers. The instrumentation will be adequate to resolve the first ten vertical modes and will thus be suitable to quantify the energy transfer between vertical modes and different frequency regimes induced by the internal tide-eddy interactions.

Tab. 5.1 List of University of Bremen, IUP mooring deployments during cruise SO283.

Station No.	**Site ID**	**Date**	**Time**	**Latitude**	**Longitude**	**Water Depth**
			(UTC)			**(m)**
SO283_7-8	ET3	2021/04/09	11:42	32° 11.30’ S	4° 38.11’ E	5130
SO283_12-8	ET4	2021/04/11	14:10	32° 42.35’ S	7° 07.43’ E	4997

The two moorings deployed included a total of 21 AQUADOPP current meters, 2 LONGRANGER 75 kHz ADCPs, 1 QUARTERMASTER 150 kHz ADCP, 1 SIGNATURE 100 kHz ADCP, 5 SBE56 temperature loggers, 24 SBE39plus temperature recorders and 10 SBE37 MICROCATs. Mooring ET4 was additionally equipped with two sediment traps, one at about 1000 m depth and the other at about 3000 m. For calibration, the MICROCATs were mounted on the rosette on station SO283 3-3 and lowered together with the CTD. During this cast the MICROCATs were set to a 6 second sampling interval and comparisons were made at the times of six bottle stops, each lasting about 8 minutes, to allow for equilibration of the MICROCATs. Both moorings were equipped with iXBLUE OCEANO acoustic releases that had been tested on station SO283_3-9 at a depth of about 3000 m. Dual parallel releases were installed in both moorings for redundancy. The anchors consisted of scrap iron plates, stacked up to the required weights. To find the suitable positions for the moorings, both targeted areas were surveyed prior to the deployment using the hull mounted multi beam echo sounder to get accurate bathymetric maps. The planned positions after the survey were 32° 11.0’ S, 4° 38.0’ E, 5130 m (ET3) and 32° 42.3’ S, 7° 7.5’ S, 5000 m (ET4).

Both moorings were deployed from the aft deck of the ship, top first, anchor last, allowing the buoyancy spheres to flow away from the ship. Deployment of the first mooring (ET3) started at about 07:00 UTC on April 9, four hours later all instruments were in the water, and after towing the mooring to the target position, the anchor was dropped at 11:42 UTC. The descent of the top float could not be observed. The second mooring was laid out on April 11. The deployment started in the morning at 06:43 UTC with the top floatation. At 10:34 UTC all instruments were in the water, but due to the strong current of about 1.5 knots the mooring had to be towed to the target position for over 3 1/2 hours. The anchor was dropped at 14:10 UTC. The descent of the top float was observed at 14:39 UTC near the position 32° 41.16’ S, 7° 8.56’ E.

5.1.2 Inverted echo sounders

Five PIES were deployed on the seafloor to measure bottom pressure and acoustic round-trip travel time in the overlying water column (Tab. 5.2). The combination of bottom pressure and acoustic travel time will allow the calculation of the potential energy of mode one internal waves. An array of five PIES around the eastern mooring (ET4) will provide information on refraction of the low-mode internal waves due to mesoscale eddies. One of the PIES was deployed near the mooring to allow direct comparison of the mooring-derived energy flux with that from the PIES.

Tab. 5.2 List of University of Bremen, IUP deployments of the pressure sensor equipped inverted echo sounders (PIES) during cruise SO283.

Station No.	Site ID	Serial No.	Date	Time	Latitude	Longitude	Water Depth
				(UTC)			(m)
SO283_8-1	P2	302	2021/04/09	18:03:25	32° 26.387' S	5° 51.025' E	5070
SO283_9-1	P5	240	2021/04/10	07:19:02	31° 38.927' S	7° 24.619' E	5080
SO283_12-1	P1	271	2021/04/11	00:12:21	32° 42.306' S	7° 07.508' E	5005
SO283_13-1	P3	201	2021/04/11	20:04:32	33° 45.097' S	6° 47.367' E	5305
SO283_14-1	P4	235	2021/04/12	07:19:27	32° 57.661' S	8° 20.909' E	4952

The PIES were programmed to acquire travel time measurements in single bursts of 24 pings every hour and hourly measurements of pressure and temperature, that occur after the travel time measurement. A steel tripod with a weight of approx. 40 kg is used as a ground weight, on which the PIES are mounted prior to the deployment. The descent of the PIES was tracked acoustically using a hydrophone deployed over the side, so that the time at which the instrument reached the bottom could be observed at each site. The descent times varied between 92 and 103 minutes, corresponding to a descent speed of about 50 meters per minute. Calibration CTD casts were made at each deployment position directly after the PIES was lowered into the water.

5.2 Project TRAFFIC

(N. Lahajnar, L. Meiritz, J. Rose, K. Heinatz, S. Hirschmann)

5.2.1 Moorings

(N. Lahajnar, L. Meiritz, J. Rose)

Moorings South Africa

One major goal of the TRAFFIC project was to deploy sediment trap moorings across the South African shelf in order to quantify and to qualitatively describe the descending particle flux and energy transfer from the photic zone to the sediment surface. Due to the complex structure of the water masses and varying upwelling intensities, the true vertical particle flux is most-likely also affected by a lateral flux component - particularly in the area of the upper slope - and thus influences sedimentation processes. Changing particle flux rates and components can lead to a biogeochemical shift of the coupled carbon, nitrogen and oxygen conditions in the SBUS region.

Here, the Benguela system acts as a sink for atmospheric CO_2, whereas the NBUS is considered as a net CO_2 source to the atmosphere.

The purpose of the sediment trap deployments is to investigate the variation of particulate matter settling from the sea surface to the bottom in space and time (Tab. 5.3). Particle flux studies represent a key link between surface ocean processes (e.g., primary productivity) and particle sedimentation and accumulation at the seafloor and thus are an invaluable tool for understanding sedimentation records. Detailed analyses of bulk composition and specific organic compounds will provide information on the sources, early diagenetic alteration and transport processes of the particulate organic matter in the water column. Additional investigations on the biological components, i.e. phytoplankton and zooplankton species being trapped over the annual sampling period, will help to understand the ecological processes in the study area.

Tab. 5.3 Sediment trap deployments in South Africa.

Mooring ID	Position	Water Depth [m]	Trap Depth [m]	Sampling Cycle [days]	Trap Type	Remarks
SBUS East-02	30°38.24'S 17°01.03'E	ca. 170	95	12	HYDROBIOS MST-12	Recovery during SO285
SBUS West-02	31°02.67'S 15°13.78'E	ca. 1290	760	12 / 6	McLANE MARK 78H-21	Recovery during SO285

Moorings Namibia

Sediment trap studies in the NBUS have been successfully carried out in the past (Vorrath et al., 2018, Emeis et al., 2018). The TRAFFIC project aimed at continuing these studies in order to reveal long-term changes and to study the energy transfer from the shelf to the open ocean. During METEOR Cruise M153 in March 2019 two sediment trap moorings were deployed on the Walvis Bay transect (23°S). Information on the physical conditions of the trap environments is provided by additional sensors attached to the system (WBST West-02) or by a second mooring close to WBST East-08 deployed within the EVAR project. This is important to interpret the particle flux over the sampling period as, for example, current speed and current direction could significantly influence the settling particles in the water column.

Both systems could have been recovered during SO283. It turned out, however, that WBST West-02 was most likely hooked by fishery activities. That is why the topfloat, one complete flotation module and one SEABIRD sensor were missing. Moreover, due to motor damage on the sediment trap, the rotation schedule had not been executed. In contrast to the deep mooring, system WBST East-08 on the inner shelf rotated completely and provided a valuable sample set for the TRAFFIC project. This was even more surprising as the complete system was overgrown by muscles and starfish (Fig. 5.2).

Fig. 5.2 Sediment trap WBST East-08 overgrown and covered by muscles and starfish.

From a first visual inspection there were seasonal changes in particle flux during the deployment period (Fig. 5.3). In addition, a first macroscopic inspection also revealed differences in particle composition and plankton species inventory.

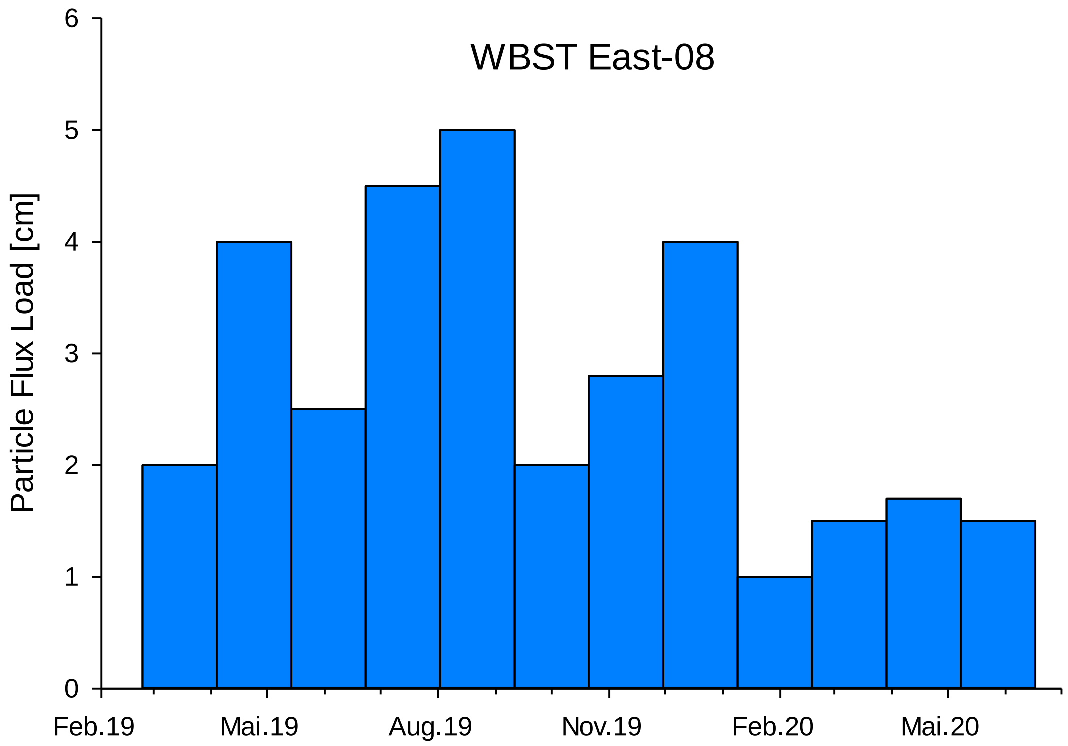

Fig. 5.3 Particle fluxes (estimates) derived from cup load measurements.

Both systems were re-deployed for the next sampling period until fall 2021 when the systems will be recovered during SO285 (Tab. 5.4). Together with our Namibian partners from NatMIRC, we seek a long-term continuation of the sediment trap studies in order to monitor interannual or even decadal changes in the NBUS.

Tab. 5.4 Sediment trap deployments in Namibia.

Mooring ID	Position	Water Depth [m]	Trap Depth [m]	Sampling Cycle [days]	Trap Type	Remarks
WBST East-09	23°01.37'S 14°02.22'E	ca. 130	75	12	HYDROBIOS MST-12	Recovery during SO285
WBST West-03	22°59.98'S 12°23.92'E	ca. 1900	1370	12 / 6	McLANE MARK 7G-21	Recovery during SO285

5.2.2 Drifting Sediment Traps

(L. Meiritz, N. Lahajnar)

Short-term drifting sediment trap systems were deployed at seven stations for 24-48-hours (Fig. 5.4). These systems were equipped with five to seven single-cup sediment traps (SAARSO trap, funnel diameter 0.015 m²) and occasionally with a HYDROBIOS MST-12 sediment trap (12 cups, funnel diameter 0.015 m²). Figure 5.4 illustrates the tracks of the drifter and Tab. 5.5 shows the deployment position, depth and duration of the entire drift experiments. After recovery, the biological composition and the preparation for nutrient analyses (carbon, nitrogen and phosphorus) were performed immediately after the samples were collected on the vessel. For this purpose, the samples were microscopically examined in detail and then filtered through 0.45 µm polycarbonate filters. Further analyses will be carried out on land in the Biogeochemistry Laboratory (Universität Hamburg).

Tab. 5.5 Drifter - short-term drifting sediment trap deployments of the SO-283 expedition.

Drifter ID	Position Start	Position End	Drifter Length [m]	Trap Depths [m]	Duration out [hours]	Drifted Distance [km]
SBUS Drifter 01	31°29.923'S 015°29.878'E	31°28.814'S 015°26.120'E	500	50,100,200,300, 400,500	39.8	8.5
SBUS Drifter02	30°59.985'S 016°59.988'E	31°02.196'S 016°58.412'E	100	20,30,50,75,100	44.2	11.4
NBUS 23 Drifter 03	23°00.006'S 012°44.976'E	22°58.498'S 012°41.432'E	500	50,100, 300,400, 500	52	9.4
NBUS 23 Drifter 04	23°00.003'S 013°34.996'E	22°59.322'S 013°28.905'E	100	20,30,50,75,100	55.3	15.6
NBUS 18 Drifter 05	17°59.988'S 11°18.009'E	17°57.844'S 11°19.261'E	500	10, 50, 100, 200, 300, 400, 500	24	5.6
NBUS 25 Drifter 06	25°00.023'S 013°54.903'E	24°52.079'S 013°41.987'E	100	20,30,50,75,100	48	22.1
NBUS 25 Drifter 07	25°00.015'S 013°20.000'E	24°52.107'S 013°16.070'E	500	50,100,300,400, 500	49	18.2

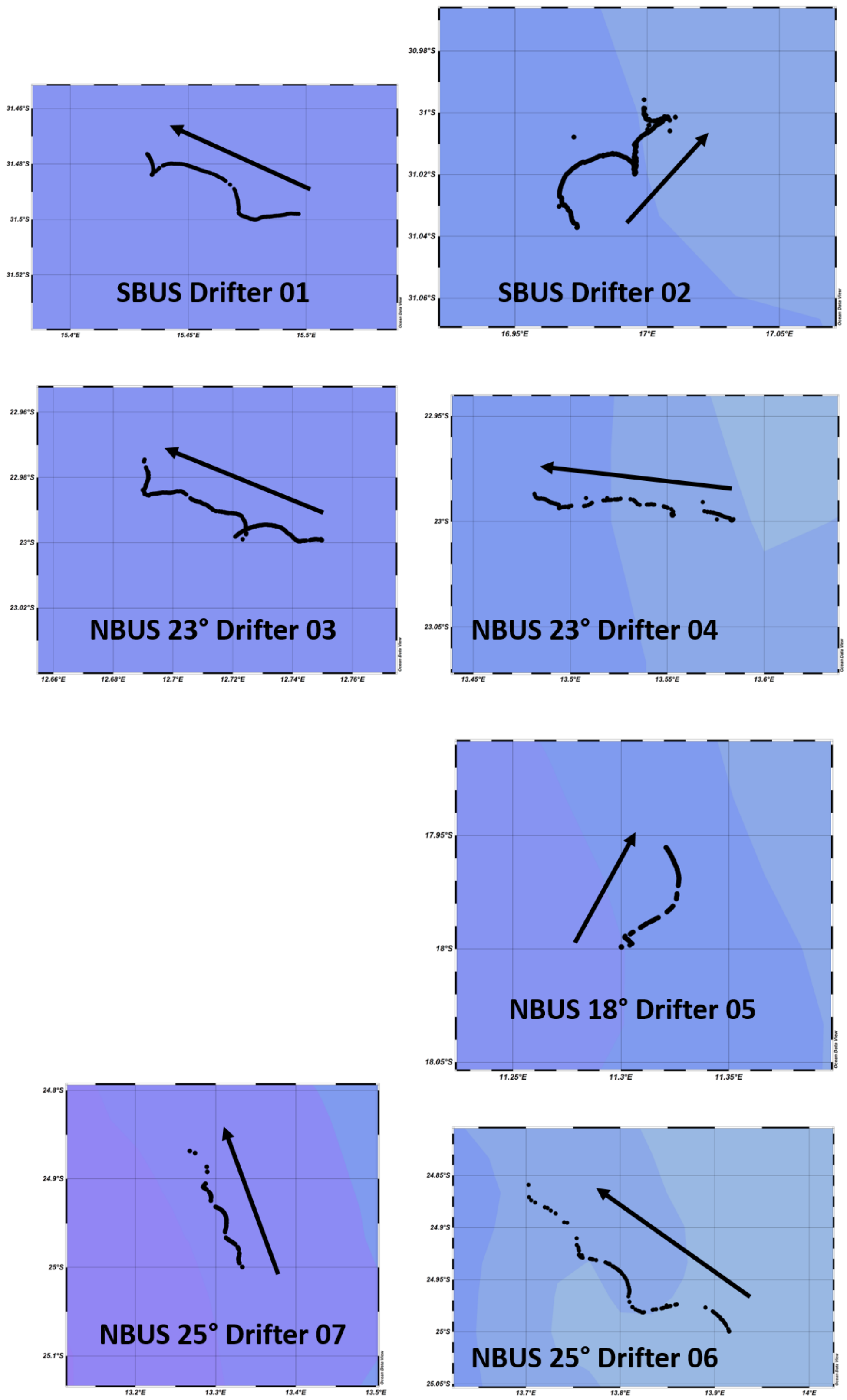

Fig. 5.4 SO-283 Drifter tracks. First row left SBUS Drifter 01, right SBUS Drifter 02; second row left NBUS 23°S Drifter 03 and right NBUS 23° Drifter 04, third row NBUS 18°S Drifter 05 and fourth row left NBUS 25°S Drifter 06 and right NBUS 25°S Drifter 07. The overall movement of the drifting systems is directed to the northwest, which is in accordance with the general wind and surface current patterns in the Benguela region. However, local current regimes might also lead to a different direction (Drifter 02 and 05). Black arrows indicate the overall movement of each drifter.

In addition to the drifter, WP-2 nets with a mesh size of 300 µm were deployed at a total of 21 stations, especially at the drifter deployment and recovery stations, in order to analyse the biological composition of the upper mesopelagic and euphotic water layer (30-300 m water depth; Fig. 5.5). Samples from the WP-2 nets were analysed in detail for biological components and, if the nets were sufficiently filled, filtered through 0.45 µm polycarbonate filters for further analysis at the Biogeochemistry Laboratory of the Universität Hamburg.

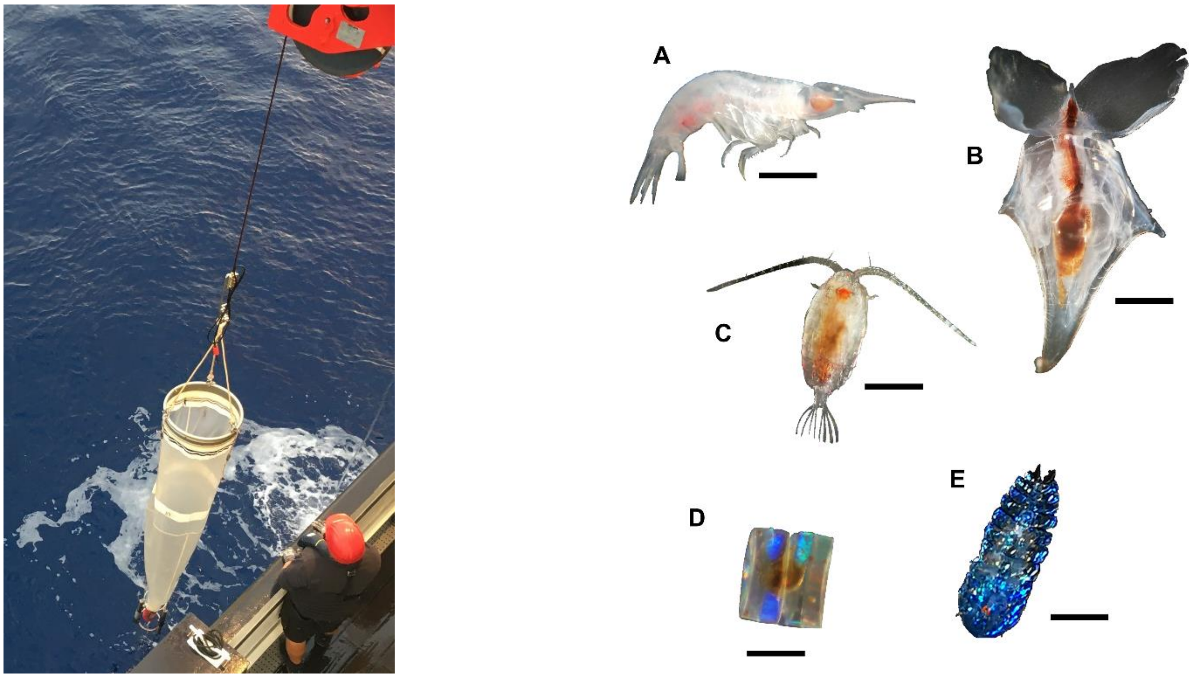

Fig. 5.5 On the left side the WP-2 net during deployment; On the right, an assemblage of various plankton organisms collected with the WP-2 Plankton-Net.. Black bars are individual scales A.) Amphipod (Family Oxycehpalidae; 1 mm) B.) Pteropod (Family: Cavoliniidae; 1 mm) C.) Copepod (Order: Calanoida 1 mm) D.) centric diatom (0.5 mm) E.) Copepod (Genus: Sapphirina; 1 mm)

5.2.3 CTD Water Sampling

(L. Meiritz, N. Lahajnar, J. Rose)

Suspended matter

All water samples were retrieved with the ship's CTD rosette (see chapter 5.4). The filtration volume of sea water on pre-combusted and tarred glass fibre filters (WHATMAN GF/F, ~0.7 µm, 47 mm diameter) varied between 5 and 30 L. The filtration was stopped when filters were satisfactorily covered (Fig. 5.6). After filtration, the samples were rinsed with deionised water to remove sea salt and subsequently dried in the ship's dry oven at 40 °C for 48 hours. In total, we collected water from 34 stations. The samples will be further analyzed in the Biogeochemistry Laboratory (Universität Hamburg) for the main nutrients and suspension load.

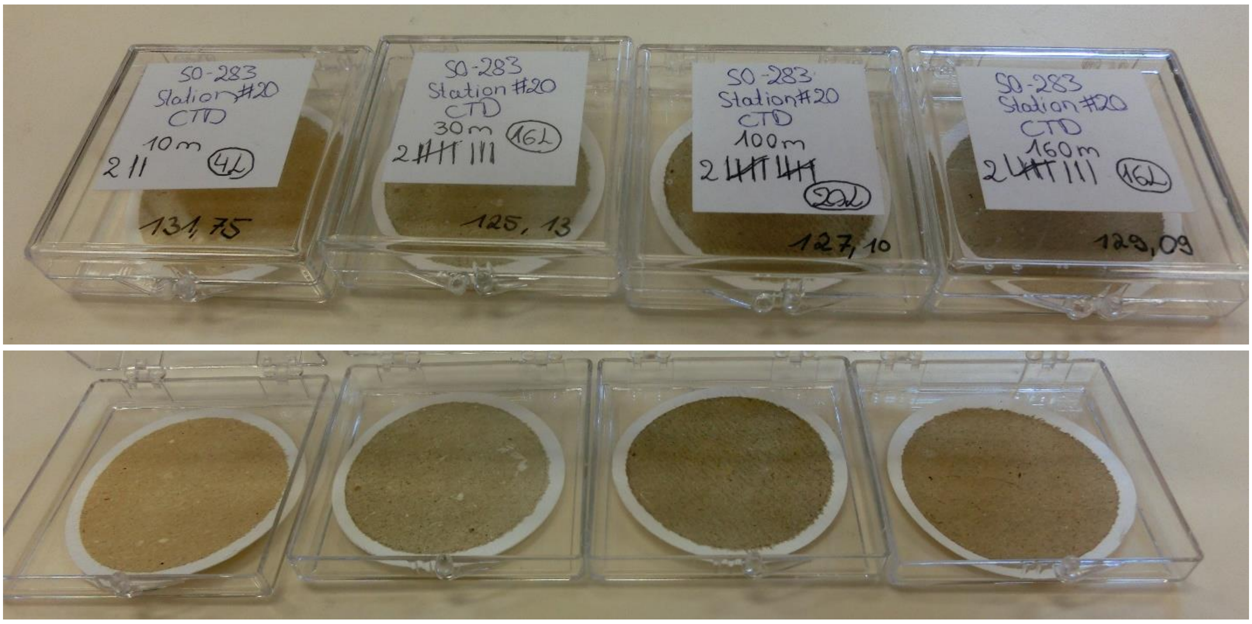

Fig. 5.6 Suspended matter load on GF/F filters from station #20. From left to right, the depth of the filtered water increases. Station 20 was a coastal station with a relatively shallow water depth of 166 m, therefore all filters are very intensely covered despite the different filtration volumes.

Nutrient and dissolved compound sampling

Nutrient (NO_x, NO_2^-, NH_4^+, PO_4^{3-} and $SiOH_4^-$) samples from 24 stations were filtered through disposable syringe filters (0.45 µm) immediately after sampling, and filled in pre-rinsed 50 ml PE bottles. On 16 stations also samples for DOC (dissolved organic carbon) and DCAA (dissolved combined amino acids) measurements were filtered through WHATMAN GF/F filter (~0.7 µm) and stored in glass vials for further analyses (see Tab. 5.6).

Tab. 5.6 Stations and water depths sampled for suspended matter. Sus = Suspension; Nuts. = Nutrients

Station	Lat. [°N]	Lon. [°E]	Depth [m]	Bottle depth [m]	Sus.	DCAA	DOC	Nuts.
1	37.5557	-15.1195	4000	0,42,450,1000,2000	x	x	x	x
2	9.3416	-23.8626	5230	0,35,460,850,2000	x	x	x	x
3	-4.5723	19.3280	4800	0,75,400,750,1500,3000	x	x	x	x
4	-19.9040	7.9343	4268	0,110,700,1500,2000	x	x	x	x
12	-32.7052	7.1252	4995	0,90,850,1000,3000	x	x	x	x
16	-31.0410	15.2300	1291	0,70,500,760,1273	x	x	x	x
20	-30.6413	17.0170	166	0,10,30,100,160	x	x	x	x
24	-31.4803	15.4355	1120	0,65,150,500,670,1120	x	x	x	x
26	-31.0337	16.9735	213	0,10,75,100,210	x	x	x	x
29	-23.0000	14.2147	108	0,30,50,70,100	x	x	x	x
43	-22.9999	12.3302	2070	0,400,700,1000,2000				x
47	-22.9750	12.6905	1155	0,200,400,600,1100	x	x	x	x
49	-17.2657	11.6983	53	5,45	x	x	x	x
50	-17.2657	11.5009	152	5,25,75,120				x
51	-17.2662	11.2747	505	25,318,499	x	x	x	x
52	-17.2659	11.1493	1102	25,100,200,300,600				x
55	-18.0000	11.2998	906	0,34,260,500,896	x	x	x	x
57	-25.0018	13.3335	1081	5,35, 100,250,500,750,1064	x		x	x
58	-25.0032	13.9147	198	0,5,13,25,75,120,150,170	x			x
59	-24.9998	14.1018	170	0,10	x			
60	-25.0002	14.3197	143	0,5,10,20,40,80,120,130	x			x
61	-24.9997	14.4167	125	0,15	x			
66	-25.0000	14.7410	50	0,13	x			
68	-25.0000	14.4960	115	0,40,65,90,109	x			x
71	-24.9998	13.9998	172	0,13	x			
72	-24.9998	13.8332	222	0,25	x			
73	-25.0005	13.7308	313	0,5,10,55,125,175,225,309	x			x
75	-24.9992	13.5468	630	0,50,250,350,500,617	x			x
76	-24.9992	13.1662	1457	0,16	x			
77	-24.9997	12.9998	1795	0,28	x			
86	-10.7332	13.1505	690	0,40	x			
87	-10.7000	13.2000	430	0,40	x			
88	-10.6665	13.2501	217	0,34	x			
90	-10.6010	13.3495	107	0,30	x			
92	10.5333	13.4497	58	0,20	x			
93	-10.4980	13.4998	42	0,20	x			
99	-9.9830	9.6670	4414	0,38,420,2000	x	x	x	x

5.2.4 Microplankton Investigation

(K. Heinatz, S. Hirschmann)

Our working group contributes to different topics of the joint research project TRAFFIC. We are investigating the base of the food chain. Therefore, phyto- and microzooplankton composition will be analysed, as well as the fitness of the primary producers, and trophic positions will be determined by stable isotope analyses.

Phytoplankton community composition

The phytoplankton community composition at each station will be assessed using FLOWCAM imaging and microscopy analysis at home-laboratories. Water samples (250 mL) from the surface (2-3 m), 10, 20, 30, 50, 100 m and chlorophyll *a*-maximum depths were taken from a CTD rosette at selected stations (Tab. 5.7). To preserve the phytoplankton for later microscopic analyses, we added Lugol solution to the water samples and stored them in the dark at 4°C.

Pigments

Water samples from the surface, 10, 20, 30, 50, 100 m and chlorophyll *a*-maximum depths, were taken from the CTD rosette at 29 stations. Different volumes, depending on the chlorophyll content, were filtered with WHATMAN® filters, grade GF/F and GF/C for pigments analyses at home laboratories, using a HPLC and fluorometry. The filters were deep-frozen with liquid nitrogen and afterwards frozen at -80 °C.

Fitness of primary producers

Water from the above-mentioned sampling depths and stations was analysed for photoactive ‘fitness’ of the primary producers using a Fast Repetition Rate Fluorometer (FASTTRACKAII, Chelsea Technology, UK). Fast Repetition Rate Fluorometry (FRRf) is a non-invasive method to measure the activity of primary producers using Chl *a* fluorescence (Oxborough et al., 2012); photons reaching the photosystem II of the algae are either used photochemically, dissociate non-radioactively or are re-emitted as fluorescence. This fluorescence is used for FRRf. Non-active photosystems are 'open' with low fluorescence. Once a photon is absorbed, the photosystem closes. With an increasing number of closed systems, the fluorescence increases. At the beginning of the exposure most of the photons are used by the algae then, gradually, the active photosystems close and the fluorescence rises due to less absorbed photons. Considering F_v the difference between the highest fluorescence signal (F_m) and the fluorescence at the beginning of the measurement (F_0), the amount of radiated energy that has been used by the algae can be calculated by the expression:

$$F_v/F_m = (F_m – F_0)/F_m$$

The relation F_v/F_m, varying between 0 and 1, is an indicator of the fitness of the algae, where 0.5 represents good condition. The values are determined both by composition and physiological condition of the primary producers (Suggett et al., 2009). For example, limitation of nutrients or too intense a radiation, lower the values.

Typically, 5 ml of sampled water were inserted in the dark chamber of the fluorometer and irradiated with saturating light flashes. The re-emitted photons were measured by the fluorescence detector. In our samples Fv/Fm values of 0.5 were rarely measured, indicating that the photosynthetically active organisms were not in best conditions. Measurements at offshore station showed mostly low values due to low biomass blurring the results (Fig. 5.7).

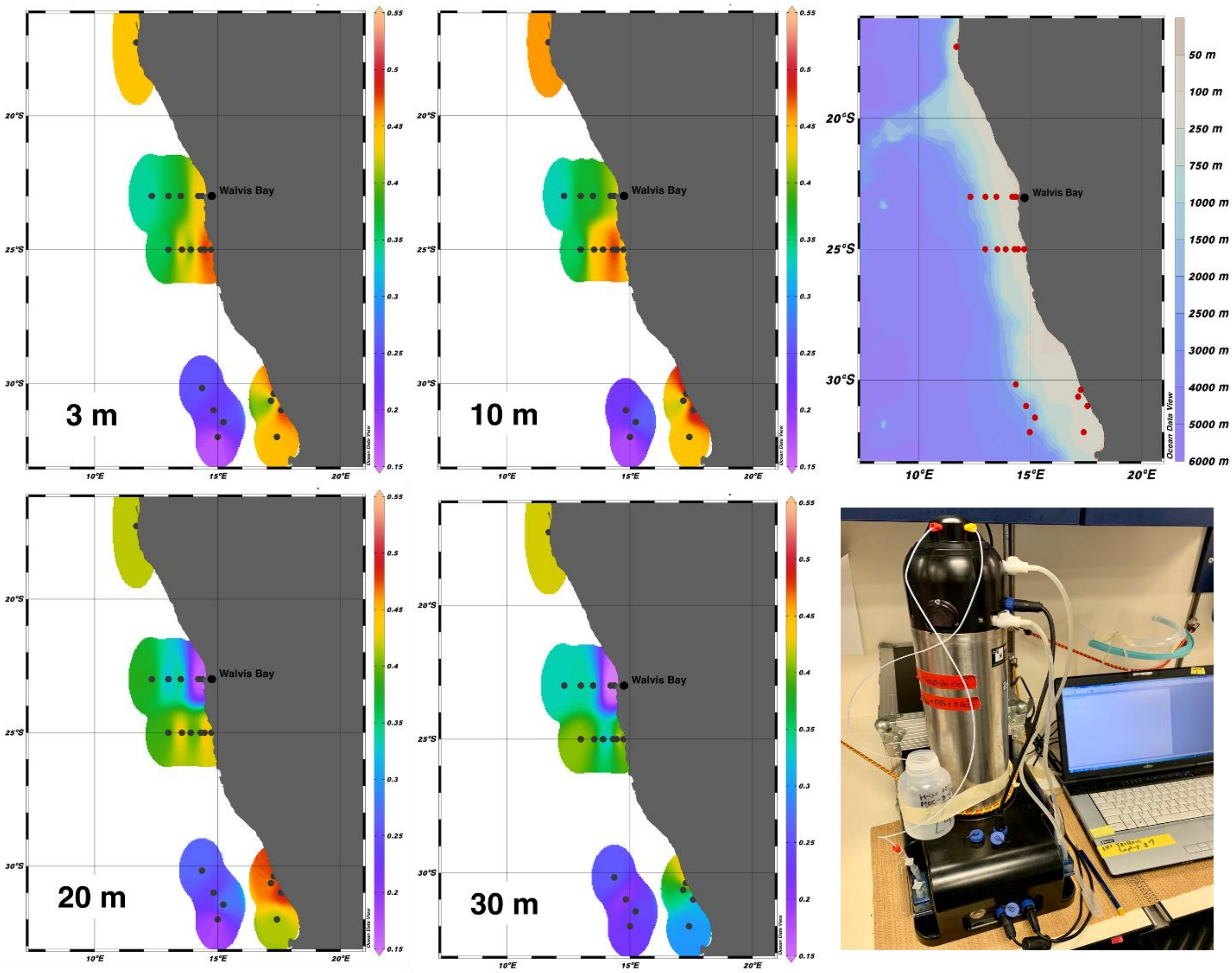

Fig. 5.7 Primary producer `fitness` in Fv/Fm values for depths from 3 to 30 m in the northern and southern Benguela Upwelling System.

Microzooplankton

The investigation of the microzooplankton community makes it possible to determine its quality and quantity as food for higher trophic levels. Sampling was conducted using APSTEIN nets with 20 µm and 55 µm mesh at all phytoplankton stations to collect material between 10 m depth and the surface. The taxonomic and stable isotopic composition of this material will be investigated in the home laboratory.

Tab. 5.7 List of sampled stations during the SO283 cruise. At every CTD station water samples were taken. APSTEIN nets (20 and 55 µm) are abbreviated as "PLA".

Station	Date	Latitude	Longitude	Gear
SO283_1	23.03.2021	37° 33,338' N	015° 07,170' W	CTD, PLA
SO283_2	29.03.2021	09° 20,507' N	023° 51,769' W	CTD, PLA
SO283_3	01.04.2021	04° 34,344' S	019° 19,685' W	CTD, PLA
SO283_4	05.04.2021	19° 54,237' S	007° 56,059' W	CTD, PLA
SO283_7	09.04.2021	32° 10,997' S	004° 38,009' E	CTD, PLA
SO283_8	09.04.2021	32° 26,385' S	005° 51,032' E	CTD, PLA
SO283_12	11.04.2021	32° 42,308' S	007° 07,507' E	CTD, PLA
SO283_15	13.04.2021	33° 06,009' S	013° 52,019' E	CTD, PLA
SO283_16	15.04.2021	31° 02,709' S	015° 13,844' E	CTD, PLA
SO283_18	16.04.2021	31° 00,026' S	017° 34,987' E	CTD, PLA
SO283_20	16.04.2021	30° 38,489' S	017° 01,009' E	CTD, PLA
SO283_21	16.04.2021	30° 22,997' S	017° 17,004' E	CTD, PLA
SO283_22	17.04.2021	31° 00,009' S	014° 49,971' E	CTD, PLA
SO283_23	17.04.2021	31° 59,976' S	015° 00,036' E	CTD, PLA
SO283_25	17.04.2021	32° 00,022' S	017° 24,969' E	CTD, PLA
SO283_27	18.04.2021	30° 10,328' S	014° 22,026' E	CTD, PLA
SO283_28	20.04.2021	23° 00,011' S	014° 22,019' E	CTD, PLA
SO283_29	20.04.2021	23° 00,002' S	014° 12,858' E	CTD, PLA
SO283_31	21.04.2021	23° 00,006' S	013° 29,978' E	CTD, PLA
SO283_36	21.04.2021	23° 00,000' S	013° 00,909' E	CTD, PLA
SO283_43	22.04.2021	22° 59,995' S	012° 19,817' E	CTD, PLA
SO283_49	24.04.2021	17° 15,934' S	011° 41,907' E	CTD, PLA
SO283_58	27.04.2021	25° 00,179' S	013° 54,875' E	CTD, PLA
SO283_60	27.04.2021	25° 00,009' S	014° 19,186' E	CTD, PLA
SO283_66	28.04.2021	24° 59,997' S	014° 44,649' E	CTD, PLA
SO283_68	28.04.2021	25° 00,000' S	014° 28,142' E	CTD, PLA
SO283_75	28.04.2021	24° 59,947' S	013° 32,812' E	CTD, PLA
SO283_77	29.04.2021	25° 00,000' S	012° 59,996' E	CTD
SO283_99	05.05.2021	10° 00,003' S	009° 40,001' E	CTD, PLA

5.3 Projects EVAR and BANINO

(B. Sabbaghzadeh, S. Beier, P. Witting, A. Andrae**)**

The BANINO project aims for a better understanding of the temperature anomalies in the Northern Benguela System, so called Benguela Niños and Niñas, caused by the variability of poleward propagation of tropical water masses. This variability has high impact on the hydrographic conditions in the ecosystem, specifically on fishery, Gammelsrød et al. 1998. The main physical mechanism behind positive temperature anomalies, i.e., Benguela Niños, is a weakening of trade winds in the equatorial Atlantic, which generates equatorial Kelvin waves related to a thermocline elevation and response in the equatorial undercurrent and finally to a poleward directed pulse of tropical water in the coastal wave guide. The locally observed variability of hydrographic conditions along the Angolan and Namibian coast reveals as elements of a long distance interaction between the equatorial current system and the subtropical ocean mediated by waves in the coastal wave guide, Florenchie et al. 2004, Lübbecke et al. 2010. The moorings at 11°S, at 18°S, 23°S and 25°S are major building block to observe this specific oceanic variability.

The local processes mediating the transport between the subthermocline water and the sea surface are related to upwelling driven by the local wind, Fennel et al., 2012, Bordbar et al. 2021, but also to mixing by internal waves and tides breaking on the shelf, Zeng et al. 2021. The latter process motivated the dense hydrographic CTD-measurements off Angola. It is aim of BANINO to understand these processes quantitatively by numerical modelling and to enhance the sparse observational hydrographic data base with synoptic hydrographic measurements in different seasons during ship cruises. The goal of this research is an understanding of the response of the circulation in the Benguela upwelling system to a climatic change of large scale and local winds. A specific issue is disentangling the poleward transport of oxygen depleted and nutrient enriched waters within the coastal undercurrent into the northern Benguela and of the wind driven cross shore transport and upwelling of these waters into the euphotic zone fueling the primary production and hence, the food chains throughout the ecosystem.

EVAR considers the hydrographic and ecosystem variability on various time scales in The Northern Benguela Upwelling System. As a specific topic of interest the consequences of intermittent sub- and anoxic conditions on microbial communities are investigated in detail. The considered players in the food web span from archaea and bacteria to macro-zoobenthos living eventually in symbiosis with denitrifying bacteria. One overarching questions of EVAR is how the different organisms deal with oxygen conditions varying on short time scales, but undergoing also a seasonal cycle and exhibiting a strong interannual variability. Another issue of interest is the dynamics, sources and sinks of climate relevant trace gasses like CO2, methane and nitrous oxides. The question, if the Benguela Upwelling system serves as a sink or a source for such gasses does not have a straightforward answer. The underway measurements and the water sampling during this cruise delivers essential data for this research and helps to enhance the sparse data base. The dissolved trace gasses are partially imported into the BUS from the oxygen minimum zone hosted by the Angola gyre with the poleward undercurrent. The gas sampling at the 18°S section addresses this process. Accordingly, the water masses may be upwelling along the Namibian coast, which is followed with the underway measurements in the coastal stripe. The sections at 23°S and 25°S are placed within the Northern Bus where dissolved gasses experience sound modification from the local microbial community, not only in the water column but also in the surface sediments. For the hydrographic conditions on this section and the sampling strategy description. The mooring at 18°S mirrors the strength of the poleward undercurrent. The moorings at 23°S and 25°S on the Namibian shelf measure and serve to characterise the hydrographic variability resulting from the remote influence via the undercurrent and the local upwelling in response to the local winds as well.

The major goal of EVAR project, is to obtain high-resolution data on the variability of present day physical forcing of the BUS, and the present and past variability of oxygen supply and the key biogeochemical feedbacks as documented in sediment achieves.

The effect on microbially driven processes of variations in oxygen levels over the ranges observed today and in the geological past will then be investigated in targeted experiments to understand their impact on oxygen, carbon and nutrient budgets and their influence on the production of greenhouse gases.

One of the major objectives is to investigate whether certain environmental conditions can be responsible for positive or negative feedbacks leading to system-wide tipping points. As the BUS is characterized by a pronounced spatial and temporal variability, these observations will be integrated into an advanced ecosystem model to judge the effects on the budgets of carbon and oxygen for the entire area.

5.3.1 IOW-Moorings

(S. Beier)

The recovery and maintenance of the three oceanographic shallow water moorings in Namibian waters (set on M157) were originally planned for expedition M172 of the R/V Meteor. Due to the pandemic, this could not be carried out as planned, resulting in an extension of the standing time. After customs clearance in the port of Walvisbay, the long-term mooring LTMB_20_2019, which has been in operation since 2003 in close cooperation with the "National Marine Information and Research Centre" (NatMIRC) was recovered at 23° latitude on 22.04.2021. Here, it was necessary to resort to an emergency releaser system, as considerable corrosion damage had occurred due to the long service life. Some oceanographic measuring instruments could therefore not be recovered. One day later, the LTMB_21 was redeployed at the same position.

At 18° latitude, a few days later on 25.04.21, the long-term mooring LTKC_10_2019, a bottom shield (TRBM) was recovered without any problems or losses.

The last oceanographic mooring in Namibian waters was successfully recovered on the morning of 28.04.2021 without any losses.

The recovered equipment of all three moorings performed well under the circumstances. The data obtained will now be processed, validated and prepared for publication at a later date.

5.3.2 GEOMAR-Mooring

(P. Witting, A. Andrae)

At the Angolan continental slope, one mooring (1200 m, offshore) was deployed at the continental slope at 11°S during Meteor cruise M158 in late September 2019, about 1.5 years before S283. The mooring was equipped with an upward-looking 75 kHz LONGRANGER ADCP at 500m depth to observe variability of the eastern boundary circulation and to determine intraseasonal to interannual variability of the transport of the Angola Current. Additionally, the mooring carried velocity (ARGONAUT), oxygen (optode), temperature and salinity (MICROCAT) loggers at several depths above and below the ADCP to record water mass variability and flow in the deeper water column. The mooring was successfully recovered on May 3 2021. The 75-kHz ADCP worked well throughout the deployment period (Fig. 5.8) and thus complements the velocity time series of the eastern boundary circulation off Angola that started in June 2013. Also, from a first inspection, all other instruments recorded valuable data. Sensor calibration from the temperature and salinity loggers is ongoing using data from the sensor calibration casts where the loggers were attached to the CTD. In the morning of May 4, the mooring was redeployed. About 1 hour after the anchor release, the position was triangulated. Its final position was 10°50,05`S 012°59,93`E.

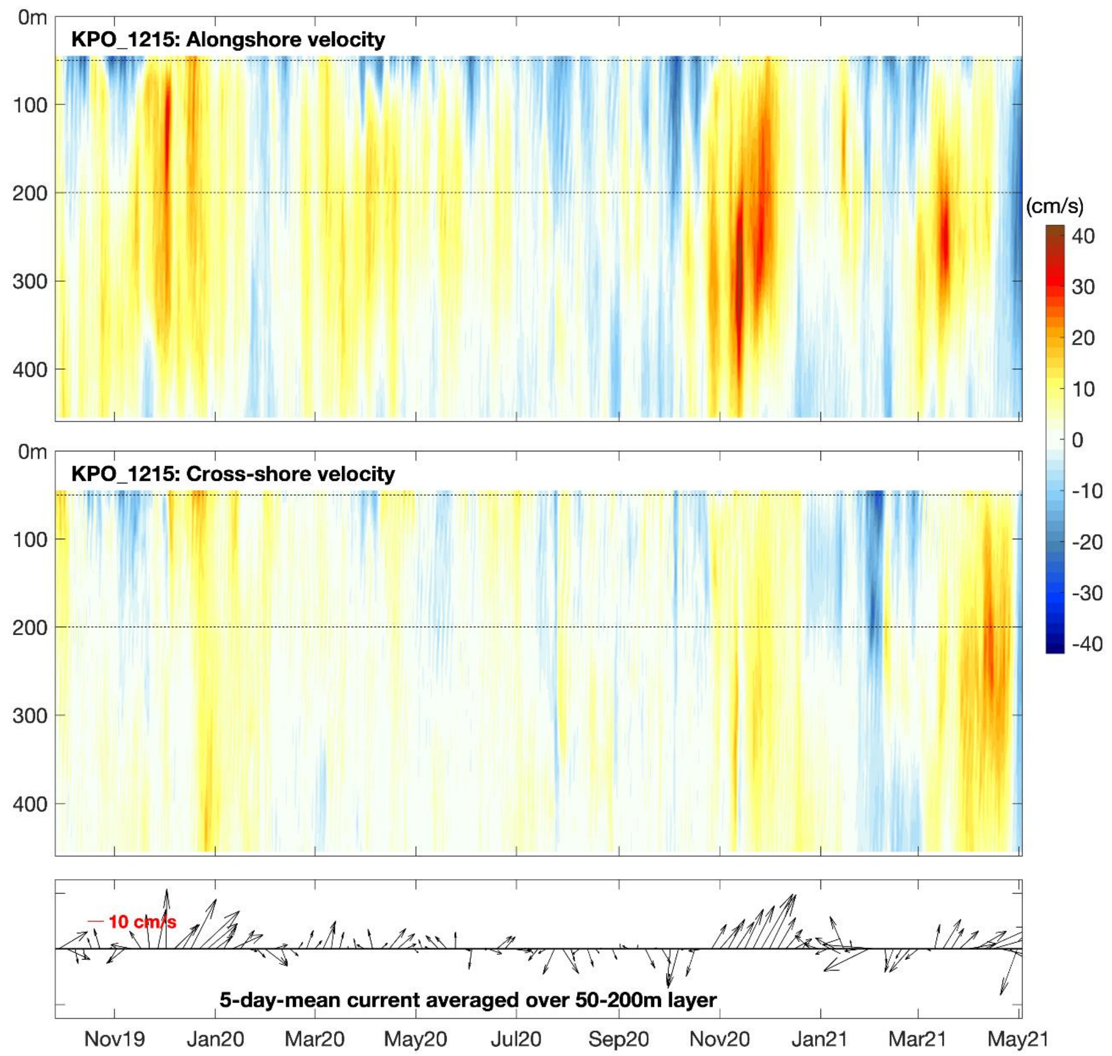

Fig. 5.8 This figure depicts the alongshore component (upper panel) and across-shore (middle panel) component and 50-5000m averages (vectors bottom panel) of current velocity measured by the mooring. The elevated variability of the eastern boundary circulation on intraseasonal time scales originates from poleward propagating coastally trapped waves. These waves are predominately excited by wind fluctuations within the western equatorial Atlantic.

5.3.3 Trace gas distribution in the Benguela upwelling system

(B. Sabbaghzadeh)

The high surface productivity and nutrient remineralization triggered by nutrient-rich upwelled waters results in significant fluxes of organic carbon to sub-surface waters (Capone and Hutchins, 2013). Hence, microbial O_2-consuming processes are promoted, driving oxygen depletion that favors trace gases i.e. N_2O and CH_4 production at relatively shallow depths (Monteiro et al., 2006; Frame et al., 2014). During upwelling, N_2O and CH_4-rich subsurface waters are also transported towards the surface waters, enhancing trace gas sea-air fluxes (Nevison et al., 1995; Charpentier, 2010; Frame et al., 2014). We investigate the seasonal cycle of these fluxes in relation to variability in both physical forcing and microbiological processes by continuous surface trace gas measurement and by measuring trace gases in discrete samples from the water column profile in the Benguela upwelling system as part of the interdisciplinary EVAR project.

Depth profile sampling of trace gases on RV SONNE (SO283)

About 300 discrete water samples from Niskin bottles were collected along the three main previous EVAR established transects in the Benguela upwelling system (Fig. 5.12) for investigation of trace gas concentrations within the water column. The transects around 17.5, 23 and 25°S represents the Angola-Benguela frontal zone, Walvis Bay and Lüderitz upwelling cells respectively, which are suggested to represent some regional hotspots of trace gases in particular in the vicinity of the upwelling cells (e.g. Sabbaghzadeh et al., 2021). For determination of trace gas concentrations, in-house designed purge and trap system (P&T) equipped with a Flame Ionization Detector (FID) for CH_4 measurements and an Electron Capture Detector (ECD) for N_2O measurements using a dynamic headspace method will be used back in IOW laboratory.

5.3.4 Hydrographic section at 10°30'S

(M. Schmidt, C. Mertens, J. Stiehler, P. Witting, A. Andrae, B. Sabbaghzadeh)

A hydrographic section perpendicularly to the coast allows to estimate the spatial extend of the currents measured at the mooring position (Fig. 5.9).

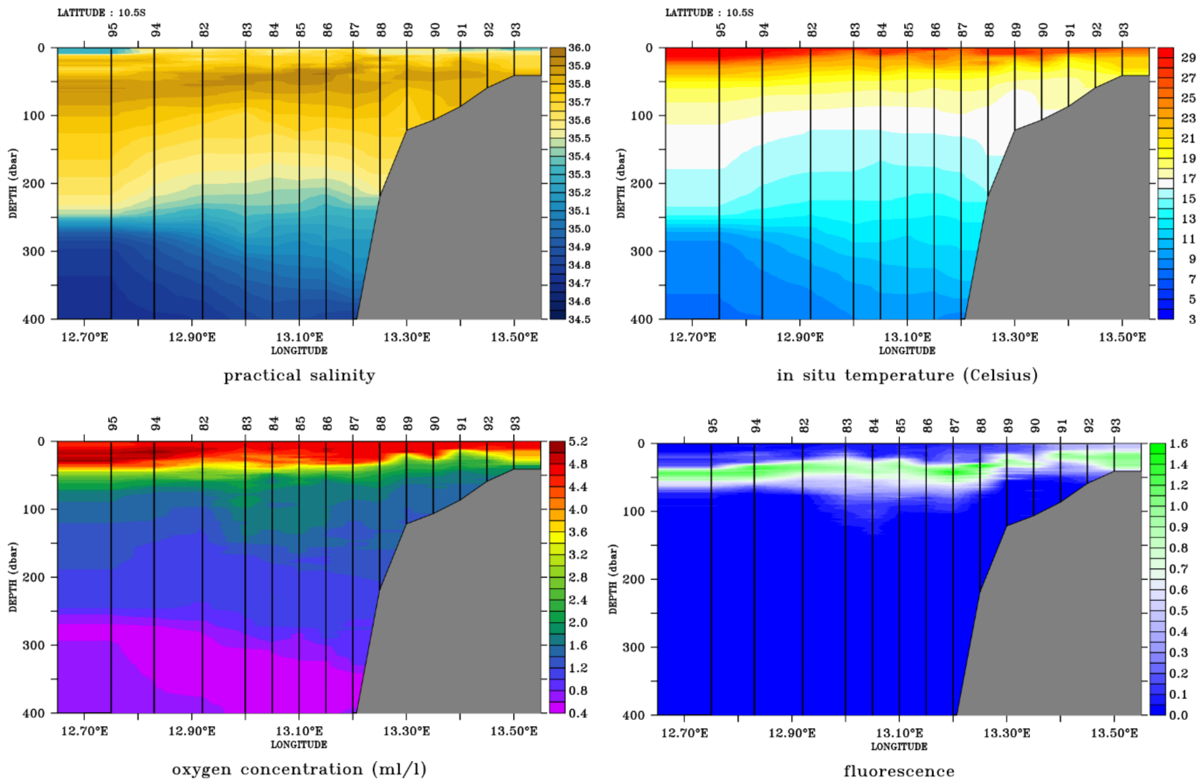

Fig. 5.9 Hydrographic section perpendicularly to the coast at 11°S. Shown are the upper 400m only, where most variability in the central waters is visible. Upper left: Salinity has a distinct maximum at 50m depth. At the surface lower salinity is met from the influence of precipitation and river discharge. Upper right: Due to the strong insolation the very surface water is about 30°C warm. In combination with the lower salinity this supports a very thin stable surface layer. Lower left: The slow ventilation leads oxygen depleted water. This oxygen minimum zone extends westward into the Angola Dome area. Lower right: Chlorophyll-a concentration derived from fluorescence. On the whole section surface chlorophyll concentration is low. Instead a deep chlorophyll maximum is met.

The spreading of isotherms and isohalines indicates a strong geostrophic current directed poleward mediating an important part of the water mass and heat transport between tropics and subtropics. It is one of the key quantities to understand the hydrographic variability in the Northern Benguela Upwelling system. It has also strong impact on the oxygen and trace gas variability in the Northern Benguela. Below the poleward current, the water is less ventilated and hosts a pronounced oxygen minimum zone. The lower boundary of this oxygen minimum zone is the Antarctic Intermediate Water with its core at about 800m depth (not shown here).

5.3.5 Hydrographic section at 17°S

(M. Schmidt, C. Mertens, J. Stiehler, P. Witting, A. Andrae, B. Sabbaghzadeh)

The hydrographic section off Walvis Bay at 17°S represents the region, where the poleward undercurrent merges into the Northern Benguela Upwelling system (Fig. 5.10). Unfortunately the station grid is too sparse clearly to identify geostrophic currents. Below 100 m depth a huge pool of oxygen depleted water is found. The lower limit of this water mass is Antarctic Intermediate Water (not shown here). In the west, oceanic water with high salinity and a deep salinity and chlorophyll maximum prevails. Near the coast salinity is lower and the water is colder than the oceanic water. The may be partially stem from local upwelling, but most probably from an equatorward directed coastal jet.

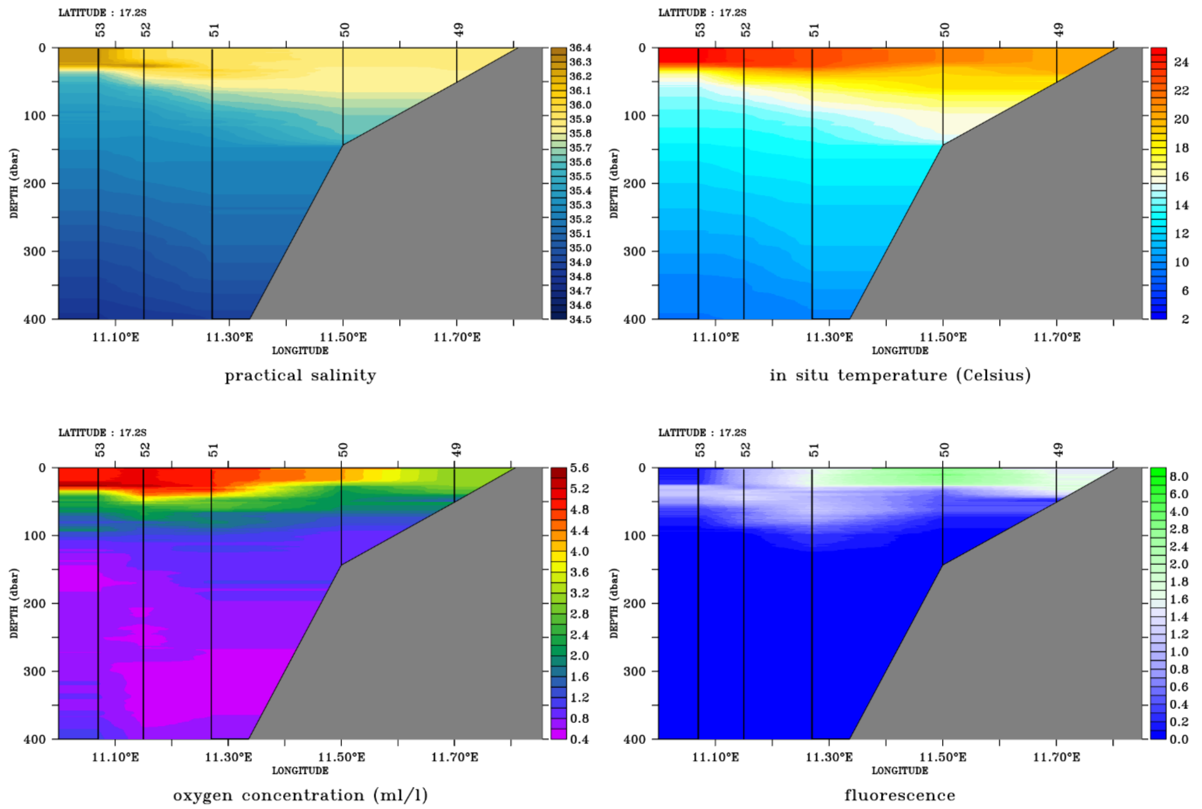

Fig. 5.10 Hydrographic section at 17°S. Salinity (upper left) and temperature (upper right) cover oceanic water in the west and coastal water in the east. The major oxygen minimum zone (lower left) is located at 300m depth. Chlorophyll concentration (lower right) has its maximum in the surface layer with the exception of the western stations, where a deep chlorophyll maximum is met.

5.3.6 Hydrographic section at 23°S

(M. Schmidt, C. Mertens, J. Stiehler, P. Witting, A. Andrae, B. Sabbaghzadeh)

The hydrographic section off Walvis Bay at 23°S shows the water masses partly with tropical origin penetrating poleward with the coastal undercurrent and are upwelled near the coast by the meridional trade winds (Fig. 5.11). The mooring at 23°S addresses the variability of this current.

The hydrographic section shows spreading isotherms indicating a developed undercurrent attached to the slope maximum of the sea floor.

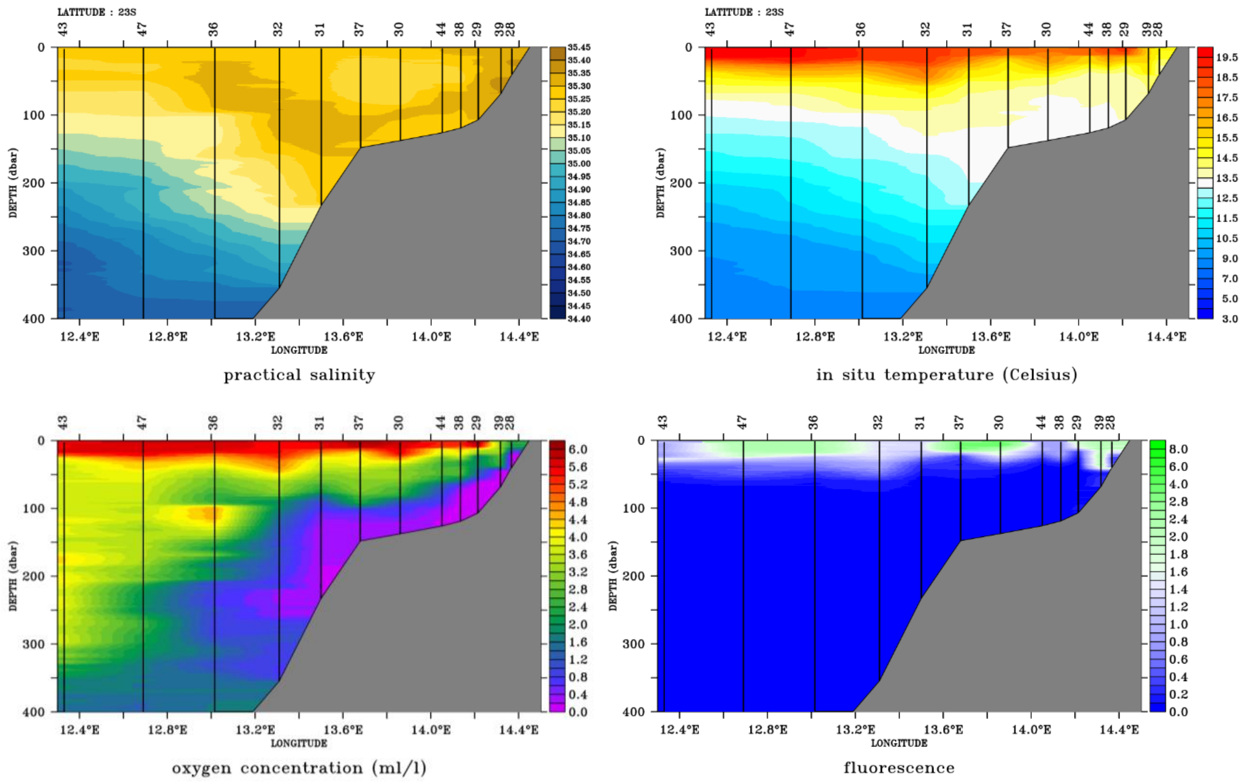

Fig. 5.11 Hydrographic section at 23°S. Salinity (upper left) and temperature (upper right) patter suggest eastward motion and upwelling of the bottom water on the shelf. The major oxygen minimum zone (lower left) is located near the bottom on the shelf, where a mud belt is located. A second minimum is found at the slope at 200m depth. Here the sloping isotherms indicate a geostrophic poleward transport of water masses with tropical origin. Chlorophyll concentration (lower right) has its maximum in the coastal upwelled water and stays confined to the surface at the whole section.

5.3.7 Hydrographic section at 25°S

(M. Schmidt, C. Mertens, J. Stiehler, P. Witting, A. Andrae, B. Sabbaghzadeh)

The hydrographic section at 25°S is located where most of the water coming from the north with the poleward undercurrent has already upwelled (Fig. 5.12). However, the salinity maximum at station 58 and 72 and the related oxygen minimum suggests that the poleward flow continues to 25°S. The bottom water on the shelf is anoxic, the sloping isotherms on the shelf indicate an equatorward directed coastal jet. Chlorophyll is confined to the sea surface, the maximum concentration is found near the coast where upwelling takes place.

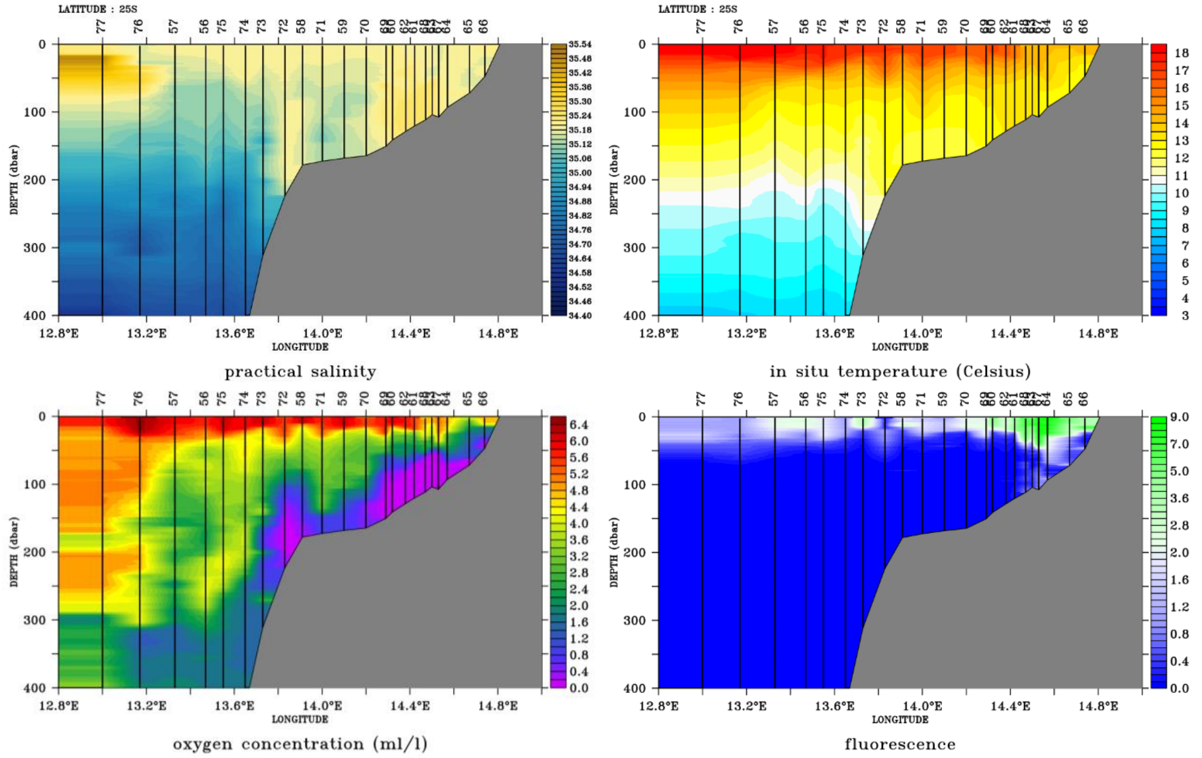

Fig. 5.12 Hydrographic section at 23°S. Salinity (upper left) and temperature (upper right) patter suggest eastward motion and upwelling of the bottom water on the shelf. The major oxygen minimum zone (lower left) is located near the bottom on the shelf. This is one of the key areas of EVAR. A second oxygen minimum is found at the slope at 200m depth. Chlorophyll concentration (lower right) has its maximum in the coastal upwelled water.

5.4 CTD-handling, Water and Plankton Sampling with CTD/Rosette

(M. Schmidt)

Most stations were started with a CTD cast (see Tab. 5.8a/b). The data recording was started on deck to allow for using the SEABIRD pressure correction algorithm that removes a potential pressure offset with pressure data on deck. Then the OPUS nitrate sensor is started. The CTD was hold on 10 m depth about 3 min to let the pumps start and fully remove air bubbles from the TC-ducts. The cast was carried out from the surface with a veer velocity of 0.5 m/s in the upper layer and 0.7 m/s if the device is below 100 m depth. About 100 m above the bottom veer velocity was 0.5 m/s and 0.3 m/s in the last 15 m above the sea floor. The device was stopped at about 5 m distance from the sea floor detected from the altimeter.

Bottles were closed during the upcast. After stopping the winch, water exchange was allowed for 2-3 min before the bottles were closed. Registration was finished on deck to get enough overlap with the OPUS nitrate sensor data for identifying start and stop in these data.

Tab. 5.8a CTD Sensor information 23.03. – 13.04 2021, stations SO283_01 – SO283_15.

Parameter	Sensor	Serial number Calibration date	Accuracy	Correction
Temperature0	SBE 3	5938 13-may-20	± 0.001 K	+1mK
Temperature1	SBE 3	4677 09-jun-20	± 0.001 K	

Conductivity0	SBE 4	4484 10-dec-19	± 0.0003 S/m	0.999841375
Conductivity1	SBE 4	4262 28-may-20	± 0.0003 S/m	0.999897605
Pressure	Digiquartz	1184 26-may-20	± 1.5dBar	
Fluorescence	ECO-AFL/FL	3332 12-aug-20		
Turbidity	ECO-NTU	3332 06-feb-18		
Temperature	SBE35RT	0082 30-jun-18		

The attached oxygen sensors suffered from damaged Clark cell membranes and are not used.

Tab. 5.8b CTD Sensor information 13.04. – 05.05.2021, station SO283_16 – SO283_99.

Parameter	**Sensor**	**Serial number Calibration date**	**Accuracy**	**Correction**
Temperature0	SBE 3	5708 11-may-20	± 0.001 K	+2mK
Temperature1	SBE 3	4677 09-jun-20	± 0.001 K	
Conductivity0	SBE 4	4261 09-feb-21	± 0.0003 S/m	1.00000425
Conductivity1	SBE 4	4262 28-may-20	± 0.0003 S/m	0.99989596
Pressure	Digiquartz	1184 26-may-20	± 1.5dBar	
Fluorescence	ECO-AFL/FL	3332 12-aug-20		
Turbidity	ECO-NTU	3332 06-feb-18		
Temperature	SBE35RT	0082 30-jun-18		
Oxygen0	SBE43	2588 23-jan-20		Soc = 0.560189 Voff=-0.479890
Oxygen1	SBE43	1451 21-aug-20		Soc = 0.480808 Voff = -0.53297

Temperature sensors

The temperature sensors were controlled mainly by comparison of the two TC-channels (see Fig. 5.13). There was no significant drift observed eventually exceeding the accuracy granted by the manufacturer. In addition, an ultra-stable resistance thermometer SBE35RT with a very low drift of < 1 mK/y was attached to the CTD device during the second cruise leg after 15th April. The long equilibration time of 10 min required for the SBE35RT was available only at a few stations. However, since the temperature variability in the NADW layer was a few mK only, good equilibration could be expected already during downcast.

The CTD is a SeaBird 9+ with double sensors and is equipped as follows:

- SBE temperature sensors
- SBE conductivity sensors
- SBE oxygen sensors
- Pressure sensor
- WETLABS fluorescence and turbidity sensors
- Altimeter to determine the distance to the bottom
- SBE35RT precision thermometer
- OPUS nitrate sensor

The CTD is combined with a deck unit SBE11plus and a rosette of 24 10 L - NISKIN bottles to be fired in selected water bodies or depth.

AUTOSAL7 8400B

Salinity measured by the CTD and the SMB thermosalinograph is controlled with salinity samples. The practical salinity scale (1978) was used. Salinity was determined by means of a GUILDLINE AUTOSAL 7 8400B (SN 62968) via the conductivity ratio with standard seawater (batch P162, ratio 0.99983, practical salinity 34.993) as reference. Salinity samples are kept in the dark and were degassed before measurement by heating them in a bath to about 35°C and opening them shortly about one hour later. After another 12 h temperature equilibration, salinometer measurements are carried out. The lab temperature was about 19°C and was varying by less than 1 degree. An AUTOSAL bath temperature of 21°C was chosen, which permitted a permanent intermittent heating and cooling for keeping the bath temperature constant.

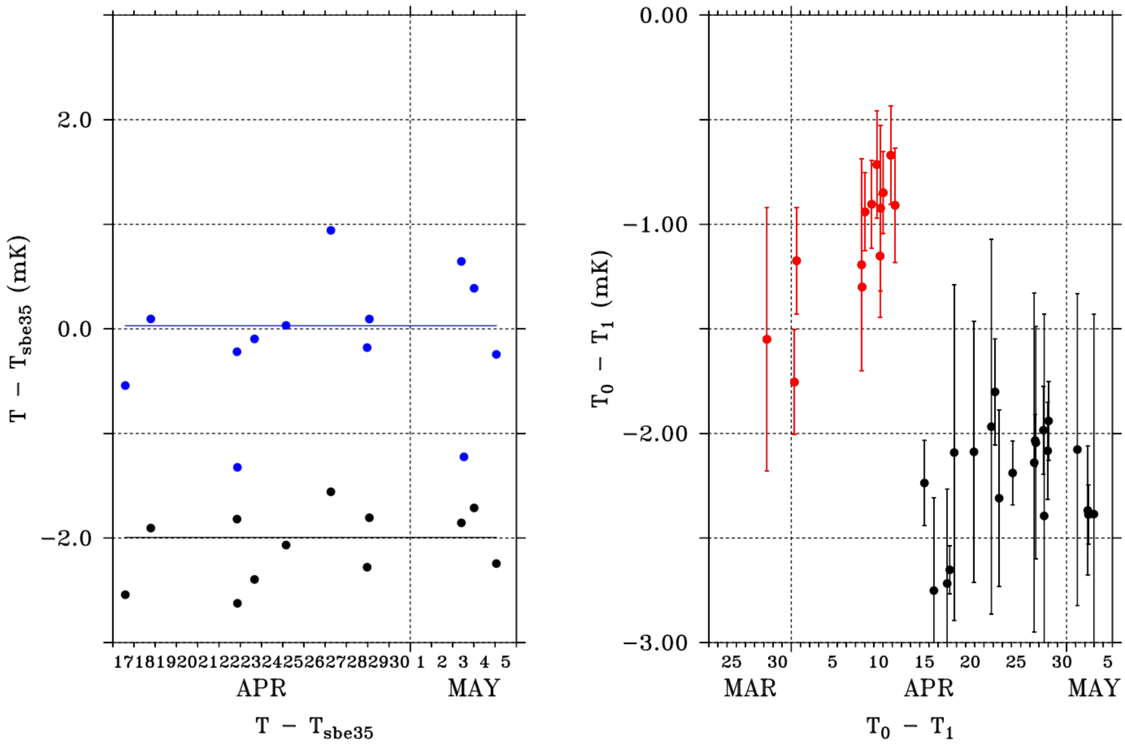

Fig. 5.13 Left: Difference between the temperature sensors and the SBE35RT readings. Note, the unit is mK. Black: channel 0, blue channel 1. Right: difference between the temperature sensor readings in homogeneous bottom waters (lowest 5 m). The error bars mark the variance. The first cruise leg is marked as red.

Conductivity sensors

The conductivity measurement was controlled with salinity samples taken in homogeneous layers. From each CTD bottle 3 samples are filled using the GEOMAR "Flens" bottles. Salinity is determined with the AUTOSAL 8400B. The correction is done as follows:

- Correct the CTD temperature
- Calculate the salinity from the Autosal readings

- Use the CTD bottle files to extract temperature and pressure corresponding to the salinity samples. Calculate the conductivity $C_{autosal}(T_{CTD}, S_{autosal}, p_{CTD})$. Use PSS68 to be consistent with the CTD.
- Plot the ratio of the CTD conductivity and the sample conductivity.
- Exclude outliers.
- Find the average ratio to correct the conductivity sensor slopes.
- Control the result and recalculate CTD salinity from the corrected conductivity. See Fig. 5.14.
- Reprocess the CTD data and apply the slope correction to the conductivity data.
-

There were significantly less samples taken during the second cruise lag. The reason is the lack of uniform layers in the upwelling areas off Namibia and especially off Angola.

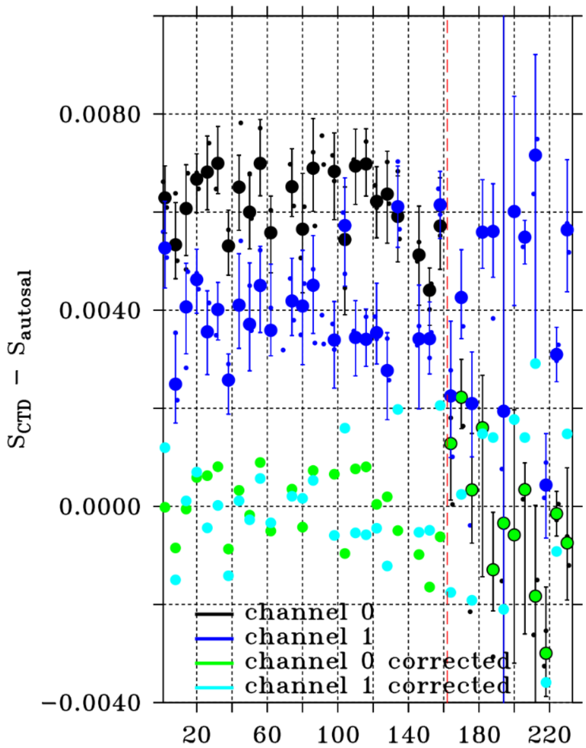

Fig. 5.14 Difference between practical salinity determined by the CTD and salinity samples. Black: channel 0, Blue: channel 1. The small dots (mostly superseded) stand for the single salinity bottles, the thick dots mark the arithmetic mean of the three samples. The error bars stand for the maximum/minimum values during closing the bottles plus the span of the variability of the AUTOSAL readings. The red line separates first and second phase of the cruise, where different sensors are used in channel 0. The green and the light blue dots mark the reduced salinity difference after applying the temperature and conductivity corrections. Since conductivity sensor 4261 was calibrated recently, no correction applies and the green dots coincide with the original data.

Oxygen sensors

The oxygen sensors are recalibrated during the cruise (Fig. 5.15). In well mixed water bodies oxygen samples are taken and measured after Winkler method with a METHROM TITRINO 848 Plus. The water layers are chosen to cover well oxygenated and oxygen depleted water as well. Two parameters need control, the sensor slope Soc and the offset Voffset. Winkler titration for small oxygen concentration is difficult. At a few hydrographic stations the bottom water was most probably anoxic. Constant low oxygen readings over a thick bottom layer, accompanied by a strong turbidity maximum indicate sulfur from hydrogen sulfide oxidation in the water column, see for example station 62. However, the oxygen sensors exhibit a long relaxation time. At station 62 the value for oxygen concentration measured within the anoxic layer during upcast is still lower than that measured during the downcast, but is still significantly above zero. Hence, we only nudge the sensor output to zero by adding a few "virtual" samplings with the lowest CTD-sensor output at station 62 and assumed titration of 0 ml/l.

To find a correction of Soc and Voffset, the following steps are made:

- Use the inverse seabird formula to transform the Winkler oxygen concentration into the corresponding sensor voltage signal. Divide by the saturation concentration, temperature and pressure correction factors.

- Estimate slope, s, and intercept, i, for the voltage signal corresponding to the Winkler samples against the CTD sensors voltage.

- Find the corrected slope and offset parameter for the oxygen sensors to reproduce the Winkler sample values.

$$Socc = \frac{Soc}{s},\ Voffsetc = Voffset + \frac{i}{Socc}$$

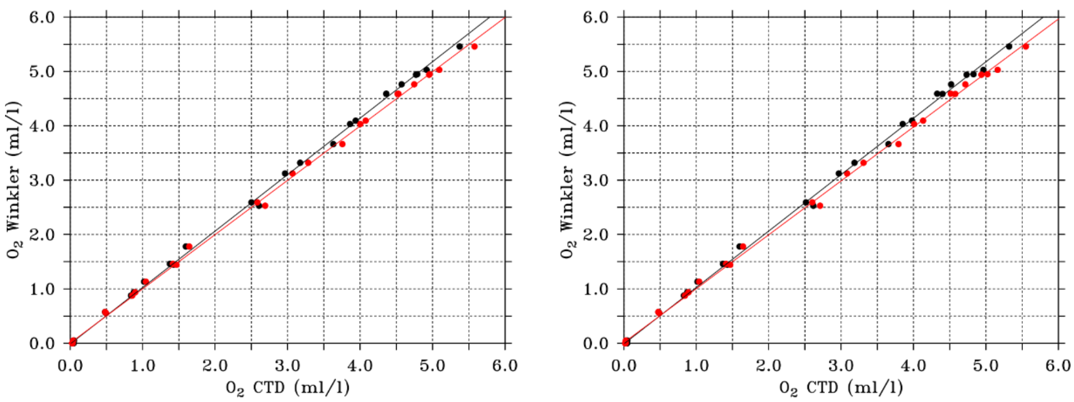

Fig. 5.15 Regression of the uncorrected (black) and corrected (red) oxygen concentration from the CTD oxygen sensors against the Winkler titrated samples. Left: Sensor 2588. Slope after correction: 0.998, offset after correction: 0.0031 ml/l. Right: Sensor 1451. Slope after correction: 0.991, offset after correction: 0.01 ml/l.

For channel 0 we expect an error of 0.2% of the concentration and an additional offset less than 0.01 ml/l. For CTD channel 1 the error is 1% of the measured concentration, the offset is 0.01ml/l. This applies to values, where samples are taken. However, during downcasts the dynamic error due to stratification, but especially due to the slow sensor response may be significantly larger.

Fluorometer

The fluorescence and backscattering data are used with manufacturer calibration. In low turbidity water bodies and in deep waters without chlorophyll the instruments reading is near zero with sufficient accuracy.

Known errors

Under stormy conditions, the TC-duct may have been contaminated with air bubbles at the beginning of the downcast. There were some events with a blocked TC duct.

Data handling

The CTD data are reprocessed with the corrections applied. After filtering the alignment of the different sensors in the TC-duct was corrected, the standard pressure and temperature correction is applied and loops are removed using the standard Seabird algorithms. Downcast data and the data for the depth, where bottles are closed (bottle files) are separated, data are averaged over 0.5 dB intervals. The data are available without any retention period.

5.5 Underway Measurements

5.5.1 Total Alkalinity (TA) and Dissolved Inorganic Carbon (DIC)

(L. Meiritz)

For the underway analysis of total alkalinity (TA) and dissolved inorganic carbon (DIC), the modified VINDTA 3C system (Versatile INstrument for the Determination of Total Alkalinity) was used (MARIANDA, Kiel, Germany). The VINDTA 3C is a combined TA and DIC titration stand. TA was determined by titration of seawater with hydrochloric acid (0.1 N HCl) and DIC was measured coulometrically. Prior to the start of the titration an internal standard referred to as 'Schiffshund, SH' was measured until the measured TA and DIC revealed an acceptable reproducibility. The SH was collected by the CTD/Rosette sampler at water-depths of about 3000 m. When the hydrochloric acid for the titration was refilled, Certified Reference Material (CRM, batch with Na_2CO_3,) was used to calibrate VINDTA 3C. Usually the samples are calibrated with a Dickson standard, but due to supply difficulties, another reference substance, in this case sodium carbonate (Na_2CO_3), had to be used to calibrate the samples with a conversion factor. For the first time the VINDTA 3C was modified to measure continuously online. For this purpose, a constant flow of about 0.5 L per minute of surface water was led through a flow cell consisting of a 0.5 L borosilicate bottle which was heated to 25°C in a tempering bath. Every 40 minutes a measurement of TA and DIC was performed. For standard and blank measurements as well as maintenance work on the device the continuous measurement was stopped. In total, more than 1,000 TA and DIC measurements were performed during the expedition SO-283 (Fig. 5.16) All data collected and presented here are preliminary. In the laboratory of the biogeochemistry working group of the ZMT, the collected data will be evaluated and corrected with the corresponding Dickson standard and acid variables.

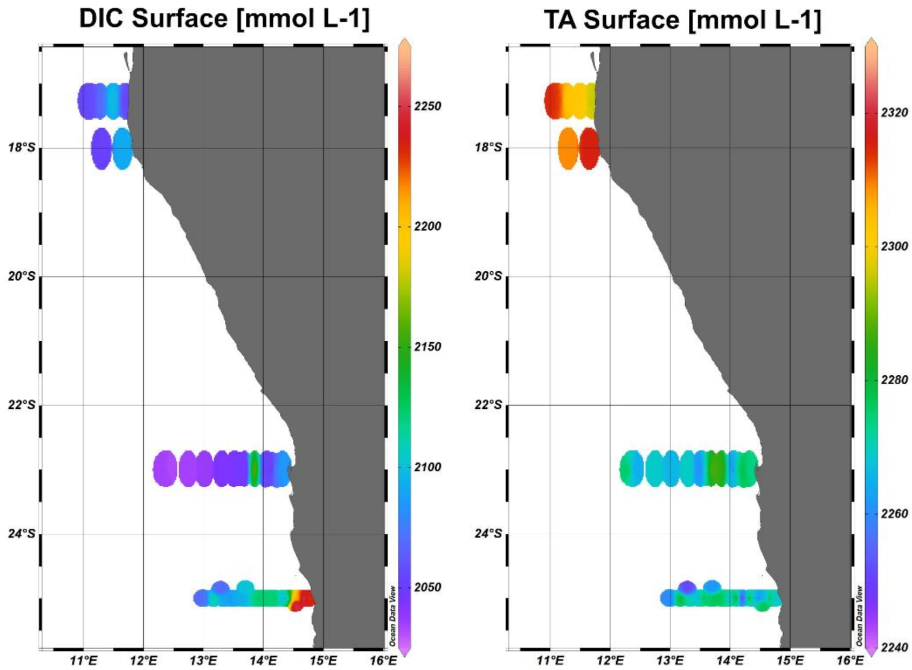

Fig. 5.16 Examples for underway measurements with the VINDTA 3C. Left surface DIC measurements and right TA measurement on the 18°, 23° and 25°S Namibian transects. All results and measurement data are preliminary and have to be calibrated.

5.5.2 pH and total carbonate (C_T)

(B. Sabbaghzadeh)

To understand the oceans' role in the global CO_2 system and to follow ongoing process of Ocean acidification (Doney et al. 2009) using high-quality pH measurement is inevitable. Spectrophotometric measurements have proven to be the most reliable method to determine seawater pH across the entire spectrum, achieving uncertainty levels below 0.01 pH units (e.g. Dickson et al. 2015). The analytical procedure is based on pH determination by adding an indicator (*m*-cresol purple) dye to seawater. The pH value is then detected by the VIS absorption spectrometry system and the determination of pH is carried out by the changes in the colour of the indicator and is calculated from the recorded absorbance spectra (Dickson, et al., 2007). During SONNE (SO283) expedition underway-measurement of pH were carried out using the automatic flow "CONTROS HydroFIA® pH system. Buffer solutions were also measured for the quality control on the regular basis during the expedition.

The total carbonate (C_T) also known as Dissolved Inorganic Carbon (DIC), is one of the four parameters measured to determine the marine carbonate system. C_T in seawater discrete samples from the designated stations were collected and they will be measured using Automated Infra-Red Inorganic Carbon Analyzer (AIRICA) system back in IOW.

The water columns were also sampled for pH measurements and DIC in the designated stations. These data along with computed TA will enable us to investigate the carbon cycle within the water column as long as the surface. The preliminary pH values for the discrete samples at each individual station are presented (Figure 5.17).

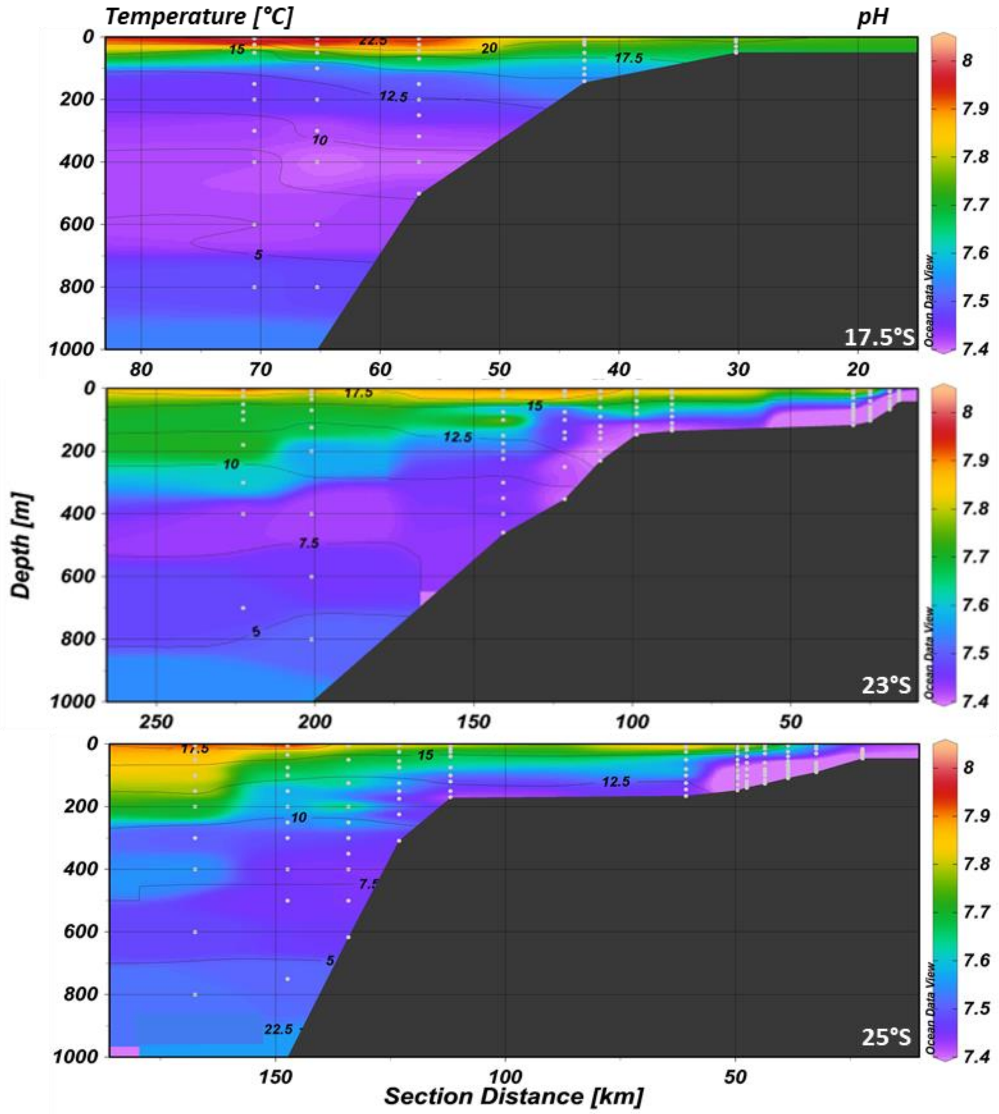

Fig. 5.17 pH-values along the three main transects in the Benguela upwelling system on RV SONNE (SO283). The overlying temperature lines were also included.

The total carbonate (C_T) also known as Dissolved Inorganic Carbon (DIC), is one of the four parameters measured to determine the marine carbonate system. C_T in seawater discrete samples from the designated stations were collected and they will be measured using Automated Infra-Red Inorganic Carbon Analyzer (AIRICA) system back in IOW.

The pH values of discrete samples from designated depths at each individual station were also measured on board and the preliminary data are presented (Figure 5.17).

5.5.3 Thermosalinograph

(M. Schmidt)

The underway measurements are carried out with a “Self-cleaning Monitoring box”, SMB, developed by the Leibniz-Institute for Baltic Sea Research Warnemünde (IOW) and 4H JENA ENGINEERING. The system consists of two identical measuring boxes, switching between a measuring or self-cleaning mode with help of a controller unit. Cleaning is done with sulfuric acid pH <3. In the beginning of the cruise the switching between both systems was a 6 hourly. Due to a lack of acid, on the second leg only a daily cleaning was possible.

Pump system
About 9l/min seawater is pumped by a radial pump through the thermosalinograph system. The inlet is in the bow of the ship at about 3m water depth. Before the split to the two measuring units, an outlet allows for taking water samples.

Temperature
The sea water temperature is determined by means of a thermometer SBE38 mounted in the water inlet at the bow of the ship.

Conductivity, Salinity
Conductivity is measured with a conductivity sensor SBE35 that is combined with its own temperature sensor.

Fluorescence and turbidity
These quantities are measured with a WETLABS ECO-AFL/FL and ECO-NTU device. These instruments are included is the cleaning procedure to avoid algae growth eventually stimulated by the fluorometer light.

Sound velocity
Sound velocity is measured by means of a sound velocity sensor (AML oceanographic) and is also calculated from the measured salinity and temperature.

The *Performance control* of the SMB is done in two ways:

- Comparing between both the sensor sets for periods of overlapping measurements or when switching between both sensors.
- Comparing with external devices. Especially for the control of conductivity measurements salinity samples are taken regularly and are measured with an AUTOSAL7 8400B.

  Fluorescence and turbidity:
  Both fluorescence and turbidity show a significant offset between both the fluorometers. Since in the open ocean away from the upwelling areas fluorescence and turbidity should be at the detection limit, the zero point of both instruments are adjusted to the minimum signal of both the instruments.

Temperature:
Temperature of the SBE38 is controlled by comparison with CTD data. The cell temperature of the SBE35 was checked not to run away from the SBE38. A better control is not possible on board.
Conductivity and salinity:
Conductivity and salinity are controlled and recalibrated by means of salinity samples. These are measure with a salinometer AUTOSAL 8400B.

5.5.4 Shipboard Acoustic Doppler Current Profiler (SADCP)

(C. Mertens, J. Stiehler)

Two shipboard acoustic Doppler current profilers (SADCPs) from RD instruments were installed into the ship's hull for continuous measurement of current velocities in the upper water column. The first ADCP with a frequency of 75 kHz and a range of up to 700 m (OS75) and the second ADCP with a frequency of 38 kHz and a range of up to 1400 m (OS38). Both ADCPs were operated in narrow band mode to achieve the maximum vertical range. Bin lengths were 8 m for the OS75 and 32 m for the OS38. The data were collected using TRDIs data acquisition software (VmDAS). Vessel position and attitude data were obtained from the ship's SEAPATH system. The OS75 was set to use its fastest possible ping rate, while the OS38 was triggered externally to avoid interferences with the EK60 and EM122 echo sounding systems. The data collection started on March 3, 2021 23:25 UTC and stopped on May 5, 2021 10:00 UTC. Both instruments functioned properly throughout the cruise. No ADCP data were collected in the exclusive economic zones of France, Spain, and Cape Verde. While in the EEZ of Namibia ADCP data were only collected between the two port calls in Walvis Bay, i.e. between April 20 and April 30, 2021. A water track calibration was used over the duration of the cruise to determine misalignment angles and amplitude factors. The estimated values appeared to be stable through time.

5.6 Argo Float Deployments

(A. Andrae)

A total of 3 standard ARGO floats (Tab. 5.9) were deployed during SO283 on behalf of the Bundesamt für Seeschifffahrt und Hydrographie in Hamburg (BSH) and as a national contribution to the international Argo program. Furthermore, one PROVOR float with Temperature, Salinity, Oxygen, Chlorophyll, turbidity sensor and additionally an Underwater Vision Profiler 6 (HYDROOPTIC, France) to measure the particle size distribution was deployed in a cyclonic eddy off South Africa. This float was funded by the EU project TRIATLAS via the Laboratoire d'Océanographie de Villefranche, France (LOV) and the Ecole normale supérieure (ENS) – PSL. This float is parking at about 300 m depth and does four profiles to 600 m depth and one profile to 1000 m depth within a 15-day cycle. As of the May 17 2021, this float is still trapped in the cyclonic eddy and has delivered 16 profiles so far. Another PROVOR float with the same setup - co-funded by BSH and TRIATLAS via LOV and ENS - was deployed off Angola to conduct two profiles to 1000 m depth and one profile to 1400 m depth within a 10-day cycle. The float parks at 250, 500 and 1000 m depth and has done six successful profiles so far (May 17 2021). Both

floats were adopted by the "Lycée Leonardo da Vinci, Paris" within the Adopt-a-float outreach program (http://www.monoceanetmoi.com/web/index.php/en/adopt-a-float-home).
Responsible persons for the ARGO operation are: rainer.kiko@obs-vlfr.fr, lars.stemmann@obs-vlfr.fr, sabrina.speich@lmd.ipsl.fr and birgit.klein@bsh.de for further information.

Tab. 5.9 Time and location of ARGO and PROVOR float deployments during RV SONNE cruise SO283.

WMO	**Float Serial Number**	**Date**	**Time**	**Latitude**	**Longitude**
			(UTC)		
6903095	P553337-20FR101	2021-04-13	09:27	33° 06.005' S	013° 52.022' E
6904109	AI2600-20DE47	2021-05-02	06:08	14° 48,002’ S	011° 05,998’ E
6904108	AI2600-20DE046	2021-05-02	17:31	12° 19,622’ S	011° 44,106’ E
6903096	P53337-20FR001	2021-05-04	10:06	10° 59,63’ S	012° 45,088’ E
6904107	AI2600-20DE045	2021-05-06	08:44	08° 21,168’ S	003° 20,980’ E

6 Ship's Meteorological Station

(M. Schmidt)

The meteorological underway data are collected and are mapped to a unique time base with one second resolution. Data dissemination is done over the WERUM system DSHIP V3.

Ship's weather station delivers meteorological standard quantities,

- wind velocity and direction,
- air pressure
- sea level pressure
- relative humidity
- precipitation

Absolute wind speed and direction is calculated from the wind relative to the ship and navigation data. Sensor type, sensor position and height and eventual data reduction to normal conditions (10 m wind speed, 2 m air temperature and humidity) are undocumented.

In addition, 3 different radiation sensors are mounted on the ships Heli-deck:

- a spectral pyranometer CMP-21 (Kipp Zonen) for global radiation covering 270 to 3000 m
- a Hemispherical Quantum Scalar Reference Sensor for measuring total incident Photosynthetically Available Radiation (400-700 nm), QSR-2000 (BIOSPHERICAL INSTRUMENTS Inc.)
- a pyrgeometer CGR-4 (Kipp Zonen) for thermal radiation covering 4500 to 42000 nm

The instruments from Kipp & Zonen have 5 y data quality guaranty, data are used without further modification.

After extraction from DSHIP, data are mapped to subsets with a reduced time resolution.

7 Station List SO283

7.1 Overall Station List

Abbreviations:
CTD: CTD-Rosette Water Sampler
PLA: APSTEIN Plankton-Net
WP-2: WP-2 Plankton Net 300 µm
MB: Multi-Beam
MOOR: Anchored Mooring
PIES: Pressure Inverted Echo Sounder
DRIFT: Drifting Sediment Trap Mooring
FLOAT: ARGO-Float Deployments

Station	Gear	Date and Time	Latitude	Longitude	Water Depth (m)
SO283_1-1	CTD	23.03.2021 16:29	37° 33.338' N	015° 07.170' W	4050
SO283_1-2	PLA	23.03.2021 15:48	37° 33.339' N	015° 07.170' W	4050
SO283_1-3	PLA	23.03.2021 15:54	37° 33.340' N	015° 07.173' W	4050
SO283_1-4	PLA	23.03.2021 15:58	37° 33.337' N	015° 07.174' W	4050
SO283_1-5	PLA	23.03.2021 16:02	37° 33.337' N	015° 07.172' W	4050
SO283_1-6	PLA	23.03.2021 16:06	37° 33.337' N	015° 07.171' W	4050
SO283_1-6	PLA	23.03.2021 16:09	37° 33.337' N	015° 07.172' W	4050
SO283_1-7	WP-2	23.03.2021 18:09	37° 33.337' N	015° 07.171' W	4050
SO283_2-1	CTD	29.03.2021 09:04	09° 20.507' N	023° 51.769' W	5229
SO283_2-2	PLA	29.03.2021 08:11	09° 20.504' N	023° 51.761' W	5229
SO283_2-3	PLA	29.03.2021 08:15	09° 20.507' N	023° 51.762' W	5229
SO283_2-4	PLA	29.03.2021 08:20	09° 20.506' N	023° 51.767' W	5229
SO283_2-5	PLA	29.03.2021 08:25	09° 20.502' N	023° 51.764' W	5229
SO283_2-6	PLA	29.03.2021 08:30	09° 20.515' N	023° 51.768' W	5229
SO283_2-7	PLA	29.03.2021 08:33	09° 20.512' N	023° 51.770' W	5229
SO283_2-8	PLA	29.03.2021 08:39	09° 20.513' N	023° 51.769' W	5229
SO283_2-9	PLA	29.03.2021 08:43	09° 20.503' N	023° 51.769' W	5229
SO283_2-10	WP-2	29.03.2021 10:40	09° 20.511' N	023° 51.760' W	5229
SO283_3-1	CTD	01.04.2021 08:36	04° 34.344' S	019° 19.685' W	4813
SO283_3-2	PLA	01.04.2021 08:17	04° 34.347' S	019° 19.678' W	4813
SO283_3-3	PLA	01.04.2021 08:22	04° 34.350' S	019° 19.681' W	4813
SO283_3-4	PLA	01.04.2021 08:26	04° 34.350' S	019° 19.685' W	4813
SO283_3-5	PLA	01.04.2021 08:34	04° 34.345' S	019° 19.685' W	4813
SO283_3-6	PLA	01.04.2021 08:40	04° 34.346' S	019° 19.685' W	4813
SO283_3-7	PLA	01.04.2021 08:44	04° 34.351' S	019° 19.686' W	4813
SO283_3-8	WP-2	01.04.2021 09:44	04° 34.346' S	019° 19.687' W	4813
SO283_3-9	MOOR	01.04.2021 11:37	04° 34.338' S	019° 19.685' W	4813
SO283_3-10	CTD	01.04.2021 15:23	04° 34.338' S	019° 19.869' W	4813
SO283_4-1	CTD	05.04.2021 08:59	19° 54.237' S	007° 56.059' W	4258
SO283_4-2	PLA	05.04.2021 08:14	19° 54.236' S	007° 56.055' W	4266
SO283_4-3	PLA	05.04.2021 08:18	19° 54.236' S	007° 56.054' W	4264
SO283_4-4	PLA	05.04.2021 08:21	19° 54.237' S	007° 56.055' W	4255
SO283_4-5	PLA	05.04.2021 08:24	19° 54.237' S	007° 56.055' W	4265
SO283_4-6	PLA	05.04.2021 08:28	19° 54.240' S	007° 56.058' W	4269
SO283_4-7	PLA	05.04.2021 08:32	19° 54.243' S	007° 56.064' W	4268
SO283_4-8	PLA	05.04.2021 08:37	19° 54.240' S	007° 56.063' W	4267

Station	Gear	Date and Time	Latitude	Longitude	Water Depth (m)
SO283_4-9	WP-2	05.04.2021 10:57	19° 54.245' S	007° 56.056' W	4246
SO283_5-1	CTD	08.04.2021 17:06	31° 55.003' S	004° 20.007' E	4820
SO283_6-1	MB	08.04.2021 20:14	32° 09.985' S	004° 36.045' E	5118
SO283_6-1	MB	08.04.2021 22:13	32° 09.995' S	004° 54.708' E	5088
SO283_6-1	MB	08.04.2021 22:35	32° 12.874' S	004° 54.981' E	4945
SO283_6-1	MB	09.04.2021 00:34	32° 12.996' S	004° 35.978' E	4923
SO283_7-1	CTD	09.04.2021 03:11	32° 10.997' S	004° 38.009' E	5124
SO283_7-2	PLA	09.04.2021 04:07	32° 10.993' S	004° 38.002' E	5128
SO283_7-2	PLA	09.04.2021 04:09	32° 10.993' S	004° 38.001' E	5134
SO283_7-3	PLA	09.04.2021 04:13	32° 10.990' S	004° 38.005' E	5122
SO283_7-4	PLA	09.04.2021 04:19	32° 10.991' S	004° 38.003' E	5128
SO283_7-5	PLA	09.04.2021 04:22	32° 10.991' S	004° 38.005' E	5122
SO283_7-6	PLA	09.04.2021 04:25	32° 10.994' S	004° 38.002' E	5126
SO283_7-7	WP-2	09.04.2021 05:50	32° 10.696' S	004° 38.093' E	5124
SO283_7-8	MOOR	09.04.2021 07:01	32° 07.984' S	004° 39.632' E	5172
SO283_7-8	MOOR	09.04.2021 11:42	32° 11.302' S	004° 38.114' E	5114
SO283_8-1	PIES	09.04.2021 18:03	32° 26.387' S	005° 51.025' E	5064
SO283_8-2	CTD	09.04.2021 20:27	32° 26.385' S	005° 51.032' E	5103
SO283_8-3	PLA	09.04.2021 21:36	32° 26.385' S	005° 51.017' E	5103
SO283_8-4	PLA	09.04.2021 21:39	32° 26.384' S	005° 51.017' E	5103
SO283_8-5	PLA	09.04.2021 21:44	32° 26.386' S	005° 51.023' E	5080
SO283_8-6	PLA	09.04.2021 21:47	32° 26.385' S	005° 51.022' E	5071
SO283_8-7	PLA	09.04.2021 21:51	32° 26.387' S	005° 51.021' E	5110
SO283_8-8	PLA	09.04.2021 21:55	32° 26.388' S	005° 51.018' E	5076
SO283_8-9	WP-2	09.04.2021 22:55	32° 26.414' S	005° 50.968' E	5077
SO283_9-1	PIES	10.04.2021 07:19	31° 38.927' S	007° 24.619' E	5074
SO283_9-2	CTD	10.04.2021 09:56	31° 38.930' S	007° 24.623' E	5070
SO283_10-1	CTD	10.04.2021 17:26	32° 27.962' S	007° 10.044' E	5220
SO283_11-1	MB	10.04.2021 19:43	32° 40.955' S	007° 05.595' E	4952
SO283_11-1	MB	10.04.2021 21:40	32° 41.140' S	007° 23.978' E	5026
SO283_11-1	MB	10.04.2021 22:08	32° 43.962' S	007° 23.053' E	5063
SO283_11-1	MB	10.04.2021 23:44	32° 43.978' S	007° 07.084' E	4974
SO283_12-1	PIES	11.04.2021 00:12	32° 42.306' S	007° 07.508' E	4999
SO283_12-2	CTD	11.04.2021 02:32	32° 42.308' S	007° 07.507' E	4998
SO283_12-3	PLA	11.04.2021 03:44	32° 42.310' S	007° 07.506' E	4996
SO283_12-4	PLA	11.04.2021 03:49	32° 42.308' S	007° 07.505' E	4997
SO283_12-5	PLA	11.04.2021 03:53	32° 42.306' S	007° 07.503' E	4998
SO283_12-6	PLA	11.04.2021 03:57	32° 42.306' S	007° 07.502' E	4996
SO283_12-7	WP-2	11.04.2021 05:15	32° 42.311' S	007° 07.506' E	4997
SO283_12-8	MOOR	11.04.2021 06:35	32° 40.765' S	007° 09.061' E	5201
SO283_13-1	PIES	11.04.2021 20:04	33° 45.097' S	006° 47.367' E	5299
SO283_13-2	CTD	11.04.2021 22:36	33° 45.096' S	006° 47.377' E	5295
SO283_14-1	PIES	12.04.2021 07:19	32° 57.661' S	008° 20.909' E	4946
SO283_14-2	CTD	12.04.2021 09:39	32° 57.664' S	008° 20.906' E	4953
SO283_15-1	CTD	13.04.2021 08:25	33° 06.009' S	013° 52.019' E	
SO283_15-2	PLA	13.04.2021 07:52	33° 06.006' S	013° 52.022' E	
SO283_15-3	PLA	13.04.2021 07:57	33° 06.008' S	013° 52.022' E	
SO283_15-4	PLA	13.04.2021 08:01	33° 06.009' S	013° 52.022' E	

Station	Gear	Date and Time	Latitude	Longitude	Water Depth (m)
SO283_15-5	PLA	13.04.2021 08:04	33° 06.009' S	013° 52.026' E	
SO283_15-6	FLOAT	13.04.2021 09:27	33° 06.007' S	013° 52.028' E	
SO283_16-1	CTD	15.04.2021 12:56	31° 02.709' S	015° 13.844' E	1291
SO283_16-2	PLA	15.04.2021 12:26	31° 02.708' S	015° 13.850' E	1290
SO283_16-3	PLA	15.04.2021 12:36	31° 02.707' S	015° 13.847' E	1291
SO283_16-4	PLA	15.04.2021 12:43	31° 02.711' S	015° 13.857' E	1291
SO283_16-5	PLA	15.04.2021 12:49	31° 02.711' S	015° 13.845' E	1291
SO283_16-6	PLA	15.04.2021 12:58	31° 02.710' S	015° 13.851' E	1292
SO283_16-7	MOOR	15.04.2021 14:12	31° 02.515' S	015° 13.627' E	1293
SO283_17-1	DRIFT	15.04.2021 20:50	31° 29.923' S	015° 29.878' E	997
SO283_18-1	CTD	16.04.2021 06:21	31° 00.026' S	017° 34.987' E	108
SO283_18-2	PLA	16.04.2021 06:15	31° 00.024' S	017° 34.991' E	108
SO283_18-3	PLA	16.04.2021 06:18	31° 00.025' S	017° 34.991' E	107
SO283_18-4	PLA	16.04.2021 06:25	31° 00.029' S	017° 34.986' E	107
SO283_18-5	PLA	16.04.2021 06:29	31° 00.021' S	017° 34.989' E	105
SO283_18-6	PLA	16.04.2021 06:33	31° 00.030' S	017° 34.985' E	107
SO283_18-7	PLA	16.04.2021 06:39	31° 00.027' S	017° 34.980' E	108
SO283_19-1	DRIFT	16.04.2021 09:43	30° 59.929' S	016° 59.983' E	192
SO283_20-1	MOOR	16.04.2021 12:07	30° 37.986' S	017° 00.853' E	164
SO283_20-2	CTD	16.04.2021 13:07	30° 38.489' S	017° 01.009' E	166
SO283_20-3	PLA	16.04.2021 12:59	30° 38.490' S	017° 01.021' E	166
SO283_20-4	PLA	16.04.2021 13:04	30° 38.490' S	017° 01.017' E	165
SO283_20-5	PLA	16.04.2021 13:10	30° 38.489' S	017° 01.011' E	166
SO283_20-6	PLA	16.04.2021 13:13	30° 38.495' S	017° 01.012' E	165
SO283_20-7	PLA	16.04.2021 13:18	30° 38.496' S	017° 01.016' E	167
SO283_20-8	WP-2	16.04.2021 13:39	30° 38.484' S	017° 01.010' E	168
SO283_21-1	CTD	16.04.2021 16:17	30° 22.997' S	017° 17.004' E	44
SO283_21-2	PLA	16.04.2021 16:31	30° 22.990' S	017° 17.008' E	43
SO283_21-3	PLA	16.04.2021 16:32	30° 22.992' S	017° 17.003' E	44
SO283_21-4	PLA	16.04.2021 16:37	30° 22.996' S	017° 17.004' E	43
SO283_21-5	PLA	16.04.2021 16:40	30° 22.993' S	017° 17.009' E	46
SO283_21-6	PLA	16.04.2021 16:44	30° 22.997' S	017° 17.005' E	43
SO283_21-7	PLA	16.04.2021 16:48	30° 22.996' S	017° 17.003' E	44
SO283_22-1	CTD	17.04.2021 02:25	31° 00.009' S	014° 49.971' E	2167
SO283_22-2	PLA	17.04.2021 02:09	31° 00.005' S	014° 49.968' E	2166
SO283_22-3	PLA	17.04.2021 02:13	31° 00.009' S	014° 49.969' E	2167
SO283_22-4	PLA	17.04.2021 02:19	31° 00.009' S	014° 49.973' E	2165
SO283_22-5	PLA	17.04.2021 02:23	31° 00.010' S	014° 49.973' E	2167
SO283_22-6	PLA	17.04.2021 02:27	31° 00.008' S	014° 49.968' E	2165
SO283_23-1	CTD	17.04.2021 08:11	31° 59.976' S	015° 00.036' E	2510
SO283_23-2	PLA	17.04.2021 07:56	31° 59.973' S	015° 00.037' E	2510
SO283_23-3	PLA	17.04.2021 08:01	31° 59.976' S	015° 00.038' E	2509
SO283_23-4	PLA	17.04.2021 08:04	31° 59.972' S	015° 00.036' E	2510
SO283_23-5	PLA	17.04.2021 08:07	31° 59.971' S	015° 00.035' E	2509
SO283_23-6	PLA	17.04.2021 08:11	31° 59.976' S	015° 00.036' E	2510
SO283_23-7	WP-2	17.04.2021 08:57	31° 59.969' S	015° 00.043' E	2510
SO283_24-1	MOOR	17.04.2021 12:04	31° 28.902' S	015° 26.255' E	1119
SO283_24-2	CTD	17.04.2021 14:09	31° 28.820' S	015° 26.130' E	1123

Station	Gear	Date and Time	Latitude	Longitude	Water Depth (m)
SO283_24-3	WP-2	17.04.2021 15:14	31° 28.822' S	015° 26.129' E	1122
SO283_25-1	CTD	17.04.2021 23:56	32° 00.022' S	017° 24.969' E	156
SO283_25-2	PLA	17.04.2021 23:52	32° 00.019' S	017° 24.967' E	158
SO283_25-3	PLA	18.04.2021 00:04	32° 00.020' S	017° 24.967' E	157
SO283_25-4	PLA	18.04.2021 00:12	32° 00.022' S	017° 24.975' E	157
SO283_25-5	PLA	18.04.2021 00:19	32° 00.023' S	017° 24.972' E	157
SO283_25-6	PLA	18.04.2021 00:24	32° 00.021' S	017° 24.977' E	157
SO283_25-7	WP-2	18.04.2021 00:36	32° 00.021' S	017° 24.970' E	157
SO283_26-1	MOOR	18.04.2021 05:27	31° 02.572' S	016° 58.718' E	212
SO283_26-2	CTD	18.04.2021 06:50	31° 02.193' S	016° 58.416' E	213
SO283_26-3	WP-2	18.04.2021 07:28	31° 02.193' S	016° 58.412' E	213
SO283_27-2	PLA	18.04.2021 18:24	30° 10.331' S	014° 22.024' E	1375
SO283_27-3	PLA	18.04.2021 18:30	30° 10.334' S	014° 22.023' E	1375
SO283_27-4	PLA	18.04.2021 18:36	30° 10.333' S	014° 22.021' E	1375
SO283_27-5	PLA	18.04.2021 18:39	30° 10.330' S	014° 22.020' E	1374
SO283_27-6	PLA	18.04.2021 18:45	30° 10.329' S	014° 22.023' E	1373
SO283_27-1	CTD	18.04.2021 18:57	30° 10.328' S	014° 22.026' E	1377
SO283_28-1	CTD	20.04.2021 17:00	23° 00.011' S	014° 22.019' E	37
SO283_28-2	PLA	20.04.2021 17:00	23° 00.011' S	014° 22.019' E	37
SO283_28-3	PLA	20.04.2021 17:06	23° 00.005' S	014° 22.015' E	81
SO283_28-4	PLA	20.04.2021 17:10	23° 00.009' S	014° 22.013' E	86
SO283_28-5	PLA	20.04.2021 17:14	23° 00.010' S	014° 22.009' E	78
SO283_29-1	CTD	20.04.2021 18:28	23° 00.002' S	014° 12.858' E	107
SO283_29-2	PLA	20.04.2021 18:26	23° 00.001' S	014° 12.856' E	108
SO283_29-3	PLA	20.04.2021 18:32	23° 00.001' S	014° 12.862' E	108
SO283_29-4	PLA	20.04.2021 18:37	23° 00.003' S	014° 12.861' E	107
SO283_29-5	PLA	20.04.2021 18:41	23° 00.003' S	014° 12.861' E	109
SO283_29-6	PLA	20.04.2021 18:46	23° 00.000' S	014° 12.858' E	108
SO283_29-7	WP-2	20.04.2021 19:06	22° 59.998' S	014° 12.852' E	108
SO283_29-8	CTD	20.04.2021 19:37	23° 00.002' S	014° 12.851' E	107
SO283_30-1	CTD	20.04.2021 21:55	22° 59.973' S	013° 51.624' E	144
SO283_31-1	CTD	21.04.2021 00:31	23° 00.006' S	013° 29.978' E	235
SO283_31-2	PLA	21.04.2021 00:25	23° 00.004' S	013° 29.978' E	234
SO283_31-3	PLA	21.04.2021 00:30	23° 00.007' S	013° 29.979' E	235
SO283_31-4	PLA	21.04.2021 00:34	23° 00.001' S	013° 29.978' E	235
SO283_31-5	PLA	21.04.2021 00:38	23° 00.004' S	013° 29.983' E	235
SO283_31-6	PLA	21.04.2021 00:42	23° 00.005' S	013° 29.991' E	234
SO283_32-1	CTD	21.04.2021 02:29	22° 59.998' S	013° 18.577' E	358
SO283_33-1	DRIFT	21.04.2021 04:55	22° 59.998' S	013° 35.000' E	144
SO283_34-1	DRIFT	21.04.2021 09:49	22° 59.992' S	012° 44.974' E	1024
SO283_35-1	MOOR	21.04.2021 14:27	22° 59.956' S	012° 23.534' E	1900
SO283_36-1	CTD	21.04.2021 18:13	23° 00.000' S	013° 00.909' E	470
SO283_36-2	PLA	21.04.2021 18:02	23° 00.006' S	013° 00.906' E	471
SO283_36-3	PLA	21.04.2021 18:08	23° 00.002' S	013° 00.910' E	471
SO283_36-4	PLA	21.04.2021 18:12	23° 00.000' S	013° 00.910' E	471
SO283_36-5	PLA	21.04.2021 18:15	22° 59.997' S	013° 00.907' E	472
SO283_36-6	PLA	21.04.2021 18:20	22° 59.998' S	013° 00.907' E	472
SO283_37-1	CTD	21.04.2021 22:09	22° 59.979' S	013° 40.733' E	150

Station	Gear	Date and Time	Latitude	Longitude	Water Depth (m)
SO283_38-1	CTD	22.04.2021 01:08	23° 00.003' S	014° 08.100' E	128
SO283_39-1	CTD	22.04.2021 02:49	22° 59.999' S	014° 19.031' E	69
SO283_40-1	MOOR	22.04.2021 05:00	23° 01.267' S	014° 13.077' E	118
SO283_42-1	MOOR	22.04.2021 16:32	22° 59.595' S	012° 23.764' E	1910
SO283_43-1	CTD	22.04.2021 20:15	22° 59.995' S	012° 19.817' E	2071
SO283_43-2	PLA	22.04.2021 19:28	22° 59.994' S	012° 19.809' E	2072
SO283_43-3	PLA	22.04.2021 19:33	22° 59.995' S	012° 19.811' E	2073
SO283_43-4	PLA	22.04.2021 19:38	22° 59.993' S	012° 19.806' E	2072
SO283_43-5	PLA	22.04.2021 19:42	22° 59.993' S	012° 19.807' E	2072
SO283_44-1	CTD	23.04.2021 05:11	23° 00.004' S	014° 03.014' E	128
SO283_44-2	MOOR	23.04.2021 05:28	22° 59.985' S	014° 03.001' E	134
SO283_45-1	MOOR	23.04.2021 06:51	23° 01.374' S	014° 02.217' E	133
SO283_46-1	DRIFT	23.04.2021 09:48	22° 58.622' S	013° 29.201' E	248
SO283_47-1	DRIFT	23.04.2021 15:09	22° 58.498' S	012° 41.432' E	1155
SO283_47-2	CTD	23.04.2021 16:09	22° 58.500' S	012° 41.430' E	1154
SO283_48-1	DRIFT	24.04.2021 15:17	17° 59.984' S	011° 18.008' E	907
SO283_49-1	CTD	24.04.2021 19:18	17° 15.934' S	011° 41.907' E	53
SO283_49-2	PLA	24.04.2021 19:19	17° 15.934' S	011° 41.907' E	53
SO283_49-3	PLA	24.04.2021 19:24	17° 15.937' S	011° 41.905' E	52
SO283_49-4	PLA	24.04.2021 19:29	17° 15.936' S	011° 41.905' E	49
SO283_49-5	PLA	24.04.2021 19:33	17° 15.936' S	011° 41.905' E	52
SO283_49-6	PLA	24.04.2021 19:37	17° 15.937' S	011° 41.905' E	51
SO283_50-1	CTD	24.04.2021 21:05	17° 15.928' S	011° 30.054' E	152
SO283_51-1	CTD	24.04.2021 23:12	17° 15.969' S	011° 16.479' E	505
SO283_51-2	WP-2	25.04.2021 00:01	17° 15.971' S	011° 16.469' E	505
SO283_52-1	CTD	25.04.2021 01:39	17° 15.959' S	011° 08.958' E	1103
SO283_53-1	CTD	25.04.2021 03:46	17° 15.953' S	011° 03.945' E	1540
SO283_54-1	MOOR	25.04.2021 09:26	17° 59.790' S	011° 39.008' E	124
SO283_54-2	CTD	25.04.2021 10:40	18° 00.037' S	011° 39.027' E	123
SO283_55-1	CTD	25.04.2021 13:11	18° 00.002' S	011° 17.997' E	906
SO283_55-2	WP-2	25.04.2021 14:05	18° 00.002' S	011° 18.004' E	907
SO283_55-3	DRIFT	25.04.2021 15:12	17° 57.342' S	011° 19.269' E	732
SO283_56-1	CTD	27.04.2021 03:40	25° 00.012' S	013° 28.020' E	799
SO283_57-1	DRIFT	27.04.2021 05:02	25° 00.003' S	013° 20.002' E	1088
SO283_57-2	CTD	27.04.2021 06:22	25° 00.111' S	013° 20.002' E	1081
SO283_57-3	WP-2	27.04.2021 07:38	25° 00.108' S	013° 20.004' E	1084
SO283_58-1	DRIFT	27.04.2021 10:58	25° 00.011' S	013° 54.907' E	180
SO283_58-2	CTD	27.04.2021 11:41	25° 00.179' S	013° 54.875' E	199
SO283_58-3	PLA	27.04.2021 11:39	25° 00.179' S	013° 54.876' E	180
SO283_58-4	PLA	27.04.2021 11:43	25° 00.178' S	013° 54.875' E	181
SO283_58-5	PLA	27.04.2021 11:47	25° 00.178' S	013° 54.875' E	183
SO283_58-6	PLA	27.04.2021 11:50	25° 00.179' S	013° 54.875' E	183
SO283_58-7	PLA	27.04.2021 11:53	25° 00.182' S	013° 54.874' E	181
SO283_58-8	WP-2	27.04.2021 12:25	25° 00.179' S	013° 54.874' E	182
SO283_59-1	CTD	27.04.2021 14:00	24° 59.983' S	014° 06.107' E	170
SO283_60-1	CTD	27.04.2021 15:59	25° 00.009' S	014° 19.186' E	143
SO283_60-2	PLA	27.04.2021 15:55	25° 00.012' S	014° 19.182' E	144
SO283_60-3	PLA	27.04.2021 16:00	25° 00.010' S	014° 19.185' E	143

Station	Gear	Date and Time	Latitude	Longitude	Water Depth (m)
SO283_60-4	PLA	27.04.2021 16:03	25° 00.012' S	014° 19.184' E	143
SO283_60-5	PLA	27.04.2021 16:06	25° 00.007' S	014° 19.184' E	144
SO283_60-5	PLA	27.04.2021 16:10	25° 00.008' S	014° 19.185' E	144
SO283_60-6	WP-2	27.04.2021 16:49	25° 00.004' S	014° 19.182' E	144
SO283_61-1	CTD	27.04.2021 18:06	24° 59.987' S	014° 24.998' E	125
SO283_62-1	CTD	27.04.2021 18:56	25° 00.005' S	014° 22.592' E	135
SO283_63-1	CTD	27.04.2021 21:04	24° 59.997' S	014° 30.001' E	107
SO283_64-1	CTD	27.04.2021 22:26	24° 59.999' S	014° 33.998' E	102
SO283_65-1	CTD	28.04.2021 00:09	25° 00.004' S	014° 40.000' E	77
SO283_66-1	CTD	28.04.2021 02:09	24° 59.997' S	014° 44.649' E	49
SO283_66-2	PLA	28.04.2021 02:04	24° 59.999' S	014° 44.648' E	51
SO283_66-3	PLA	28.04.2021 02:09	24° 59.998' S	014° 44.649' E	49
SO283_66-4	PLA	28.04.2021 02:12	24° 59.999' S	014° 44.647' E	49
SO283_66-5	PLA	28.04.2021 02:16	24° 59.996' S	014° 44.646' E	50
SO283_66-6	PLA	28.04.2021 02:20	24° 59.994' S	014° 44.646' E	50
SO283_66-7	WP-2	28.04.2021 02:42	24° 59.998' S	014° 44.644' E	49
SO283_67-1	CTD	28.04.2021 04:19	25° 04.743' S	014° 32.050' E	109
SO283_67-2	MOOR	28.04.2021 05:00	25° 04.802' S	014° 32.070' E	107
SO283_68-1	CTD	28.04.2021 08:02	25° 00.000' S	014° 28.142' E	115
SO283_68-2	PLA	28.04.2021 08:01	25° 00.000' S	014° 28.143' E	114
SO283_68-3	PLA	28.04.2021 08:10	24° 59.998' S	014° 28.137' E	117
SO283_68-4	PLA	28.04.2021 08:13	25° 00.000' S	014° 28.138' E	115
SO283_68-5	PLA	28.04.2021 08:19	25° 00.002' S	014° 28.140' E	117
SO283_68-6	PLA	28.04.2021 08:23	25° 00.002' S	014° 28.142' E	115
SO283_68-7	WP-2	28.04.2021 08:48	25° 00.000' S	014° 28.144' E	115
SO283_69-1	CTD	28.04.2021 10:20	24° 59.940' S	014° 17.111' E	157
SO283_70-1	CTD	28.04.2021 11:37	24° 59.994' S	014° 11.991' E	171
SO283_71-1	CTD	28.04.2021 13:39	24° 59.991' S	013° 59.995' E	173
SO283_72-1	CTD	28.04.2021 15:29	24° 59.992' S	013° 49.989' E	223
SO283_73-1	CTD	28.04.2021 16:49	25° 00.031' S	013° 43.848' E	313
SO283_74-1	CTD	28.04.2021 18:17	24° 59.984' S	013° 38.975' E	428
SO283_75-2	PLA	28.04.2021 19:37	24° 59.944' S	013° 32.818' E	626
SO283_75-3	PLA	28.04.2021 19:42	24° 59.945' S	013° 32.817' E	630
SO283_75-4	PLA	28.04.2021 19:46	24° 59.947' S	013° 32.815' E	629
SO283_75-5	PLA	28.04.2021 19:50	24° 59.947' S	013° 32.813' E	631
SO283_75-1	CTD	28.04.2021 19:51	24° 59.947' S	013° 32.812' E	630
SO283_76-1	CTD	28.04.2021 23:21	24° 59.947' S	013° 09.976' E	1458
SO283_77-1	CTD	29.04.2021 01:51	25° 00.000' S	012° 59.996' E	1795
SO283_78-1	DRIFT	29.04.2021 05:09	24° 52.609' S	013° 17.080' E	1045
SO283_79-1	DRIFT	29.04.2021 09:50	24° 51.894' S	013° 42.109' E	360
SO283_80-1	CTD	02.05.2021 05:24	14° 48.001' S	011° 06.001' E	3067
SO283_80-2	FLOAT	02.05.2021 06:09	14° 48.002' S	011° 05.998' E	3070
SO283_81-1	FLOAT	02.05.2021 17:29	12° 19.594' S	011° 44.074' E	3036
SO283_81-2	CTD	02.05.2021 18:37	12° 19.832' S	011° 44.131' E	3039
SO283_82-1	CTD	03.05.2021 04:11	10° 53.003' S	012° 54.986' E	1297
SO283_83-1	MOOR	03.05.2021 05:29	10° 49.448' S	012° 59.851' E	1250
SO283_83-2	CTD	03.05.2021 08:15	10° 49.621' S	013° 00.133' E	1223
SO283_84-1	CTD	03.05.2021 09:47	10° 47.923' S	013° 02.953' E	1156

Station	Gear	Date and Time	Latitude	Longitude	Water Depth (m)
SO283_85-1	CTD	03.05.2021 11:15	10° 45.981' S	013° 06.054' E	935
SO283_86-1	CTD	03.05.2021 12:31	10° 43.993' S	013° 09.002' E	691
SO283_87-1	CTD	03.05.2021 13:48	10° 41.995' S	013° 12.001' E	441
SO283_88-1	CTD	03.05.2021 15:07	10° 39.999' S	013° 14.997' E	218
SO283_89-1	CTD	03.05.2021 16:05	10° 38.027' S	013° 17.934' E	121
SO283_90-1	CTD	03.05.2021 16:56	10° 36.057' S	013° 20.969' E	106
SO283_91-1	CTD	03.05.2021 17:46	10° 33.965' S	013° 24.007' E	85
SO283_92-1	CTD	03.05.2021 18:32	10° 31.997' S	013° 26.974' E	60
SO283_93-1	CTD	03.05.2021 19:18	10° 29.875' S	013° 29.991' E	41
SO283_94-1	CTD	04.05.2021 00:06	10° 56.063' S	012° 50.011' E	1388
SO283_95-1	CTD	04.05.2021 02:04	10° 59.996' S	012° 45.000' E	1424
SO283_96-1	MB	04.05.2021 03:41	10° 52.898' S	012° 54.100' E	1307
SO283_97-1	MOOR	04.05.2021 05:13	10° 49.390' S	012° 59.579' E	1217
SO283_98-1	FLOAT	04.05.2021 10:03	10° 59.945' S	012° 45.099' E	1436
SO283_99-1	CTD	05.05.2021 01:11	10° 00.003' S	009° 40.001' E	4420
SO283_99-2	PLA	05.05.2021 01:42	09° 59.997' S	009° 40.002' E	4413
SO283_99-3	PLA	05.05.2021 01:47	09° 59.998' S	009° 40.001' E	4415
SO283_99-4	PLA	05.05.2021 01:51	09° 59.997' S	009° 40.001' E	4415
SO283_99-5	PLA	05.05.2021 01:55	09° 59.999' S	009° 40.000' E	4420
SO283_99-6	WP-2	05.05.2021 03:17	10° 00.003' S	009° 40.011' E	4417
SO283_100-1	CTD	05.05.2021 05:27	09° 58.807' S	009° 33.083' E	4527
SO283_101-1	FLOAT	06.05.2021 08:45	08° 21.169' S	003° 21.030' E	5525

8 Data and Sample Storage and Availability

The sediment trap and drifter material will be stored at the Universität Hamburg, Institute of Geology (person in charge: Luisa Meiritz). The biological material (microplankton) from APSTEIN Net hauls will be stored at the Universität Hamburg, Institute of Marine Ecosystem Research and Fisheries (person in charge: Rolf Koppelmann). Hydrography data derived from moorings in the EEZ of Namibia are stored at the IOW (person in charge: Volker Mohrholz). Hydrography data derived from one mooring in the EEZ of Angola are stored at GEOMAR (person in charge: Marcus Dengler).

CTD, ADCP, SMB and EM-122 bathymetry data will be transferred to PANGAEA data base (www.pangaea.de) as an established open-access data repository, member of World Data System WDS, International Council for Science ICSU. These data are also automatically transferred to the Federal Maritime and Hydrographic Agency (BSH). Data obtained from EK-60 are stored at the ZMT (person in charge: Tim Dudeck). Underway measurements on water chemistry and trace gases are stored at the IOW (person in charge: Bita Sabbaghzadeh) and at the ZMT (DIC, Total Alkalinity; person in charge: Tim Rixen).

Table 8.1 Overview of data availability

Type	Database	Available	Free Access	Contact
Hydrography (TSG, SMB)	PANGAEA	December 2021	December 2021	martin.schmidt@io-warnemuende.de
CTD	PANGAEA	December 2021	December 2021	cmertens@uni-bremen.de

				martin.schmidt@io-warnemuende.de
ADCP (38, 75 kHz)	PANGAEA	December 2021	December 2021	mdengler@geomar.de cmertens@uni-bremen.de
EK-60	PANGAEA	December 2021	May 2023	tim.dudeck@leibniz-zmt.de
Microplankton	PANGAEA	December 2021	May 2023	rolf.koppelmann@uni-hamburg.de
Underway Data (Water chemistry)	PANGAEA MEMENTO	May 2022	December 2022	bita.sabbaghzadeh@io-warnemuende.de
Trace gases	PANGAEA MEMENTO	May 2022	December 2022	bita.sabbaghzadeh@io-warnemuende.de

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10 References

Bordbar, H. M., Mohrholz, V. Schmidt, M., 2021. Mesoscale and sub-mesoscale ocean dynamics across the Benguela Upwelling System and their modulating impacts on the coastal and offshore upwelling. In review.

Capone, D.G., & Hutchins, D.A., 2013. Microbial biogeochemistry of coastal upwelling regimes in a changing ocean. Nature Geoscience, 6(9), 711–717.

Charpentier, J., Farias, L., & Pizarro, O., 2010. Nitrous oxide fluxes in the central and eastern South Pacific. Global Biogeochem. Cycles, 24, GB3011. doi:10.1029/2008GB003388.

Dickson, A.G., Sabine, C.L., & Christian, J.R., 2010. Guide to the best practices for ocean CO_2 measurements. PICES special publication 3.

Dickson, A. G., Cam, M. F., Spitzer, P., Fisicaro, P., Stoica, D., Pawlowicz, R., & R. Feistel. R., 2015. Metrological challenges for measurements of key climatological observables. Part 3: Seawater pH. Metrologica.

Doney, S.C., Fabry, V.J., Feely R.A., Kleypa, J.A., 2009. Ocean acidification: The other CO_2 problem. Ann. Rev. Mar.Sci. 1: 169–192.

Emeis, K., Eggert, A., Flohr, A., Lahajnar, N., Nausch, G., Neumann, A., Rixen, T., Schmidt, M., Van der Plas, A., Wasmund, N., 2018. Biogeochemical processes and turnover rates in the Northern Benguela Upwelling System. Journal of Marine Systems 188, 63-80.

Fennel, W., Junker, T., Schmidt, M., Mohrholz, V., 2012. Response of the Benguela Upwelling Systems to spatial variations in the wind stress, Cont. Shelf Res. 45: 65-77.

Florenchie, P., C. J. C. Reason, J. R. E. Lutjeharms, M. Rouault, C. Roy, and S. Masson, 2004. Evolution of Interannual Warm and Cold Events in the Southeast Atlantic Ocean, J Climate, 17(12), 2318-2334, doi: 10.1175/1520-0442(2004)017

Frame, C., Deal, E., Nevison, C. D., & Casciotti, K. L., 2014. N_2O production in the eastern South Atlantic: Analysis of N_2O stable isotopic and concentration data. Global Biogeochem. Cycles 28, 1262–1278. doi: 10.1002/2013GB004790.

Gammelsrød, T., C. H. Bartholomae, D. C. Boyer, V. L. L. Filipe, and M. J. O’Toole, 1998. Intrusion of warm surface water along the Angolan–Namibian coast in February–March 1995: The 1995 Benguela Niño. South Afr. J. Mar. Sci., 19, 41–56, doi:10.2989/025776198784126719.

Garcia-Reyes, M., Sydeman, W.J., Schoeman, D.S., Rykaczewski, R.R., Black, B.A., Smit, A.J., Bograd, S.J., 2015. Under Pressure: Climate Change, Upwelling, and Eastern Boundary Upwelling Ecosystems. Frontiers in Marine Science, 2, 109. doi: 10.3389/fmars.2015.00109.

Lübbecke, J. F., Böning, C.W., Keenlyside, N.S., and Xie, S.-P., 2010. On the connection between Benguela and equatorial Niños and the role of the South Atlantic Anticyclone, J. Geophys. Res.,115, C09015, doi:10.1029/2009JC005964.

Monteiro, P.M.S., Van der Plas, A., Mohrholz, V., Mabille, E., Pascall, A., & Joubert, W., 2006. Variability of natural hypoxia and methane in a coastal upwelling system: Oceanic physics or shelf biology? Geophysical Research Letters, 33(16). http://doi.org/ 10.1029/2006GL026234.

Nevison, C. D., Weiss, R. F., Erickson III, D. J., 1995. Global oceanic emissions of nitrous oxide. J. Geophys. Res., 100, 15809–15820.

Oxborough, K. Moore, C.M., Suggett, D.J., Lawson, T., Chan, H.G., Geider, R.J., 2012. Direct estimation of functional PSII reaction center concentration an PSII electron flux on a volume basis: a new approach to the analysis of Fast Repetition Rate Fluorometry (FRRF) data. Limnology and Oceanography: Methods 10, 142-154.

Rykaczewski, R.R., Dunne, J.P., Sydeman, W.J., García-Reyes, M., Black, B.A., Bograd, S.J., 2015. Poleward displacement of coastal upwelling-favorable winds in the ocean's eastern boundary currents through the 21st century. Geophysical Research Letters, 42 (15), 6424-6431.

Sabbaghzadeh, B., Arévalo-Martinez, D.L., Glockzin, M., Otto, S., Rehder, G., 2021. Meridional and Cross-Shelf Variability of N_2O and CH_4 in the Eastern-South Atlantic. Journal Geophysical Research, 2020JC016878, in revision.

Suggett, D.J., Moore, C.M., Hickman, A.E., Geider, R.J., 2009. Interpretation of fast repetition rate (FRR) fluorescence: signatures of phytoplankton community structure versus physiological state. Marine Ecology Progress Series 376, 1-19.

Vorrath, M.-E., Lahajnar, N., Fischer, G., Libuku, V.M., Schmidt, M., Emeis, K.-C., 2018. Spatiotemporal variation of vertical particle fluxes and modelled chlorophyll a standing stocks in the Benguela Upwelling System. Journal of Marine Systems 180, 59-75.

Zeng, Z., Brandt, P., Lamb, K.G., Greatbatch, R.J., Dengler, M., Claus, M., Chen, X., 2021, Three Dimensional Numerical Simulations of Internal Tides in the Angolan Upwelling Region. J. Geophys. Res. Oceans, 126, e2020JC016460, https://doi.org/ 10.1029/2020JC016460

11 Abbreviations

ADCP	Acoustic Doppler Current Profiler
AIRICA	Automated Infra-Red Inorganic Carbon Analyzer
BANINO	Benguela Niños: Physical Processes and long term Variability (BMBF research project)
BMBF	German Ministry for Education and Research
BSH	Bundesamt für Seeschifffahrt und Hydrographie / Federal Maritime and Hydrographic Agency
BUS	Benguela Upwelling System

Chl. *a*	Chlorophyll *a*
CRM	Certified Reference Material
CTD	Conductivity Temperature Depth
DCAA	Dissolved Combined Amino Acids
DFG	Deutsche Forschungsgemeinschaft
DIC	Dissolved Inorganic Carbon
DOC	Dissolved Organic Carbon
ECD	Electron Capture Detector
EEZ	Exclusive Economic Zone
EK60 / 122	Echo Sounder
ENS	Ecole Normale Supérieure
ET 3 / 4	Energy Transfer 3 / 4
EVAR	Effects of Variability in Physical Forcing on Carbon and Oxygen Budget (BMBF Research Project)
FID	Flame Ionization Detector
FRRF	Fast Repetition Rate Fluorometry
GENUS	Geochemistry and Ecology of the Namibian Upwelling System (BMBF research project)
GEOMAR	Helmholtz-Zentrum für Ozeanforschung GEOMAR, Kiel
HPLC	High Pressure Liquid Chromatography
ICSU	International Council for Science
IOW	Leibniz-Institut für Ostseeforschung Warnemünde
IUP	Institute of Environmental Physics
KPO-1215	Kiel Physikalische Ozeanographie
LOV	Laboratoire d'Océanographie de Villefranche
LTKC	Long Term Kunene Cell
LTMB	Long Term Mooring Mudbelt
N-/SBUS	Northern/ Southern Benguela Upwelling System
NADW	North Atlantic Deep Water
NatMIRC	National Marine Information and Research Centre
NBUS	Northern Benguela Upwelling Systems
OS 38 / 75	Ocean Surveyor 38 / 75 kHz
P&T	Purge and Trap system

PIES	Pressure Inverted Echo Sounders
PREFACE	Project Enhancing Prediction of Tropical Atlantic Climate and its Impacts
PSS68	Practical Salinity Scale 1968
SACUS	Southwest African Coastal Upwelling System and Benguela Niños (BMBF research project)
SADCP	Shipboard Acoustic Doppler Current Profiler
SBUS	Southern Benugela Upwelling Systems
SH	‘Schiffshund’ Internal Standard
SMB	Self-cleaning Monitoring Box
TA	Total Alkalinity
TC	Temperature Conductivity
TRAFFIC	Trophic TRAnsfer eFFICiency in the Benguela Current (BMBF research project)
TRBM	Trawl Resistant Bottom Mount
TRR181	Energy Transfers in Atmosphere and Ocean
UHB	Universität Bremen
UHH	Universität Hamburg
UTC	Coordinated Universal Time
VINDTA	Versatile INstrument for the Determination of Total Alkalinity
WBST	Walvis Bay Sediment Trap
WDS	World Data System
WMO	World Meteorological Organisation
WP-2 Net	Working Party 2 Net
ZMT	Zentrum für Marine Tropenökologie