1st Weekly Report of M120, Recife – Walvis Bay

November 17th to18th, 2015

METEOR cruise M120 began on Saturday, October 17th in Recife, Brazil. The research cruise is part of the cooperative project SACUS „Southwest African Coastal Upwelling System and Benguela Niños“ funded by the German Ministry for Education and Research and the EU funded collaborative project PREFACE „Enhancing prediction of tropical Atlantic climate and its impacts“. The investigations in both projects focus on the upwelling regions of Angola and Namibia. The research objectives within the SACUS project aim at physical mechanisms of regional climate variability and change and its consequences for the ocean's biogeochemistry, hypoxia and marine ecosystems in the upwelling regions. Research within PREFACE focuses on a better understanding of the tropical Atlantic climate system, improved simulation and prediction of tropical Atlantic climate on seasonal and longer time scales and improved quantification of climate change impacts, including fish stock changes in the eastern upwelling regions of the tropical Atlantic.
M120 contributes to the projects‘ research goals by investigating the variability of eastern boundary current transport, water mass variability, and the propagation of coastal waves in the eastern upwelling regions of the South Atlantic. Additionally, the cruise focuses on a quantitative understanding of the physical processes controlling the mixed-layer heat and freshwater budgets. The observational program is complimented by measurements of greenhouse gas concentrations of CO_2, N_2O, CH_4 and CO_2 isotopes and measurements of the atmospheric concentrations and size distribution of aerosols.

International Cooperation

The scientific team of M120 includes 22 scientists and technicians (Fig, 1). Apart of participants from the Helmholtz Centre for Ocean Research Kiel, the Leibniz Institute for Baltic Sea Research Warnemünde and the Max-Plank-Institute for Meteorology, three international groups have joined the cruise. Particularly noteworthy is the participation of two young scientists from the National Institute of Fisheries in Angola who participate in a capacity building program on ocean observing systems and data processing during the cruise. Additionally, we welcomed onboard two participants from the Niels Bohr Institute of the University of Copenhagen, Denmark and one participant from the Institute of Marine Research in Bergen, Norway. The three international institutes are partners in the EU-PREFACE project that interconnects scientists from 8 European and 9 African countries.

Fig. 1. Scientific participants of M120 onboard Meteor in the harbor of Recife (Photo: Tina Dippe)

Underway measurements along the transatlantic transect at 12°S

FS METEOR left the port of Recife on Saturday at 7.30am local time and reached the first position of the transatlantic transect on Sunday at 9am board time. Since then, hourly measurements of temperature and salinity in the upper 400m of the water column are being conducted using an underway-CTD system. Additionally, upper ocean velocities are continuously recorded by the two shipboard Ocean Surveyors and concentrations of greenhouse gases in the surface layer are measured. In combination with bottom pressure sensors moored at the western and eastern boundary of the transect and the currently deployed western and eastern boundary current arrays, the data set will be used for investigating water mass variability associated with the meridional circulation variability across 12°S.

During our first two days, the meteorological conditions have been perfect for a fast transit towards Africa. The vessel steams against weak trade winds (2-3 Bft.) and weak swell from the south east with a mean velocity of about 11 knots. The current speed is faster than we had anticipated allowing us to make up time that we had lost due to repairs of METEOR‘s central hydraulic system.

We are experiencing an excellent onboard atmosphere to which the sunny weather and warm temperatures certainly contribute. Moreover, the cooperation with Captain Rainer Hammacher and the crew of METEOR has been outstanding.

Best regards from the tropical South Atlantic
Marcus Dengler and the participants of the M120 cruise

M120, Recife – Walvis Bay

October 17th to November 18th 2015

2nd Weekly Report, October 25th, 2015

During the transit from Brazil to Angola along 12°S our activities concentrated on sampling temperature and salinity profiles from the upper 400m of the water column while steaming and on chemical underway measurements of the concentration of trace gases in the near-surface waters and the atmosphere. Additionally, upper ocean velocity profiles were collected with METEOR's two Ocean Surveyors.

Underway-CTD and current measurements along the 12°S transect

Since leaving the exclusive economic zone of Brazil eight days ago, we are collecting profiles of temperature and salinity using an underway-CTD system at a sampling rate of one profile every hour (Fig. 1). These measurements are carried out by dropping a probe with conductivity, temperature and pressure sensors into the water while METEOR is at full speed. The probe is attached to a thin tether on a winch attached to the gunwale at the stern of METEOR. Once deployed, the loosely-tethered probe descents at high velocities of 3 ms^{-1} to 4 ms^{-1} to about 400m depth. Finally, the probe is pulled back onto the vessel using the winch.

Our cruise track across the Atlantic crosses the northward flank of the southern subtropical gyre in the region of the westward flowing South Equatorial Current (SEC). The westward velocities associated with the SEC are pronounced in the already processed velocity data from the Ocean Surveyor west of about 12°W (Fig. 2). However, an intensified SEC was observed during a previous METEOR cruise M98 carried out in July 2013 that crossed the Atlantic at exactly the same latitude. A likely explanation of the observed differences in the strength of the SEC is the seasonal variability of the trade winds that are more intense during the boreal summer period compared to October in our region. The vertical distribution of temperature and salinity obtained from the underway-CTD data (Fig. 2) show a pronounced uplift of the thermocline and halocline towards the east that is also associated with a decrease in mixed-layer depth in the eastern part of the transect. This characteristic is caused by the spatially rotating trade winds in our study area.

Fig. 1: Underway-CTD measurements on FS METEOR. Robert Kopte is recovering the probe after collecting a CTD profile. Amaro Francisco and Jonas Boomers are assisting by keeping the gibbet of the winch in the right position. (Photo: Thilo Klenz)

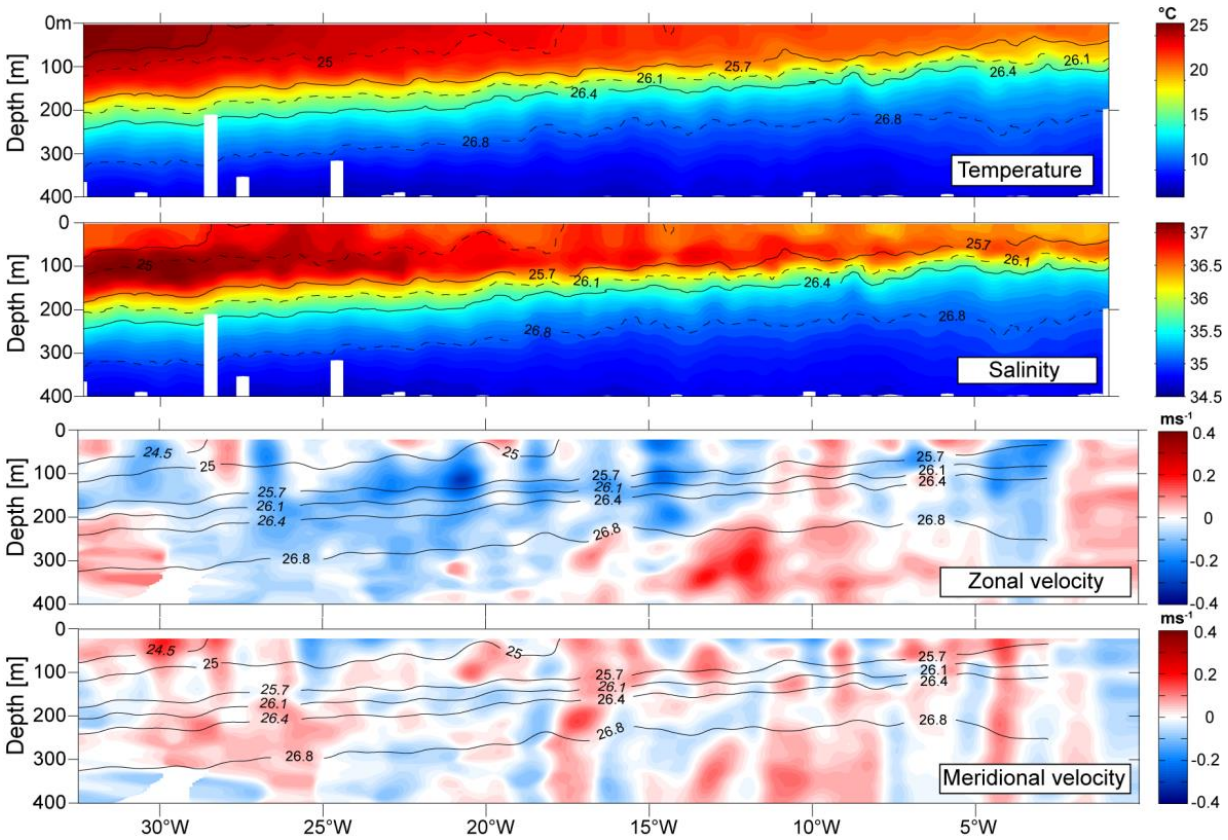

Fig. 2: Temperature and salinity distribution from the underway-CTD measurements and distribution of zonal and meridional velocity from the Ocean Surveyor along the 12°S transect. Black lines indicate isopycnals in kg m^{-3}.

Apart from the analysis of water mass changes mention in the earlier report, the data set will be used in conjunction with additional meteorological data collected by METEOR to quantitatively advance understanding of the mixed-layer heat and salt balance.

Trace gas concentrations in the near-surface waters along 12°S

The chemical group participating in M120 collected measurements along the transit cruise track using their underway system to continuously measure concentrations of climate-relevant trace gases in the near-surface waters and the atmosphere. While searching for regions of sinks or sources of trace gases in the ocean, much of the data collected so far showed the surface ocean to be in equilibrium with the atmosphere above. Only carbon dioxide indicated weakly undersaturated concentrations in the near-surface ocean that is probably caused by increased primary productivity in the eastern regions of our cruise track. However, due to the decrease in temperature and increase in primary productivity in the eastern boundary upwelling regions, we expect stronger signals to be picked up by our measurement system, soon.

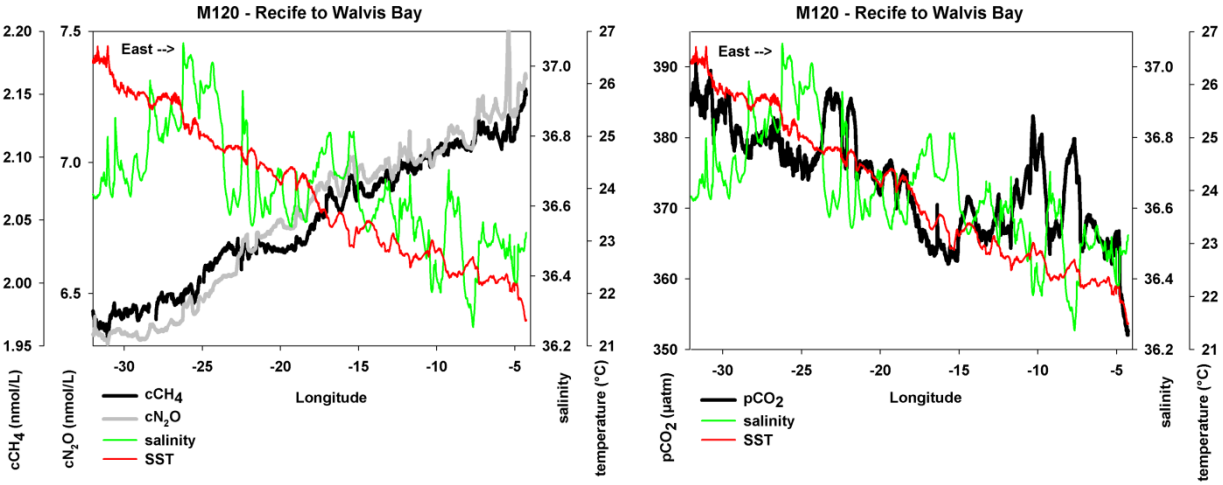

Fig. 3: Concentrations of the methane (CH_4) und nitrous oxide (N_2O), both left panel and carbon dioxide (CO_2, right panel) in relation to temperature (SST, red line) and salinity of the near-surface waters.

Apart from conducting measurements and data analysis, our daily work schedule includes preparation of instruments for the mooring deployments as well as testing and ballast calibrations of the gliders that will be deployed off Angola and Namibia. Greatly acknowledged is the professional support by the crew of METEOR during these preparations. Scientific discussions are enhanced during our daily board seminar during which scientists and students are giving talks on research questions related to the cruise.

On Wednesday afternoon, METEOR will arrive at the position of our first CTD station of a section along 11°S off Angola. We are also looking forward to recovering the first mooring of the eastern boundary transport array on Thursday mooring.

Best regards from the tropical South Atlantic
Marcus Dengler and the participants of the M120 cruise

M120, Recife – Walvis Bay

October 17th to November 18th 2015

3nd Weekly Report, November 1st, 2015

After transiting for 11 days we reached Angolan waters on Wednesday afternoon and started the work on a cross-slope section at about 11°S. An integral component of the eastern boundary current system here is the Angola current, a poleward undercurrent usually observed at the continental slope. It carries nutrient-rich and oxygen-poor water masses from the eastward currents near the equator poleward. Using a mooring array as well as transects oriented perpendicular to the coastline, we aim at determining the strength of the circulation and intraseasonal to interannual variability of the transport and the hydrographic properties of the Angola Current. Additionally, coastally trapped waves propagate poleward along the eastern boundary of the tropical Atlantic. These signals are often forced at remote location, such as the western equatorial Atlantic, from where they propagate eastward along the equator before propagating poleward along the coast. In the upwelling regions of Angola and Namibia their presence may lead to variability of the sea surface temperature which in turn affects climate variability.

Mooring work off Angola along 11°S

During METEOR cruise M98 in July 2013, nearly 2 ½ years ago, two moorings and two bottom shields were deployed at the 11°S transect. Due to several different circumstances, the moored equipment could not be serviced as scheduled last year. We are thus relieved to have recovered most of our instruments after the unexpectedly long deployment period. The two most important components of the array, a bottom shield deployed at 500m (Fig. 1) and a mooring deployed at 1200m depth were recovered. We were particularly pleased by the fact that all recovered instruments had recorded data during the whole deployment period. Two 2.5-year time series of horizontal velocity from acoustic Doppler current profilers in the 1200m mooring and the bottom shield, both delivered velocity data from the upper 500m of the water column (Fig. 2). The velocity time series show a pronounced semi-annual cycle in the flow along the

Fig. 1: Recovery of a bottom shield deployed at 500m depth along 11°S. (Photo: Toralf Henne)

eastern boundary. Additionally, prolonged periods of equatorward flow are indicated. The time series also reveal strongly elevated intraseasonal variability of the currents that are likely caused by the presence of coastally trapped waves. A remarkable characteristic of the intraseasonal variability is that several of these structures exhibit decreasing velocities towards the surface suggesting that these signals cannot be seen by satellite altimetry. We are convinced that the two velocity time series will be adequate to determine transport variability at the eastern boundary of Angola. They will allow quantification the strength and the variability of the Angola current for the first time and thus provide important information on the generation of variability of sea surface temperature and water mass variability in the upwelling regions. Moreover, the time series will provide new constraints on the drift of larvae and juvenile fish – important information for fisheries research in the upwelling regions of Angola and Namibia.

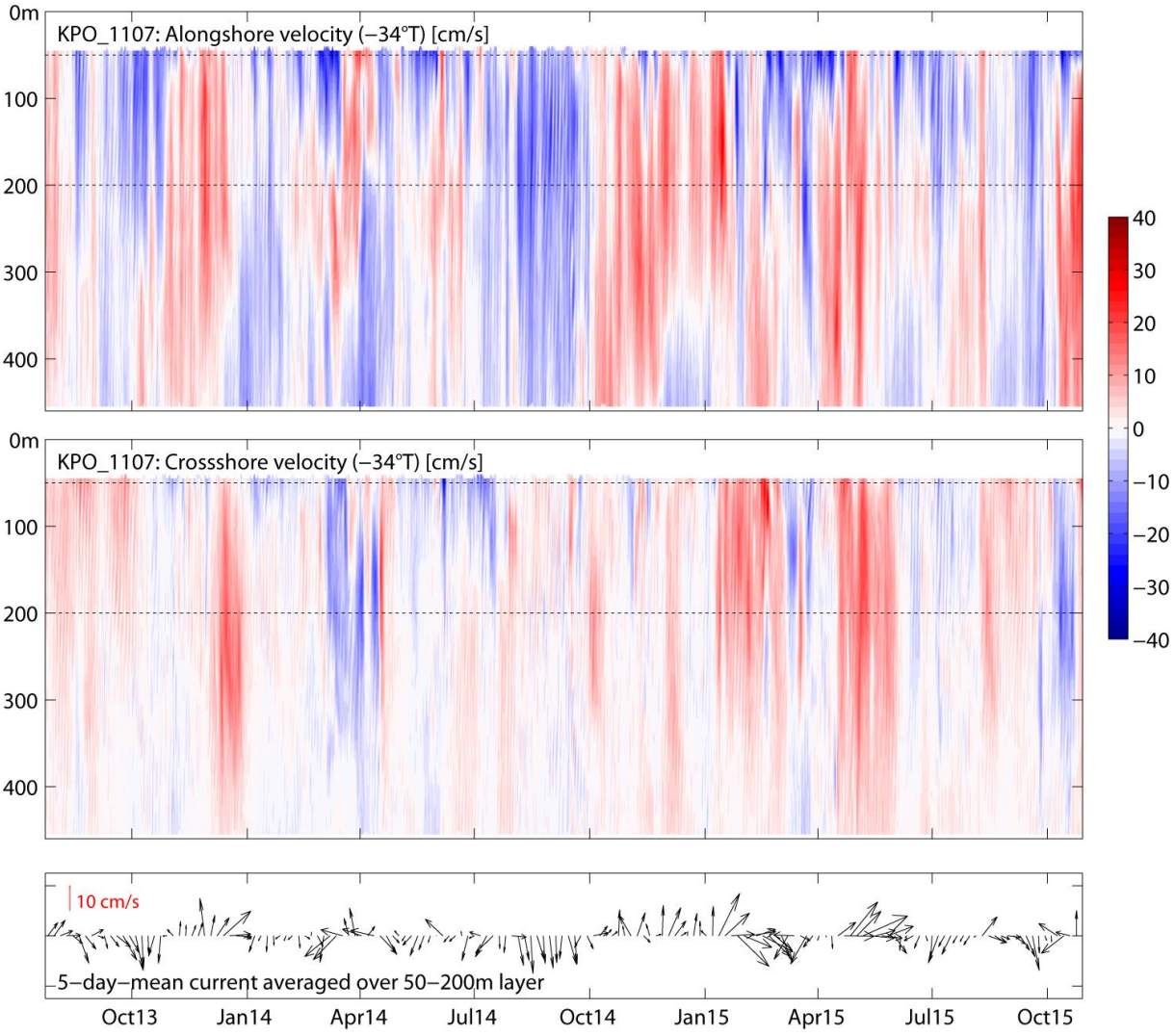

Fig. 2: Time series of the flow parallel to the continental slope (upper panel), across the continental slope (middle panel) and horizontal velocity vectors at 11°S. The time series was recorded by acoustic Doppler current profiler mounted to the mooring deployed at 1200m depth at 13°E (see Fig. 3 for mooring position)

Velocity and hydrographic measurements along the 11°S transect

Measurements along the 11°S transect complementing the moored observations include hydrographic and oxygen profiles (CTD/O_2), turbulence measurements in the water column and continuous shipboard velocity profiles from the vessel mounted Ocean Surveyors. Additionally, the water samples from the CTD rosette were analysed for concentration of nutrients and samples for the analysis of trace gases (N_2O and CH_4) were prepared. The shipboard velocity data revealed interesting aspects of the eastern boundary circulation: While the alongshore velocity structure at 11°S during the M98 cruise in July 2013 showed a weak poleward Angola Current attached to the continental slope between 50 and 200m depth (Fig. 3), the observed flow structure was very different this time. Instead of poleward flow, elevated equatorward flow in the upper 500m of the water column at the continental slope persisted during the section occupation period. The contrasting flow of these two realisations illustrates the enhanced variability of eastern boundary circulation that is also reflected in the velocity time series from the mooring and the bottom shield.

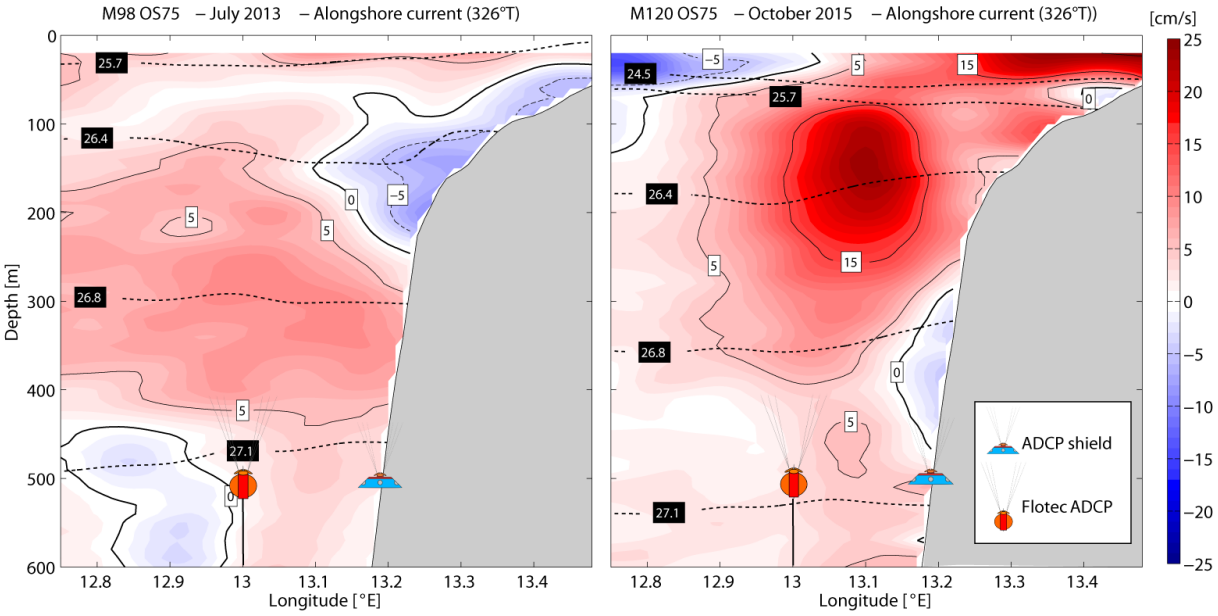

Fig. 3: Alongshore flow at 11°S transect during M98 in July 2013 (left) und during M120 (right).

The measurement program at 11°S was completed yesterday evening. Currently, we are steaming toward the 6°S transect. Shortly before leaving 11°S we deployed a glider with a turbulence probe attached that will continue to sample data along the 11°S transect for the next month. The glider positions as well as the collected data can be viewed online at http://gliderweb.geomar.de.

Best regards from the tropical South Atlantic
Marcus Dengler and the participants of the M120 cruise

M120, Recife – Walvis Bay

October 17th to November 18th 2015

4th Weekly Report, November 8th, 2015

This afternoon, Meteor reached the 18°S section (Fig. 1) and we were able to successfully recover a bottom shield moored at 125m depth on the shelf. In the past week, our measurement programme focussed on observing the variability of the eastern boundary circulation and water mass variability along the sections perpendicular to the continental slope at 6°S and 15°S and on the redeployment of moorings and a bottom shield as part of the eastern boundary transport array along 11°S. Additionally, we performed microstructure measurements at the CTD stations using a turbulence probe.

Glider measurements at the Angola-Benguela Front

A focus of our observational program is to determine the variability of the hydrographic properties and the circulation in the Angola-Benguela frontal zone. The front separates warm waters to the north from cold surface waters to the south. Its meridional positions varies between 15°S and 18°S and a temperature difference across the front ranges from 5°C and 8°C. Shortly before METEOR arrived in the region of the frontal zone, satellite based measurements of sea surface temperature showed a fascinating southward displacement of the frontal zone (Fig. 1) above the continental slope and the shelf region off southern Angola. A strengthening of the

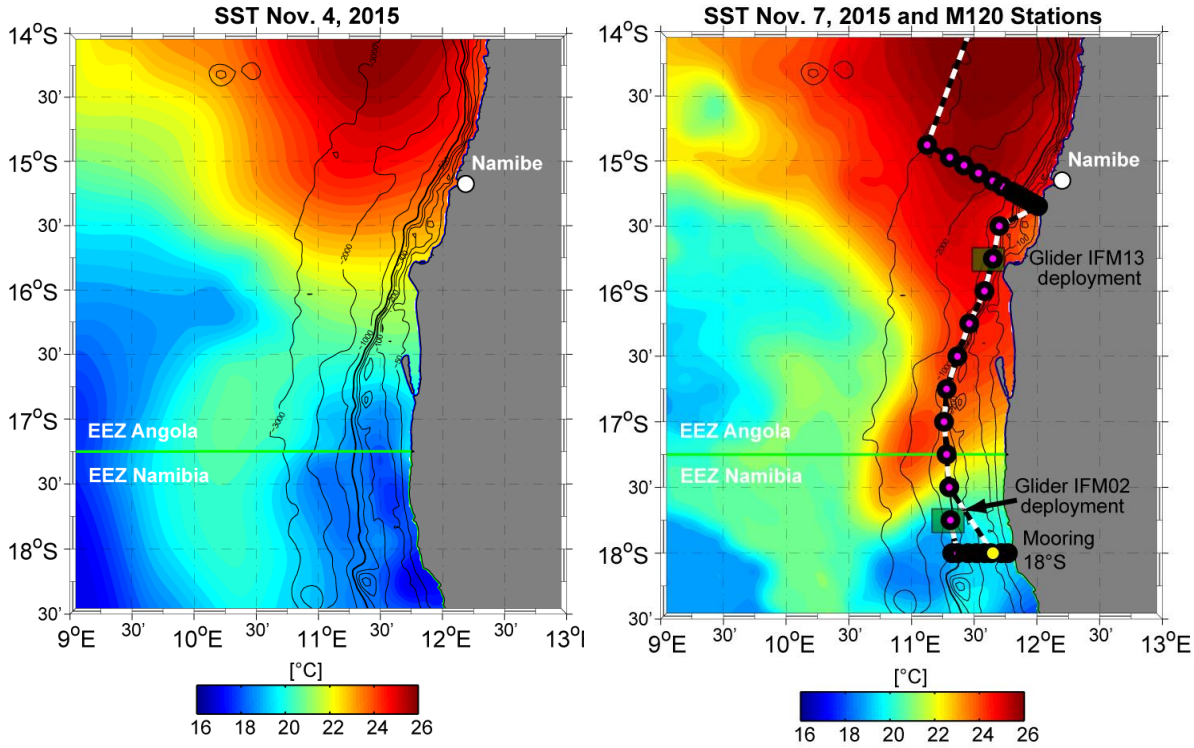

Fig. 1.: Sea surface temperature from November 4th (left panel) and November 7th 2015 (right panel) from satellite observations. The southward displacement of the front resulted in a sea surface temperature increase of more than 5°C in the region of the continental slope and shelf from 15°30'S to 17°30'S.

trade winds accompanied the southward displacement of the front. Our CTD and underway-CTD measurements along the warm water tongue (Fig. 1, right) indicated that the elevated temperatures were limited to a 20m-thick surface layer. We are now looking forward to obtaining results from the analysis of the ocean-atmosphere heat and freshwater fluxes on both sides of the front that can be calculated from METEORs on board sensors. To advance understanding of the variability of ocean-atmosphere interactions and ocean feedback processes in the frontal region, we are deploying two gliders that will survey the frontal region along meridional transect in the next 30 days. One glider was already deployed in the northern region on Saturday; the deployment of the second glider will follow on Monday. The autonomous observatories will collect data on climate-relevant parameters such as variability of mixed-layer depth and heat content and stratification in the thermocline as well as variability of water masses and currents. Additionally, one of the gliders carries a turbulence probe that will be used to quantify mixing and turbulent heat and freshwater fluxes. The other glider has an additional nitrate sensor attached and will survey the variability of nutrient concentration across the front.

Mixing at the continental margins

A second focus of our measurement program is investigating turbulent mixing processes in the Angolan and Namibian upwelling regions. Mixing processes just below the surface mixed layer impact the mixed-layer heat and freshwater budgets. Using microstructure measurements, we can quantify the flux of heat and freshwater due to turbulent mixing from the surface mixed layer to the deeper ocean. Furthermore, the turbulence data set will be used to investigate mixing processes along the continental margins of Angola and Peru. Due to interactions with the sloping topography at the continental slopes, energy from the ocean tides is transferred to turbulence leading to elevated turbulent dissipation in those regions (Fig. 2).

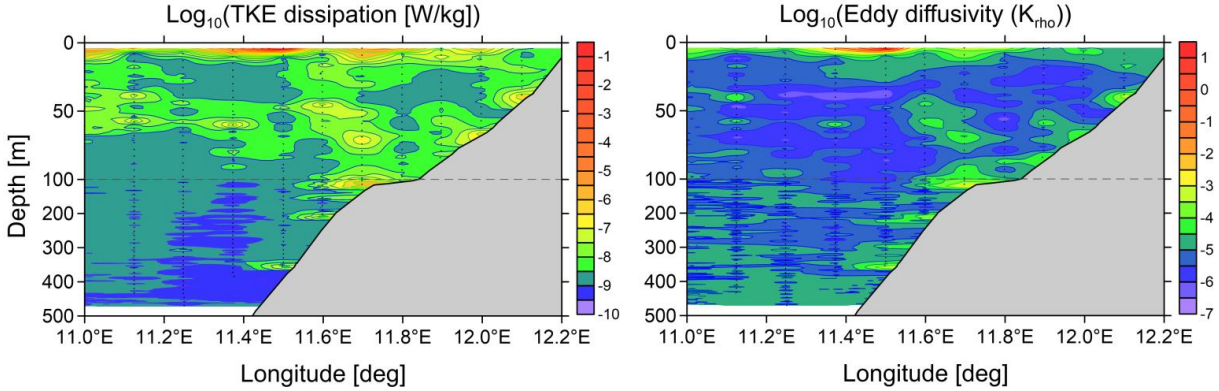

Fig. 2.: Dissipation rate of turbulent kinetic energy (left panel) and turbulent eddy diffusivities (in m^2s^{-1}, right panel) along the 6°S section. Elevated turbulence is found near the sea surface and near the ocean floor.

During the upcoming week, we will complete the 18°S section (Fig. 1) and work along a similar meridional section along 20°S. Both of these sections are surveyed on a regular basis by our Namibian colleagues and partners within EU-PREFACE project from the National Marine Information and Research Center (NatMIRC) in Swakopmund, Namibia.

Best regards from the tropical South Atlantic
Marcus Dengler and the participants of the M120 cruise

M120, Recife – Walvis Bay

October 17th to November 18th 2015

5th Weekly Report, November 15th, 2015

Two day ago we reached our final working area at 23°S. Due to strong winds reaching 8 Beaufort and swell of more than 3.5m we had to postpone our mooring operations and the deployment of a glider. Currently, we are working on a hydrographic section along 23°S. During the past week we additionally completed our mooring activities and section work at 18°S and 20°S. All moorings were successfully recovered and redeployed. We are also happy to report that all instruments functioned well.

Current measurements from the Namibian Shelf

In the framework of the projects BMBF-SACUS and EU-PREFACE, we use bottom shields and moorings equipped current profilers on the Namibian shelf to observe the variability of the circulation, with a particular focus on the southward propagation of coastally trapped waves. These observatories were deployed and serviced in cooperation with our Namibian colleagues from National Marine Information and Research Center in Swakopmund in September 2014 and January 2015 using the Namibian Research Vessel MIRABILIS. The data sets of the instruments we recovered show elevated variability in the alongshore flow component having periods between one and two weeks superposed on weaker variability having longer time scales (Fig. 1). The shorter period variability can be interpreted in terms of coastal trapped waves that propagate southward along the coast. Between 18°S and 20°S a

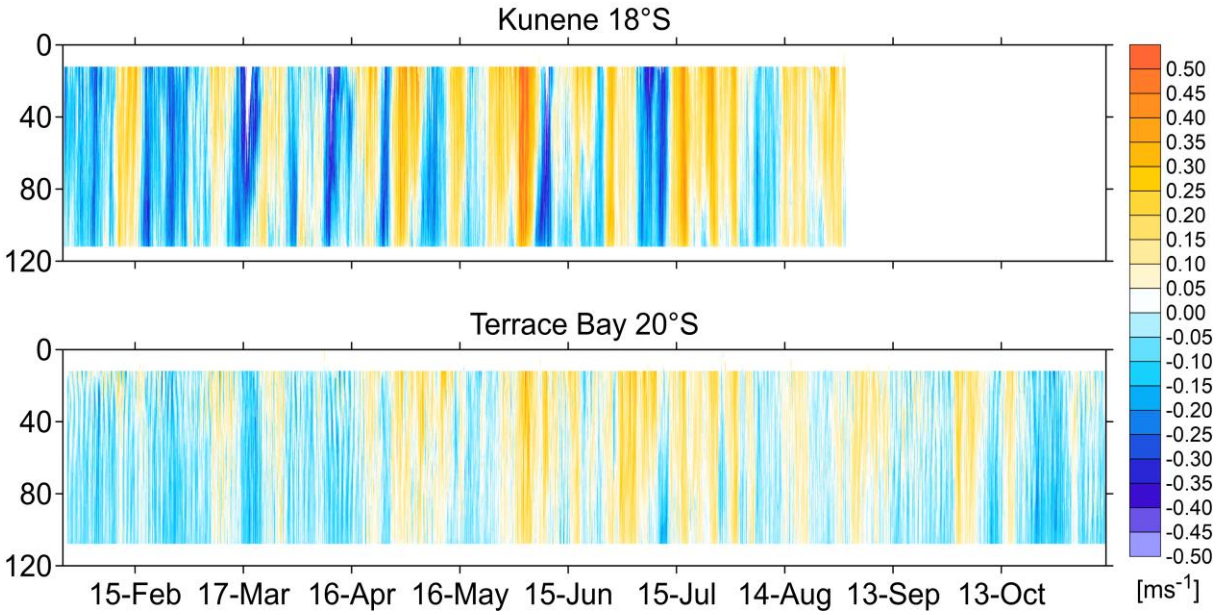

Fig. 1: Time series of alongshore flow on the shelf at 18°N and 20°N from end of January to November 2015. Both time series we collected by acoustic Doppler current profilers mounted in bottom shields and deployed at 125m depth.

weakening of their amplitudes can be observed (Fig. 1). This may be due to the Walvis Ridge that connects to the African coast just south of 18°S.

Trace gases in the surface waters

The chemists have continued their underway measurement program using their mobile equilibrator system. To date, they were able to record 25000 data points of trace gas concentrations measured every minute. Additionally, they performed 62 independent measurements of atmospheric trace gas concentrations. Most fascinating are the near-coastal concentration of the "big three" traces gases, namely carbon dioxide, methane and nitrous oxide (Fig. 2). On the shelf near Walvis Bay at 23°S, methane concentrations as high as 200 nmol/L were measured in the near surface waters. These concentrations are two orders of magnitude larger than the equilibrium concentration of sea water with the atmosphere that are between 2 nmol/L and 3 nmol/L. In the ocean, methane is produced during the degradation process of organic material in anoxic conditions only. We observed these anoxic conditions in the near-bottom waters on the shelf. As methane is oxidized as soon as oxygen is present in the water column, fast vertical exchange processes are required to sustain the high concentrations in the ocean surface layer.

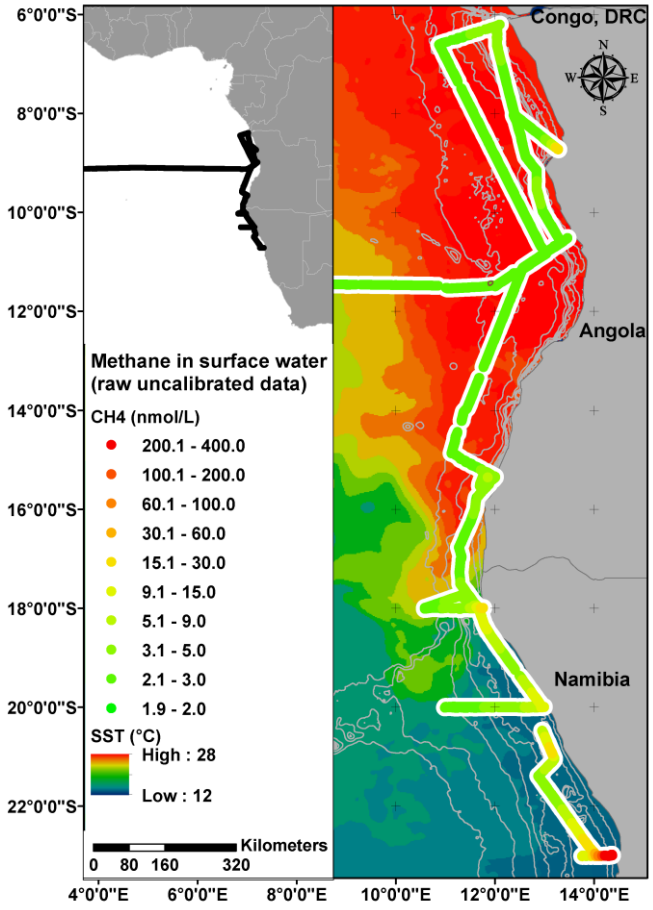

Fig. 2: Near-surface concentrations of methane (circles) measured during M120 and sea surface temperatures from satellite retrievals (contours).

Imaging of fishes in the deep sea multi-beam echo sounder

A major objective of the PREFACE project is to improve understanding of the effects of climate variability and change on fisheries in the eastern boundary upwelling regions of the tropical Atlantic. To investigate the impact of physical parameters such as currents and temperature on the habitat of fish, we analysed the water column backscatter of R/V METEOR's deep sea multi-beam echo sounder. To date, standard data processing techniques for evaluating fish stock from this instrument have not been developed. Marek Ostrowski from the Institute of Marine Research in Bergen devoted a large part of his time on board processing and interpreting the water column data set. A particular interesting behaviour of mesopelagic fish stock was observed off Angola along 11°S (Fig. 3). There, shoals of fish were preferentially found in regions of low alongshore flow.

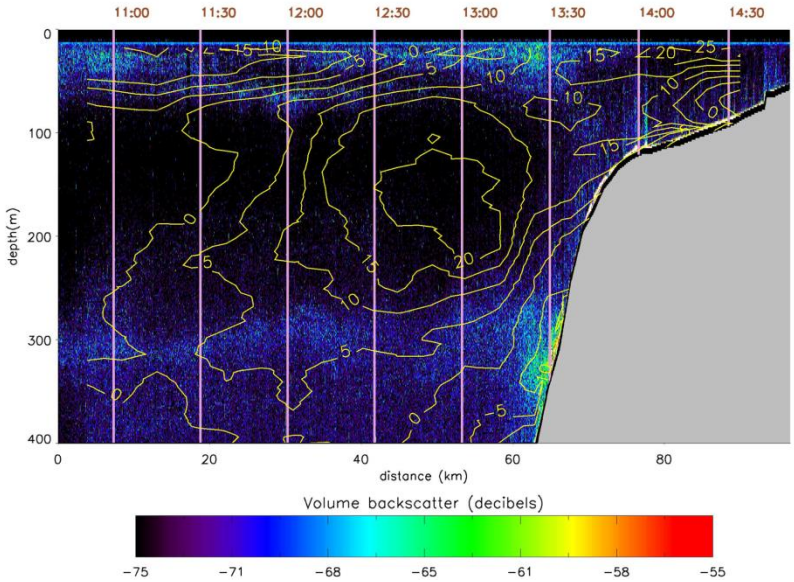

Fig. 3: Strength of volume backscatter signal of the deep water multi-beam echo sounder (EM122) in decibel (color). Elevated values indicate fish stock. Superposed is the alongshore flow from the shipboard ADCP (in cm/s) collected simultaneously (yellow contours)

As predicted by our board meteorologist Carola Heitmann-Bacza from the German Weather Service, the southeast trade wind has significantly weakened in the last hours and we expect to carry out the postpone mooring and glider operations tomorrow. Additionally, we will complete the 23°S section within the remaining two day which completes our measurement program. We thank Captain Hammacher and his crew for the excellent collaboration and the pleasant atmosphere during the cruise.

Best regards from the tropical South Atlantic
Marcus Dengler and the participants of the M120 cruise