METEOR-Berichte

Sonderforschungsbereich 754
'Climate-Biogeochemistry Interactions in the Tropical Ocean':

Organic matter fluxes and biogeochemical processes in the OMZ off Peru

Cruise No. M138

01 June – 03 July 2017

Callao (Peru) – Bahia Las Minas (Panama)

H. Bange, D. Arévalo-Martínez, A. Baker, L. Bristow, K. Burmeister, C. Cisternas-Novoa, M. Fischer, T. Fischer, C. Frey, M. Gledhill, H. Hauss, H.-J. Hoving, C. Karthäuser, J. Meyer, F. Le Moigne, S. Lennartz, C. Löscher, M. Lohmann, M. Maßmig, K. Nachtigall, A. Paul, B. Quack, C. Rohleder, F. Schütte, M. Sun, P. Tuchen, and R. Xie

Chief Scientist: Hermann W. Bange

Institution: GEOMAR, Kiel, Germany

2017

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1 Summary / Zusammenfassung

1.1 Summary

The oxygen minimum zone (OMZ) in the eastern tropical South Pacific Ocean is tightly connected to the coastal upwelling system off Peru. The high biological productivity off Peru is therefore, driven by the complex interplay between the amount of nutrients recycled by remineralisation processes in the OMZ and the upwelling which brings these nutrients to the surface layer. However, surprisingly little is known about organic matter cycling and its effects on biogeochemical processes in the OMZ off Peru. To this end we conducted a first comprehensive study on the role of organic matter for the biogeochemical processes and the maintenance of the OMZ off Peru. M138 combined measurements of marine biogeochemistry, microbiology, physical oceanography and air chemistry with foci on (i) the efficiency of the biological pump, (ii) the nitrogen cycle processes in the OMZ, (iii) the ventilation of the OMZ as well as (iv) the air/sea gas exchange across the ocean/atmosphere interface and (v) aerosol deposition. The METEOR cruise M138 was performed as part of the third phase of the SFB754 'Climate-Biogeochemistry Interactions in the Tropical Ocean' (www.sfb754.de).

1.2 Zusammenfassung

Die Sauerstoffminimumzone (SMZ) im tropischen Südostpazifik ist eng mit dem Küstenauftrieb vor Peru verknüpft. Die hohe biologische Produktivität vor Peru wird deshalb durch das komplexe Zusammenspiel von dem Ausmaß der Remineralisierung von Nährstoffen in der SMZ und dem Auftrieb, der diese Nährstoffe in die Oberflächenschicht bringt, getrieben. Jedoch ist überraschend wenig über die Rolle des Umsatzes (i.e. Remineralisierung) von organischem Material und dessen Einfluss auf die biogeochemischen Prozesse und Aufrechterhaltung der SMZ vor Peru bekannt. Für M138 haben wir Messungen von Biogeochemie, Mikrobiologie, phys. Ozeanographie und Luftchemie miteinander verknüpft. Besondere Schwerpunkte lagen dabei auf der Untersuchung der Effizienz der biologischen Pumpe, des Stickstoffkreislaufes in der SMZ, der Ventilation der SMZ sowie dem Austausch von Spurengasen über die Ozean/Atmosphäre-Grenzschicht und der Aerosoldeposition. Die METEOR-Fahrt M138 ist Teil der dritten Phase des Sonderforschungsbereiches 754 'Wechselwirkungen von Klima und Biogeochemie im tropischen Ozean' (www.sfb754.de).

2 Participants

1	Arévalo-Martínez, Dr.	Damian	Chem. Oceanogr.	Scientist	GEOMAR
2	Bange, Prof. Dr.	Hermann	Chem. Oceanogr.	Chief scientist	GEOMAR
3	Bristow, Dr.	Laura	Microbiology	Scientist	MPI
4	Burmeister	Kristin	CTD	PhD student	GEOMAR
5	Cisternas-Novoa, Dr.	Carolina	Biol. Oceanogrpahy	Scientist	GEOMAR
6	Eck	Lucas	Nutrients, O2	Student Helper	GEOMAR
7	Fischer	Martin	Microbiology	PhD student	Univ. Kiel
8	Fischer, Dr.	Tim	CTD	Scientist	GEOMAR
9	Frey, Dr.	Claudia	Microbiology	Scientist	Princeton Univ.
10	Gledhill, Dr.	Martha	Chem. Oceanogr.	Scientist	GEOMAR
11	Hauss, Dr.	Helena	Biol. Oceanogr.	Scientist	GEOMAR
12	Hoving, Dr.	Henk-Jan	Biol Ocenaogr.	Scientist	GEOMAR
13	Karthäuser	Clarissa	Microbiology	PhD Student	MPI
14	Laursen	Erik	Microbiology	Technician	SDU
15	Le Moigne, Dr.	Frederic	Biol. Oceanogr.	Scientist	GEOMAR
16	Lennartz	Sinikka	Nutrients, O2	PhD student	GEOMAR
17	Lohmann	Martina	Nutrients, O2	Technician	GEOMAR
18	Löscher, Dr.	Carolin	Microbiology	Scientist	SDU
19	Martens	Wiebke	CTD	Technician	GEOMAR
20	Maßmig	Marie	Biol. Oceanogr.	PhD Student	GEOMAR
21	Meyer, Dr.	Judith	Biol. Oceanogr.	Scientist	GEOMAR
22	Nachtigall	Kerstin	Nutrients, O2	Technician	GEOMAR
23	Niemeyer	Daniela	Biol. Oceanogr.	PhD student	GEOMAR
24	Paul, Dr.	Allanah	Biol. Oceanogr.	Scientist	GEOMAR
25	Schütte, Dr.	Florian	CTD, glider	Scientist	GEOMAR
26	Sun	Mingshuang	Chem. Oceanogr.	PhD Student	GEOMAR
27	Tuchen	Philipp	CTD	PhD Student	GEOMAR
28	Witt	René	CTD, moorings	Technician	GEOMAR
29	Xie, Dr.	Ruifang	Chem. Oceanogr.	Scientist	GEOMAR

GEOMAR – GEOMAR Helmholtz Institute for Ocean Research, Kiel, Germany
MPI – Max Planck Institute for Marine Microbiology, Bremen, Germany
SDU – University of Southern Denmark, Odense, Denmark
Univ. Kiel – University of Kiel, Kiel, Gerrnany
Princeton Univ. – Princeton University, Princeton, NJ, USA

Group photo of the participants with devices typical for their work during M138

Standing in the back row (from left to right): Henk-Jan Hoving, Judith Meyer, Daniela Niemeyer, Carolin Löscher, Helena Hauss, Damian Arévalo Martínez, Carolina Cisternas Novoa, Allanah Paul, Laura Bristow, Wiebke Martens, Martin Fischer, Kerstin Nachtigall, Lucas Eck, Martha Gledhill, Martina Lohmann, Philipp Tuchen, Kristin Burmeister, Rene Witt and Hermann Bange. *Front row (from left to right)*: Marie Maßmig, Claudia Frey, Clarissa Karthäuser, Frederic LeMoigne, Sinikka Lennartz, Ruifang Xie, Florian Schütte, Mingshuang Sun and Tim Fischer.

Email addresses (as of 18 February 2019)

1	Arévalo-Martínez, Dr.	Damian	darevalo@geomar.de
2	Bange, Prof. Dr.	Hermann	hbange@geomar.de
3	Bristow, Dr.	Laura	lbristow@biology.sdu.dk
4	Burmeister	Kristin	kburmeister@geomar.de
5	Cisternas-Novoa, Dr.	Carolina	ccisternas@geomar.de
6	Eck	Lucas	lucas.eck@gmx.de
7	Fischer	Martin	mfischer@ifam.uni-kiel.de
8	Fischer, Dr.	Tim	tfischer@geomar.de
9	Frey, Dr.	Claudia	claudia.frey@unibas.ch
10	Gledhill, Dr.	Martha	mgledhill@geomar.de
11	Hauss, Dr.	Helena	hhauss@geomar.de
12	Hoving, Dr.	Henk-Jan	hhoving@geomar.de
13	Karthäuser	Clarissa	ckarthae@mpi-bremen.de
14	Laursen	Erik	eriklaursen@biology.sdu.dk
15	Le Moigne, Dr.	Frederic	frederic.lemoigne@mio.osupytheas.fr
16	Lennartz	Sinikka	sinikka.lennartz@uol.de
17	Lohmann	Martina	martina.lohmann@gmx.net
18	Löscher, Dr.	Carolin	cloescher@biology.sdu.dk
19	Martens	Wiebke	wmartens@geomar.de
20	Maßmig	Marie	massmig@bafg.de
21	Meyer, Dr.	Judith	jumeyer@geomar.de
22	Nachtigall	Kerstin	knachtigall@geomar.de
23	Niemeyer	Daniela	dniemeyer@geomar.de
24	Paul, Dr.	Allanah	apaul@geomar.de
25	Schütte, Dr.	Florian	fschuette@geomar.de
26	Sun	Mingshuang	misun@geomar.de
27	Tuchen	Franz Philipp	ftuchen@geomar.de
28	Witt	René	rwitt@geomar.de
29	Xie, Dr.	Ruifang	rxie@geomar.de

3 Research Program

3.1 Objectives

The overall objective of M138 was
to conduct a comprehensive biogeochemical study on the role of organic matter for the biogeochemical processes and the maintenance of the oxygen minimum zone off Peru.

To this end we undertook a measurement campaign that covered the major aspects of organic matter cycling and its links to major nitrogen and carbon cycle processes in the water column off Peru. The specific goals of M138 were:

- to assess the distribution of particles and organic matter in the OMZ off Peru,
- to quantify particle/organic matter fluxes through the OMZ and decipher the role of zooplankton therein,
- to decipher the role of particles/organic matter availability for N_2 fixation, N loss, N_2O formation, microbiological diversity and activity,
- to assess the role of anoxia on particle remineralization rates and elemental stoichiometry, and
- to investigate the variability of the hydrodynamical forcing relevant for nutrient turnover.

3.2 Overview of the Research Program

The OMZ off Peru is one of the areas, where the effect of future deoxygenation is predicted to be most intense. Previous studies the SFB754 in the waters off Peru suggested a co-occurrence of oxic and anoxic biogeochemical key processes in the OMZ, which directly raised the question about the ecological niche enabling this. Moreover, the particular importance of particle abundances was further suggested by model studies which showed that particle-associated processes may regulate the OMZ's biogeochemistry (including N cycle processes) in the Peruvian OMZ. Thus, several sub-projects of the SFB754 were involved in M138 in order to decipher and assess the importance of particles and organic matter dynamics for the biogeochemistry of the Peruvian OMZ. The results of M138, together with the results from the SFB754 cruises M135-M137 will shed light onto fundamental questions regarding particle-related nutrient budgets, processes and O_2 dynamics. The list of major work packages (WP) of M138 is given below. For the details of the measurements during M138 see Section 5 - Preliminary Results.

- WP01 – N compounds, dissolved trace gases, N_2O production
  PIs: H. Bange, GEOMAR; C. Frey, B. Ward, Princeton Univ.
- WP02 – Viral lysis
  PI: R. Schmitz-Streit, CAU Kiel
- WP03 – N cycle processes
  PIs: G. Lavik and M. Kuypers, MPI Bremen
- WP04 – N_2 fixation
  PI: U. Riebesell, GEOMAR

- WP05 – Physical oceanography
  PI: M. Dengler, GEOMAR
- WP06 – Bacterial activity and DOC
  PI: A. Engel, GEOMAR
- WP07 – Zooplankton, particle flux
  PI: R. Kiko, GEOMAR
- WP08 – Export fluxes and composition of sinking particles
  PI: A. Engel, GEOMAR
- WP09 – Trace metals, Th export flux and organic nutrients
  PIs: M. Gledhill and E. Achterberg, GEOMAR
- WP10 – Water column geobiology
  PI: C. Löscher, SDU, Odense, Denmark
- WP11 – Halocarbons and aerosols
  PIs: B. Quack, GEOMAR; A. Baker, Univ. East Anglia, Norwich, UK

3.3 Modification of the Original Proposal

The following points have been modified from the original proposal:

- Caused by the move of the co-proponent Dr. C. Löscher from CAU Kiel to University of Southern Denmark (SDU in Odense) we added the new WP10 'Water Column Geobiology' to address the new research topic of Dr. Löscher.
- Dr. Claudia Frey from the group of Prof. Bess Ward at Princeton University joined WP01. To this end the topic N_2O production was added to WP01.
- WP02 was modified to focus on the importance of viral lysis on bacterial communities and particle dynamics in OMZ.
- Complementary atmospheric halocarbon (i.e. canister sampling) and aerosol (filter) sampling was added as a new WP11. Sampling during the cruise was done by H. Bange. Trace gas and aerosol measurements will be performed in cooperation with B. Quack, GEOMAR, and Alex Baker, Univ. East Anglia, Norwich, UK.
- The Equatorial transect from 4°S 86°W to 2°N 86°Wwas added as an extension of the original cruise track. Therefore, the port of call at the end of the cruise was changed from Callao (Peru) to Bahia las Minas (Panama).
- The berths reserved for observers were not requested by the Peruvian Authorities. Therefore, these berths were given to colleagues from the SFB754.
- During the cruise we noted a meso-scale eddy structure which was about to detach from the coast at around 15°S. In order to investigate the hydrographic and biogeochemical settings of an emerging eddy the original cruise track was modified to allow a high-resolution survey of the eddy structure.

3.4 Measures to Conduct a Responsible Marine Research

We strictly followed the DFG regulations summarized in the *„Erklärung zu einer verantwortungsvollen Meeresforschung“* and the OSPAR Code „Code of Conduct for Responsible Marine Research in the Deep Seas and High Seas of the OSPAR Maritime Area” to avoid unnecessary environmental and ecosystem disturbances.

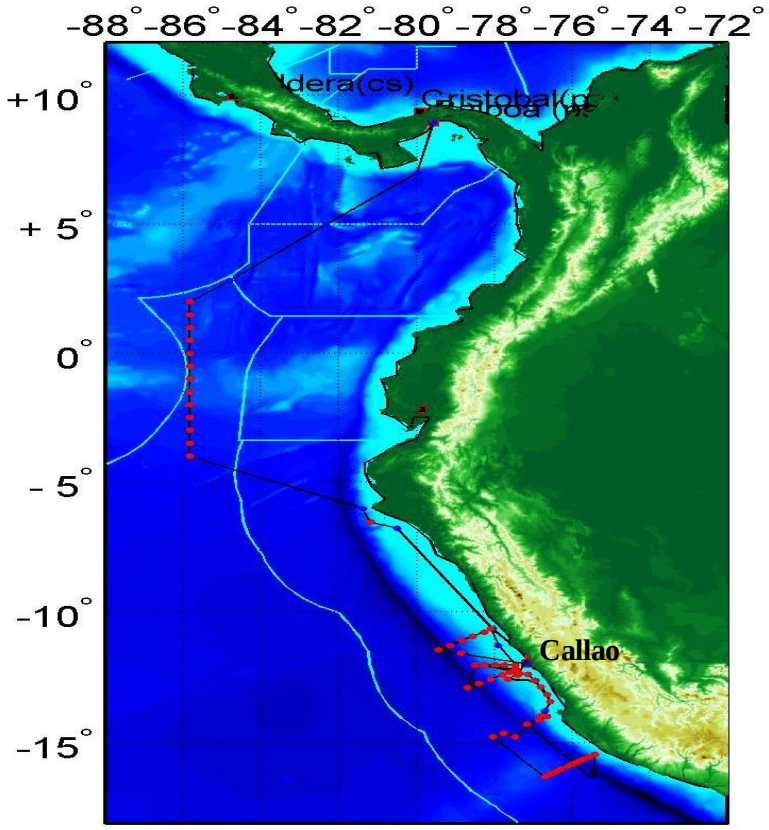
4 Narrative of the Cruise

4.1 Narrative

The scientific team of M138 (29 scientists from GEOMAR Kiel, Univ. Kiel, MPI Bremen, SDU Odense, DK, and Princeton Univ., USA) embarked on Meteor on 31 May 2017. Unfortunately, customs clearance of both the outgoing containers from M137 and the containers for M138 was delayed considerably. To this end, R/V Meteor left the port of Callao with a delay of about 10 hours on 01 June at 18:00h (LT). R/V Meteor headed northwest for a test station at 11°36’S 78°53’W on 2 June 14.00h (LT). This was followed by the Transect A towards the coast from 11°28’S 79°26’W to 10°40’S 78°5’W which consisted of four regular CTD/RO stations (#879 - #882) and two 24h stations (#883 and #884). At station #882 we deployed a first drifting sediment trap array (which was unfortunately caught by fishermen after two days. The buoy of the trap was brought to Ancon by the fishermen). Transect A was followed by a transit to the south along the coast. Transect B (i.e., the so-called IMARPE transect along 12°S from 77°28’W to 78°30’W) consisting of CTD/RO stations #885 - #888 was started on 08 June. At station #888 we also deployed a second drifting sediment trap array. Transect B was followed by a transit to Transect C. This transect (from 12°55’S 78°42’W to 12°13’S to 77°26’W) consisted of four regular CTD/RO stations (#889 - #891, #894) and two 24h stations (#892 and #897). At station #893 we recovered Glider IFM07. At station #895 and #896 we recovered Glider IFM09 and mooring KPO1180, respectively. From station #897 we went northwest to station #898 to recover the second drifting sediment trap array at 12°3’S 78°17’W on 13 June. The regular CTD/RO stations #899 to #903 formed Transect D on the shelf parallel to the coast south of Callao/Lima (14/15 June). This was followed by Transect E (#904 - #906, from 14°S 76°40’W to 14°17’S 77°10’W). Stations #904 and #906 were 24h stations. At station #906 we deployed a third drifting sediment trap array. From #906 we performed an ADCP transect to survey a mesoscale eddy structure (18/19 June). This was followed by the Transect F (‘eddy transect’, stations #907 - #916; from 15°26’S 75°26’W to 16°15’S 76°43’W). Stations #907 and #912 were 24h stations. This was followed by a transit to stations #917 and #918 which complement Transect E. At station #919 (on 23 June) we recovered the third drifting sediment trap array. The mooring KPO1183 was recovered at station #920 on 23 June). This was followed by a northward transit along coast. The moorings KPO1182 and KPO1183 were recovered at stations #921 (24 June) and #922 respectively (24 June). From station #922 we went to the Bay of Ancon to pick up the lost buoy of the first drifting sediment array. The last station off Peru was #923 (CTD calibration station) which was performed on 26 June during the northward transit to the Equator transect. Regular CTD/RO stations #924 - #936 formed the Equator transect from 4°S to 2°N along 85°50’W. The Equator transect was finished on 30 June and was followed by the transit to Balboa. We arrived in Balboa in the morning of 03 July. The passage through the Panama Canal

started on 03 July at 20:00h (LT). We arrived in the Port of Bahia Las Minas in the morning of 04 July. The scientific team of M138 disembarked from Meteor on 05 July 2017 at 12:00h (LT).

4.2 Cruise track



Filled red circles indicate locations of sampling stations. Filled blue circles indicate waypoints without sampling; white lines indicate EEZs.

5 Preliminary Results

5.1 Physical Oceanography

(K. Burmeister, T. Fischer, W. Martens, F. Schütte, F.P. Tuchen, R. Witt, P. Brandt, M. Dengler)

5.1.1 CTD and O_2 measurements and calibration

(T. Fischer)

During M138 117 profiles of pressure (p), temperature (T), conductivity (c) and oxygen (O_2) were recorded. In the Peruvian upwelling regime, the CTD-O_2 profiles ranged to 2000m or to the bottom, along the equator transect they ranged to 1000m. When additional sample water was needed, additional CTD casts at the same place were conducted which usually ranged to 500m. We used a Seabird Electronics (SBE) 9plus system, attached to the water sampler carousel, and the latest Seabird Seasave software. The SBE underwater unit had two sensor sets: p #1162, T1 #4051, c1 #2512, $O_2$1 #2669, T2 #2120, c2 #3374, $O_2$2 #992. The two sensor sets worked properly during the entire cruise. The secondary sensor set was chosen for report, for being slightly less noisy. Conductivity was calibrated using a linear relation in p, T and c. This relation was obtained by fitting the according CTD salinity to 200 water samples, which were analyzed with a Guildline Autosal salinometer. Rms salinity misfit was 0.0013 after removal of 33% of bottle values. Oxygen was calibrated using a relation linear in T and O_2, and quadratic in p. Winkler titration of 400 bottle samples led to a relation with an rms misfit of 1 µmol/kg (33% of bottle values removed). Further sensors were attached to the carousel and recorded, but were not calibrated: a fluorescence and turbidity sensor (Wetlabs), and a Photosynthetically Active Radiation (PAR) sensor (Biospherical).

Preliminary results and outlook

Among others one CTD section was done to investigate an interesting mesoscale variability feature west of the Peruvian coast. The anticyclonic eddy was detected with the help of satellite data. It was generated near shelf break of the Pervian coast, most likely due to instabilities of the boundary undercurrent. The anticyclonic rotation could also be seen in a VmADCP section crossing the eddy from northwest to southeast, which was first done to locate the eddy center. In the following CTD section the different water mass properties of the eddy are visible (Fig. 5.1).

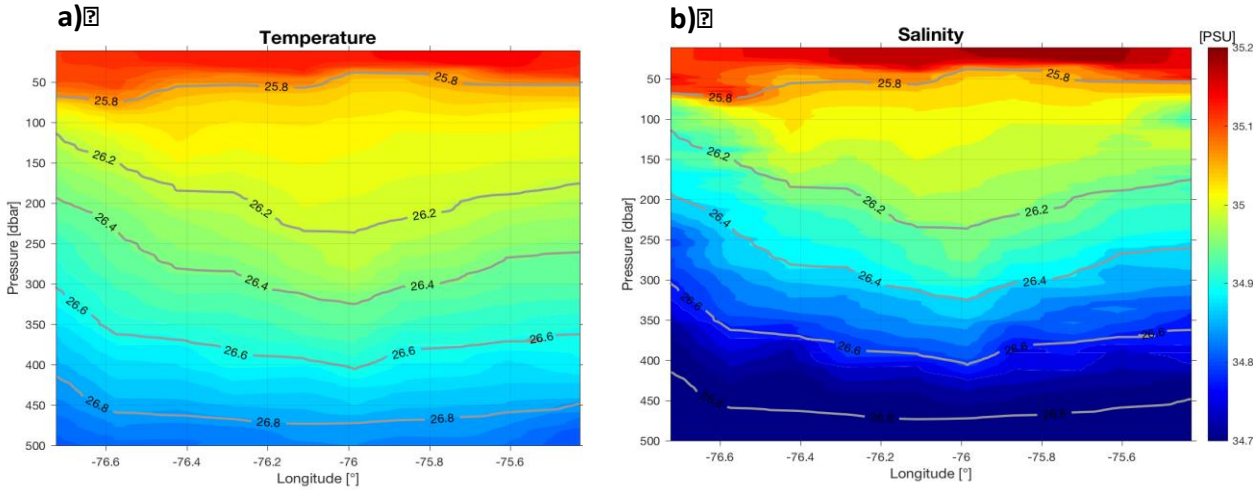


Fig. 5.1: CTD section of **a)** temperature and **b)** salinity from 0 to 500m depth during the eddy crossing.

5.1.2 Shipboard microstructure measurements

(T. Fischer)

A MSS90-D microstructure profiler (#073) of Sea and Sun Technology was used to infer turbulent dissipation rate and diapycnal diffusivity, aiming at calculating diapycnal fluxes of several solutes including oxygen and nitrous oxide (N_2O). The loosely tethered profiler was equipped with 3 airfoil shear sensors and a fast thermistor, as well as with a pressure, a conductivity, and a temperature sensor. Profiler sink velocity was adjusted to 0.6 m/s. In total 118 profiles to usually 200m depth were recorded at 37 ship stations, generally 3 microstructure profiles following a CTD cast. The system worked well throughout the cruise and there were no technical issues beyond maintenance.

5.1.3 Glider operations

(F. Schütte)

During M138 two autonomous glider systems (IFM07 and IFM09) manufactured by Teledyne Webb Research were recovered. Both gliders were encompassed with a set of build-in sensors; a CTD, an Aanderaa optode to measure dissolved oxygen and a Wetlabs combined Chl-a fluorescence and turbidity sensor. Additional IFM09 was also equipped with a Rockland-Scientific-Microrider (MR 90). A Microrider is a microstructure profiler to infer turbulent dissipation rate and diapycnal diffusivity, the particularly aiming in this case was to quantifying the diapycnal flux of oxygen from the shelf in the OMZ. Two very fast temperature sensors were installed as well as two shear sensors. The recovery of IFM07 (IFM09) was done at 12° 32S 77°54W (12° 25S 77° 25W) on the 10^{th} (11^{th}) June. On both days the weather was cloudy with restricted visibility but only slightly disturbed by wind wave. The night before the recoveries the gliders where commanded to stop deep diving and to start shallow (100m) dives. 15 minutes before the recoveries both gliders were drifting on the surface. Both gliders were regularly sending its position and as such the recoveries worked out without any problem. Both Glider were only partly covered by biofouling, so good data is expected. The gliders were cleaned, opened and the memory cards (system & data) were removed, backed up and saved.

5.1.4 Vessel-mounted ADCP

(K. Burmeister)

Underway-current measurements were performed continuously throughout the entire cruise using two vessel mounted ADCPs (VMADCPs): a 75kHz RDI Ocean Surveyor (OS75) mounted in the ship's hull, and a 38kHz RDI Ocean Surveyor (OS38) placed in the moon pool. The OS38 was aligned to zero degrees (relative to the ship's center line) in order to reduce interference with the OS75, which was aligned to 45 degrees. The OS75 worked well throughout the cruise. Two configurations set up were used depending on the water depth. For a water depth deeper than 300m, the OS75 was configured with 100 bins of 8 m, pinging 25 times per minute. To ensure a data range up to 600 m, it was run in the less precise but more robust narrowband mode. In shallower water depth (<300 m), the configuration was set to 128 bins of 4 m, pinging 37.5 times per minute and the more precise but less robust broadband mode was used. The OS38 worked

well until June 16, 2017. As for the OS75, two configurations set ups were used depending on the water depth. For a water depth deeper than 300m, it was set up to 55 bins of 32 m, pinging 17 times per minute, with a range up to 1500 m. For a water depth shallower than 300m, the configuration was set to 80 bins of 16 m. The instrument ran in narrowband mode, as the broadband mode did not work. This was probably related to the problems that occurred after June 16, 2017. From June 16 to 17 the maximum depth range decreased to 1000 m and data gaps of 1/2 to 6 hours occurred before the OS38 broke down completely. After a thorough check of the OS38 the Meteor technicians found the error to be a short circuit in the watertight sealed main connector. Unfortunately this could not be repaired on board. During the entire cruise, the SEAPATH navigation data was of high quality. Post processing of the data was carried out separately for each instrument. Accounting for a time shift of the heading and position data recorded by the SEAPATH device relative to the raw OS data allowed for a significant reduction in the scatter of the calibration angles and amplitude factors.

Preliminary results and outlook

Several VMADCP transects perpendicular to the coast and one transect along the coast of Peru as well as two traditional transects in the Pacific, one along 12°S (IMARPE section) and one across the equator along 85°50'W were done. A first view on the preliminary processed VMADCP data of the transects of the coast of Peru shows on average the southward flowing peruvian undercurrent (see Fig. 5.2) which is modulated by mesoscale variability (in terms of velocities and directions) (see Fig. 5.2). The ADCP data will be further processed and analyzed ashore. In addition backscatter data will be used to identify zooplankton dial vertical migration patterns of the coast of Peru, complementary to Multinet, UVP and PELAGIOS data that were collected during this cruise.

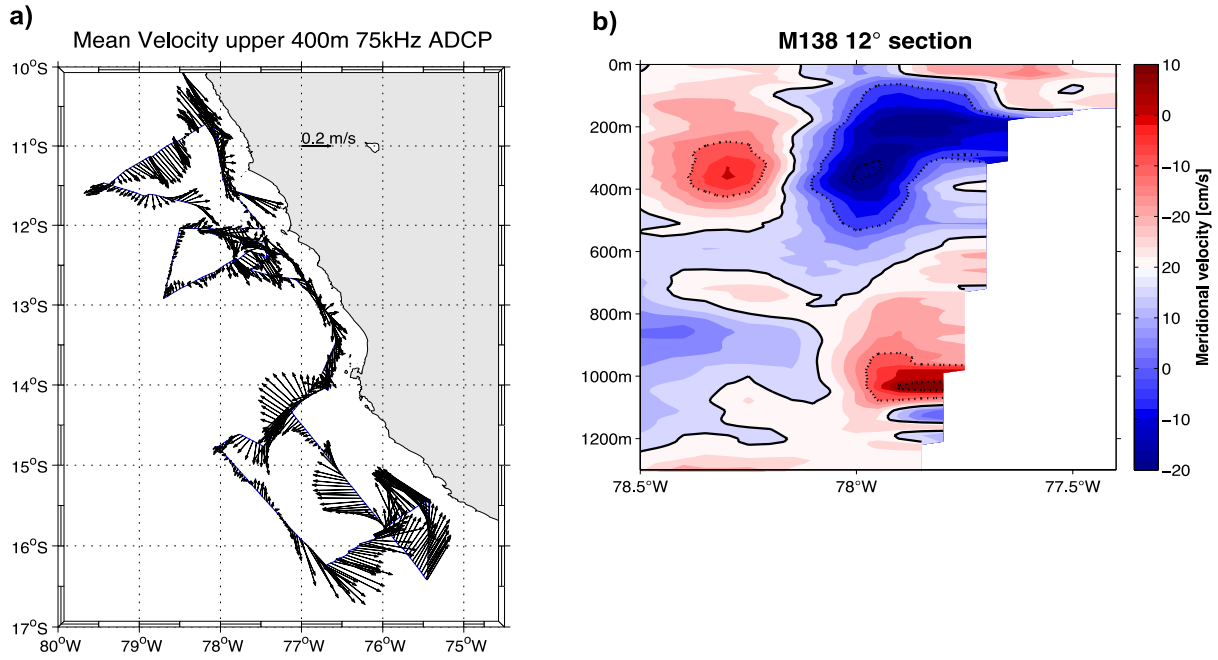


Fig. 5.2: a) Alongtrack velocities of the upper 400 m off the coast of Peru measured by OS75 during M138. b) Meridional velocities along the IMARPE (12°S) section measured by OS75 and OS38 from June 7-8, 2017. Red colours indicate northward velocities, blue colours indicate southward velocities. The southward flowing poleward directed boundary undercurrent is clearly visible in the upper 500m next to the shelf.

5.1.5 Underway RapidCast and UCTD measurements and calibration

(F. Schütte)

Additional to the CTD profiles a total of around 400 underway conductivity-temperature-depth (uCTD) profiles were taken during transits to increase the resolution and to observe near surface ocean variability of smaller time and spatial scales. The probes were lowered from the stern moving at speeds between 6 and 12kn from two different winch systems during the cruise. From the beginning of the cruise until the 12th June the underway RapidCast system was installed and allows continues and more less autonomous sampling in a yo-yo mode which results in a profile every 1-5 min for a depth of 30 to 125 m. Unfortunately on the 12th June technical problems with the RapidCast system appear. From profile to profile it became harder unwinding the whinch freely. We had to interrupt the measurements, because it was no longer possible to reach depths beyond 30m. A first diagnose shows that the motor of the winch has problems with its bearings. From the 13th of June to the end of the cruise the uCTD system was installed on the starboard stern instead. These winch systems worked well until the end of the cruise. By operations with waves higher than two meters it was difficult with both systems to recover the probe without hitting the boat, even with the help of a pole. Three probes (s/n 54, 155 and 195) were used and worked well during the whole cruise. All of them are equipped with a temperature, conductivity and pressure sensor from SeaBird and records data with a frequency of 16 Hz. For calibration of the temperature and salinity measurements from the three probes sensors profiles were collected shortly after CTD stations (s/n 54 on CTD cast at ship station 915-3, s/n 155 on CTD cast 104 and s/n 195 on CTD cast 116). Additionally, the probes were attached to the CTD rosette (s/n 54 on CTD cast 103, s/n 155 on CTD cast 103 and s/n 195 on CTD cast 103) to identify possible pressure offsets. Ongoing calibration includes now thermal lag calculation, pressure offsets from CTD/O_2 comparison and temporal sensor drifts determined from nearby CTD/O_2 profiles and surface temperature and salinity measurements from the thermosalinograph.

Preliminary results and outlook

To increase the CTD resolution of the section through the anticyclonic mode water eddy uCTD profiles were conducted during steaming time in between the regular CTD stations. Fig. 5.3 shows the different view on the temperature sections ones conducted with the regular 10 CTD stations (a) and (b) with the additional 45 uCTD profiles in between. Due to the higher resolution small-scale variability and submesoscale processes are can be resolved.

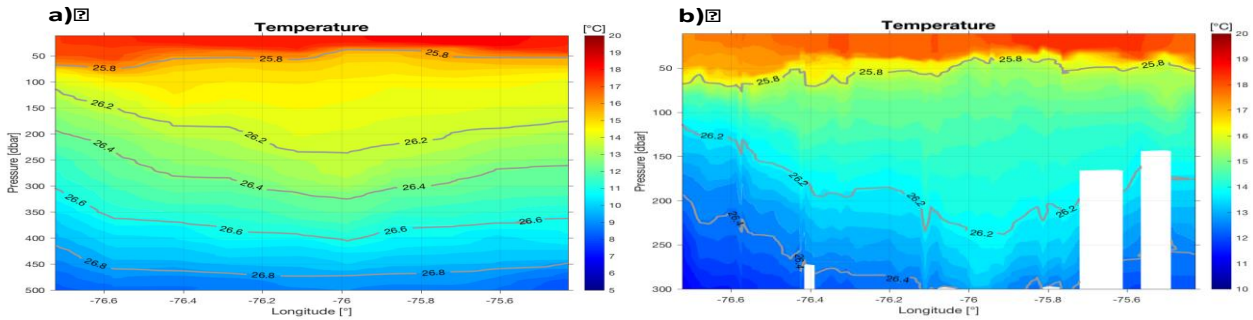


Fig. 5.3: a) Temperature section through the anticyclonic mode water eddy based on 10 CTD profiles and b) the same temperature section with four times higher resolution based on the 10 CTD profiles and the additional 42 uCTD profiles.

5.1.6 Thermosalinograph

(F.P. Tuchen)

Underway measurements of sea surface temperature (SST) and sea surface salinity (SSS) are continuously done by the ship's dual thermosalinograph. One is located at the starboard side (TSG1) while the other thermosalinograph's inlet is at the portside (TSG2). In general, the system worked well throughout the cruise (see Fig. 5.4). During the extent of research cruise M138 a total of 24 water samples (see Tab. 5.1 for details) have been taken from the TSG system in order to measure the salinity of the probe with a Guildline AUTOSAL salinometer (GEOMAR AS7 was used during the cruise). Salinity measurements are used to quantify the offset and the drift of the TSG sensors.

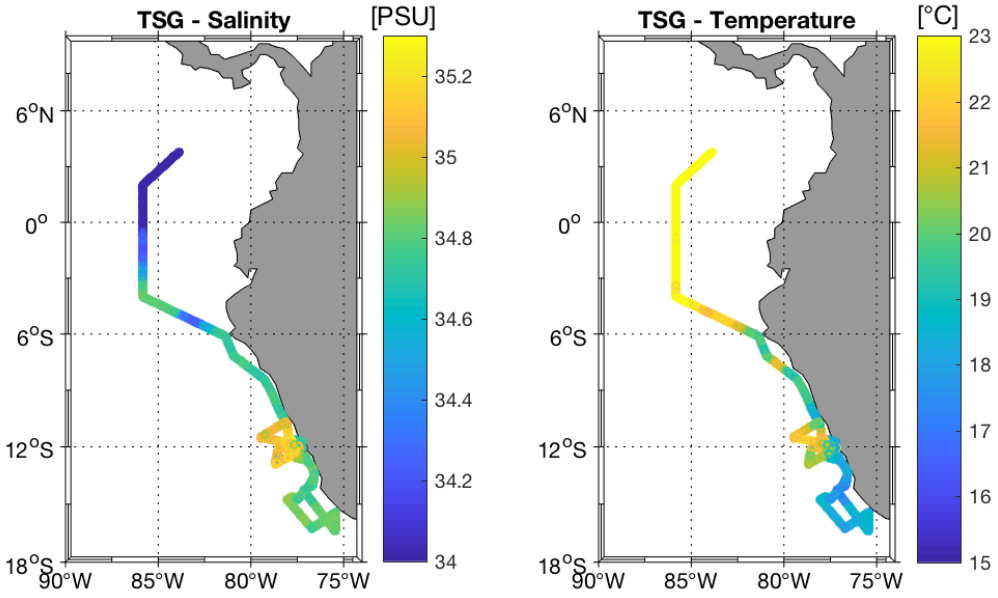


Fig. 5.4: Uncalibrated salinity and temperature measurements from the ship's TSG system until the 30th of June 2017.

The two external temperature sensors, T1sec from TSG1 and T2sec from TSG2, and both conductivity sensors (S1, S2) will be calibrated against the 5dbar values from the CTD/O_2 profiles taken during the cruise. From the salinometer measurements a preliminary mean offset of 0.3461 PSU can be identified from the 24 water samples (see Fig. 5.5). During the cruise a few sudden decreases of salinity occurred, which are associated with the cleaning of the conductivity cells with freshwater.

Tab.5.1: List of samples which have been taken regularly during M138 from the ship's TSG system.

Kiste	Flasche	Datum	Zeit (UTC)	Reise	LAT	LON	Salzgehalt (TSG)	Salzgehalt (Autosal)
36	932	12.06.17	21:26	M138	-12,1920	-77,5427	35,1090	35,4269
36	1374	13.06.17	09:30	M138	-12,0580	-78,2734	35,0842	35,3826
36	311	13.06.17	20:58	M138	-12,2767	-77,5549	34,9525	35,2438
36	1198	14.06.17	09:43	M138	-12,9186	-76,8222	34,7983	35,1037
36	542	15.06.17	12:11	M138	-14,0002	-76,6601	34,7403	35,0773
36	1528	15.06.17	20:48	M138	-14,0000	-76,6600	34,7413	35,0835
36	923	16.06.17	08:58	M138	-14,2124	-77,0344	34,7436	35,0927
36	502	17.06.17	12:15	M138	-14,2848	-77,1670	34,7472	35,0927
36	885	18.06.17	17:00	M138	-15,4380	-75,4639	34,7749	35,1353
36	1093	19.06.17	00:45	M138	-15,4299	-75,4324	34,7813	35,1382
36	469	19.06.17	18:53	M138	-15,5394	-75,6121	34,8364	35,1983
36	1066	20.06.17	11:34	M138	-15,8599	-76,1099	34,8202	35,1831
36	718	20.06.17	21:36	M138	-15,9161	-76,0530	34,8198	35,1815
36	677	21.06.17	15:38	M138	-16,0818	-76,4260	34,8047	35,1647
36	1225	22.06.17	15:22	M138	-15,2028	-77,6480	34,8413	35,2015
36	741	23.06.17	11:17	M138	-14,7669	-77,4821	34,7357	35,0947
36	634	23.06.17	23:37	M138	-13,8141	-76,7290	34,7726	35,1200
36	937	24.06.17	15:47	M138	-12,3644	-77,3639	34,8955	35,2375
36	635	25.06.17	20:15	M138	-8,6470	-79,1510	34,7376	35,1045
36	727	26.06.17	21:37	M138	-6,4663	-81,2304	34,7258	35,0935
36	935	27.06.17	16:57	M138	-4,7458	-84,2672	34,7773	35,1453
36	730	28.06.17	11:10	M138	-3,2569	-85,8333	34,7678	35,1242
36	351	29.06.17	10:06	M138	-0,2160	-85,8333	33,8722	34,2230
36	1079	29.06.17	13:45	M138	0,2721	-85,8328	33,2760	33,6127

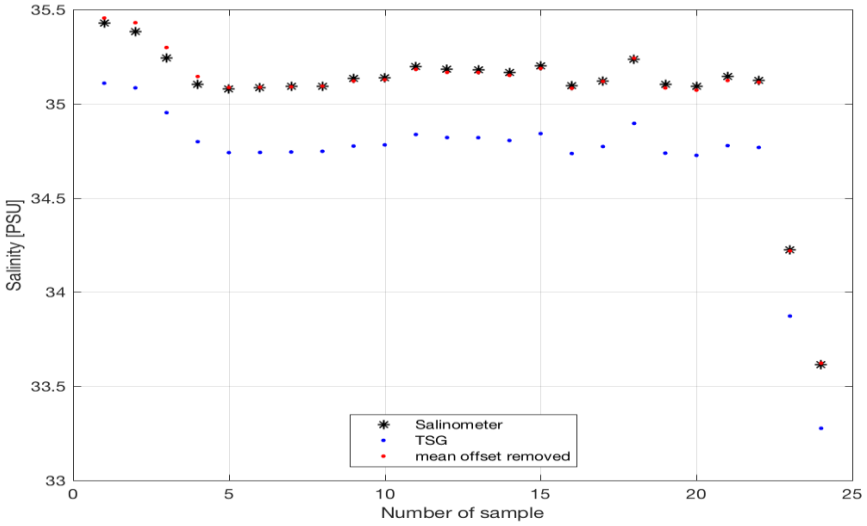


Fig. 5.5: Comparison between salinity measurements from the TSG systemand salinity values from the salinometer measurements.

5.1.7 Mooring operations

(F. Schütte, K. Burmeister)

Fig. 5.6 shows the exact positions of the different moorings recovered during M138.

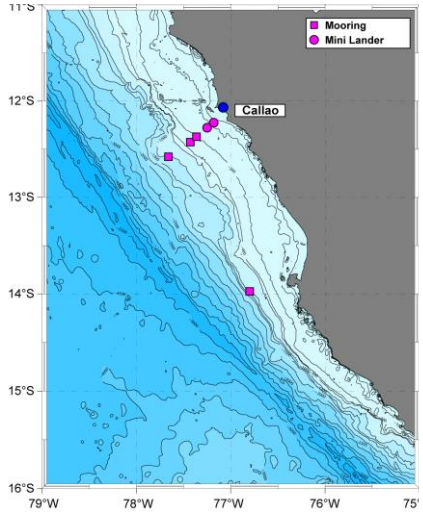


Fig. 5.6

Tab. 5.2 shows the time and position of the mooring deployment and recovery. All moorings were recovered successfully.

Tab. 5.2

Mooring	Date in 2017 / Time (UTC)		Position		Depth
	deployed	recovered	Lat., °S	Long., °W	m
KPO 1180	21 April / 14:20	11 June / 14:22	12° 25.652’	077°25.658’	301
KPO 1181	19 April / 12:38	24 June / 15:45	12° 22.288’	077° 21.779’	203
KPO 1182	28 April / 17:08	24 June / 11:23	12° 34.732’	077° 39.618’	999
KPO 1183	14 April / 23:37	23 June / 20:40	13° 58.414’	076° 47.942’	990

Instrument performance

Overall the moored instruments recovered during M138 worked very successful. Tab. 5.3 shows the instrument performance for each mooring and sensor type (T - temperature; C - conductivity; P - pressure; U,V- zonal, meridional velocity; O_2 - oxygen) calculated as the percentage of maximum obtainable data. For the calculation of the instrument performance, every instrument was weighted homogeneously taking the following instrument types into account: MicroCAT (T, C, P), O_2 -Logger (T, O_2), ADCP (U, V), Aquadopp (P, U, V), moored profiler M-CTD MMP (T, C, U, V,P). Very good instrument performance was obtained for three of three MicroCATs (20s sampling interval) and one of one Aquadopp (1min sampling interval). Two of four ADCPs performed completely (1min and 5min pinging rate). One ADCP worked for 19 days until the battery was down due to a fast pinging rate of 10s. One ADCP stopped its measurements after 7 days (1 min pinging rate). The moored profiler and the O_2-Logger worked for 2 complete days. A summarized description over the performance of all instrument types is given in the following. Details are shown in Tab. 5.3.

Tab. 5.3

Sensor type:	T	C	P	U,V	O_2
Mooring	%	%	%	%	%
KPO_1180	4	4	52	52	4
KPO_1181	100	100	100	55	
KPO_1182	100	100	100	100	
KPO_1183	100	100	100	26	
all moorings	76	76	88	58	4

Instrument calibration for MicroCATs

CTD cast calibrations were performed for all MicroCATs as post-deployment calibrations (CTD cast 103). 5 calibration stops were done over the whole profile range, each stop lasting 3 min in order to ensure equilibrium at the calibration points. The calibration of the MicroCATs will be completed after the cruise.

5.2 Nutrients and Oxygen

5.2.1 Nutrients

(K. Nachtigall, M. Lohmann)

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

- Nitrite and Nitrate – Q-068-05 Rev 7; Nitrate is determined as nitrite after reduction on a cadmium coil. The nitrite is determined with a colorimetric metric method where sulphanilamide is forming a diazo compound.
- Phosphate – Q-064-05 Rev 4; this is the colorimetric method based on reaction with molybdate and antimony ions.
- Silicate – Q-066-05 Rev 3; this is the colorimetric method where a silico-molybdate complex is reduced to molybdenum blue.
- Ammonia – Holmes et al., 1999; this is a fluorometric method with ortho-Phthaldeialdehyde.

All together 1917 nutrient samples from 104 CTD casts were sampled during the cruise, of which 95 samples were taken as triplicates from varying depths. Furthermore, 113 samples were measured from 11 trace metal CTD casts, 24 single underway samples for the trace metal group and 72 samples from 7 Methane incubation experiments. For ammonia, 1183 samples were measured from 79 CTD casts. The precision of this method was calculated from all together 95 triplicates that were taken at most of the stations and determined to be: 0,024 µmol/L. Maximum sampling depths were different at every station and ranged between 4000m and 127m whereas the shallowest depths were about 5m to 15m below surface. The 14ml polyethylene sampling tubes and the respective caps were rinsed at least three times with the sampling water before the final sample was taken. The samples were measured directly after sampling with a max. delay of two hours or less. If the start of measurement was delayed for more than one hour, the samples

were stored meanwhile in the fridge. The precisions of the nutrient measurements were calculated from the triplicate samples taken at most of the stations and determined to be: 0.11 µmol/L for nitrate, 0,01 µmol/L for nitrite, 0.03 µmol/L for phosphate and 0.09 µmol/L for silicate. Additionally to the CTD samples, 23 bottles of Reference Material for Nutrients in Seawater (RMNS) from the General Environmental Technos (KANSO) Co., Ltd., Osaka/Japan, were measured as triplicates at least once a day, resulting in 57 measurements during the cruise. The standard deviation of the measured replicates was determined to be 0.11 µmol/L for nitrate, 0.03 µmol/L for phosphate, 0,002 µmol/L for nitrite and 0.26 µmol/L for silicate. All measurements and data sets have been finished on board.

5.2.2 Oxygen

(S. Lennartz, L. Eck, M. Lohmann)

Observing and understanding the concentration of dissolved oxygen in the ocean is one of the key objectives of the SFB754. While the CTD system is capable to measure dissolved oxygen in the ocean at high vertical resolution, the sensors need to be carefully calibrated. Thus high quality reference observations are essential. During the whole cruise samples for the determination of dissolved oxygen after Winkler (1888) were taken from a total of 93 CTD casts with 100 ml WOCE bottles with well-defined volumes (calibrated flasks) to calibrate the oxygen sensors (SBE 43) and to support chemical and biological CTD data. Oxygen samples were always taken prior to all other parameters immediately after the CTD was fixed on deck. It was ensured that the sample bottles were flushed with at least 3 times its volume and the samples were free of air-bubbles. Maximum sampling depths were different at every station and ranged between 4000m and 127m whereas the shallowest depths were about 5m to 15m below surface.
The precision of the oxygen concentration measurements determined from the titration was 0.41 µmol/L (arithmetical average of all standard deviations, not respecting a few clear outliers) based on 103 replicate measurements with 3 replicates each. Standard measurements for the determination of the thiosulfate factor were carried out on a daily basis. In addition to that once a week a standard solution of Potassium Iodate from Wako (034-10251 CSK Standard Solution) was measured to support the quality of the own standard solution. The following reagents were used during this cruise:

- sulfuric acid (50%)
- zinc iodide starch solution (500 mL, Merck KGaA)
- stock solution: sodium thiosulfate pentahydrate (49,5 g L^{-1}); stock solution was diluted by a factor of 10 to create the working solution (0.02 mol L^{-1})
- fixation solution: manganese(II)chloride (600 g L^{-1}), sodium iodide (600 g L^{-1}) and sodium hydroxide (320 g L^{-1})
- standard solutions: potassium hydrogen diiodate (0,325 g·L^{-1}, homemade) and potassium iodate (CSK Standard Solution, 0.01 N, 300 mL, Wako Pure Chemical Industries, Ltd., Japan)

Titrations were performed within the WOCE bottles using a 20 mL Piston Burette (Nr. M 005684) TITRONIC universal from Schott Instruments. Dosing accuracy reported by the company is 0.15%, referred to the nominal volume, indicated as a measurement uncertainty with

a confidence level of 95%. The iodate standard was added with a 50 mL Piston Burette (Nr. M 001545) TITRONIC universal from Schott Instruments. 1 mL of the fixation solutions (NaI/NaOH and $MnCl_2$) were dispensed with a high precision bottle-top dispenser (0.4-2.0 mL, Ceramus classic, Hirschmann). Note: Possible sampling, storing (air bubbles) or measuring failures were recorded. Results derived from those measurements were not considered in the data evaluation.

5.3 N compounds and trace gases

(D. Arévalo-Martínez, M. Sun, T. Fischer, A. Kock, T. Steinhoff, H. Bange)

Background

Given the climatic relevance of marine-derived greenhouse gases (GHG), the investigation of their distribution and emissions from key oceanic regions is a crucial need in our efforts to better understand potential responses of the ocean and the overlying atmosphere to environmental changes such as warming and deoxygenation. Low-oxygen waters connected to coastal upwelling systems and the associated oxygen minimum zones (OMZ) are well-recognized strong sources of, for instance, N_2O, CO_2 and CH_4 (Capone and Hutchins, 2013). Our main goals during the M138 cruise were: i) to assess the distribution of different GHG which are relevant for the biogeochemical cycling of carbon and nitrogen in the OMZ off Peru, and ii) to decipher the role of particles/organic matter availability for N_2O and CH_4 formation and consumption in the OMZ. In order to achieve these goals, we used a combination of continuous and discrete measurement methods as well as coordinated sampling in cooperation with participants of other working packages.

Continuous surface measurements

Continuous measurements of dissolved N_2O, CO_2 and CO in seawater were carried out by means of an autonomous equilibrator headspace setup (GO-System; General Oceanics, Inc.) coupled to an off-axis integrated cavity output spectroscopy analyzer (model DLT-100, Los Gatos Research, Inc.). The combined setup is shown in Fig. 5.7. Water was drawn into the system at ca. 3 L min^{-1} by using a LOWARA submersible pump installed in the ship's moon pool at about 6 m depth . In order to correct for potential warming of the seawater between intake and equilibrator, the water temperature at the equilibrator was constantly monitored by means of a high accuracy digital thermometer (Fluke) and at the intake by a Seabird SBE38 thermometer. Ambient air measurements were carried out every six hours by drawing air into the system from a suction point located at the ship's mast at about 30 m high. Control measurements and calibration procedures were performed every ~6 and 24 h respectively, by means of 3 standard gas mixtures (Deuste Steininger GmbH) bracketing the expected concentrations in this area.

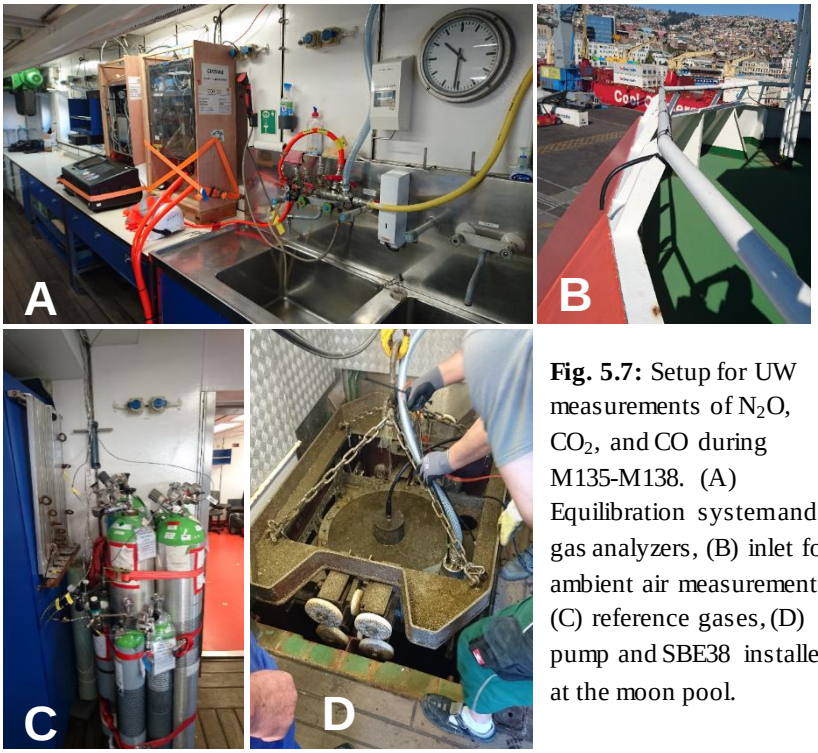


Fig. 5.7: Setup for UW measurements of N_2O, CO_2, and CO during M135-M138. (A) Equilibration system and gas analyzers, (B) inlet for ambient air measurements, (C) reference gases, (D) pump and SBE38 installed at the moon pool.

The continuous system has been on board since the R/V METEOR cruise M135 and provided a unique record of the surface distribution of N_2O, CO_2 and CO during the autumn-winter period off Peru. Preliminary results from the M138 cruise are shown below.

Discrete sampling: Surface

Discrete samples for N_2O and CH_4 measurements were collected daily (N_2O) or in 6-12 h intervals (CH_4) by sampling from the same water stream that fed the continuous setup (see above). For N_2O, bubble-free triplicate samples were collected and immediately sealed by means of butyl stoppers and aluminum crimps. Subsequently a 10 mL headspace of helium and 50 µL of a saturated mercuric chloride ($HgCl_2$) solution were added. After an equilibration period of at least 2 hours the headspace sample was measured by means of a gas chromatograph equipped with an electron capture detector (GC/ECD). The GC/ECD was calibrated on a daily basis using dilutions of one standard gas mixture (Deuste Steininger GmbH). Samples for CH_4 analysis were preserved with $HgCl_2$ and the measurements will be carried out at GEOMAR by means of an analytical system similar to that used for N_2O during the cruise, but using a flame ionization detector (FID) instead of an ECD. DIC/TA samples were collected daily in 500 mL glass bottles, after which they were preserved to be measured at GEOMAR. DIC/TA data together with ancillary parameters will be used to compute final pCO_2 values. The map in Fig. 5.8 shows the locations in which the surface samples were collected.

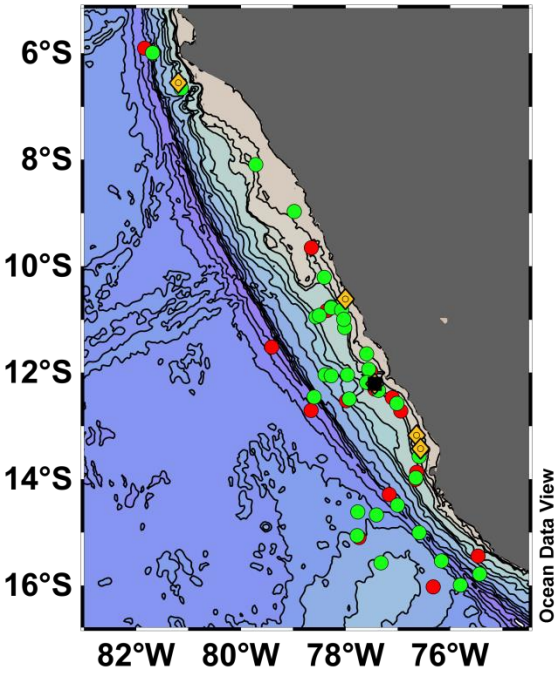


Fig. 5.8: Locations for discrete shallow sampling of trace gases during M138. Red dots = underway N_2O, green dots = underway CH_4, yellow triangles = zodiac sampling, black square = pump profiler.

Discrete sampling: Depth profiles of N_2O, hydroxylamine (NH_2OH) and CH_4

Sampling for N_2O, NH_2OH -an important intermediate in the nitrogen cycle-, and CH_4 were performed in conjunction with several biological parameters and incubation work from other groups as well as with microstructure measurements. Samples were drawn directly from 10 L Niskin bottles mounted on a standard CTD/Rosette. Glass vials of 20 - 50 mL were used and the samples were treated as explained above. N_2O samples were measured on board whereas CH_4 samples were only preserved and stored for posterior analysis in Kiel. Tab. 5.4 shows an overview of the sampling locations and depths during the cruise.

Tab. 5.4: Sampling locations for N_2O and CH_4 during M138 (depths may vary for each gas).

Station	Position	Depths [m]
879-1	11°28'S 78°26'W	5,10,15,30,50,55,65,75,100,200,300,350,400,600,800,1000,2000
882-11	10°57.05'S 78°33.64'W	5,15,25,30,75,100,150,200,220,260,300,350,400,500,600,700,800,900,1000
883-4	10°46.74'S 78°16.21'W	5,10,15,20,30,50,75,100,150,190,200,250,275,300
884-2	10°40.2'S 78°05.4'W	5,10,15,20,25,30,50,75,130
885-1	12°2.4'S 77°27.6'W	5,10,15,20,25,30,40,50,55,75,100,135
886-1	12°2.4'S 77°45'W	5,10,15,20,30,50,65,75,100,150,200,250
887-1	12°2.4'S 78°00'W	5,10,15,20,30,45,50,75,100,200,300,350,400,600,800,1000
888-1	12°2.4'S 78°30'W	5,10,15,20,30,50,60,75,100,150,200,300,350,400,600,800,1000,2000
889-1	12°55'S 78°42'W	5,10,20,50,75,100,200,270,300,400,600,800,1000
892-1	12°25.09'S 78°48.74'W	5,10,25,45,50,70,75,100,120,145,200,300,350,400,600,800,1000
894-1	12°18.40'S 77°37.27'W	5,10,15,30,40,50,75,100,120,200,300,375,400
897-1	12°12.6'S 77°26.4'W	5,10,15,20,30,35,75,100,150
899-1	12°24'S 77°09'W	5,10,12,15,20,50,75,100,127
900-1	12°38.4'S 76°58.2'W	5,10,15,16,20,40,50,75,100,150
901-1	12°53.4'S 76°49.2'W	5,10,15,20,25,30,50,75,100,145
902-1	13°10.8'S 76°38.4'W	5,10,15,20,25,40,50,75,100,120
903-2	13°25.8'S 76°33.6'W	5,10,12,15,20,50,75,100,120
904-5	14°0.0'S 76°39.6'W	5,8,10,15,20,30,50,75,100,200,300,375,400,bottom
905-1	14°7.1'S 76°52.14'W	5,10,15,20,25,30,50,75,100,200,300,400,600,800,1000
906-1	14°17.07'S 77°10.01'W	5,12,20,22,50,100,200,300,350,600,800,1000,2000

907-14	15°25.8'S 75°25.8'W	10,20,30,40,50,55,75,100,200,300,325,500
908-3	15°31.49'S 75°35.75'W	5,10,25,35,40,50,75,100,200,300,400,600,800
909-1	15°36.26'S 75°43.18'W	5,10,15,35,40,50,60,75,100,200,225,300,500,600
910-3	15°41.47'S 75°51.17'W	5,10,15,20,25,35,45,50,75,100,200,300,400,500,600,800
911-1	15°46.67'S 75°59.15'W	5,10,20,30,35,40,50,75,100,200,250,300,400,500,600
912-1	15°51.6'S 76°06.6'W	5,10,15,20,25,40,45,50,75,100,200,250,300,400,500,600,700,800
913-1	15°58.39'S 76°17.12'W	5,10,20,30,40,50,60,75,100,200,300,350,400,500,600
914-3	16°04.03'S 76°25.77'W	5,10,15,20,30,40,50,60,75,100,200,300,325,400,500,600,700,800
915-3	16°09.67'S 76°34.42'W	5,10,15,20,50,65,75,80,100,200,300,350,400,500,600
916-3	16°15.15'S 76°43.07'W	5,10,15,20,40,50,60,75,100,200,300,350,400,600,800
917-1	14°46'S 78°01.98'W	5,15,30,75,100,200,300,600,800
918-1	14°37'S 77°45.8'W	12,22,42,52,62,75,82,102,202,302,312,402,602,802
924-1	04°00'S 85°50.0'W	20,40,50,75,100,150,200,250,300,350,400,600,800
926-1	03°00'S 85°50'W	20,40,50,75,100,150,200,250,300,350,400,600,800
928-1	02°00'S 85°50'W	20,40,50,75,100,150,200,250,300,350,400,600,800
930-1	01°00'S 85°50'W	20,40,50,75,100,150,200,250,300,350,400,600,800
932-1	00°00' 85°50'W	20,40,50,75,100,150,200,250,300,350,400,600,800
934-1	01°00'N 85°50'W	20,40,50,75,100,150,200,250,300,350,400,600,800
936-1	02°00'N 85°50'W	20,40,50,75,100,150,200,250,300,350,400,600,800

In order to investigate near-surface gradients of N_2O off the Peruvian coast, five detailed surveys of the upper 10 m of the water column were carried out in selected stations on board of a zodiac. Sampling was carried out as for the conventional depths profiles but by using either a single Niskin bottle or a small submersible pump which could be lowered to the upper 15 - 150 cm of the water column. Additionally, we collected samples for depth profiles of N_2O and NH_2OH by using a continuous pump profiler developed by S. Lennartz (GEOMAR); see Section 5.16.

Incubation experiments for methane (CH_4) production

Methane (CH_4), the most abundant hydrocarbon in the atmosphere, plays an important role in regulating the Earth's radiation balance and atmospheric chemistry in the troposphere. Although the coastal upwelling area off Peru is one of the most biologically productive regions of the world's ocean, with a large and persistent OMZ, the emissions as well as the transfer mechanisms (production and consumption) of CH_4 have not been quantified so far. To this end, incubation experiments were conducted in addition to the CTD/Rosette sampling. For this, three different water types were used: surface seawater from a nearshore station (885-3; 5 m), surface seawater from an offshore station (888-3; 5 m) and seawater from the OMZ (904; 300 m). This allowed comparing the different CH_4 transfer processes under varying environmental regimes. In order to determine the potential CH_4 production or consumption rate off Peru, two inhibitors were used during the incubations: 2-bromoethanesulfonate (BES) (for inhibiting CH_4 production) and molybdate (for blocking CH_4 consumption). Different treatments were setup by adding DMSP, DMSO, trimethylamine and methylphosphonic acid in order to test the possible correlation between CH_4 production and the microbial degradation of these methyl-rich organic phosphorus or sulfur compounds, which have been reported as possible precursors of CH_4 through methylotrophic methanogenesis. The samples will be processed at GEOMAR in Kiel.

Planned measurements and time line

Analysis of samples for DIC/TA as well as for CH_4 concentrations in depth profiles and incubations will take place at the Chemical Oceanography Department of GEOMAR. The measurements are expected to be completed within nine months after the end of the cruise. Data

analysis for the N_2O measurements performed on board is expected to be finalized within eight months after the end of the cruise. The samples for determination of N_2O concentrations in the water column across the 85°W section will be analyzed in Kiel within the context of a Bachelor thesis (over the following six months). Data analysis of continuous surface measurements of N_2O, CO_2 and CO is expected to be completed within six months after the end of the cruise.

Preliminary results

Underway measurements of N_2O, CO_2 and CO in surface waters were conducted during 30 days. Fig. 5.9 shows the distribution of these three gases along the cruise track, as well as the sea surface temperature (SST) which was recorded simultaneously.

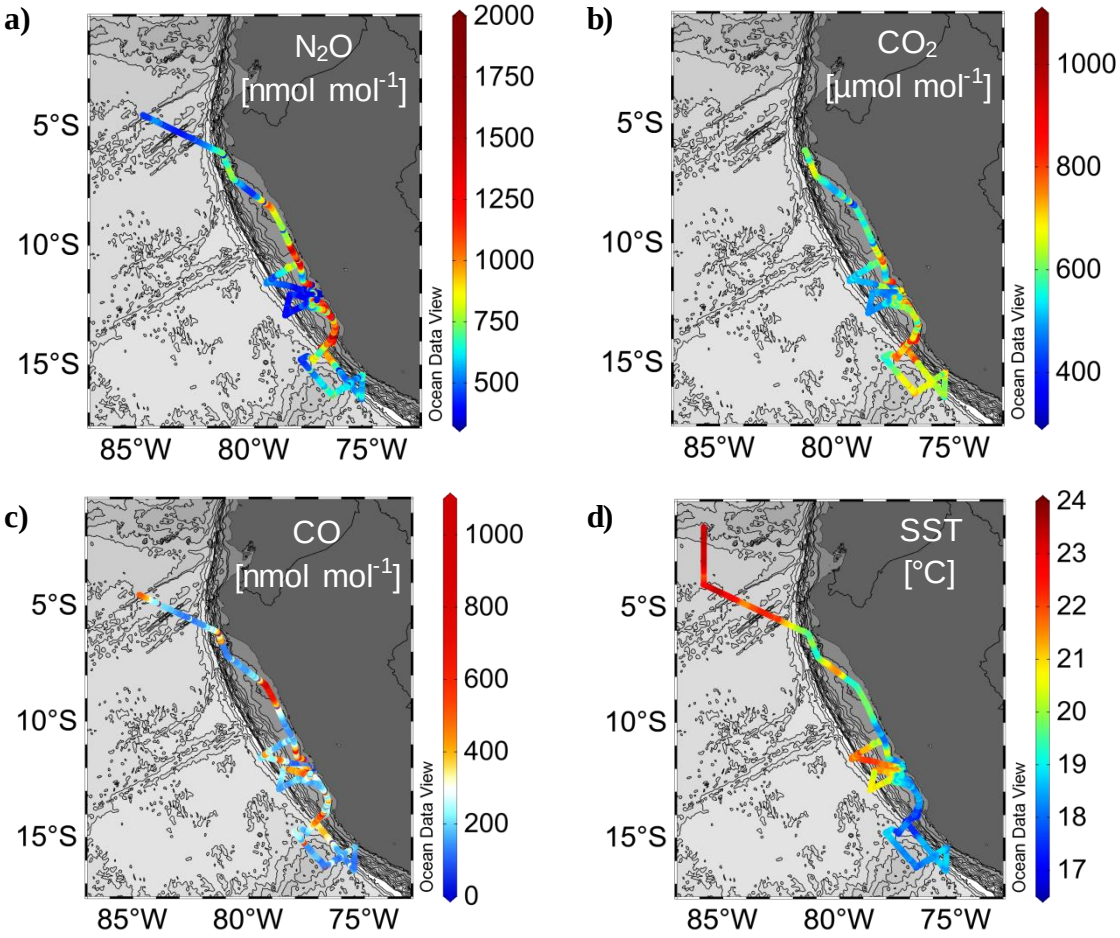


Fig. 5.9: Preliminary results of continuous measurements of dissolved N_2O (a), CO_2 (b) and CO (c) during M138. Along-track SST as measured by the ship's thermosalinograph is shown in (d).

Results from continuous measurements show a strong source of N_2O and CO_2 from surface waters in the Peruvian upwelling, particularly in the near-coastal area between 9°S and 16°S where seawater values surpassed atmospheric equilibrium (~329 ppb for N_2O und ~ 408 ppm for CO_2) by about one order of magnitude (Fig. 5.9). In agreement with past surveys which took place during the M91 and the SO-243 cruises (December 2012 and October 2015, respectively) the highest N_2O and CO_2 values were consistent with the location of the upwelling centres off Chimbote, Callao and Pisco. Episodic undersaturation of CO_2 was observed at discrete locations along the coast, suggesting strong biological drawdown in response to enhanced primary production after upwelling events. Likewise, observations show that the coastal waters off Peru were a net source of CO to the atmosphere. Thus, despite the clearly dominant

diurnal variability (production enhanced at noon, microbial consumption at dawn and night), a cross-shelf gradient in CO could be observed along the cruise track (Fig. 5.9).

5.4 N_2O Production

(C. Frey, H. Bange, B. Ward)

Background

Nitrous oxide (N_2O) has become the third most important anthropogenic greenhouse gas, after CO_2 and methane (IPCC, 2013). Oceanic N_2O emissions to the atmosphere represent up to 35 % of the global natural sources, and oxygen minimum zones (OMZs) are the major sites for net N_2O production (Naqvi et al. 2010, Codispoti , 2010; Arévalo-Martínez et al. 2015). In order to understand changes in the magnitude of N_2O production in response to global change, it is necessary to determine the individual contributions of the major microbial pathways (nitrification and denitrification) to the N_2O budget. The potential niche overlap of nitrifiers and denitrifiers in OMZs makes it difficult to distinguish between these two N_2O sources. An increasing number of studies suggests that ammonium oxidizing archaea contribute significantly to N_2O production in the suboxic water masses overlaying OMZs (Santoro et al. 2011, Löscher et al. 2012), but a recent studies suggest denitrification as a largely overlooked N_2O source (Babbin et al. 2015, Ji et al. 2015). For this reason, I want to study the spatial distribution of N_2O concentration, and N_2O production activity related to the concentration of dissolved oxygen, organic matter supply and the mixing of oxygen depleted OMZ water with oxygenated surface water. I will take advantage of tracer incubation techniques to identify the major N_2O production pathways in OMZs. My results will provide essential knowledge about the regulation of different marine N_2O production pathways to determine the oceanic source for N_2O. Additionally, I investigate N-loss isotope effects in the Peruvian coastal upwelling zone in austral summer. Eddies are present in all OMZs during all seasons (Chelton et al. 2011). Since eddies lead to heterogeneity in OMZ N-loss processes (Bourbannais et al. 2015), a different signal in the natural abundance stable isotope in nitrate and nitrite is expected which impacts both the global rate of N-loss as well as the ocean's N isotope budget. This data can help to reevaluate N-loss pathways and rates as well as the impact of eddies on the global N cycle.

Measurements

At all 8 24h stations tracer incubations were performed. For the ^{15}N tracer studies, seawater was collected from the selected depth into gas-tight 60mL glass serum bottles, 3mL He headspace was created and ^{15}N tracer was amended with either $^{15}N\text{-}NO_2^-$, $^{15}N\text{-}NH_4^+$, $^{15}N\text{-}NO_3^- + {}^{14}N\text{-}NO_2^-$ and $^{15}N\text{-}NH_2OH$ to a final concentration of 0.5 µmol L^{-1} or 3 µmol^{-1} for NO_3^- (Ji et al. 2015). Duplicates were incubated in the dark around *in situ* temperatures. After 0, 12 and 24 hours the incubations were terminated and samples preserved with the addition of $HgCl_2$. The seawater samples will then be analyzed for ^{15}N values in N_2O in the laboratory of the Geoscience department, Princeton University. At the first two 24h stations incubations were performed at 5 different depth along the natural oxygen gradient, whereas at the 24h stations in transect C only one depth at the interface was sampled, remaining oxygen was purged out and an oxygen gradient with 5 oxygen concentrations was manipulated. Where ever ^{15}N-hydroxylamine was used as tracer, the *insitu* concentration of hydroxylamine was measured on board according to

Kock and Bange (2013). Incubations simulating the mixing between OMZ water and oxygenated (surface) water with different partition between O_2-rich and OMZ waters (1% and 10% of surface water) were performed on transect F at a coastal and offshore station. Water samples for natural abundance stable isotopes were collected at 25 stations along 3 transects (12 depths/profile) with standard depth at 500m, 400m, 350m, 300m, 250m, 200m, 150m, 100m, 75m, 50m, 25m, 10m. Samples for N and O isotopic composition of NO_3^- were collected in 50 mL plastic vails and frozen at -20°C until analysis at the GEOMAR, Kiel. For NO_2^- isotopic analysis, a separate set of samples was collected and preserved with NaOH (1 mL of 4M NaOH in 50 mL, pH=12.5) and frozen upon analysis to prevent oxygen isotope exchange with water during storage (Casciotti et al., 2007). NO_2^- isotopic analysis will be done at the Princeton University.

Tab. 5.4: List of sampled stations for natural abundance stable isotopes and incubations for N_2O production rates.

station	date	Lat (S)	Long (W)	profile #	samples	# of depths
879-1	03.06.2017	-11,4665	-79,4367	2	NO_3- Isotopes	12
880-1	03.06.2017	-11,2948	-79,1423	4	NO_3- Isotopes (filtered, unfiltered)	12
880-4	03.06.2017	-11,3127	-79,1647	6	NO_3- Isotopes (filtered, unfiltered)	12
881 -1	04.06.2017	-11,124	-78,8532	7	NO_3- Isotopes	12
882-1	04.06.2017	-10,9507	-78,5608	8	NO_3- Isotopes	12
882-3	04.06.2017	-10,9507	-78,5608	9	DNA filter	5
882-11	04.06.2017	-10,9515	-78,563	13	Incubation for N2O production (depth profile)	5
883-4	05.06.2017	-10,7792	-78,2708	14	NO_3- Isotopes	12
883-7	05.06.2017	-10,7782	-78,27	16	DNA filter	5
883-14	06.06.2017	-10,7807	-78,2758	18	Incubation for N_2O production (depth profile)	5
884-1	07.06.2017	-10,6697	-78,0898	19	NO_3- Isotopes	12
889-1	08.06.2017	-12,9165	-78,6995	29	NO_3- Isotopes	12
891-1	09.06.2017	-12,601	-78,108	32	NO_3- Isotopes	12
892-1	09.06.2017	-12,4182	-78,8123	34	NO_3- Isotopes	12
892-3	09.06.2017	-12,418	-77,8122	36	N_2O Incubations (oxygen manipulation)	1
894-1	11.06.2017	-12,3228	-77,6195	42	NO_3- Isotopes	12
894-4	11.06.2017	-12,3228	-77,6195	44	N_2O Incubations (oxygen manipulation)	1
897-1	11.06.2017	-12,21	-77,4398	46	NO_3- Isos	6
899-1	13.06.2017	-12,3993	-77,151	55	NO_3- Isos	6
900-1	13.06.2017	-12,649	-76,9698	56	NO_3- Isos	6
902-1	14.06.2017	-13,1792	-76,641	58	NO_3- Isos	6
903-1	14.06.2017	-13,43	-76,56	59	NO_3- Isos	6
904-5	15.06.2017	-14,000	-76,6612	61	NO_3- Isos	6
904-7	15.06.2017	-14,000	-76,66	63	N_2O Incubations	2
906-1	16.06.2017	-14,2835	-77,1685	68	NO_3- Isos	12

906-7	17.06.2017	-14,2878	-77,166	69	N_2O Incubations (organic matter addition, DNA filter)	2
907 -7	18.06.2017	-15,4267	-75,434	76	N_2O production + DNA filter, surface mixing	2
907-14	19.06.2017	-15,4312	-75,4283	78	NO_3- Isos	12
908-3	19.06.2017	-15,5395	-75,6107	80	NO_3- Isos	12
910-3	19.06.2017	-15,708	-75,8685	83	NO. Isos	12
912-1	20.06.2017	-15,86	-76,11	85	NO_3- Isos	12
912 -11	20.06.2017	-15,8597	-76,1098	88	N_2O production + DNA filter, surface mixing	2
914-3	21.06.2017	-16,0873	-76,4247	93	NO_3- Isos	12
915-3	21.06.2017	-16,1608	-76,5737	95	NO_3- Isos	12
916-3	21.06.2017	-16,2788	-76,7233	97	NO_3-Isos	12
917-3	22.06.2017	-14,7802	-78,042	99	N_2O production + DNA filter, OM addition	2

Measurements in the lab after the cruise with time line

The analysis of ^{15}N-N_2O of the tracer incubation experiments and samples for natural abundance N and O isotopes in nitrite will be done according to Weigand et al. (2016) at a Delta V^{Plus} (Thermo Fisher Scientific, Waltham, MA). The analysis of 1050 serum bottles will take 4-6 months. The analysis of the 300 samples for natural abundance N and O isotopes in nitrate will be done with the Denitrifier method (Sigman 2001) by Frederike Korth (SFB754) at GEOMAR and can take 4-8 weeks.

5.5 Microbial Nitrogen Transformations

(L. Bristow, C. Karthäuser, G. Lavik, M. Kuypers)

During M138 an extensive program was undertaken to examine the potential importance of particles and their associated microenvironments to the microbial nitrogen cycle. Sinking of aggregated particles is considered to be one of the main mechanisms of organic matter export from the surface ocean to deeper water layers. Aggregated particles are characterized by strong chemical gradients, resulting in substrate availabilities very different to ambient waters (e.g. Kalvelage et al, 2015; Stocker 2012). Such small-scale reaction zones offer microniches for microorganisms that may allow the co-existence of aerobic and anaerobic activities (e.g. Klawoon et al, 2015) and hence may strongly regulate microbial diversity and function within low oxygen regions. Water and single aggregate samples were collected from the OMZ along the five cruise transects. Samples were collected with a CTD rosette (water samples), and a marine snow catcher (MSC; single aggregates). Water samples (total 13 stations; 6 experimental depths per CTD; Tab. 5.5) were amended with different combinations of ^{15}N and ^{14}N labeled substrates to determine rates of microbial nitrogen transformations (anammox, denitrification, nitrate reduction, ammonia oxidation, nitrite oxidation, DNRA; Holtappels et al, 2011). At 6 of these stations (Tab. 5.5; SizeFrac), rates were conducted in three size fractions (bulk, < 10 µm and < 1.6 µm; alongside size fractionated DNA/RNA sampling; Martin Fischer, CAU Kiel) to assess which of these nitrogen cycling processes are particle associated and how / if this varies across

chemical gradients. To assess the regulation of these microbial nitrogen cycling processes across size fractions, oxygen sensitivity experiments were conducted in bulk and < 1.6 µm water samples (Tab. 5.5; OxSens). In addition to these experiments background parameters were collected at all experimental depths and additional depths for context (Tab. 5.5, including N_2/Ar ratios, POM concentrations in different size fractions and FISH (fluorescence insitu hybridization). Single aggregates were collected at 11 stations from the MSC (Tab. 5.5). These were incubated with the same $^{15}N/^{14}N$ substrates as the water samples but incubated under constant rotation, to mimic sinking. In addition, single aggregates were collected at each station for the determination of carbon content, visualization and characterization of the microbial community, elemental composition and sinking velocity. At 6 of these stations (Tab. 5.5; SC_SizeFrac), additional samples were collected from the MSC, termed bulk (immediately after recovery of the MSC), suspended (after 3 hours of settling) and sinking (from the MSC tray). From each of these fractions, experiments were conducted to determine microbial nitrogen transformations (^{15}N addition), oxygen consumption (^{18}O addition; Holtappels et al, 2014), and samples for DNA (Martin Fischer, CAU Kiel), FISH and POC concentration. On the return of the samples to MPI Bremen within approximately 12 months, microbial nitrogen transformation rates will be determined by GC-IRMS in both water and single aggregate incubation experiments. This will allow us to determine the partitioning of nitrogen loss processes (anammox and denitrification) and the processes supplying the substrates for these processes (namely nitrate reduction, ammonia oxidation and nitrite oxidation) between the free living (< 1.6 µm) and particle associated fractions. These rates will then be correlated with single aggregate properties such as size, carbon content, and sinking velocity. Analysis of the microbial community in the different size fractions (Martin Fischer, CAU Kiel), alongside FISH and nanoSIMS analyses on slices of individual aggregates will allow us to assess which microorganisms are the key players in each fraction and if particle associated, their location within an aggregate. Taken together, these results will be correlated with the primary productivity data (Allanah Paul, B2)) and scaled up in collaboration with other groups onboard (UVP and sediment trap data; B8 and B9), allowing us to assess the contribution of microniches to microbial nitrogen cycling in low oxygen regions.

Tab. 5.5: Sampling stations and depths for the CTD and Marine Snow Catcher.

Stn	CTD			Marine Snow Catcher	
	Experimental Depths (m)	Background Depths (m)	Experiment Type	Deployment Depth (m)	Experiment Type
882	75, 200, 260, 300, 350, 400	5, 25, 36, 500	Bulk	260	SingleAgg
883	30, 150, 200, 230, 250, 300	5, 20, 100, 275	SizeFrac	150	SC_SizeFrac
886	120, 200	5, 30, 50, 70, 100, 150, 220, 250	Ox Sens	-	-
892	100, 135, 145, 200, 300, 400	5, 25, 55, 500	SizeFrac	135	SC_SizeFrac
894	75, 150, 190, 250, 350, 470	5, 15, 50, 100	Bulk	150	SingleAgg

897	50, 75, 100, 120, 160	5, 10, 35	Bulk	-	SingleAgg
898	80, 100, 122, 150, 200, 300	5, 20, 60, 500	SizeFrac	120	SC_SizeFrac
904	50, 100, 120, 150, 200, 300	5, 15, 70, 450	SizeFrac	50	SC_SizeFrac
906	60, 80, 100, 150, 200, 300	15, 40, 400, 500	Bulk	60	SingleAgg
907	80, 90, 100, 150, 200, 300	15, 35, 60, 400	Bulk	100	SingleAgg
912	70, 90, 100, 150, 200, 300	13, 46, 60, 400	SizeFrac	90	SC_SizeFrac
915	70, 90, 100, 150, 200, 300	15, 40, 60, 400	SizeFrac	100	SC_SizeFrac
919	100, 120, 135, 180, 200, 300	10, 50, 250, 400	Bulk	150	SingleAgg

5.6 Nitrogen Fixation

(A. Paul, U. Riebesell)

A distinct feature present in the eastern tropical South Pacific Ocean (ETSP) is the biogeochemical signature in nutrient stoichiometry of excess phosphate (P*). Although co-occurrence of inorganic phosphate loss, DOP accumulation and dinitrogen (N_2) fixation in the ESTP is spatially evident (Meyer et al. 2017), and there is evidence from the eastern tropical North Atlantic Ocean that DOP accumulation may support N_2 fixation (Meyer et al. 2016), the extent of this in the ETSP is not clear. Recent work has also highlighted that N_2 fixation can occur in environments previously not considered to fulfil the classical ecological niche for diazotrophs (high nitrate, cool temperatures, below euphotic zone; e.g. Löscher et al. 2014, Dekaezemaker et al. 2013). Current methods also potentially exclude small non-phototrophic diazotrophs which appear to dominate the diastrophic community in the ETSP (Löscher et al. 2014) due to commonly used filter pore size. Hence, fixed N inputs by diazotrophs may have been previously underestimated. The aim of this project was to improve estimates on fixed nitrogen inputs in the Peru upwelling system by modifying existing methods for N_2 fixation rate estimations to better incorporate the contribution of smaller, non-phototrophic diazotrophs, and exploring environmental controls on N_2 fixation rates.

Scientific objectives:

- Explore vertical/spatial variability in N_2-fixation rates, in particular, measure N_2-fixation rates and link to macronutrient availability (P*, DOP) through vertical and spatial survey across Peru upwelling region
- Test a modified method which includes in size >0.3 µm (includes smaller bacteria) and compare to current filter pore size >0.7 µm
- Determine distribution of diazotroph marker pigments using phytoplankton pigment analyses by HPLC

No measurements were performed on board. Samples were collected from 28 vertical CTD casts along transects A-F, including stable isotope incubations for dinitrogen fixation and carbon uptake rates which were carried out at 12 stations along transects A-F, with a focus on the upper 200m of the water column (2-7 depths; usually 5 depths for incubations: surface (5m), chlorophyll maximum, upper oxycline, lower oxycline, below the oxycline). Additional samples were taken from 7 vertical CTD casts along the equatorial transect, including one stable isotope incubation (see also summary table below). Samples for phytoplankton pigment concentrations were collected by filtration of seawater through GF/F filters, and stored at -80°C immediately after filtration. These pigments will then be extracted and analysed in Kiel by High Performance Liquid Chromatography (HPLC) in 2017. Seawater samples (4mL) were collected for analyses of the phytoplankton community composition by flow cytometry to compliment phytoplankton pigment data, fixed with hexamine/formalin solution and stored at -80°C. These samples will also be analysed in 2017. Stable isotope incubations using ^{15}N-N_2 were carried out using the dissolved gas method slightly modified from Mohr et al. (2010). In addition, ^{13}C-labelled $NaHCO_3$ was added to the incubations to determine inorganic carbon uptake rates. Particulate matter samples for elemental and isotopic composition were collected from the CTD directly as well as at the end of the incubations onto both GF/F (0.7 µm pore size) and GF75 (0.3 µm pore size) filters. Analysis of these samples by Isotope Ratio Mass Spectrometry (IRMS) is anticipated by mid 2018 and the data will then be used to calculate estimated rates of dinitrogen fixation and inorganic carbon uptake. Judith Meyer collected samples for DOP analyses were also collected on board and will analyse these in Kiel. Preparation of a manuscript is foreseen by the end of 2018.

Tab. 5.7: Summary of samples collected from vertical CTD casts.

	Station number	Depths (m)	Parameter(s)
1	881-1	200, 60, 20, 10, 5	Particulate C and N concentration including natural abundance C/N isotope ratio, phytoplankton pigments, flow cytometry (phytoplankton)
2	882-3	260, 75, 36, 25, 5	Particulate C and N concentration including natural abundance C/N isotope ratio, phytoplankton pigments, flow cytometry (phytoplankton), rates of nitrogen fixation and inorganic carbon uptake
3	883-4	30, 20, 5	Particulate C and N concentration including natural abundance C/N isotope ratio, phytoplankton pigments, flow cytometry (phytoplankton), rates of nitrogen fixation and inorganic carbon uptake
4	884-1	25, 5	Particulate C and N concentration including natural abundance C/N isotope ratio, phytoplankton pigments, flow cytometry (phytoplankton), rates of nitrogen fixation and inorganic carbon uptake
5	885-3	55, 40, 5	Particulate C and N concentration including natural abundance C/N isotope ratio, phytoplankton pigments, flow cytometry (phytoplankton), rates of nitrogen fixation and inorganic carbon uptake
6	889-2	200, 100, 70, 20, 5	Particulate C and N concentration including natural abundance C/N isotope ratio, phytoplankton pigments, flow cytometry (phytoplankton), rates of nitrogen fixation and inorganic carbon uptake
7	890-1	200, 85, 60, 35, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
8	891-1	200, 90, 45, 35, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
9	892-14	150, 80, 60, 30, 5	Particulate C and N concentration including natural abundance C/N

			isotope ratio, phytoplankton pigments, flow cytometry (phytoplankton), rates of nitrogen fixation and inorganic carbon uptake
10	894-1	100, 55, 30, 15, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
11	897-11	65, 45, 35, 15, 5	Particulate C and N concentration including natural abundance C/N isotope ratio, phytoplankton pigments, flow cytometry (phytoplankton), rates of nitrogen fixation and inorganic carbon uptake
12	899-1	25, 12, 10, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
13	900-1	40, 16, 15, 10, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
14	902-1	40, 20, 15, 10, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
15	904-6	150, 70, 25, 15, 5	Particulate C and N concentration including natural abundance C/N isotope ratio, phytoplankton pigments, flow cytometry (phytoplankton), rates of nitrogen fixation and inorganic carbon uptake
16	905-1	30, 20, 10, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
17	906-9	80, 55, 35, 15, 5	Particulate C and N concentration including natural abundance C/N isotope ratio, phytoplankton pigments, flow cytometry (phytoplankton), rates of nitrogen fixation and inorganic carbon uptake
18	907-1	100, 60, 35, 15, 5	Particulate C and N concentration including natural abundance C/N isotope ratio, phytoplankton pigments, flow cytometry (phytoplankton), rates of nitrogen fixation and inorganic carbon uptake
19	908-1	600, 300, 200, 50, 35, 25, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
20	909-1	600, 300, 200, 50, 35, 18, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
21	910-1	600, 300, 200, 45, 25, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
22	911-1	600, 300, 200, 40, 30, 20, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
23	912-12	600, 200, 100, 50, 40, 15, 5	Particulate C and N concentration including natural abundance C/N isotope ratio, phytoplankton pigments, flow cytometry (phytoplankton), rates of nitrogen fixation and inorganic carbon uptake
24	913-1	600, 300, 200, 60, 30, 20, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
25	914-1	600, 300, 200, 70, 35, 20, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
26	915-3	600, 300, 200, 80, 60, 15, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
27	916-1	600, 300, 200, 65, 45, 15, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
28	917-3	140, 100, 60, 28, 5	Particulate C and N concentration including natural abundance C/N isotope ratio, phytoplankton pigments, flow cytometry (phytoplankton), rates of nitrogen fixation and inorganic carbon uptake
29	924-1	600, 300, 200, 100, 45, 20, 6	Phytoplankton pigments, flow cytometry (phytoplankton)
30	924-2	300, 6	Particulate C and N concentration including natural abundance C/N isotope ratio, phytoplankton pigments, flow cytometry (phytoplankton), rates of nitrogen fixation and inorganic carbon uptake
31	926-1	600, 300, 200, 150, 50, 42, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
32	928-1	600, 300, 200, 100, 40, 30, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
33	930-1	600, 300, 200, 100, 50, 25, 5	Phytoplankton pigments, flow cytometry (phytoplankton)

34	932-1	600, 300, 200, 100, 40, 25, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
35	934-1	600, 300, 200, 100, 75, 35, 5	Phytoplankton pigments, flow cytometry (phytoplankton)
36	936-1	600, 300, 200, 100, 55, 45, 5	Phytoplankton pigments, flow cytometry (phytoplankton)

5.7 Viral Lysis

(M. Fischer, R. Schmitz-Streit)

Background

Aggregated particles are characterized by strong chemical gradients offering micro-niches for microbes that may allow the co-existence of e.g. aerobic and anaerobic activities in OMZ waters (Stocker, 2012). Thus, microbial processes associated with particle related micro-niches may strongly regulate nutrient cycling processes in OMZ waters. Marine viruses have the capability to effect both particle aggregation and disaggregation, and hence, remineralisation and organic matter export dynamics (reviewed in Suttle, 2007), but they are so far largely understudied in OMZ waters. Consequently, to better define the regulation of nutrient regeneration and N-loss and N-gain in OMZ waters it is necessary to focus on the regulation of microbial activity under micro aerobic conditions and substrate availability related to micro-niches e.g. related to aggregated particles and virus distribution. In order to address the topic of the N-cycling in OMZ waters with a focus on micro-niches, meta-omic tools will be applied to further contribute to the understanding of N-loss and N-gain processes on the genetic and molecular level. In addition, the potential effects and the diversity of marine viruses in the OMZ will be investigated using meta-omic tools. A special focus will be set on their influence on the N-cycling and the prediction of phage-host relationships within and outside OMZs.

Measurements and sampling performed on board

During the cruise samples from 42 stations were taken for microbial analysis on DNA and RNA level. Samples were taken from 6 depths which were either fixed (500/600m, 5m) or depending on conditions in the water column (Oxycline, Chlorophyll maximum, O_2 minimum). A detailed listing of the samples taken can be found in the attached list (Tab. 5.8). Samples for viral composition were taken at all eight 24h stations. Therefore, 30L from 4 different depths were obtained. Viruses were enriched using $FeCl_3$ precipitation as well as tangential flow filtration technique. Corresponding samples for DNA/RNA extraction for snow catcher samples and N-fixation incubations were taken at multiple stations. For snow catcher samples, size fractionated filtration using 3 size fractions (10µm, 1.6µm, 0.22µm) was performed to investigate size distribution and differentiate between particle associated and free microbiota. An N-fixation experiment under addition of enriched viruses was performed at station 924 in cooperation with B2. In addition, particles from the free floating sediment trap were provided from B9 for microbial community analysis.

Tab. 5.8: List of stations sampled during M138 for microbial DNA/RNA analysis

Station number	Station number	Station number	Station number	Station number	Station number
879	887	898	906	913	926
880	888	899	907	914	919

882	890	900	908	915	928
883	891	902	909	916	930
884	892	903	910	917	932
885	894	904	911	918	934
886	897	905	912	924	936

Measurements and sampling in home laboratory

After arrival of the samples, DNA and RNA will be extracted from the samples. For the analysis of microbial community composition, 16S rRNA gene analysis using MiSeq Illumina sequencing will be applied. In addition, shotgun metagenomic and metatranscriptomic analysis will be applied for multiple samples to identify potential hosts for the extracted viruses. Functional gene analysis will be performed by qRT-PCR for selected genes.

Timeline

Results will be generated in batches with a priority on samples important for cooperation partners (B2, B9 and B4) and virus analysis. First results can be expected in the first half of 2018. All relevant results will be obtained within the timeframe of the SFB 754 until 2019.

5.9 Surface Drifting Sediment Traps

(C. Cisternas-Novoa, F. Le Moigne, A. Engel)

Scientific motivation

Climate models predict a decline in dissolved oxygen concentration and a consequent expansion of the Oxygen Minimum Zones (OMZ) in the future ocean. One crucial biogeochemical mechanism is the process by which of carbon is transferred into the deep ocean, the biological carbon pump (BCP). There is currently little consensus on the fate of sinking particles and the efficiency of the BCP in OMZ areas. Previous particles flux studies have shown that the BCP is more efficient in suboxic zones relative to surrounding well oxygenated waters. However, incubations performed on sinking material collected in oxic and suboxic areas have observed similar remineralisation rate in both conditions suggesting that suboxic conditions do not enhance the transfer of sinking OM through the mesopelagic zone. Moreover, the export flux of particulate Nitrogen is deemed to have a strong influence of the amount of N lost as gas through microbial processes like annamox and/or denitrification (Kalvelage et al., 2013). This work aims to better understand the influence of particle export on the biogeochemistry of tropical OMZs.

Methodology and sample collection

Three surface tethered sediment traps (Engel et al., 2017) were deployed, unfortunately the first sediment trap was entangled in a fishing net, the sediment trap array was cut, thus the samples could not be recovered. The next two sediment traps were successfully deployed for periods of 6 and 7 days. Deployments dates (UTC time), locations, traps depths and parameters sampled are presented in Fig. 5.10 and Tab. 5.9. The design of the trap devices and the drifting array follows (Knauer et al., 1979), with 12 particle interceptor traps (PITs) mounted on a polyvinyl chloride (PVC) cross frame. The PITs are made of acrylic tubes with an inside diameter of 7 cm, an outside diameter of 7.6 cm and a height of 53 cm. PVC crosses with PITs were attached to a

floating line, with a buoy in surface and a weight at the bottom of the line. Prior to each deployment, PITs were filled with 1.5 L of filtered surface seawater (0.2 µm pore size cartridge) collected from the CTD at 200m near the deployment site. A brine solution was prepared by dissolving 50 g L^{-1} sodium chloride with filtered surface seawater and subsequently filtered through a 0.2 µm cartridge to remove excess particulates. This was added at the bottom of the PITs. 20 mL of formalin was added per liter of solution (final concentration 0.74% formalin).

Tab 5.9: Deployments dates, depths and parameters for traps 5, 6, and 7.

	Trap 5	Trap 6	Trap 7
Deployment date	05-06-17 23:56	08-06-17 15:50	17-06-17 14:26
Recovery date	Not recovered	14-06-17 12:30	24-06-17 12:00
Depths	50, 100, 150, 200, 300, 400, 500, 600 m	60, 100, 150, 200, 300, 400, 500, 600 m	50, 100, 150, 200, 300, 400, 500, 600 m
Parameters	Not recovered	POC, PN, POP, mass, Chl-a, Bsi, PAA, PCHO, TEP, CSP, DNA	POC, PN, POP, mass, Chl-a, Bsi, PAA, PCHO, TEP, CSP, DNA, imaging gels

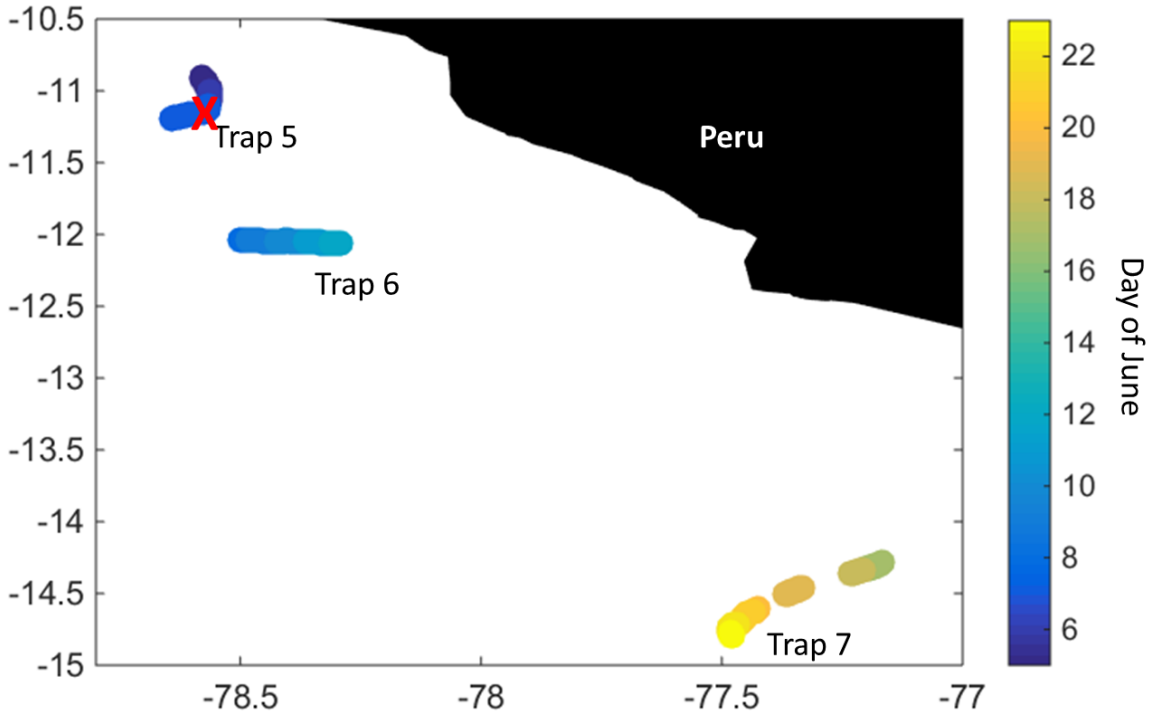


Fig 5.10: Sediment trap drift locations, red cross in trap 5 trajectory indicates when it was entangled in a fishing net.

Additionally to the two successful trap deployments, water from the CTD was sampled at stations corresponding the trap deployments and recovery locations and also, once per day when no trap recovery nor deployment occurred; additionally transect F (mode Eddy survey) and equatorial transect were sampled. The parameters sampled from the CTD and associated depths are presented in Tab. 5.10.

Future work and outlook

All parameters from traps and CTDs (Tab. 5.9 and Tab. 5.10) will be analysed following methods presented in (Cisternas Novoa et al., 2015; Engel et al., 2017). The elemental fluxes of the various trap parameters will be calculated at each depth. The concentration of the various CTD parameters will serve as background information for both traps and also general biogeochemical status of the water column. The gels for imaging used on trap 4 will be analysed using methods presented in (Laurenceau-Cornec et al., 2015) in order to get more information on the type of particles present at each depth.

Tab 5.10: CTD sampling summary. Stations ID, parameters and sampling depth are provided for each CTD sampled. (ns: not sampled)

Meteor station	Pigments	POC	TEPmicro	CSPmicro	POP
879	5, 30, 60, 80, 100, 200, 300, 600, 1000, 1500 and 2000 m	5, 30, 60, 80, 100, 200, 300, 600, 1000, 1500 and 2000 m	ns	ns	ns
880	5, 20, 50, 65, 80, 100, 150, 200, 375, 400, and 600 m	5, 20, 50, 65, 80, 100, 150, 200, 375, 400, and 600 m	5, 20, 375 and 600 m	ns	ns
882	20, 50, 100, 150, 200, 300, 400, 500 and 600 m	20, 50, 100, 150, 200, 300, 400, 500 and 600 m	20, 50, 100, 150, 200, 300, 400, 500 and 600 m	20, 50, 100, 150, 200, 300, 400, 500 and 600 m	20, 50, 100, 150, 200, 300, 400, 500 and 600 m
883	5, 20, 60, 80, 100, 150, 185, 200, 250 and 300 m	5, 20, 60, 80, 100, 150, 185, 200, 250 and 300 m	5, 60, 100 and 300	ns	ns
884	5, 20, 50, 100 and 130 m	5, 20, 50, 100 and 130 m	5, 20, 50, 100 and 130 m	ns	ns
886	5, 20, 30, 50, 65, 70, 100, 120, 150, 200 and 250 m	5, 20, 30, 50, 65, 70, 100, 120, 150, 200 and 250 m	5, 65, 120 and 250 m	ns	ns
888	20, 60, 100, 150, 200, 300, 400, 500 and 600 m	20, 60, 100, 150, 200, 300, 400, 500 and 600 m	20, 60, 100, 150, 200, 300, 400, 500 and 600 m	20, 60, 100, 150, 200, 300, 400, 500 and 600 m	20, 60, 100, 150, 200, 300, 400, 500 and 600 m
892	5, 20, 50, 70, 80, 100, 120, 145, 200, 400 and 600 m	5, 20, 50, 70, 80, 100, 120, 145, 200, 400 and 600 m	20, 70, 145 and 200 m	ns	ns
894	5, 20, 40, 60, 75, 100, 120, 200 and 400 m	5, 20, 40, 60, 75, 100, 120, 200 and 400 m	5, 60, 200 and 400 m	ns	ns
897	15, 35, 65, 100 and 150 m	15, 35, 65, 100 and 150 m	15, 35, 65, 100 and 150 m	ns	ns
898	20, 60, 100, 150, 200, 300, 400, 500, and 600 m	20, 60, 100, 150, 200, 300, 400, 500, and 600 m	20, 60, 100, 150, 200, 300, 400, 500, and 600 m	20, 60, 100, 150, 200, 300, 400, 500, and 600 m	20, 60, 100, 150, 200, 300, 400, 500, and 600 m
904	5, 10, 20, 50, 70, 100, 120 and 150 m	5, 10, 20, 50, 70, 100, 120 and 150 m	ns	ns	ns
906	20, 50, 100, 150, 200, 300, 400, 500 and 600 m	20, 50, 100, 150, 200, 300, 400, 500 and 600 m	20, 50, 100, 150, 200, 300, 400, 500 and 600 m	20, 50, 100, 150, 200, 300, 400, 500 and 600 m	20, 50, 100, 150, 200, 300, 400, 500 and 600 m
907	5, 20, 30, 40, 60, 80, 110, 200, 400, 450 and 500	5, 20, 30, 40, 60, 80, 110, 200, 400, 450 and 500	10, 60, 200 and 500 m	ns	ns
908	ns	5, 25, 35, 50, 200, 300, 600 and 1500	5, 30, 200, and 600 m	ns	ns
909	ns	5, 18, 25, 50, 200, 300 and 600 m	ns	ns	ns
910	ns	5, 20, 30, 40, 200, 300 and 600 m	ns	ns	ns
911	ns	5, 15, 25, 45, 200, 300 and 600 m	ns	ns	ns
912	5, 20, 45, 50, 60, 80, 100, 200, 300, and 600	5, 20, 45, 50, 60, 80, 100, 200, 300, and 600	5, 41, 90, and 600 m	ns	ns
913	ns	5, 20, 30, 60, 200, 300 and 600 m	ns	ns	ns
914	ns	5, 15, 30, 60, 200, 300, and 600 m	ns	ns	ns
915	ns	5, 15, 60, 80, 200, 300, and 600 m	5, 60, 400, and 600 m	ns	ns
916	ns	5, 15, 45, 65, 200, 300, and 600 m	ns	ns	ns
919	10, 50, 100, 150, 200, 300, 400, 500, and 600 m	10, 50, 100, 150, 200, 300, 400, 500, and 600 m	10, 50, 100, 150, 200, 300, 400, 500, and 600 m	10, 50, 100, 150, 200, 300, 400, 500, and 600 m	10, 50, 100, 150, 200, 300, 400, 500, and 600 m
924	ns	6, 20, 45, 100, 200, 300 and 600 m	6, 200, 400 and 600 m	ns	ns
926	ns	5, 42, 50, 150, 200, 300 and 600 m	ns	ns	ns
928	ns	5, 30, 40, 100, 200, 300 and 600 m	5, 200, 270, and 600 m	ns	ns
930	ns	5, 25, 50, 100, 200, 300 and 600 m	ns	ns	ns
932	ns	5, 25, 40, 100, 200, 300 and 600 m	5, 175, 325, and 600 m	ns	ns
934	ns	5, 35, 75, 100, 200, 300 and 600 m	ns	ns	ns
936	ns	5, 45, 55, 100, 200, 300 and 600 m	ns	ns	ns
879	ns	ns	ns	ns	ns
880	ns	ns	ns	ns	ns

882	20, 50, 100, 150, 200, 300, 400, 500 and 600 m	20, 50, 100, 150, 200, 300, 400, 500 and 600 m	20, 50, 100, 150, 200, 300, 400, 500 and 600 m	20, 50, 100, 150, 200, 300, 400, 500 and 600 mns	20, 50, 100, 150, 200, 300, 400, 500 and 600 m
884	ns	ns	ns	ns	ns
886	ns	ns	ns	ns	ns
888	20, 60, 100, 150, 200, 300, 400, 500 and 600 m	20, 60, 100, 150, 200, 300, 400, 500 and 600 m	20, 60, 100, 150, 200, 300, 400, 500 and 600 m	20, 60, 100, 150, 200, 300, 400, 500 and 600 m	20, 60, 100, 150, 200, 300, 400, 500 and 600 m
892	ns	ns	ns	ns	ns
894	ns	ns	ns	ns	ns
897	ns	ns	ns	ns	ns
898	ns	ns	20, 60, 100, 150, 200, 300, 400, 500, and 600 m	20, 60, 100, 150, 200, 300, 400, 500, and 600 m	20, 60, 100, 150, 200, 300, 400, 500, and 600 m
904	ns	ns	ns	ns	ns
906	20, 50, 100, 150, 200, 300, 400, 500 and 600 m	20, 50, 100, 150, 200, 300, 400, 500 and 600 m	20, 50, 100, 150, 200, 300, 400, 500 and 600 m	20, 50, 100, 150, 200, 300, 400, 500 and 600 m	20, 50, 100, 150, 200, 300, 400, 500 and 600 m
907	5, 20, 30, 40, 60, 110, 200, 400, and 500	5, 20, 30, 40, 60, 110, 200, 400, and 500	ns	ns	ns
908	5, 25, 35, 50, 200, 300, 600 and 1500	5, 25, 35, 50, 200, 300, 600 and 1500	ns	ns	ns
909	5, 18, 25, 50, 200, 300 and 600 m	10, 505, 18, 25, 50, 200, 300 and 600 m	ns	ns	ns
910	5, 15, 25, 45, 200, 300 and 600 m	5, 20, 30, 40, 200, 300 and 600 m	ns	ns	ns
911	Ns	5, 20, 30, 40, 200, 300 and 600 m	ns	ns	ns
912	5, 20, 45, 50, 60, 80, 100, 200, 300, and 600 m	5, 20, 45, 50, 60, 80, 100, 200, 300, and 600 m	ns	ns	ns
913	5, 20, 30, 60, 200, 300, and 600	5, 20, 30, 60, 200, 300, and 600 m	ns	ns	ns
914	5, 15, 30, 60, 200, 300, and 600 m	5, 15, 30, 60, 200, 300, and 600 m	ns	ns	ns
915	5, 15, 60, 80, 200, 300, and 600 m	5, 15, 60, 80, 200, 300, and 600 m	ns	ns	ns
916	5, 15, 45, 65, 200, 300, and 600 m	5, 15, 45, 65, 200, 300, and 600 m	ns	ns	ns
919	ns	ns	10, 50, 100, 150, 200, 300, 400, 500, and 600 m	10, 50, 100, 150, 200, 300, 400, 500, and 600 m	10, 50, 100, 150, 200, 300, 400, 500, and 600 m
924	6, 20, 45, 100, 200, 300 and 600 m	6, 20, 45, 100, 200, 300 and 600 m	ns	ns	ns
926	5, 42, 50, 150, 200, 300 and 600 m	5, 42, 50, 150, 200, 300 and 600 m	ns	ns	ns
928	5, 30, 40, 100, 200, 300 and 600 m	5, 30, 40, 100, 200, 300 and 600 m	ns	ns	ns
930	5, 25, 50, 100, 200, 300 and 600 m	5, 25, 50, 100, 200, 300 and 600 m	ns	ns	ns
932	5, 25, 40, 100, 200, 300 and 600 m	5, 25, 40, 100, 200, 300 and 600 m	ns	ns	ns
934	5, 35, 75, 100, 200, 300 and 600 m	5, 35, 75, 100, 200, 300 and 600 m	ns	ns	ns
936	5, 45, 55, 100, 200, 300 and 600 m	5, 45, 55, 100, 200, 300 and 600 m	ns	ns	ns

5.10 Biological Carbon Pump

(R. Xie, M. Gledhill, E. Achterberg)

Scientific rational and Objectives

Our main objective is to apply the ^{234}Th tracer to provide a comprehensive understanding of the supply processes of organic matter to the Peruvian oxygen minimum zone, where direct observations of particle export are lacking during the previous phases of the SFB 754 program, and its contribution to oxygen consumption during degradation. The radionuclide ^{234}Th, with a half-life of 24.1 days, is constantly produced by the decay of its parent ^{238}U. While U is highly soluble and conservative in oxygenated waters, Th is very particle reactive. The deficit of ^{234}Th in the upper water column thus is used to quantify export fluxes from the euphotic zone to the deeper ocean. Conversely, as particles remineralize below the photic zone, ^{234}Th is released back to the water column; thus the vertical profiles of ^{234}Th allow the estimation of remineralization rates. With information on the particulate carbon to ^{234}Th (POC/^{234}Th) ratios from sinking particles, or any chemical parameters of which the ratio to ^{234}Th can be determined, one can estimate the export fluxes of carbon (or nitrogen, phosphorus, or trace metals). When compared

with data on primary production, these estimates on carbon export allow the evaluation of the efficiency of the biological carbon pump.

Methods

During M138, unfiltered seawater samples (4L each) for the activities of total ^{234}Th, which include both dissolved and particulate phases, were collected from NISKIN bottles mounted on a traditional CTD at 12 stations (Tab. 5.11). These were primarily located at eight of the nine 24-hr stations, three sediment trap deployment and recovery sites, and one eddy periphery site. Three stations were sampled along a transect within an anticyclonic eddy around 16°S. High vertical resolution sampling was performed at the upper 200 m where most of the biological activities occur; additional depths were sampled down to 600 m, or 60 m above the seafloor. Deep seawater at 1000 m, 1500 m, and 2000 m were sampled at two stations for calibration purpose. Filtered (0.2 Acropak® polycarbonate membrane) seawater (15 ml) for uranium concentrations was sampled from the same NISKIN bottles for ^{234}Th.

At each CTD station, except the very first CTD station, suspended (1 - 50 µm on polycarbonate membranes) and sinking particulates (>50 µm on Nitex mesh) were collected using the Challenger stand-alone pump system (SAPS) (Tab. 5.12) deployed with a plastic cable. Three of these SAPS stations were sampled at sites where sediment traps were deployed, and additional two SAPS stations were positioned where sediment traps were recovered, to investigate the agreement and differences in carbon export estimated between these two methods. The chemical separation of thorium from seawater on board followed Pike et al. (2005). Thorium was co-precipitated with MnO_2 and filtered onto 25 mm QMA filters. These precipitates were dried in an oven at 55˚C for several hours before analysis. For the sinking particulates, each mesh filter was evenly split in halves using a ceramic knife. One half of each filter was folded and kept at a -20˚C freezer until further processing for trace metal analysis in home laboratory, while the other half was split equally into four quarters. Particles from ach quarter was re-suspended in filtered (0.2 µm) trace-metal-clean seawater, and re-filtered onto (1) pre-combusted QMA filters for Th, POC, and PON; (2) pre-combusted GFF filters for PIP; (3) pre-combusted GFF filters for POP; and (4) GFF filters for pigment. Pigment samples were stored in a -80˚C fridge until further analysis at home laboratory. Filters with samples of Th, POC, PON, PIP, and POP were dried in an oven at 55˚C. Filters of both total and particulate ^{234}Th were mounted onto the Risø sample holders, and initial activities of ^{234}Th were counted on the Risø low-level beta GM multicounter.

Polycarbonate filters with suspended particles for trace metals were folded and stored at -20˚C until analysis at home laboratory.

Tab. 5.11: List of seawater stations for total ^{234}Th.

Station #	Cast #	Latitude	Longitude	Sample depths (m)
879	1	-11°28.05'	-79°26.27'	2000, 1500, 1000, 600, 300, 200
879	3	-11°29.64'	-79°28.70'	100, 80, 60, 30,5
882	10	-10°57.11'	-78°33.74'	600,500,400,300,200,150,100,70,50,20
883	12	-10°46.74'	-78°16.21'	250,200,150,100,80,60,30,5
888	7	-12°01.98'	-78°29.97'	600,500,400,300,200,150,100,80,60,50,20
892	14	-12°25.07'	-77°48.74'	500,400,300,200,150,100,80,60,50,5
898	1	-12°03.48'	-78°16.40'	600,500,400,300,200,150,100,80,60,20
898	2	-12°03.48'	-78°16.40'	2000, 1500, 1000

904	16	-13°59.84'	-76°39.59'	450,300,150,100,70,50,20,15,10,5
906	18	-14°17.92'	-77°10.76'	600,500,400,300,200,150,100,70,50,40,20
907	11	-15°25.78'	-75°25.91'	500,400,300,200,150,100,80,60,40,5
912	3	-15°51.59'	-76°06.60'	600,300,200,150,100,80,60,50,45,20,5
915	1	-16°09.69'	-76°34.40'	500,400,300,200,150,100,70,60,40,15,5
919	1	-14°45.59'	-77°28.98'	600,500,400,300,200,150,100,60,50,30,10

Tab. 5.12: List of SAPS stations for particulate ^{234}Th.

SAPS number	Station number	Cast number	Latitude	Longitude	Sample depths (m)
SAPS 1	882	13	-10°57.10'	-78°33.81'	50, 100, 300
SAPS 2	883	14	-10°46.84'	-78°16.55'	30,100,200
SAPS 3	888	4	-12°02.39'	-78°30.00'	50, 100, 300
SAPS 4	892	13	-12°25.07'	-77°48.74'	50, 100, 200
SAPS 5	898	3	-12°03.48'	-78°16.40'	60, 100, 300
SAPS 6	904	14	-14°00.09'	-76°39.70'	20, 50, 150
SAPS 7	906	16	-14°17.03'	-77°10.04'	50, 100, 300
SAPS 8	907	13	-15°25.70'	-75°24.86'	40,100,300
SAPS 9	912	5	-15°51.59'	-76°06.60'	50,100,300
SAPS 10	915	5	-16°09.69'	-76°34.40'	70,150,300
SAPS 11	919	3	-14°45.59'	-77°28.98'	50,100,300

Parameters to be measured at home laboratory

Filters of both total and particulate ^{234}Th will be counted on the Risø low-level beta GM multicounter again 5 months after sample collection, to determine the actual ^{234}Th activities at time of filtration, for total ^{234}Th, or sampling, for particulate ^{234}Th. After the final counting, total ^{234}Th samples will be dismounted and dissolved in a mixture of H_2O_2 and HNO_3 and analyzed on the Element ICP-MS to determine chemistry yield, following Pike et al. (2005). For particulate ^{234}Th samples, they will be dismounted so that the POC and PON content will be concurrently measured to determine the POC/^{234}Th or PON/^{234}Th ratios. PIP and POP samples will be analyzed following methods in Lomnitz et al. (2016). Pigment samples will be measured on the ultrahigh performance liquid chromatography electrospray ionization mass spectrometer (UHPLC-ESI-MS). Seawater samples for uranium concentrations will be measured on the Element ICP-MS. We expect all chemical processing and analysis be done within a year from the end of M138.

Tab. 5.13: Timeline of chemistry measurement in home laboratory at GEOMAR.

Parameters	Contact person	Present affiliation	Email	Time results expected
234Th activities, POC, PON, PIP, POP, uranium conc.	Ruifang Xie	GEOMAR	rxie@geomar.de	July 2018
Pigment	Martha Gledhill	GEOMAR	mgledhill@geomar.de	July 2018

5.11 Dissolved Organic Matter, Cell Abundance and Extracellular Enzyme Rates

(M. Maßmig, A. Engel)

Background

In order to study the influence of oxygen concentrations on the bacterial growth and degradation of organic matter, seawater was sampled at 21 CTD stations and 5-11 depths along the different transects - including the stations of sediment trap deployment and recovery (Fig. 5.11). The different depths covered a broad range of *in-situ* oxygen concentrations crossing the upper and lower oxycline (Tab. 5.14). Organic matter hydrolysis by extracellular enzymes is the key step in bacterial degradation of organic matter. The rates of the three abundant extracellular enzymes leucine aminopeptidase, ß glucosidase and alkaline phosphatase were measured with different concentrations of fluorescent substrate analogues to achieve Michalis Menten kinetics according to Hoppe (1983). The enzymes were incubated under two oxygen levels (oxic and suboxic conditions) at 13°C. Since enzymes are known to be pH sensitive also the pH was measured at all depth. Enzymerate measurements will be compared to bacterial cell abundances (determined by flow cytometry after Gasol and del Giorgio (2000)). In order to describe the *in situ* substrate availability for bacteria, samples for dissolved organic carbon concentrations (DOC), as well as concentrations and composition of dissolved amino acids (DAA) and dissolved high molecular weight carbohydrates (DCHO) were taken, filtered and stored at +4°C or -20°C respectively. DOC will be analyzed with a high temperature combustion method after Sugimura and Suzuki (1988) and Engel and Galgani (2016). For analyzes of DAA the high performance liquid chromatography method after Lindroth and Mopper (1979) will be applied and DCHO will be analyzed after Engel and Händel (2011). Additionally, dissolved organic phosphorous (DOP) was sampled at selected depths and will be determined after Grasshof (1999). Samples for bacterial abundances, DOC, DAA, DCHO and DOP were shipped frozen or cooled to the home laboratory at GEOMAR and will be analyzed within the next six month. Data will be available in OceanRep within the next 2 years. Since oxygen has a higher electron potential than alternative electron acceptors and thus provides more energy to the microbial community as nitrate, we expect higher growth and degradation rates under oxic conditions. However former studies, did not find any oxygen dependence of bacterial biomass production as well as enzyme activity (Pantoja et al. 2009). Here we collected more data to find possible statistical correlations and dependencies between oxygen concentrations and the bacterial degradation of organic matter as well as extracellular enzyme rates. As enzymes in the field are known to be inversely correlated with their respective nutrient concentrations as it is described for depth profiles of peptidase and dissolved inorganic nitrogen (Nausch and Nausch, 2000), or in experiments with alkaline phosphatase and phosphorus forms (Torriani 1960), we also expect lower enzyme rates at higher nutrient concentrations.

Tab.5.14: CTD profiles and depths sampled for dissolved organic carbon (DOC), dissolved high molecular weight carbohydrates (DCHO), dissolved amino acids (DAA), cell abundance, extracellular enzyme rates (Enzymes), pH and dissolved organic phosphorous (DOP).

station		lat 'S	long 'W	depth					
1	880-1/4	11°1769	079°0854	5	20	50	65	80	
				100	150	200	375	400	600
2	552-10	10°57.114	078°33.739	20	50	70	100	150	
				200	260	300	400	500	600
3	883-12	10°46.73	078°16.21	5	20	30	40	60	
				80	100	150	190	200	250
4	884-1	10°40.180	078°05.390	5	20	50	100	130	
5	886-3	12°02.978	077°45.156	5	20	30	50	65	
				70	100	120	150	200	250
6	888-7	12°01.983	078°29.966	20	60	70	80	100	
				150	200	300	400	500	600
7	892-3	12°25.082	077°48.736	5	20	50	70	80	
				100	120	145	200	400	600
8	894-4	12°19.374	077°371.78	5	20	40	60	75	
				100	120	200	400		
9	897-12	12°12.60	077°26.40	15	35	65	100	150	
10	898-1	12°03.478	078°16.398	20	60	70	80	100	
				150	200	300	400	500	600
11	902-1	13°10.762	076°38.451	5	15	25	40	150	
12	904-16	13°59.837	076°39.594	5	10	20	50	70	
				100	120	200	400	500	542
13	906-18	14°17.920	077°10.762	20	40	50	70	100	
				150	200	300	400	500	600
14	907-7	15°25.782	075°25.898	10	20	30	40	60	
				100	130	200	400	450	500
15	908-3	15°32.367	075°36.647	5	20	25	30	40	
				100	200	400	600	1500	
16	912-11	15°51.587	076°06.596	5	20	41	51	54	
				90	200	400	600		
17	915-3	16°09.649	076°34.428	5	15	20	60	65	
				80	100	150	200	400	600
18	919-1	14°45.589	077°28.979	10	30	50	60	100	
				150	200	300	400	500	600
19	924-1	03°59.988	85°49.839	6	20	45	100	200	
				275	300	400	600		
20	928-1	01°59.984	085°50.000	5	20	30	100	200	
				230	270	400	600		
21	932-1	00°00.019	85°50.034	5	20	25	40	100	
				175	200	250	325	400	600

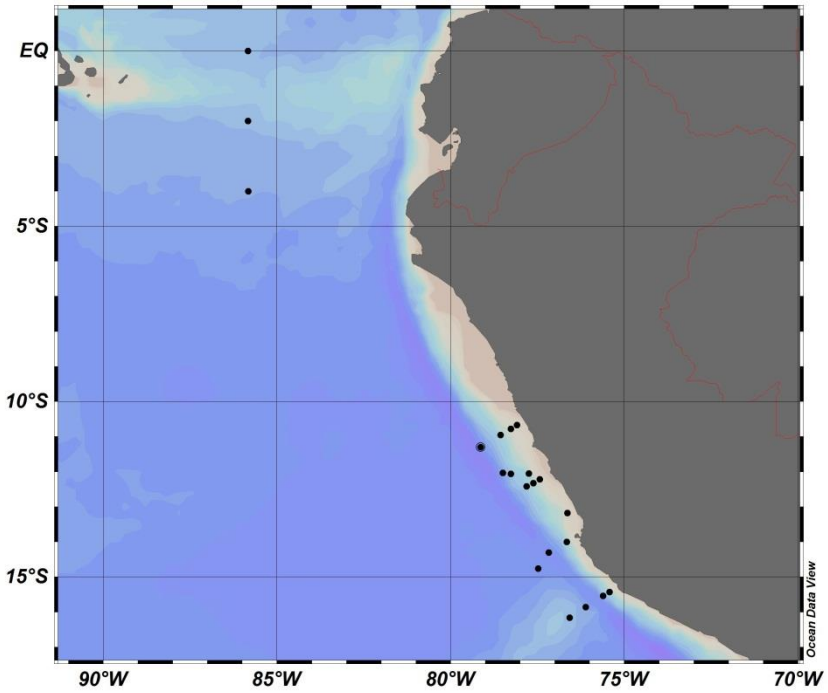


Fig. 5.11: Map of all sampled CTD profiles during M138. The black dots indicate sampled stations for the parameters listed in Tab. 5.14.

5.12 Zooplankton Distribution and Migration

(H. Hauss, H.-J. Hoving, R. Kiko)

Zooplankton organisms are an essential component of pelagic elemental cycles. In particular, diurnal vertical migrations (DVM) of pelagic organisms strongly impact nutrient fluxes and oxygen consumption at depth. In the Eastern Tropical Pacific, the intense OMZ is structuring the pelagic habitat and impacting both nighttime and daytime distributions of animals. On this cruise, we specifically aimed to resolve the fine-scale distribution of zooplankton in the upper oxycline to address whether metazoan animals may contribute to sharpening of the oxygen gradient by respiration, and to provide ammonium for anaerobic N-loss processes by excretion. Furthermore, we strived to expand the ecological knowledge on fragile organisms (such as giant rhizaria, medusae, ctenophores and siphonophores) in this area. Since these are notoriously undersampled by nets, and because the depth resolution of net samples remains rather coarse, we employed *in situ* imaging techniques in addition to net sampling. A Hydrobios Multinet Midi with an aperture of 0.25 m^2 and 5 nets (mesh size 200 µm) was deployed for vertically stratified hauls. To determine the main distribution and migration of zooplankton in the upper 1000 m, vertical hauls were conducted on the positions of the 24h-stations at night and day (8*2 = 16 hauls) and another one at the recovery size of the first sediment trap (also day and night). Standard depths were used for these deployments (1000-600-300-200-100-0 m). In addition, it was aimed to resolve the fine-scale distribution of zooplankton in the upper oxycline. To this end, oblique hauls were conducted by towing the same net (ship speed 2 kn) and the five nets closed according to the oxygen concentration (target ranges approximately 0-0.5-1-2-3 and >3ml/L). This was also done on the 24h- stations during day and night (8*2 = 16 hauls). In total, 170 samples were collected and fixed in 4% formaldehyde in seawater solution. They will be scanned and analyzed using automated imaging software allowing taxonomical classification as

well as the estimation of taxon-specific biomass and metabolic rates. In addition, microzooplankton samples were taken at each 24h-station from CTD-casts at four depths (OMZ core, oxyline, Chl-a maximum and surface) for counts (Lugol-fixed 250 ml) and protozoan DNA. An Underwater Vision Profiler 5 (UVP 5) was mounted in an external frame on the CTD-rosette during 43 casts. With this frame, it could also be attached on the PELAGIOS (another 16 vertically stratified towed casts). The instrument consists of one down facing HD camera in a steel pressure case and two red LED lights which illuminate a 0.93L-water volume. During the downcast, the UVP takes 3-11 pictures of the illuminated field per second. For each picture, the particles in each image are counted and sized immediately and the data stored in the instrument for later analysis. Furthermore, images of particles with a size > 500 µm are saved as separate "vignettes" - small cut-outs of the original picture – which allow for later, computer assisted identification of these particles and their assignment into different particle, phyto- and zooplankton groups. Since the UVP5 was integrated in the CTD and has its own pressure sensor, fine-scale vertical distribution of particles and major planktonic groups can be related to environmental data. The pressure case of the UVP5 is rated to 6000 m depth and therefore it is usually deployed on all CTD casts. However, because a crack was identified in one of the glass housing of the light unit, we did a 500 m pressure test with the light unit only as advised by the manufacturer and subsequently only performed CTD profiles up to 600 m depth. PELAGIOS consists of an aluminum frame with a forward looking high definition camera. The water column in front of the camera is illuminated by 6 LEDs. A battery provides power to the camera and the lights and a Hydrobios depth sensor provides online information on the depth of the instrument. An O_2 logger was mounted on the system to store concomitant O_2 data. PELAGIOS was attached to the CTD cable and towed by the ship at 1 knot. This resulted in horizontal pelagic video transects in which organisms > 1cm could be identified and quantified and correlated with environmental parameters such as depth, oxygen, temperature. Since we deployed PELAGIOS and UVP together it is also possible to correlate macrozooplankton distribution and abundance with mesozooplankton and particles. PELAGIOS with the UVP was deployed at 8 stations, each during day and night. The depths at which the system was deployed ranged from 10-480 m. A total of about 60 hours of video was collected. This video will be analyzed after the cruise and each organism will be identified to the lowest possible taxonomic unit, and quantified. This will allow an analysis of vertical distribution and abundance during day and night which will give insight in the daily vertical migration of some abundant taxa. Preliminary analysis already shows interesting and interspecific differences between daily vertical migrations of krill (*Euphausia mucronata*), squat lobsters (*Pleuroncodes monodon*) and medusae. The analysis of the pelagic transect video will also provide one of the first views into the ecosystem of the Peruvian upwelling region, and how the strong oxygen minimum zone impacts distribution of larger organisms in the water column.

5.13 Trace Metals and Organic Nutrients

(J. Meyer, M. Gledhill, R. Xie, E. Achterberg)

Background and Objectives

The aim of our program undertaken on cruises M135-M138 is to determine the fluxes of Fe, dissolved organic nitrogen (DON) and dissolved organic phosphorus (DOP), and processes affecting Fe behaviour in the Peruvian shelf region, with an emphasis on the effects of spatial and temporal variations in redox conditions in the water column. The availability of Fe, phosphorus (P) and nitrogen (N) in the surface ocean controls primary productivity, di-nitrogen fixation, microbial community structure and thus carbon cycling. Large deviations in water column oxygen saturation result in enhanced biogeochemical transformations of Fe, N and P in OMZs. OMZs can represent a key source of Fe, N and P to overlying surface waters and off shore regions. The focus of M138 has been on processes occurring in the surface waters (<600 m).

Methods: Trace metals

Trace metal (TM) sampling in the water column was carried out on four cruises M135-M138 with the sampling procedure remaining the same on all 4 cruises. A trace metal clean sampling rosette and winch were operated from Meteor's A-frame with the winch container mounted in the central position at the stern of the ship. A pre-fabricated lab container with in-built air filtration was positioned forward and starboard of this. The trace metal clean sampling rosette was equipped with GO-FLO bottles which were stored in the trace metal clean lab container when not in use. Before trace metal (CTD-TM) stations, GO-Flo bottles were covered with protective plastic caps, bottoms and gloves over the spigots inside the clean container. They were then carried onto deck and mounted onto the trace metal sampling rosette. Immediately (maximum 5 minutes) before deployment the protective plastic was removed. Upon return to deck, gloves were immediately added to the spigots and then the GO-FLO bottles returned to the clean laboratory for sampling. Surface (~2-3 m depth) seawater was sampled from a custom-built towed-fish via acid washed 1 cm diameter tubing with suction provided by a peristaltic pump. Water was pumped directly into the purpose-built clean air laboratory container. Sampling for contamination-sensitive parameters (trace metals, particles for elemental analysis) was undertaken inside the clean container. Positive air pressure was maintained in the container via a continuous inward air flow, with dust particles in this air flow removed by a HEPA filter. Inside the laboratory, clean suits were worn and all labware was free from exposed metal components. N_2 gas was used to overpressure (0.2 atm) all Go-Flo bottles. O_2 samples were collected immediately after bottles were in the clean container. Sampling then proceeded around the Go-Flo bottles in the order trace metals, isotopes, nutrients, salinity. Overall 11 TM stations were sampled with 95 dissolved trace metal samples collected and acidified for analysis in Kiel. A further 50 underway time points were sampled during M138 for macronutrient (nitrate, nitrite, phosphate, silicate) and trace element concentrations.

Methods: Trace elements

Samples were collected in acid washed 125 mL LDPE sample bottles for dissolved (0.2 µm filter capsule) trace metal concentrations (metals: Fe, Zn, Mn, Mg, Cu, Co, Cd, Al). Samples were acidified with 180 µL concentrated (10 M) UpA grade hydrochloric acid (Romil), in batches and

under a laminar flow hood, within 2 days of collection. These samples will be measured on return to GEOMAR via pre-concentration on a SeaFAST system (ESI) and subsequent analysis on an Element 2 ICP-MS (Thermo Scientific) following the method of Rapp et al. (2017).

Methods: Major nutrients:
Samples were collected for dissolved macronutrients analyses. 12 mL samples were collected in plastic test tubes for macronutrient concentrations. Macronutrients were stored refrigerated and measured onboard within 1 day of collection.

Methods: Particles
At all off shelf CTD-TM stations, 2-4 L of seawater was filtered through Sartorius PES 0.2 µm filters to collect sufficient particles for elemental analysis in Kiel. Filters were mounted on plastic, acid cleaned, filter holders and attached directly to Go-Flo bottles (still under N_2) and then allowed to drain for approximately 2-3 hours. Filters were then frozen in a -20°C freezer. They will be digested and analysed via ICP-MS in Kiel.

Methods: Cd isotopes
Samples were collected in acid washed 1-4 L LDPE bottles for dissolved (0.2 µm filter capsule) Cd isotopic analysis. These samples were then stored sealed in plastic bags and will be analysed upon return to Kiel. A total of 30 samples were kept for analysis, collected from 2 stations along the 14 S section.

Tab 5.15: List of Stations and measured parameters: Trace metals, nutrients and Cd isotopes.

Station	Cast	Date	Time (UTC)	Depth (m)	Dissolved trace metals	Nutrients	Cd isotopes
880	Towfish	4.6.2017	02:47	2	X	X	
882	Towfish	4.6.2017	08:47	2	X	X	
882	TM_86	5.6.2017	11:06:33	300	X	X	
882	TM_86	5.6.2017	11:07:24	300	X	X	
882	TM_86	5.6.2017	11:08:20	260	X	X	
882	TM_86	5.6.2017	11:09:48	220	X	X	
882	TM_86	5.6.2017	11:13:49	150	X	X	
882	TM_86	5.6.2017	11:14:57	100	X	X	
882	TM_86	5.6.2017	11:15:47	75	X	X	
882	TM_86	5.6.2017	11:16:37	50	X	X	
882	TM_86	5.6.2017	11:19:20	35	X	X	
882	Towfish	5.6.2017	12:20	2	X	X	
883	Towfish	5.6.2017	14:45	2	X	X	
883	TM_87	6.6.2017	08:13:41	300	X	X	
883	TM_87	6.6.2017	08:13:41	250	X	X	
883	TM_87	6.6.2017	08:13:41	200	X	X	
883	TM_87	6.6.2017	08:13:41	150	X	X	
883	TM_87	6.6.2017	08:13:41	100	X	X	
883	TM_87	6.6.2017	08:13:41	75	X	X	
883	TM_87	6.6.2017	08:13:41	50	X	X	

883	TM_87	6.6.2017	08:13:41	30	X	X	
883	TM_87	6.6.2017	08:13:41	20	X	X	
883	Towfish	6.6.2017	13:00	2	X	X	
883	Towfish	6.6.2017	17:09	2	X	X	
884	TM_88	6.6.2017	21.23	100	X	X	
884	TM_88	6.6.2017	21.23	75	X	X	
884	TM_88	6.6.2017	21.23	50	X	X	
884	TM_88	6.6.2017	21.23	25	X	X	
884	TM_88	6.6.2017	21.23	20	X	X	
884	Towfish	6.6.2017	23:10	2	X	X	
885	Towfish	7.6.2017	12:53	2	X	X	
885	TM_89	7.6.2017	15.15	130	X	X	
885	TM_89	7.6.2017	15.15	100	X	X	
885	TM_89	7.6.2017	15.15	55	X	X	
885	TM_89	7.6.2017	15.15	40	X	X	
885	TM_89	7.6.2017	15.15	30	X	X	
885	TM_89	7.6.2017	15.15	20	X	X	
886	Towfish	7.6.2017	18:26	2	X	X	
887	Towfish	8.6.2017	00:22	2	X	X	
888	Towfish	8.6.2017	07:17	2	X	X	
888	TM_90	8.6.2017	14.1	600	X	X	
888	TM_90	8.6.2017	14.1	500	X	X	
888	TM_90	8.6.2017	14.1	400	X	X	
888	TM_90	8.6.2017	14.1	300	X	X	
888	TM_90	8.6.2017	14.1	200	X	X	
888	TM_90	8.6.2017	14.1	100	X	X	
888	TM_90	8.6.2017	14.1	75	X	X	
888	TM_90	8.6.2017	14.1	50	X	X	
888	TM_90	8.6.2017	14.1	20	X	X	
892	TM_91	10.6.2017	23.27	500	X	X	
892	TM_91	10.6.2017	23.27	200	X	X	
892	TM_91	10.6.2017	23.27	150	X	X	
892	TM_91	10.6.2017	23.27	80	X	X	
892	TM_91	10.6.2017	23.27	60	X	X	
892	TM_91	10.6.2017	23.27	50	X	X	
892	TM_91	10.6.2017	23.27	20	X	X	
892	Towfish	11.6.2017	02:45	2	X	X	
894	Towfish	11.6.2017	05:56	2	X	X	
897	TM_92	12.6.2017	06:20	150	X	X	
897	TM_92	12.6.2017	06:20	120	X	X	
897	TM_92	12.6.2017	06:20	100	X	X	
897	TM_92	12.6.2017	06:20	75	X	X	
897	TM_92	12.6.2017	06:20	65	X	X	
897	TM_92	12.6.2017	06:20	55	X	X	
897	TM_92	12.6.2017	06:20	15	X	X	
898	TM_93	13.6.2017	07:17	600	X	X	

898	TM_93	13.6.2017	07:17	500	X	X	
898	TM_93	13.6.2017	07:17	400	X	X	
898	TM_93	13.6.2017	07:17	300	X	X	
898	TM_93	13.6.2017	07:17	200	X	X	
898	TM_93	13.6.2017	07:17	150	X	X	
898	TM_93	13.6.2017	07:17	100	X	X	
898	TM_93	13.6.2017	07:17	80	X	X	
898	TM_93	13.6.2017	07:17	60	X	X	
898	TM_93	13.6.2017	07:17	20	X	X	
899	Towfish	14.6.2017	01:18	2	X	X	
900	Towfish	14.6.2017	03:37	2	X	X	
901	Towfish	14.6.2017	10:50	2	X	X	
902	Towfish	14.6.2017	16:35	2	X	X	
903	Towfish	14.6.2017	18:40	2	X	X	
904	Towfish	15.6.2017	02:04	2	X	X	
904	TM_94	15.6.2017	21:05	540	X	X	X
904	TM_94	15.6.2017	21:05	450	X	X	X
904	TM_94	15.6.2017	21:05	150	X	X	X
904	TM_94	15.6.2017	21:05	100	X	X	X
904	TM_94	15.6.2017	21:05	90	X	X	X
904	TM_94	15.6.2017	21:05	70	X	X	X
904	TM_94	15.6.2017	21:05	60	X	X	X
904	TM_94	15.6.2017	21:05	50	X	X	X
904	TM_94	15.6.2017	21:05	40	X	X	X
904	TM_94	15.6.2017	21:05	30	X	X	X
904	TM_94	15.6.2017	21:05	20	X	X	X
904	TM_94	15.6.2017	21:05	15	X	X	X
904	TM_94	16.6.2017	21:05	10	X	X	X
905	Towfish	16.6.2017	03:50	2	X	X	X
906	Towfish	16.6.2017	05:15	2	X	X	
906	TM_95	16.6.2017	21:19	600	X	X	X
906	TM_95	16.6.2017	21:19	575	X	X	X
906	TM_95	16.6.2017	21:19	550	X	X	X
906	TM_95	16.6.2017	21:19	525	X	X	X
906	TM_95	16.6.2017	21:19	475	X	X	X
906	TM_95	16.6.2017	21:19	350	X	X	X
906	TM_95	16.6.2017	21:19	200	X	X	X
906	TM_95	16.6.2017	21:19	150	X	X	X
906	TM_95	16.6.2017	21:19	100	X	X	X
906	TM_95	16.6.2017	21:19	80	X	X	X
906	TM_95	16.6.2017	21:19	60	X	X	X
906	TM_95	16.6.2017	21:19	50	X	X	X
906	TM_95	16.6.2017	21:19	40	X	X	X
906	TM_95	16.6.2017	21:19	30	X	X	X
906	TM_95	16.6.2017	21:19	20	X	X	X
906	TM_95	16.6.2017	21:19	15	X	X	X

906	TM_95	16.6.2017	21:19	10	X	X	X
Transect	Towfish	17.6.2017	16:05	2	X	X	X
Transect	Towfish	17.6.2017	17:30	2	X	X	
Transect	Towfish	17.6.2017	19:00	2	X	X	
Transect	Towfish	17.6.2017	20:25	2	X	X	
Transect	Towfish	17.6.2017	22:05	2	X	X	
Transect	Towfish	17.6.2017	23:25	2	X	X	
Transect	Towfish	18.6.2017	01:00	2	X	X	
Transect	Towfish	18.6.2017	02:30	2	X	X	
Transect	Towfish	18.6.2017	04:00	2	X	X	
Transect	Towfish	18.6.2017	05:30	2	X	X	
Transect	Towfish	18.6.2017	07:00	2	X	X	
Transect	Towfish	18.6.2017	10:30	2	X	X	
907	Towfish	19.6.2017	14:27	2	X	X	
908	Towfish	19.6.2017	19:45	2	X	X	
909	Towfish	19.6.2017	23:00	2	X	X	
910	Towfish	20.6.2017	03:35	2	X	X	
911	Towfish	20.6.2017	04:38	2	X	X	
912	Towfish	21.6.2017	09:25	2	X	X	
913	Towfish	21.6.2018	10:17	2	X	X	
914	Towfish	21.6.2017	14:00	2	X	X	
915	Towfish	21.6.2017	18:55	2	X	X	
Transect	Towfish	22.6.2017	07:05	2	X	X	
Transect	Towfish	22.6.2017	08:35	2	X	X	
Transect	Towfish	22.6.2017	10:00	2	X	X	
Transect	Towfish	22.6.2017	11:30	2	X	X	
Transect	Towfish	22.6.2017	13:02	2	X	X	
Transect	Towfish	22.6.2017	14:31	2	X	X	
Transect	Towfish	22.6.2017	16:00	2	X	X	
Transect	Towfish	22.6.2017	17:30	2	X	X	
916	Towfish	22.6.2017	18:27	2	X	X	
917	Towfish	22.6.2017	23:30	2	X	X	
918	Towfish	23.6.2017	02:30	2	X	X	

Methods: Aerosol sampling

Eolian-derived trace metals were collected on acid-cleaned Whatman 41 filters via two aerosol collectors positioned at the front of Meteor. Sampling was stopped when there was risk of contamination from the ship's exhaust, either when the ship was at stations, or when the wind was coming from behind the ship. Cadmium isotopes on both the labile and detrital eolian fractions will be measured at home laboratory in Kiel.

Dissolved organic nitrogen and phosphorus and organic phosphorous bioavailability

During research expedition M138, the contribution of dissolved organic phosphorus (DOP) and nitrogen (DON) to the overall nutrient in the eastern tropical South Pacific (ETSP) was

investigated. Moreover, the change in the fraction of bioavailable DOP between onshore and offshore stations and how organic phosphorus was recycled and whether the micro-organisms utilization characteristics of DOP varied in the study area. Biogeochemical samples were collected from the CTD. 30 mL samples for DON/DOP and 40 mL samples for phosphomonoesters were transferred into sterile syringes and filtered through combusted Whatman GF/F filters into acid-cleaned HDPE bottles or falcon tubes, respectively. Samples were frozen immediately in a -20° freezer and will be analyzed on return to GEOMAR within the next 6 months. DON/DOP concentrations will be determined using a nutrient analyzer following the breakdown of the organic compounds to inorganic nitrogen and phosphorus, respectively. Samples for phosphomonoesters will be analyzed following the method of e.g. Björkman and Karl (2001). For determination of alkaline phosphatase activity (APA), an enzyme that hydrolyzes a broad spectrum of DOP compounds and gives an indication of the DOP utilization on a community level, 100 mL of sample was collected from the CTD and enzyme activity was determined directly onboard using the fluorogenic substrate methylumbelliferyl phosphate (MUF-P). The alkaline phosphatase hydrolyses MUF-P and yields a highly fluorescent product. The increase in fluorescence over the course of 3-4 hours was detected using a microplate reader. Samples were taken from 36 vertical CTD casts on transects A-F off the Peruvian coast and from 5 CTD casts on the equatorial transect. Sampling focused on the upper 200 m of the water column, where water was collected from 7-12 distinct depth.

Tab. 5.16: List of Stations for DON/DOP, phosphomonesters and alkaline phosphatase activity.

Station	CTD Profile	Depth
880-4	6	200, 150, 100, 75, 65, 50, 30, 15, 5
881-1	7	200, 150, 100, 70, 50, 20, 10, 5
882-1	8	200, 150, 100, 75, 36, 25, 15, 5
882-3	9	260
883-6	14	200, 150, 100, 50, 30, 20, 10, 5
884-1	19	130, 100, 75, 50, 30, 25, 20, 15, 10, 5
885-1	20	135, 100, 75, 55, 40, 25, 15, 5
886-1	22	200, 150, 100, 65, 30, 15, 5
887-1	25	200, 150, 100, 75, 50, 30, 15, 5
888-7	28	200, 150, 100, 70, 50, 20, 5
889-1	29	200, 150, 100, 75, 50, 20, 10, 5
890-1	31	200, 140, 100, 75, 50, 35, 15, 5
891-1	32	200, 150, 100, 75, 50, 35, 15, 5
892-1	34	200, 140, 100, 75, 50, 25, 15, 5
894-1	42	200, 150, 100, 75, 50, 30, 15, 5
897-1	46	150, 100, 75, 45, 35, 15, 5
899-1	55	150, 100, 75, 50, 25, 15, 5
900-1	56	147, 100, 75, 50, 20, 15, 5
902-1	58	118, 100, 75, 50, 25, 15, 10, 5
903-2	59	117, 100, 75, 50, 20, 15, 10, 5
904-5	61	200, 150, 100, 75, 50, 30, 15, 10, 5
905-1	67	200, 150, 100, 75, 50, 30, 20, 10, 5
906-1	68	200, 150, 100, 75, 50, 37, 22, 12, 5
906-7	69	250, 150, 90, 55, 40, 15, 5
907-1	74	200, 150, 100, 80, 60, 35, 25, 15, 5

907-14	78	600, 500, 400, 300, 200, 150, 100, 75, 50, 30, 10
908-1	79	600, 500, 400, 300, 200, 150, 100, 75, 50, 25, 15, 5
909-1	81	600, 500, 400, 300, 200, 100, 75, 50, 30, 18, 10, 5
910-1	82	600, 500, 400, 300, 200, 150, 100, 75, 50, 25, 15, 5
911-1	84	600, 500, 400, 300, 200, 150, 100, 75, 50, 30, 15, 5
912-12	89	600, 500, 400, 300, 200, 150, 100, 75, 50, 40, 15, 5
913-1	91	600, 500, 400, 300, 200, 150, 100, 75, 50, 30, 20, 5
914-1	92	600, 500, 400, 300, 200, 150, 100, 75, 50, 35, 20, 5
915-3	95	600, 500, 400, 300, 200, 150, 100, 80, 50, 20, 15, 5
916-3	97	200, 150, 100, 75, 50, 15, 5
917-3	99	300, 200, 150, 100, 60, 35, 28, 15, 5
918-1	100	200, 150, 100, 75, 60, 42, 32, 15, 5
924-1	104	300, 200, 150, 100, 75, 45, 20, 15, 6
926-1	107	360, 200, 150, 100, 75, 50, 42, 20, 5
928-1	109	270, 245, 200, 150, 100, 75, 50, 30, 5
930-1	111	325, 200, 100, 75, 50, 25, 15, 5
932-1	113	325, 200, 150, 100, 75, 50, 40, 25, 5
934-1	115	350, 200, 150, 100, 75, 50, 35, 20, 5
936-1	117	200, 100, 50, 20, 5

Parameters to be measured in the laboratory at GEOMAR

Data	Contact person	Present affiliation	Email	Time results expected
Trace metals (dissolved and particles)	Mark Hopwood	GEOMAR	mhopwood@geomar.de	June 2018
Cd isotopes	Ruifang Xie	GEOMAR	rxie@geomar.de	Dec 2018
DON	Judith Meyer	GEOMAR	jumeyer@geomar.de	June 2018
DOP	Judith Meyer	GEOMAR	jumeyer@geomar.de	June2018
Phosphomonesters	Judith Meyer	GEOMAR	jumeyer@geomar.de	June 2018
Alkaline phosphatase activity	Judith Meyer	GEOMAR	jumeyer@geomar.de	June2018

5.14 Water Column Geobiology

(C. Löscher, E. Laursen)

Scientific background and objectives

In a broad context, our overarching scientific goal was to understand and reconstruct the relationship between environmental change and biological evolution. Specifically, we were interested in whether the oxygen minimum zone (OMZ) of Peru does over geological timescales truly expand, or whether it is rather oscillating at its lateral boundaries. The Gaia principle proposes that organisms interact with their surrounding on Earth to form a synergistic self-regulating, system that helps to maintain and perpetuate the conditions for life on Earth (Lovelock and Margulis 1974). This has shown to hold true for moderate changes in climate. Through Earth history, however, several events of extreme climates occurred, which were accompanied by mass extinctions and subsequent periods of extreme evolutionary radiation, e.g. snowball Earth or the massive anoxia during the Cretaceous. Thus, it there seems to be an upper

limit to what can be balanced. Particularly for OMZs connected to eastern boundary upwelling systems, we hypothesize that a self-regulating feedback loop regulating the oceanic oxygen budget exists. If true, this could mean that the Ocean will be able to counteract climate change at least to a certain degree through microbial activity. In order to address this fundamental topics, we are using an interdisciplinary approach combining meta-omic tools including molecular clocks with biogeochemical rate measurements (carbon fixation, oxygen consumption), chemical profiling using micro-sensors and ultimately box modeling to predict future scenarios.

List/description of measurements performed on board

The following samples have been taken:

1. Combined Nucleic acid/ protein filter samples
2. Pigment samples for Synchotron analysis
3. Flow cytometry samples
4. Lipid filter samples
5. Chromium particulate and dissolved samples

Incubations have been performed for:

1. High resolution carbon fixation (^{13}C labelling)
2. Oxygen uptake ($^{18}O_2$ labelling)

List of stations sampled and indicate which depths have been sampled

For meta-omics, including proteomics, pigment studies and lipidomics, 9-12 depth of every station have been sampled. We further took larger volume samples for in depth lipid isotope analysis and chromium from 5 depth at all 24h stations. Incubations for carbon fixation were performed from 5 depth at every second station, at all stations during the eddy transect. Oxygen uptake experiments were performed with samples from the OMZ, including oxyclines, in order to determine the oxygen dependent respiration of organic matter. We took samples from every second station and every station during the eddy transect.

List/description of measurements in the lab after the cruise

Filter samples will be extracted for proteins and nucleic acids in our home lab, we will generate high-throughput metagenomics/- transcriptomic and proteomic libraries. Those libraries will be compared to our lipidomic samples, which will be analyzed in the lab of Julio Sepulveda, University of Colorado, Boulder, USA. We will use a bioinformatic pipeline, which will be used to predict pigments and lipids present/abundant under different environmental conditions and at spots of high C fixation, as modified from Brocks et al. (2009). A confirmation of the prediction pipeline will be obtained via the obtained shotgun lipidomics and proteomics, Synchotron analysis will be used to establish the redox state of pigments. Recovering those lipids and pigments from fossil records of major episodes of ocean anoxia (e.g. mid-late Cretaceous ocean anoxic events) will be used to shed light on the difference in OMZ dynamics between climate change over geological timescales and rapid climate change on human timescales. This will ultimately lead to an understanding of the ability of life to counteract climate change.

Time line, indicate when all measurements will be finished
All measurements are expected to be finished within the runtime of the NITROX project, which will end by June, 2018.

5.15 Submersible Pump

(S. Lennartz)

The submersible pumping system was created to obtain high resolution or even continuous depth profiles of chemical parameters such as trace gases. The system is currently under development and had its second test phase during M138. The motivation for submersible pump profiles is based on several advantages:

1) High resolution profiles in targeted depths: The submersible pump ensures a constant high water flow from the inlet depth which can be surveyed live with the MicroCAT CTD attached close to the inlet of the pump. Like this, small scale gradients can be targeted. This is especially useful in regions with strong gradients in environmental parameters such as oxygen, like the study area during M138.
2) Continuous depth profiles: For continuous underway measurements of e.g. trace gases, a high water flow is needed. For example equilibrator systems can be connected to the submersible pump to obtain continuous depth profiles instead of discrete CTD sampling. Hence, complete variations of parameters with depths can be resolved.
3) Faster access to water from depths: Some parameters, such as NO, are unstable in seawater and would be artificially brought out of their natural concentration when brought to the surface by a Niskin bottle rosette in the standard CTD casts. With the submersible pump, it takes 2-3m for the water from any depth within the depth range to reach the sampling point, where the sample can be fixated to preserve its original concentration. Therefore, the submersible pump enables the sampling of these parameters.

The aims of the test phase 2 were to test the deployment down to 150m for the first time using the live MicroCAT CTD and new electronic contacts to improve the handling onboard, compared to the previous prototype. In addition, several methods to fix the tubing to the deployed wire were tested. The system was successfully tested 2 times during station 884 and 897. MicroCAT and the new electronic part worked as planned and enabled targeting scientifically interesting depth for sampling. Two different fixing systems during deployment were tested, the best one identified and ideas for further improvements were developed. Samples from both pump and standard CTD/Rosette casts were taken to test the comparability of the sampling systems.

Tab. 5.17: Sampled parameters and depths

Profile	Parameter	Sampled depths	# of replicates
Profile 1 (St. 884)	Carbon disulfide (CS_2)	2, 16, 30, 40, 50, 60, 70 m	1 replicate each
Profile 2 (St. 897)	Hydroxylamine	10, 19.5, 29.5, 40.04, 50.02, 45.38, 60.78, 89.22, 109.29, 130.29 m	3 replicates each
Profile 2 (St. 897)	Nitrous oxide (N_2O)	10, 19.5, 29.5, 40.04, 50.02, 45.38, 60.78, 89.22, 109.29, 130.29 m	3 replicates each

Samples for both parameters were stored and will be measured in the laboratory after the cruise. Ssamples will be measured and evaluated within 4 months after the cruise. While the system technically was tested successfully, no preliminary results for the single parameters are available until analysis are performed after the cruise.

5.16 Aerosol Sampling

(H. Bange, A Baker)

Background

Aerosol chemical composition has a significant influence on several processes that are important for our understanding of the Earth System. Examples of these include: the radiative balance of the lower atmosphere; the transfer of nutrients to the surface ocean via atmospheric deposition; impacts on atmospheric chemistry, such as ozone destruction; the formation of cloud condensation nuclei. Aerosol chemistry over the tropical eastern Pacific is very poorly studied, but the region has a number of characteristics that suggest that aerosols may play significant roles there. Deposition of nutrients originating from land-based sources may be important for microbial productivity in the open South Pacific gyre (where nitrogen is limiting for growth) and coastal and equatorial upwelling zones (where iron is limiting). A previous study (M91) indicated that relatively high concentrations of copper in the region might be associated with emissions from the very large smelter works in southern Peru and northern Chile (Baker et al., 2016). Copper has the potential to be toxic to marine phytoplankton. The upwelling waters in the region are associated with high concentrations of iodide and this species is known to react with ozone at the sea surface. This reaction destroys ozone and promotes the emission of iodine-containing gases into the atmosphere. These gases cause further ozone destruction before being cycled into the aerosol phase. The chemistry of iodine in aerosols in the region might therefore be unusual in comparison to that over the majority of the ocean. The work conducted during M138 extends that conducted during M91 in several ways. During the earlier cruise, aerosol samples were collected in bulk on a single filter. For M138 a size fractionating collection device was deployed as this allows better aerosol source identification and better determination of the deposition rates of aerosol components. In most cases, the size fractionation will be determined at a boundary of 1 µm (particle diameter). One sample (#10) was collected with much finer size resolution. This sample was targeted to the potential smelter emissions observed previously at the southern extreme of the cruise track. Samples for major ions and trace metal analysis were collected separately during M138 in order to extend the range of potential analytes determined.

Additional measurements (relative to M91) include soluble organic nitrogen (by difference between total nitrogen and the sum of nitrate and nitrite), iodine speciation and total (in addition to soluble) trace metals.

Samples collected

A summary of the trace metal samples collected during the cruise is given in Tab. 17. Details for the major ions samples collected alongside the TM samples are very similar. In both cases, the first 3 samples were blanks designed to assess potential contamination from the sampling equipment and procedures.

Tab. 5.18: Trace metal aerosol sample collection times, locations and the volume of air processed for each sample.

	Start				End				Air Vol.
Sample	Date	Time	Lat	Lon	Date	Time	Lat	Lon	(m^3)
TM04	06/06/2017	15:12	-10.67	-78.09	08/06/2017	16:45	-12.04	-78.50	2406.6
TM05	08/06/2017	17:25	-12.03	-78.50	10/06/2017	19:00	-12.44	-77.81	2937.0
TM06	10/06/2017	19:35	-12.44	-77.81	12/06/2017	18:00	-12.21	-77.44	2143.8
TM07	12/06/2017	18:35	-12.21	-77.44	14/06/2017	18:30	-13.42	-76.56	1077.0
TM08	14/06/2017	19:15	-13.43	-76.56	16/06/2017	18:00	-14.33	-77.16	1170.0
TM09	16/06/2017	19:00	-14.35	-77.16	17/06/2017	18:00	-14.58	-76.93	1267.8
TM10	17/06/2017	19:00	-14.68	-76.85	20/06/2017	18:40	-15.90	-76.08	4095.0
TM11	20/06/2017	19:15	-15.90	-76.07	22/06/2017	18:00	-14.80	-78.00	1851.0
TM12	22/06/2017	18:45	-14.77	-78.03	24/06/2017	18:00	-12.08	-77.33	2484.0
TM13	24/06/2017	18:40	-11.99	-77.32	26/06/2017	20:45	-6.42	-81.25	1641.6
TM14	26/06/2017	22:20	-6.34	-81.27	28/06/2017	21:00	-1.95	-85.83	853.2
TM15	28/06/2017	22:00	-1.85	-85.83	01/07/2017	18:15	5.29	-82.22	1298.4
TM04	06/06/2017	15:12	-10.67	-78.09	08/06/2017	16:45	-12.04	-78.50	2406.6

Planned measurements and time line

The measurements planned for each sample type are listed in Table 2. The time-line for these analyses is unclear at present. Most of the analyses are dependent on the success of a grant proposal which will be submitted to the UK NERC in January 2018. If this proposal is funded, analysis should be complete by the end of 2019. If the proposal is unsuccessful the work may take longer.

Tab. 5.19: Measurements planned for each sample type.

Sample type	Measurements
Major ions	Na^+, NH_4^+, Mg^{2+}, K^+, Ca^{2+}, Cl^-, NO_3^-, SO_4^{2-}, Br^-, oxalate ($C_2O_4^{2-}$) and methanesulphonate ($CH_3SO_3^-$) Total soluble nitrogen (and dissolved organic N by calculation) Total soluble iodine Iodide (I^-) and iodate (IO_3^-)
Trace metals	Soluble Fe, Al, Mn, Ti, Zn, V, Cu, Ni, Co, Cd, Pb, Th Total Fe, Al, Mn, Ti, Zn, V, Cu, Ni, Co, Cd, Pb, Th

5.17 Halocarbons

(B. Quack, E. Atlas, S. Lennartz, H. Bange, S. Fuhlbrügge, K. Krüger)

Marine emissions of volatile, short-lived halogenated compounds (halocarbons) influence the oxidative capacity of the troposphere and are involved in aerosol formation. In regions of strong tropical deep convection they are transported into the stratosphere, where the halogens take part in ozone destruction. Oceanic upwelling systems, where cold, nutrient rich deep waters foster enhanced biological activity in the surface, are important source regions for brominated compounds such as bromoform ($CHBr_3$) and dibromomethane (CH_2Br_2), as well as iodinated methyl iodide (CH_3I). The tropical East Pacific is subject to strong interannual changes in atmospheric and oceanographic conditions known as the El Niño – Southern Oscillation (ENSO). During normal conditions, a strong upwelling band can be observed at the western coast of South America especially close to Peru, called the "Peruvian Upwelling". During anomalous warm phases, called El Niño, the upwelling ceases with severe consequences for biogeochemical cycles in the tropical East Pacific. We identified the Peruvian upwelling as strong source for iodinated and only moderate source for brominated halocarbons on the M91 cruise in December 2012 during regular climate conditions. We calculated a significant contribution of organoiodine emissions to the tropospheric iodine loading during this season. During the onset of the ENSO-warm phase, which was investigated during the ASTRA-OMZ cruise in October 2015, the emissions changed to higher emissions of brominated halocarbons, while all atmospheric measurements revealed similar mixing ratios as for the normal conditions. During the M138 cruise in June 2017 a third data set was intended during expected La Nina conditions to further reveal the biogeochemical cycling of the halocarbon for the atmosphere in this important region. During the cruise, halocarbon samples were taken both from the surface ocean (60) and the atmosphere (55) in an approximate interval of 12 hours. Oceanic samples taken from the surface underway pump system from 5m depth in 250ml brown glass bottles were conserved with the addition of 250µl hydrochloric acid (>35%). The GC-MS analysis in single ion-mode was performed in August 2017 at GEOMAR using a combined gas chromatography and mass spectrometry (GC-MS) system equipped with a purge and trap tower. The samples were analyzed for brominated, chlorinated and iodinated substances, including methyl iodide (CH_3I), dichloromethane (CH_2Cl_2), chloroform ($CHCl_3$), tetrachloromethane (CCl_4), dibromomethane (CH_2Br_2), chloroiodomethane (CH_2ClI), dibromochloromethane ($CHBr_2Cl$), bromoiodomethane (CH_2BrI), bromoform ($CHBr_3$), and diiodomethane (CH_2I_2). For atmospheric samples, air was pumped into stainless steel canisters using a metal bellows pump. 55 atmospheric samples were taken and sent to Miami where they were analysed for over 50 trace

gases including a range of halocarbons (CH_3I, $CHBr_3$ etc.), alkanes, and DMS at the Rosenstiel School for marine and atmospheric sciences. First results reveal elevated concentrations of the brominated compounds in surface sea water, 20->40 pmol/L for $CHBr_3$ and 5-15 pmol /L for CH_2Br_2, while the concentrations of the chlorinated compounds CH_2Cl_2 and $CHCl_3$ were >10 pmol/L. The air samples have been analyzed in September and the first general impressions show some urban signatures in a few samples (high NMHC, CH_2Cl_2, etc.). There was higher CH_2Br_2 and $CHBr_3$ during the 1st week of the cruise of about 2.7 ppt for CH_2Br_2 and 4.5 ppt $CHBr_3$, then decreasing to about 2 ppt CH_2Br_2 and 2.5 ppt $CHBr_3$ for the remainder. Some interesting variations (day/night and regional) appear with CH_2ClI, which needs closer analysis as these first impressions of the data are rough estimates. Saturation anomalies and sea-to-air fluxes of the compounds will be calculated and compared to the data of the other preceding two cruises M91 and SO243. Analysis of other details of the oceanic halocarbon surface seawater concentrations is in progress. The atmospheric distribution and origin of the compounds will also be evaluated with the meteorological analysis of the cruise, backward trajectories and mixing layer heights from the radio soundings and international data bases.

Tab. 5.20: Surface sampling for dissolved halocarbons; the sampling depth is 5m.

Sample #	UTC time	local time	Date	lat	lat	long	lon
001	00:00	19:00	02.06.2017	11°36	S	78°58	W
002	12:00	07:00	03.06.2017	11°32	S	79°25	W
003	23:00	18:00	03.06.2017	11°19	S	79°10	W
004	13:00	08:00	04.06.2017	10°57	S	78°33	W
005	00:00	19:00	04.06.2017	10°57	S	78°33	W
006	12:00	07:00	05.06.2017	10°56	S	78°31	W
007	00:00	19:00	05.06.2017	10°46	S	78°16	W
008	12:00	07:00	06.06.2017	10°46	S	78°17	W
009	00:00	19:00	06.06.2017	?	S	?	W
010	12:00	07:00	07.07.2017	11°58	S	77°31	W
011	00:00	19:00	07.07.2017	12°02	S	77°58	W
012	10:00	06:00	08.06.2017	12°02	S	78°29	W
013	00:00	19:00	08.06.2017	12°48	S	78°40	W
014	12:00	07:00	09.06.2017	12°36	S	78°06	W
015	00:00	19:00	09.06.2017	12°25	S	77°48	W
016	12:00	07:00	10.06.2017	12°25	S	77°48	W
017	00:00	19:00	10.06.2017	12°25	S	77°48	W
018	12:00	07:00	11.06.2017	12°25	S	77°28	W
019	12:00	07:00	12.06.2017	12°12	S	77°26	W
020	00:00	19:00	12.06.2016	12°05	S	78°03	W
021	12:00	07:00	13.06.2017	12°02	S	78°15	W
022	00:00	19:00	13.06.2017	12°26	S	77°06	W
023	12:00	07:00	14.06.2017	13°07	S	76°40	W
024	00:00	19:00	14.06.2017	13°40	S	76°36	W
025	12:00	07:00	15.06.2017	14°00	S	76°39	W
026	00:00	19:00	15.06.2017	13°59	S	76°39	W
027	12:00	07:00	16.06.2017	14°17	S	77°10	W

028	00:00	19:00	16.06.2017	14°17	S	77°09	W
029	12:00	07:00	17.06.2017	14°17	S	77°10	W
030	01:30	20:30	17.06.2017		S		W
031	12:00	07:00	18.06.2017	15°44	S	75°26	W
032	00:00	19:00	18.06.2017	15°25	S	75°25	W
033	12:00	07:00	19.06.2017	15°26	S	75°28	W
034	00:00	19:00	19.06.2017	15°41	S	75°01	W
035	12:00	07:00	20.06.2017	15°51	S	76°06	W
036	00:00	19:00	20.06.2017	15°51	S	76°06	W
037	12:00	07:00	21.06.2017	15°59	S	76°17	W
038	00:00	19:00	21.06.2017	16°09	S	76°33	W
039	12:00	07:00	22.06.2017	15°38	S	77°15	W
040	00:00	19:00	22.06.2017	14°36	S	77°45	W
041	12:00	07:00	23.06.2017	14°48	S	77°28	W
042	00:00	19:00	23.06.2017	13°41	S	76°40	W
043	12:00	07:00	24.06.2017	12°34	S	77°39	W
044	00:40	19:40	24.06.2017	11°37	S	77°37	W
045	12:00	07:00	25.06.2017	09°59	S	78°30	W
046	00:00	19:00	25.06.2017	08°04	S	79°43	W
047	12:00	07:00	26.06.2017	06°35	S	81°10	W
048	12:00	07:00	27.06.2017	05°09	S	83°23	W
049	00:00	19:00	27.06.2017	04°09	S	85°30	W
050	12:00	07:00	28.06.2017	03°12	S	85°45	W
051	10:30	05:30	29.06.2017	00°00		85°50	W
052	00:00	19:00	29.06.2017	1°37	N	85°50	W

Tab. 5.21: Canister sampling for measurements of atm. compounds.

		Local time	Date(UTC)	Sample time (UTC)	
Sample #	Canister #	LT(start)	Date(2017)	Start	Stop
1	833	13:00:00	04.06.2017	18:00:00	18:05:00
2	597	19:00:00	04.06.2017	00:00:00	00:10:00
3	626	06:55:00	05.06.2017	11:55:00	12:05:00
4	608	18:58:00	05.06.2017	23:58:00	00:05:00
5	908	06:57:00	06.06.2017	11:57:00	12:03:00
6	803	17:05:00	06.06.2017	00:05:00	00:10:00
7	563	07:10:00	07.06.2017	12:10:00	12:15:00
8	906	19:09:00	07.06.2017	00:09:00	00:15:00
9	942	07:05:00	08.06.2017	12:05:00	12:10:00
10	565	19:00:00	08.06.2017	00:00:00	00:08:00
11	753	07:05:00	09.06.2017	12:05:00	12:10:00
12	671	19:06:00	09.06.2017	00:06:00	00:13:00
13	685	07:00:00	10.06.2017	12:00:00	12:05:00
14	979	18:50:00	10.06.2017	23:50:00	00:00:00
15	822	07:00:00	11.06.2017	12:00:00	12:06:00

16	679	14:20:00	11.06.2017	00:20:00	00:26:00
17	770	07:01:00	12.06.2017	12:01:00	12:08:00
18	814	19:10:00	12.06.2017	00:10:00	00:15:00
19	530	07:01:00	13.06.2017	12:01:00	12:06:00
20	987	19:00:00	13.06.2017	00:00:00	00:06:00
21	766	07:10:00	14.06.2017	12:10:00	12:15:00
22	678	19:05:00	14.06.2017	00:05:00	00:10:00
23	681	07:05:00	15.06.2017	12:05:00	12:10:00
24	540	19:00:00	15.06.2017	00:00:00	00:06:00
25	686	07:05:00	16.06.2017	12:05:00	12:10:00
26	903	19:05:00	16.06.2017	00:05:00	00:10:00
27	842	07:00:00	17.06.2017	12:00:00	12:05:00
28	961	19:05:00	17.06.2017	00:05:00	00:10:00
29	731	06:58:00	18.06.2017	11:58:00	12:05:00
30	744	19:00:00	18.06.2017	00:00:00	00:06:00
31	990	07:01:00	19.06.2017	12:01:00	12:08:00
32	978	19:01:00	19.06.2017	00:01:00	00:07:00
33	777	07:05:00	20.06.2017	12:05:00	12:10:00
34	790	19:00:00	20.06.2017	00:00:00	00:05:00
35	923	07:05:00	21.06.2017	12:05:00	12:10:00
36	762	19:05:00	21.06.2017	00:05:00	00:11:00
37	760	07:05:00	22.06.2017	12:05:00	12:11:00
38	909	19:09:00	22.06.2017	00:09:00	00:14:00
39	656	07:05:00	23.06.2017	12:05:00	12:10:00
40	963	19:10:00	23.06.2017	00:10:00	00:15:00
41	541	07:03:00	24.06.2017	12:03:00	12:08:00
42	932	19:05:00	24.06.2017	00:05:00	00:10:00
43	764	07:00:00	25.06.2017	12:00:00	12:06:00
44	918	19:01:00	25.06.2017	00:01:00	00:08:00
45	920	07:15:00	26.06.2017	12:15:00	12:20:00
46	593	19:05:00	26.06.2017	00:05:00	00:12:00
47	661	07:03:00	27.06.2017	12:03:00	12:07:00
48	667	19:03:00	27.06.2017	00:03:00	00:08:00
49	694	07:05:00	28.06.2017	12:05:00	12:12:00
50	737	19:05:00	28.06.2017	00:05:00	00:13:00
51	750	07:00:00	29.06.2017	12:00:00	12:08:00
52	919	19:01:00	29.06.2017	00:01:00	00:07:00
53	808	07:15:00	30.06.2017	12:15:00	12:20:00
54	612	19:01:00	30.06.2017	00:01:00	00:07:00
55	999	18:55:00	01.07.2017	23:55:00	00:00:00

5.18 Plastic/Microplastic Sampling

(C. Löscher, H. Hauss, H.-J. Hoving, D. Niemeyer, E. Laursen)

Scientific background and objectives

Several researchers who filtered CTD samples during M138 noted a remarkable amount of coloured non-natural fibres on their filters which sometimes made up a large part of the complete particulate material on the filters (which was not the case on previus cruises since 2008). It was decided to attempt a quantification of microplastic fibres for the remainder of the cruise. In addition to these very small fibres, it was noted during zodiac sampling that in some locations particles of ~0.5 cm in diameter, clearly derived from plastic packing and bags, are swimming in the water in a high abundance. Besides, we are observing larger plastic waste swimming at the surface. While it is obvious that the increasing abundance of plastics is problematic per se, plastics possibly also comprise toxic compounds. This abundance of plastics was not visible five or ten years, ago, we were speculating that the recent flooding of the area around Lima could be the reason for increased plastic contamination. However, we found those particles sometimes in highest abundance in deeper waters, with a yet unconstrained origin. Sampling for plastics was not originally planned for that cruise, but observing the contamination in those waters urged us to spontaneously start a first sampling campaign off Peru. First dissections of pelagic squat lobsters (*P. monodon*) yielded several plastic items in their stomach contents.

List/description of measurements performed on board

The following samples have been collected:

1. Filter samples for mass spectrometry
2. Filters for microscopy
3. Filters for Raman analysis
4. Lugol fixed water samples for direct counts
5. Formaldehyde-fixed zooplankton samples can be used for stomach content analysis after scanning.

List of stations sampled and indicate which depths have been sampled

Surface samples were taken from the moon-pool pump every 30 nautical miles at a transect from the outermost station at 16°S to the coast. At the 85°W transect, 5 vertical profiles with 5 depth were sampled in a distance of 1 °. On all 24h-stations (8), discrete samples at four depths were Lugol-fixed for microplankton counts, that may also be used for fibre counts.

List/description of measurements in the lab after the cruise

Mass spectrometry of artificial carbon species, electron microscopy, Raman laser spectrometry, plastic counts.

Time line, indicate when all measurements will be finished

All measurements are expected to be finished within 6-12 months.

Preliminary results

Our results so far are based on the observations of fibers on our filters, which we documented photographically (Fig. 5.X).

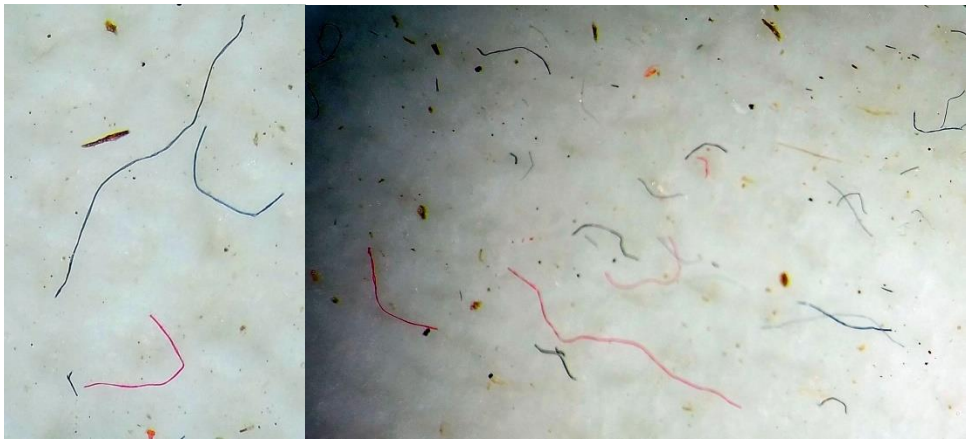


Fig. 5.12: Photography of plastic fibers from surface waters off Peru on a GFF filter.

Across the 85°W transect, we observed highest abundances of those fibers at the depth of the oxygen minimum core. As we hit the equatorial upwelling system, we found higher abundances of plastic fibers at 100m depth, thus above the oxycline.

6 Ship's Meteorological Station

(C. Rohleder, DWD; translation by M. Knobelsdorf, DWD)

The research vessel (R/V) METEOR left the port of Callao late afternoon of 01 June 2017 on research trip M138. It was a heavily cloudy sky with a wind of strength 3 to 4 Bft from the southeast and a swell of two meters. At the time of departure an almost stationary subtropical high was located in the south eastern Pacific. The research area was on the northeastern fringe. To the north of the cruising area was the tropical low pressure zone with a trough extending southeastwards along the South American Pacific coast. During the first days of the cruise it weakened while a steady and moderate trade wind set in. As a consequence in the second half of the week the height of the sea reached up to four meters. Due to a strong temperature inversion the work took place under covered sky with a little precipitation at times. Close to the coast with relatively cool uplift water the mostly good visibility dropped with the occurrence of areas of haze. At the beginning of the second working week the stable weather conditions changed due to a far to the south northeastward moving storm low. At the northeastern flank of the low a weak high pressure zone dominated the wind conditions as the strong southeast trade winds weakened. Land-onshore circulation mostly occurred close to the coast. During the next following days the storm low pushed gradually to the southeast. An associated trough increased the pressure gradient in the research area. Towards the end of the week the wind freshened and in the third week reached gusts up to 7 Bft. During the course of the third week of the research journey a weak high pressure ridge gradually extended eastwards into the research area, hence the wind dropped significantly. During the second part of the week some local high centers formed with mostly light winds from variable directions developing. During the last weeks the sky was often

overcast and now the sun set in for quite a while. On Saturday the 24th the sun was shining for 4.8 hours. On the day, the work ended in the research area close to Lima, Callao and Pisco. In the evening local fishermen delivered a taken mooring in the Bay of Ancon to R/V METEOR. Later R/V METEOR cruised along the Peruvian coast to the north-west. In the late evening of the 27th R/V METEOR arrived at the second working area of this research trip. Along 85.8° W and between 04°S and 02°N 13 CTD were conducted. While reaching the research area, R/V METEOR experienced a field of swell generated from a storm low close to the Chilean coast well far in the south. Swell heights of 3.5 m were observed. While the work lasted at least for two days to the east of the Galapagos Islands the swell decreased. On Friday, the 30th, only heights of a maximum of two meters were reached. At this time R/V METEOR was already at about 02°N and on the way to Panama Canal. While driving further northeast R/V METEOR got closer to the ITCZ which was located between 05°N and 12°N, the shower and thunderstorm risk increased. Just before arriving Bahia de Panama R/V METEOR experienced a heavy thunderstorm-cluster with precipitations about 40 mm. Further, the full transit through the Panama Canal was characterized by frequent showers and thunderstorms in the vicinity of the ship. In the morning of the 04th of July R/V METEOR finally reached the port in the Bahía las Minas close to Cristobal. All research projects during this journey have been carried out and the weather has had no negative impact on the work.

7 Station List

CTD/RO = CTD + Rosette with Niskin bottles
ISP = in-situ Pumps
FST = Floating Sediment Trap
MSC = Marine Snow Catcher
MSN = Multi Net
MSS = Microstructure Probe
PELAGIOS = Towed Camera System
TM-CTD/RO = Trace Metal-free CTD/RO
WP2 Net = Plankton Net

Event # M138_	Time [UTC]	Lat, °S	Long, °W	Depth, m	Gear
0879-1	2017-06-03 03:06:00.0	-11.467	-79.437	5859	CTD/RO
0879-2	2017-06-03 05:49:00.0	-11.472	-79.440	5849	MSS
0879-3	2017-06-03 07:16:00.0	-11.494	-79.478	5690	CTD/RO
0880-1	2017-06-03 19:09:00.0	-11.295	-79.142	3939	CTD/RO
0880-2	2017-06-03 20:40:00.0	-11.296	-79.144	3936	MSS
0880-3	2017-06-03 21:51:00.0	-11.309	-79.161	3909	CTD/RO
0880-4	2017-06-03 22:44:00.0	-11.313	-79.165	3929	CTD/RO
0881-1	2017-06-04 03:06:00.0	-11.124	-78.853	2258	CTD/RO
0881-2	2017-06-04 04:39:00.0	-11.143	-78.865	2270	MSS
0882-1	2017-06-04 09:01:00.0	-10.951	-78.561	1077	CTD/RO
0882-2	2017-06-04 09:55:00.0	-10.951	-78.562	1076	MSN
0882-3	2017-06-04 11:41:00.0	-10.951	-78.562	1076	CTD/RO
0882-4	2017-06-04 13:07:00.0	-10.952	-78.563	1081	CTD/RO
0882-5	2017-06-04 14:31:00.0	-10.952	-78.564	1084	CTD/RO
0882-6	2017-06-04 15:06:00.0	-10.951	-78.565	1084	MSN
0882-7	2017-06-04 16:28:00.0	-10.947	-78.566	1078	PELAGIOS
0882-8	2017-06-04 20:24:00.0	-10.888	-78.569	982	MSN
0882-9	2017-06-04 21:02:00.0	-10.878	-78.577	991	FST (Trap 5) deployment
0882-10	2017-06-04 23:56:00.0	-10.952	-78.562	1081	CTD/RO
0882-11	2017-06-05 01:20:00.0	-10.952	-78.563	1080	CTD/RO
0882-12	2017-06-05 02:07:00.0	-10.952	-78.564	1082	MSC
0882-13	2017-06-05 02:57:00.0	-10.952	-78.564	1082	ISP
0882-14	2017-06-05 05:20:00.0	-10.952	-78.564	1083	MSN
0882-15	2017-06-05 06:08:00.0	-10.944	-78.568	1086	PELAGIOS
0882-16	2017-06-05 09:16:59.0	-10.906	-78.589	1077	MSN
0882-17	2017-06-05 10:47:00.0	-10.951	-78.562	1077	TM-CTD/RO
0883-1	2017-06-05 15:20:00.0	-10.779	-78.271	615	MSN
0883-2	2017-06-05 16:29:00.0	-10.782	-78.271	308	PELAGIOS
0883-3	2017-06-05 20:33:00.0	-10.762	-78.272	300	MSN
0883-4	2017-06-05 21:07:00.0	-10.779	-78.271	307	CTD/RO
0883-5	2017-06-05 21:45:00.0	-10.781	-78.272	309	MSS
0883-6	2017-06-05 23:03:00.0	-10.779	-78.270	306	CTD/RO
0883-7	2017-06-06 00:22:00.0	-10.778	-78.270	305	CTD/RO
0883-8	2017-06-06 01:09:00.0	-10.778	-78.270	306	MSC
0883-9	2017-06-06 01:50:00.0	-10.779	-78.270	305	MSN
0883-10	2017-06-06 02:21:00.0	-10.781	-78.271	306	PELAGIOS
0883-11	2017-06-06 06:38:00.0	-10.779	-78.270	306	MSN

0883-12	2017-06-06 07:12:00.0	-10.779	-78.270	307	CTD/RO
0883-13	2017-06-06 07:50:00.0	-10.779	-78.270	306	TM-CTD/RO
0883-14	2017-06-06 08:57:00.0	-10.781	-78.276	313	ISP
0883-15	2017-06-06 11:30:00.0	-10.781	-78.276	312	CTD/RO
0883-16	2017-06-06 12:02:00.0	-10.782	-78.281	318	MSS
0884-1	2017-06-06 15:23:00.0	-10.670	-78.090	135	CTD/RO
0884-2	2017-06-06 16:00:00.0	-10.671	-78.090	135	MSS
0884-3	2017-06-06 17:05:00.0	-10.678	-78.091	137	Zodiak sampling
0884-4	2017-06-06 19:57:00.0	-10.678	-78.091	137	Submersible pump
0884-5	2017-06-06 21:17:00.0	-10.678	-78.091	137	TM-CTD/RO
0884-6	2017-06-06 22:10:00.0	-10.678	-78.093	138	MSC
0885-1	2017-06-07 13:18:00.0	-12.040	-77.460	136	CTD/RO
0885-2	2017-06-07 13:45:00.0	-12.042	-77.461	136	MSS
0885-3	2017-06-07 14:37:00.0	-12.040	-77.461	137	CTD/RO
0885-4	2017-06-07 15:09:00.0	-12.040	-77.461	137	TM-CTD/RO
0886-1	2017-06-07 18:50:00.0	-12.040	-77.750	247	CTD/RO
0886-2	2017-06-07 19:21:00.0	-12.041	-77.750	249	MSS
0886-3	2017-06-07 20:19:00.0	-12.050	-77.753	269	CTD/RO
0886-4	2017-06-07 21:33:00.0	-12.050	-77.753	270	CTD/RO
0887-1	2017-06-08 00:30:00.0	-12.040	-78.000	1765	CTD/RO
0887-2	2017-06-08 01:51:00.0	-12.041	-78.002	1777	MSS
0888-1	2017-06-08 07:28:00.0	-12.040	-78.500	3043	CTD/RO
0888-2	2017-06-08 08:53:00.0	-12.041	-78.502	3062	MSS
0888-3	2017-06-08 10:23:00.0	-12.039	-78.500	3052	CTD/RO
0888-4	2017-06-08 11:50:00.0	-12.040	-78.500	3055	ISP
0888-5	2017-06-08 14:07:00.0	-12.040	-78.500	3058	TM-CTD/RO
0888-6	2017-06-08 15:08:00.0	-12.040	-78.501	3061	FST (Trap 6) deployment
0888-7	2017-06-08 17:18:00.0	-12.033	-78.500	3059	CTD/RO
0889-1	2017-06-09 01:22:00.0	-12.917	-78.700	5017	CTD/RO
0889-2	2017-06-09 03:34:00.0	-12.917	-78.700	5014	CTD/RO
0890-1	2017-06-09 07:27:00.0	-12.750	-78.404	5936	CTD/RO
0891-1	2017-06-09 11:55:00.0	-12.601	-78.108	3129	CTD/RO
0891-2	2017-06-09 13:58:00.0	-12.601	-78.108	3130	CTD/RO
0892-1	2017-06-09 18:28:00.0	-12.418	-77.812	1098	CTD/RO
0892-2	2017-06-09 20:12:00.0	-12.418	-77.812	1099	CTD/RO
0892-3	2017-06-09 21:31:00.0	-12.418	-77.812	1098	CTD/RO
0892-4	2017-06-09 22:15:00.0	-12.418	-77.812	1098	WP2 Net
0892-5	2017-06-09 22:55:00.0	-12.418	-77.812	1100	CTD/RO
0892-6	2017-06-10 00:03:00.0	-12.418	-77.812	1099	CTD/RO
0892-7	2017-06-10 00:53:00.0	-12.418	-77.812	1101	MSC
0892-8	2017-06-10 01:44:00.0	-12.418	-77.812	1098	MSN
0892-9	2017-06-10 03:11:00.0	-12.419	-77.812	1099	PELAGIOS
0892-10	2017-06-10 08:00:00.0	-12.413	-77.813	1110	MSN
0892-11	2017-06-10 08:39:00.0	-12.418	-77.812	1099	CTD/RO
0892-12	2017-06-10 09:53:00.0	-12.420	-77.815	1108	MSS
0892-13	2017-06-10 11:08:00.0	-12.418	-77.812	1101	ISP
0892-14	2017-06-10 13:59:00.0	-12.418	-77.812	1100	CTD/RO
0893-1	2017-06-10 16:04:00.0	-12.541	-77.898	1561	Glider (IFM 07) recovery
0892-15	2017-06-10 17:47:00.0	-12.415	-77.813	1104	MSN
0892-16	2017-06-10 18:19:00.0	-12.422	-77.812	1093	PELAGIOS
0892-17	2017-06-10 22:19:00.0	-12.418	-77.813	1103	MSN
0892-18	2017-06-10 23:25:00.0	-12.418	-77.812	1102	TM-CTD/RO
0892-19	2017-06-11 00:21:00.0	-12.419	-77.812	1099	CTD/RO

0892-20	2017-06-11 01:47:00.0	-12.420	-77.812	1095	MSS
0894-1	2017-06-11 05:09:00.0	-12.307	-77.621	923	CTD/RO
0894-2	2017-06-11 05:47:00.0	-12.307	-77.621	498	MSS
0894-3	2017-06-11 07:02:00.0	-12.323	-77.620	536	CTD/RO
0894-4	2017-06-11 08:27:00.0	-12.323	-77.620	509	CTD/RO
0894-5	2017-06-11 09:29:00.0	-12.323	-77.620	510	MSC
0894-6	2017-06-11 10:11:00.0	-12.325	-77.619	508	MSS
0895-1	2017-06-11 13:29:00.0	-12.434	-77.413	298	Glider (IFM 09) recovery
0896-1	2017-06-11 14:18:00.0	-12.423	-77.434		Mooring (KPO 1180) recovery
0896-2	2017-06-11 15:36:00.0	-12.437	-77.420	305	CTD/RO
0897-1	2017-06-11 18:10:00.0	-12.210	-77.440	160	CTD/RO
0897-2	2017-06-11 18:39:00.0	-12.212	-77.441	159	MSS
0897-3	2017-06-11 19:45:00.0	-12.235	-77.449	165	CTD/RO
0897-4	2017-06-11 20:40:00.0	-12.235	-77.449	164	CTD/RO
0897-5	2017-06-11 21:43:00.0	-12.235	-77.449	164	WP2 Net
0897-6	2017-06-11 22:43:00.0	-12.235	-77.449	165	Submersible pump
0897-7	2017-06-12 01:15:00.0	-12.210	-77.440	159	MSN
0897-8	2017-06-12 01:38:00.0	-12.211	-77.440	159	MSN
0897-9	2017-06-12 02:23:00.0	-12.212	-77.440	160	PELAGIOS
0897-10	2017-06-12 06:15:00.0	-12.209	-77.440	158	TM-CTD/RO
0897-11	2017-06-12 06:57:00.0	-12.210	-77.440	159	CTD/RO
0897-12	2017-06-12 08:18:00.0	-12.210	-77.440	159	CTD/RO
0897-13	2017-06-12 09:10:00.0	-12.210	-77.440	159	CTD/RO
0897-14	2017-06-12 09:41:00.0	-12.210	-77.440	160	MSS
0897-15	2017-06-12 12:21:00.0	-12.210	-77.440	160	MSN
0897-16	2017-06-12 12:50:00.0	-12.211	-77.440	159	MSN
0897-17	2017-06-12 13:29:00.0	-12.211	-77.440	159	PELAGIOS
0897-18	2017-06-12 17:23:00.0	-12.210	-77.440	160	Zodiak sampling
0897-19	2017-06-12 19:52:00.0	-12.210	-77.440	159	CTD/RO
0897-20	2017-06-12 20:16:00.0	-12.210	-77.441	160	MSS
0898-1	2017-06-13 01:50:00.0	-12.058	-78.273	2174	CTD/RO
0898-2	2017-06-13 03:10:00.0	-12.058	-78.273	2175	CTD/RO
0898-3	2017-06-13 05:07:00.0	-12.058	-78.273	2173	ISP
0898-4	2017-06-13 07:23:00.0	-12.058	-78.273	2172	TM-CTD/RO
0898-5	2017-06-13 08:14:00.0	-12.058	-78.273	2173	MSN
0898-6	2017-06-13 09:20:00.0	-12.058	-78.273	2175	MSC
0898-7	2017-06-13 10:24:59.0	-12.061	-78.274	2160	MSS
0898-8	2017-06-13 11:54:00.0	-12.043	-78.261	2155	FST (Trap 6) recovery
0898-9	2017-06-13 13:52:00.0	-12.058	-78.273	2176	MSN
0899-1	2017-06-13 23:50:00.0	-12.400	-77.151	135	CTD/RO
0899-2	2017-06-14 00:17:00.0	-12.400	-77.150	135	MSS
0900-1	2017-06-14 03:58:00.0	-12.640	-76.970	150	CTD/RO
0900-2	2017-06-14 04:29:00.0	-12.640	-76.970	150	MSS
0901-1	2017-06-14 08:02:00.0	-12.890	-76.820	148	CTD/RO
0901-2	2017-06-14 08:32:00.0	-12.891	-76.820	149	MSS
0902-1	2017-06-14 13:03:00.0	-13.179	-76.641	123	CTD/RO
0902-2	2017-06-14 13:27:00.0	-13.180	-76.641	127	MSS
0902-3	2017-06-14 14:36:00.0	-13.183	-76.646	125	Zodiak sampling
0903-1	2017-06-14 19:10:00.0	-13.430	-76.560	123	Zodiak sampling
0903-2	2017-06-14 21:15:00.0	-13.430	-76.560	122	CTD/RO
0903-3	2017-06-14 21:48:00.0	-13.432	-76.563	122	MSS
0904-1	2017-06-15 02:23:00.0	-14.000	-76.660	594	CTD/RO
0904-2	2017-06-15 03:03:00.0	-14.000	-76.660	556	MSN

0904-3	2017-06-15 03:52:00.0	-14.001	-76.660	598	MSN
0904-4	2017-06-15 04:47:00.0	-14.001	-76.661	599	PELAGIOS
0904-5	2017-06-15 09:33:00.0	-14.000	-76.661	562	CTD/RO
0904-6	2017-06-15 11:06:01.0	-14.000	-76.660	555	CTD/RO
0904-7	2017-06-15 12:23:00.0	-14.000	-76.660	594	CTD/RO
0904-8	2017-06-15 13:23:00.0	-14.000	-76.660	594	CTD/RO
0904-9	2017-06-15 14:02:00.0	-14.000	-76.660	557	MSN
0904-10	2017-06-15 14:52:00.0	-14.002	-76.660	559	MSN
0904-11	2017-06-15 15:13:00.0	-14.000	-76.661	559	PELAGIOS
0904-12	2017-06-15 20:32:00.0	-14.000	-76.661	559	WP2 Net
0904-13	2017-06-15 21:17:00.0	-14.000	-76.661	595	TM-CTD/RO
0904-14	2017-06-15 22:14:01.0	-14.002	-76.662	597	ISP
0904-15	2017-06-16 00:47:00.0	-13.997	-76.660	552	MSC
0904-16	2017-06-16 01:15:00.0	-13.997	-76.660	594	CTD/RO
0904-17	2017-06-16 02:31:00.0	-13.997	-76.660	635	CTD/RO
0905-1	2017-06-16 05:35:00.0	-14.119	-76.870	2229	CTD/RO
0906-1	2017-06-16 10:27:00.0	-14.284	-77.169	4702	CTD/RO
0906-2	2017-06-16 11:54:00.0	-14.286	-77.174	4731	MSS
0906-3	2017-06-16 13:13:00.0	-14.285	-77.168	4709	MSN
0906-4	2017-06-16 14:16:00.0	-14.296	-77.170	4623	MSN
0906-5	2017-06-16 15:48:00.0	-14.288	-77.166	4766	PELAGIOS
0906-6	2017-06-16 21:20:00.0	-14.287	-77.168	4733	TM-CTD/RO
0906-7	2017-06-16 22:39:00.0	-14.288	-77.166	4748	CTD/RO
0906-8	2017-06-16 23:54:00.0	-14.287	-77.166	5914	CTD/RO
0906-9	2017-06-17 01:16:00.0	-14.288	-77.168	5948	CTD/RO
0906-10	2017-06-17 01:51:00.0	-14.284	-77.171	5670	WP2 Net
0906-11	2017-06-17 02:19:00.0	-14.284	-77.175	5595	MSN
0906-12	2017-06-17 03:19:00.0	-14.278	-77.177	4732	MSN
0906-13	2017-06-17 03:51:00.0	-14.272	-77.176	4852	PELAGIOS
0906-14	2017-06-17 09:06:00.0	-14.286	-77.168	5721	CTD/RO
0906-15	2017-06-17 10:08:00.0	-14.289	-77.166	4776	MSC
0906-16	2017-06-17 10:41:00.0	-14.287	-77.167	4734	ISP
0906-17	2017-06-17 12:59:00.0	-14.283	-77.169	4699	FST (Trap 7) deployment
0906-18	2017-06-17 15:02:00.0	-14.299	-77.179	4713	CTD/RO
0907-1	2017-06-18 14:04:00.0	-15.430	-75.433	813	CTD/RO
0907-2	2017-06-18 14:44:00.0	-15.429	-75.436	841	MSN
0907-3	2017-06-18 15:43:00.0	-15.426	-75.446	941	MSN
0907-4	2017-06-18 16:34:00.0	-15.434	-75.457	903	PELAGIOS
0907-5	2017-06-18 20:40:00.0	-15.461	-75.512	1050	WP2 Net
0907-6	2017-06-18 22:19:00.0	-15.427	-75.435	823	CTD/RO
0907-7	2017-06-18 23:49:00.0	-15.430	-75.430	774	CTD/RO
0907-8	2017-06-19 01:06:00.0	-15.429	-75.434	821	MSN
0907-9	2017-06-19 02:02:00.0	-15.430	-75.440	876	MSN
0907-10	2017-06-19 02:39:00.0	-15.436	-75.444	898	PELAGIOS
0907-11	2017-06-19 07:46:00.0	-15.430	-75.431	786	CTD/RO
0907-12	2017-06-19 08:45:00.0	-15.430	-75.438	861	MSC
0907-13	2017-06-19 09:32:00.0	-15.428	-75.411	514	ISP
0907-14	2017-06-19 11:48:00.0	-15.431	-75.429	759	CTD/RO
0907-15	2017-06-19 12:31:00.0	-15.432	-75.435	833	MSS
0908-1	2017-06-19 16:06:00.0	-15.525	-75.598	292	CTD/RO
0908-2	2017-06-19 16:44:00.0	-15.525	-75.598	2229	MSS
0908-3	2017-06-19 18:23:00.0	-15.540	-75.611	2492	CTD/RO
0909-1	2017-06-19 21:10:00.0	-15.604	-75.720	3912	CTD/RO

0909-2	2017-06-19 21:58:00.0	-15.604	-75.723	3967	MSS
0910-1	2017-06-20 00:17:00.0	-15.690	-75.854	5621	CTD/RO
0910-2	2017-06-20 01:12:00.0	-15.694	-75.858	5622	MSS
0910-3	2017-06-20 02:14:00.0	-15.708	-75.869	5159	CTD/RO
0911-1	2017-06-20 04:50:00.0	-15.777	-75.986	4228	CTD/RO
0911-2	2017-06-20 05:28:00.0	-15.778	-75.985	4228	MSS
0912-1	2017-06-20 08:32:00.0	-15.860	-76.110	3678	CTD/RO
0912-2	2017-06-20 09:41:00.0	-15.860	-76.110	3679	MSS
0912-3	2017-06-20 10:53:00.0	-15.860	-76.110	3678	CTD/RO
0912-4	2017-06-20 11:54:00.0	-15.860	-76.110	3678	MSC
0912-5	2017-06-20 12:15:00.0	-15.860	-76.110	3679	ISP
0912-6	2017-06-20 14:33:00.0	-15.860	-76.110	3681	MSN
0912-7	2017-06-20 15:40:00.0	-15.860	-76.105	3681	MSN
0912-8	2017-06-20 16:30:00.0	-15.871	-76.103	3636	PELAGIOS
0912-9	2017-06-20 21:15:00.0	-15.917	-76.054	2957	WP2 Net
0912-10	2017-06-20 22:24:00.0	-15.859	-76.110	3683	CTD/RO
0912-11	2017-06-20 23:44:00.0	-15.860	-76.110	3679	CTD/RO
0912-12	2017-06-21 01:01:00.0	-15.860	-76.110	3678	CTD/RO
0912-13	2017-06-21 02:16:00.0	-15.860	-76.110	3679	CTD/RO
0912-14	2017-06-21 02:49:00.0	-15.860	-76.110	3678	MSN
0912-15	2017-06-21 03:52:00.0	-15.860	-76.107	3681	MSN
0912-16	2017-06-21 04:28:00.0	-15.861	-76.108	3674	PELAGIOS
0913-1	2017-06-21 10:32:00.0	-15.974	-76.285	3284	CTD/RO
0913-2	2017-06-21 11:14:00.0	-15.974	-76.284	3286	MSS
0914-1	2017-06-21 14:14:00.0	-16.067	-76.429	3194	CTD/RO
0914-2	2017-06-21 14:53:00.0	-16.067	-76.427	3192	MSS
0914-3	2017-06-21 15:59:00.0	-16.087	-76.425	3199	CTD/RO
0915-1	2017-06-21 19:14:00.0	-16.162	-76.573	2700	CTD/RO
0915-2	2017-06-21 20:00:00.0	-16.164	-76.570	2805	MSS
0915-3	2017-06-21 21:59:00.0	-16.161	-76.574	2683	CTD/RO
0915-4	2017-06-21 23:00:00.0	-16.160	-76.573	2621	MSC
0915-5	2017-06-21 23:30:00.0	-16.160	-76.571	2552	ISP
0916-1	2017-06-22 03:45:00.0	-16.253	-76.717	2989	CTD/RO
0916-2	2017-06-22 04:23:00.0	-16.259	-76.715	2991	MSS
0916-3	2017-06-22 05:46:00.0	-16.279	-76.723	3007	CTD/RO
0917-1	2017-06-22 18:47:00.0	-14.767	-78.033	4157	CTD/RO
0917-2	2017-06-22 19:58:00.0	-14.768	-78.034	4155	MSS
0917-3	2017-06-22 21:00:00.0	-14.780	-78.042	4129	CTD/RO
0918-1	2017-06-22 23:43:00.0	-14.615	-77.763	4251	CTD/RO
0919-1	2017-06-23 02:42:00.0	-14.760	-77.483	4155	CTD/RO
0919-2	2017-06-23 03:41:00.0	-14.760	-77.483	4153	MSC
0919-3	2017-06-23 04:04:00.0	-14.760	-77.483	4154	ISP
0919-4	2017-06-23 06:20:00.0	-14.760	-77.483	4156	CTD/RO
0919-5	2017-06-23 11:50:00.0	-14.797	-77.477	4103	FST (Trap 7) recovery
0920-1	2017-06-23 20:33:00.0	-13.965	-76.801		Mooring (KPO 1183) recovery
0921-1	2017-06-24 11:14:00.0	-12.571	-77.660		Mooring (KPO 1182) recovery
0922-1	2017-06-24 15:40:00.0	-12.264	-77.363		Mooring (KPO 1181) recovery
0923-1	2017-06-26 15:28:00.0	-6.557	-81.191	1858	Zodiak sampling
0923-2	2017-06-26 18:30:00.0	-6.557	-81.191	1858	CTD/RO
0924-1	2017-06-28 02:21:00.0	-4.000	-85.831	3446	CTD/RO
0924-2	2017-06-28 05:25:00.0	-3.999	-85.840	3430	CTD/RO
0925-1	2017-06-28 09:11:00.0	-3.500	-85.835	3388	CTD/RO
0926-1	2017-06-28 12:43:00.0	-2.999	-85.834	3216	CTD/RO

0927-1	2017-06-28 16:35:00.0	-2.500	-85.834	3184	CTD/RO
0928-1	2017-06-28 20:24:00.0	-2.000	-85.833	2710	CTD/RO
0929-1	2017-06-29 00:02:00.0	-1.499	-85.835	2561	CTD/RO
0930-1	2017-06-29 03:32:00.0	-1.000	-85.834	2238	CTD/RO
0931-1	2017-06-29 07:45:00.0	-0.500	-85.833	2765	CTD/RO
0932-1	2017-06-29 11:26:00.0	0.000	-85.834	2909	CTD/RO
0933-1	2017-06-29 15:08:00.0	0.500	-85.834	2813	CTD/RO
0934-1	2017-06-29 18:54:00.0	1.000	-85.833	2766	CTD/RO
0935-1	2017-06-29 22:56:00.0	1.501	-85.833	2828	CTD/RO
0936-1	2017-06-30 02:52:00.0	2.001	-85.833	2588	CTD/RO

CTD/RO = CTD + Rosette with Niskin bottles
ISP = in-situ Pumps
FST = Floating Sediment Trap
MSC = Marine Snow Catcher
MSN = Multi Net
MSS = Microstructure Probe
PELAGIOS = Towed Camera System
TM-CTD/RO = Trace Metal-free CTD/RO
WP2 Net = Plankton Net

8 Data and Sample Storage and Availability

Data and sample management will be conducted on behalf of the SFB754 by the Kiel Data Management Team (KDMT). The KDMT maintains an information and data sharing system for ongoing marine research projects at GEOMAR and Kiel University. This Ocean Science Information System (OSIS-Kiel) is accessible for all project participants and can be used to share and edit common expedition information and to share ongoing research data as they become available. For non-authenticated users the central OSIS provides all general information about the expedition, related research projects and yet available publications in peer reviewed articles or data publications. Alternatively the submission status of data files including the responsible investigator as contact may be visible for concluded cruises and ongoing research. Some members of the KDMT are active PANGAEA data curators. They will assist researchers during preparation of their sample archival and data publication procedures in a World Data Centre (e.g. PANGAEA: www.pangaea.de) which will then warrant long-term archival and access to the data. The data publication process will be based on the available files in OSIS and is therefore transparent to all reviewers and other researchers. This cooperation with a World Data Centre and the International Geo Sample Numbers (IGSN) union will make the data and samples globally trackable. Links to data publishers or principle investigators provide contact information for external scientists. Acquired seismic, bathymetric and/or hydro-acoustic raw data as well as processed seismic data will be archived in the IT storage infrastructure at GEOMAR. Bathymetric raw data are submitted in addition to the BSH, processed data may be made publicly available on researcher's consent via Google Earth and/or the Marine Geoscience Data System at the Lamont-Doherty Earth Observatory. Contact information for access to these large volume data files and metadata information will be provided by the central OSIS. Additionally,

N_2O and CH_4 data will be archived in MEMENTO (The MarinE MethanE and NiTrous Oxide database) hosted by GEOMAR: https://memento.geomar.de/de.

Time line for data management and storage:

- Availability of metadata in OSIS-Kiel (https://portal.geomar.de/osis):
  2 weeks after the cruise – 18 July 2017,
- Availability of data in OSIS-Kiel (https://portal.geomar.de/osis):
  12 months after the cruise – 04 July 2018,
- Availability of data in a WDC/PANGAEA (http://www.pangaea.de or more specific http://www.pangaea.de/search?q=campaign:M138):
  3 years after the cruise – 04 July 2020.

The PIs of the work packages as listed under Section 3-Research Program are responsible for the handling and submission of the WP data to the SFB754/OSIS-Kiel:

WP	Data	PI, affiliation; email
01	Nutrients, O_2, N compounds, N_2O prod., trace gases	Hermann Bange, GEOMAR; hbange@geomar.de
02	Viral lysis	Ruth Schmitz-Streit, CAU Kiel; rschmitz@ifam.uni-kiel.de
03	N cycle processes	Gaute Lavik, MPI Bremen; glavik@mpi-bremen.de
04	N_2 fixation	Ulf Riebesell, GEOMAR; ureibesell@geomar.de
05	CTD, microstructure, moorings and gliders	Marcus Dengler, GEOMAR; mdengler@geomar.de
06	Bacterial activity, DOC	Anja Engel, GEOMAR; aengel@geomar.de
07	Zooplankton, particle flux	Rainer Kiko, GEOMAR rkiko@geomar.de
08	Export flux, particle composition	Anja Engel, GEOMAR aengel@geomar.de
09	Trace metals, Th export flux, org. nutrients	Eric Achterberg, GEOMAR, eachterberg@geomar.de
10	Water column geobiology	Carolin Löscher, SDU, Odense, DK cloescher@biology.sdu.dk
11	Atm. trace gases and aerosols	Birgit Quack, GEOMAR; Alex Baker, UEA bquack@geomar.de; alex.baker@uea.ac.uk

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10 References

Arévalo-Martínez, D.L., Kock, A., Löscher, C.R., Schmitz, R.A., Bange, H.W., 2015. Evidence of massive nitrous oxide emissions from the tropical South Pacific Ocean. Nature Geoscience 8, 530-533.

Babbin, a. R., D. Bianchi, a. Jayakumar, and B. B. Ward. 2015. Rapid Nitrous Oxide Cycling in the Suboxic Ocean. Science 348(6239):1127–1129.

Baker, A. R., Thomas, M., Bange, H. W., and Plasencia Sánchez, E.: Soluble trace metals in aerosols over the tropical south-east Pacific offshore of Peru, Biogeosciences, 13, 817-825, 10.5194/bg-13-817-2016, 2016.

Bjorkman, K. M. and Karl, D. M.: A novel method for the measurement of dissolved adenosine and guanosine triphosphate in aquatic habitats: applications to marine microbial ecology, J. Microbiol. Methods, 47(2), 159–167, 2001.

Bourbonnais, Annie et al. 2015. "N-Loss Isotope Effects in the Peru Oxygen Minimum Zone Studied Using a Mesoscale Eddy as a Natural Tracer Experiment." Global Biogeochemical Cycles 29:793–811.

Brocks J. J. , and Banfield J. (2009) Unravelling ancient microbial history with community proteogenomics and lipid geochemistry. Nature Reviews Microbiolog y 7, 601 (2009).

Capone, D.G., and Hutchins, D.A.: Microbial biogeochemistry of coastal upwelling regimes in a changing ocean, Nature Geoscience, 6, 711–717, doi:10.1038/ngeo1916 2013.

Casciotti, Karen L., John Karl Böhlke, Matthew R. McIlvin, Stanley J. Mroczkowski, and Janet E. Hannon. 2007. "Oxygen Isotopes in Nitrite: Analysis, Calibration, and Equilibration." Analytical Chemistry 79(6):2427–36.

Cisternas Novoa, C., Lee, C. and Engel, A., 2015. Transparent exopolymer particles (TEP) and Coomassie stainable particles (CSP): Differences between their origin and vertical distributions in the ocean. Marine Chemistry, 175: 56-71.

Codispoti, Louis A. 2010. "Interesting Times for Marine N2O." Science 332:1339–40.

Dekaezemacker, J., S. Bonnet, O. Grosso, T. Moutin, M. Bressac, and D. G. Capone (2013). Evidence of active dinitrogen fixation in surface waters of the eastern tropical South Pacific during El Niño and La Niña events and evaluation of its potential nutrient controls. Global Biogeochem. Cycles 27: 768–779.

Engel, A., Wagner, H., Le Moigne, F.A.C. and Wilson, S.T., 2017. Particle export fluxes to the oxygen minimum zone of the Eastern Tropical North Atlantic Biogeosciences 14: 1825-1838.

Engel, A., and Galgani, L. (2016). The organic sea-surface microlayer in the upwelling region off the coast of Peru and potential implications for air-sea exchange processes. Biogeosciences 13, 989–1007. doi:10.5194/bg-13-989-2016.

Engel, A., and Händel, N. (2011). A novel protocol for determining the concentration and composition of sugars in particulate and in high molecular weight dissolved organic matter (HMW-DOM) in seawater. Mar. Chem. 127, 180–191. doi:10.1016/j.marchem.2011.09.004.

Gasol, J. M., and Del Giorgio, P. A. (2000). Using flow cytometry for counting natural planktonic bacteria and understanding the structure of planktonic bacterial communities. Sci. Mar. 64, 197–224. doi:10.3989/scimar.2000.64n2197.

Grasshoff, K., Kremlin, K., and Ehrhardt, M. (1999). Methods of seawater analysis. 3rd ed. , eds. K. Grasshoff, K. Kremlin, and M. Ehrhardt Weinheim: Wiley-VCH, Weinheim.

Holmes, R.M., Aminot, A., Kerouel, R., Hooker, B.A., Peterson, B.J., 1999. A simple and precise method for measuring ammonium in marine and freshwater ecosystems. Canadian journal of Fisheries and Aquatic Sciences 56, 1801-1808.

Holtappels M, Tiano L, Kalvelage T, Lavik G, Revsbech NP, et al. (2014) Aquatic Respiration Rate Measurements at Low Oxygen Concentrations. PLoS ONE 9(2): e89369. Doi:10.1371/journal.pone.0089369

Holtappels M, Lavik G, Jensen MM, Kuypers MMM (2011) 15N-Labeling Experiments to Dissect the Contributions of Heterotrophic Denitrification and Anammox to Nitrogen Removal in the OMZ Waters of the Ocean. Methods In Enzymology 486: 223-251

Hoppe, H. G. (1983). Significance of exoenzymatic activities in the ecology of brackish water: measurements by means of methylumbelliferyl-substrates. Mar. Ecol. Prog. Ser. 11, 299–308.

IPCC (INTERGOVERNMENTAL PANNEL ON CLIMATE CHANGE - IPCC). 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge UK and New York, USA: Cambridge University Press.

Ji, Qixing, Andrew R. Babbin, Amal Jayakumar, and Bess B. Ward. 2015. "Nitrous Oxide Production by Nitrification and Denitrification in the Eastern Tropical South Pacific Oxygen Minimum Zone." Geophysical Research Letters.

Kalvelage T, Lavik G, Jensen MM, Revsbech NP, Löscher C, Schunck H, et al. (2015) Aerobic Microbial Respiration in Oceanic Oxygen Minimum Zones. PLoS ONE 10(/): e0133526. doi: 10.1371/journal.pone.0133526

Kalvelage, T. et al., 2013. Nitrogen cycling driven by organic matter export in the South Pacific oxygen minimum zone. nature Geoscience, 6: 228-234.

Knauer, G.A., Martin, J.H. and Bruland, K.W., 1979. Fluxes of particulate carbon, nitrogen, and phosphorus in the upper water column of the northeast Pacific. Deep-Sea Research, 26(1): 97-108.

Klawoon I, Bonaglia S, Brüchert V, Ploug H. (2015) Aerobic and anaerobic nitrogen transformation processes in N2-fixing cyanobacterial aggregates. The ISME Journal 9: 1456-1466

Kock, Annette and Hermann W. Bange. 2013. "Nitrite Removal Improves Hydroxylamine Analysis in Aqueous Solution by Conversion with iron(III)." Environmental Chemistry 10(1):64.

Laurenceau-Cornec, E.C. et al., 2015. The relative importance of phytoplankton aggregates and zooplankton fecal pellets to carbon export: insights from free-drifting sediment trap deployments in naturally iron-fertilised waters near the Kerguelen Plateau. Biogeosciences, 12: 1007-1027.

Lindroth, P., and Mopper, K. (1979). High performance liquid chromatographic determination of subpicomole amounts of amino acids by precolumn fluorescence derivatization with o-phthaldialdehyde. Anal. Chem. 51, 1667–1674. doi:10.1021/ac50047a019.

Löscher, C. R. et al. 2012. "Production of Oceanic Nitrous Oxide by Ammonia-Oxidizing Archaea." Biogeosciences 9(7):2419–29.

Löscher, C. R., Großkopf, T., Desai, F. D., Gill, D., Schunck, H., Croot, P. L., Schlosser, C., Neulinger, S. C., Pinnow, N., Lavik, G., Kuypers, M. M. M., LaRoche, J., and Schmitz, R. A

(2014). Facets of diazotrophy in the oxygen minimum zone waters off Peru. The ISME Journal 8: 2180–2192.

Lomnitz, U., Stefan Sommer, S., Dale, A. W., Löscher, C. R., Noffke, A., Wallmann, K., Hensen, C., 2016. Benthic phosphorus cycling in the Peruvian oxygen minimum zone. Biogeosciences 13, 1367-1386.

Lovelock, J.E.; Margulis, L. (1974). "Atmospheric homeostasis by and for the biosphere: the Gaia hypothesis". Tellus. Series A. Stockholm: International Meteorological Institute. 26 (1–2): 2–10.

Meyer J., C. R. Löscher, S. C., Neulinger, A. F. Reichel, A. Loginova, C. Borchard, R. A. Schmitz, H. Haus, R. Kiko, and u. Riebesell (2016). Changing nutrient stoichiometry affects phytoplankton production, DOP accumulation and dinitrogen fixation – a mesocosm experiment in the eastern tropical North Atlantic. Biogeosciences 13: 781-794.

Meyer J., C. R. Löscher, G. Lavik and U. Riebesell (2017). Mechanisms of P* reduction in the Eastern Tropical South Pacific. Frontiers in Marine Science 4:1-12.

Mohr, W., Grosskopf, T., Wallace, D., and LaRoche, J.: Methodological underestimation of oceanicnitrogen fixation rates, PLoS One, 5, e12 583.

Naqvi, S. W. A. et al. 2010. "Marine Hypoxia/anoxia as a Source of CH_4 and N_2O." Biogeosciences 7(7):2159–90.

Nausch, M., and Nausch, G. (2000). Stimulation of peptidase activity in nutrient gradients in the Baltic Sea. Soil Biol. Biochem. 32, 1973–1983. doi:10.1016/S0038-0717(00)00173-5.

Pantoja, S., Rossel, P., Castro, R., Cuevas, L. A., Daneri, G., and Córdovan, C. (2009). Microbial degradation rates of small peptides and amino acids in the oxygen minimum zone of Chilean coastal waters. Deep. Res. II Trop. Stud. Oceanogr. 56, 1055–1062. doi:10.1016/j.dsr2.2008.09.007.

Pike, S., Buesseler, K., Andrews, J., Savoye, N., 2005. Quantification of 234Th recovery in small volume sea water samples by inductively coupled plasma-mass spectrometry. Journal of Radioanalytical and Nuclear Chemistry 263, 355-360.

Rapp, I., Schlosser, C., Rusiecka, D., Gledhill, M., Achterberg, E.P. (2017). Automated preconcentration of Fe, Zn, Cu, Ni, Cd, Pb, Co, and Mn in seawater with analysis using high-resolution sector field inductively-coupled plasma mass spectrometry. Analytica Chimica Acta, 976, 1-13. DOI: 10.1016/j.aca.2017.05.008.

Santoro, Alyson E., Carolyn Buchwald, Matthew R. McIlvin, and Karen L. Casciotti. 2011. "Isotopic Signature of N2O Produced by Marine Ammonia-Oxidizing Archaea." Science 333:1282–85.

Stocker R (2012) Marine Microbes See a Sea of Gradients. Science 338: 628-633

Sugimura, Y., and Suzuki, Y. (1988). A high-temperature catalytic oxidation method for the determination of non-volatile dissolved organic carbon in seawater by direct injection of a liquid sample. Mar. Chem. 24, 105–131. doi:10.1016/0304-4203(88)90043-6.

Sigman, D. M. et al. 2001. "A Bacterial Method for the Nitrogen Isotopic Analysis of Nitrate in Seawater and Freshwater." Analytical Chemistry 73:4145–53.

Suttle, C.A. (2007) Marine viruses--major players in the global ecosystem. Nat. Rev. Microbiol., 5, 801-812, doi:10.1038/nrmicro1750

Torriani, A. (1960). Influence of inorganic phosphate in the formation of phosphatases by Escherichia coli. Biochim. Biophys. Acta 38, 460–469. doi:10.1016/0006-3002(60)91281-6.

Weigand, M.Alexandra, Julien Foriel, Bruce Barnett, Sergey Oleynik, and Daniel M. Sigman. 2016. "Updates to Instrumentation and Protocols for Isotopic Analysis of Nitrate by the Denitrifier Method." Rapid Communications in Mass Spectrometry 30(12):1365–83.

Winkler, L.W., 1888. Die Bestimmung des im Wasser gelösten Sauerstoffes. Ber. Dtsch. Chem. Ges., 21, 2843–2854.