SONNE-Berichte

MICRO-FATE

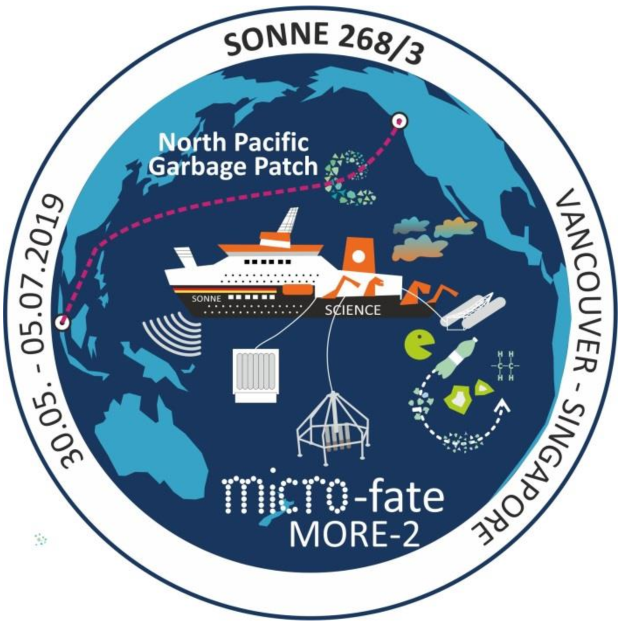
Characterization of the fate and effects of microplastic particles between hotspots and remote regions in the Pacific Ocean

MORE-2

Measuring Ocean REferences (of aerosol, clouds and trace-gases for evaluations of satellite retrievals and model simulations) - part 2

Cruise SO268-3

30.5.2019 – 5.7.2019,
Vancouver (Canada) – Singapore



S. Kinne, A. Jahnke, C. Abele, M. Banu Tekman, M. Bergmann, M. Bohn, A. Caba, T. Dufek, T. Gaudl, S. Gerdes, R. Kleinschek, P. Klöckner, M. Knapp, R. Kroke, S. Lips, T. Machnitzki, J. Menken, L. Moldaenke, S. Reichelt, E. Rojo-Nieto, T. Ruhtz, C. Rummel, R. Rynek, M. Schmitt-Jansen, M. Schneider, C. Schniotalla, G. Veit-Köhler, A. Weitz and A. Welsch

chief scientists: Stefan Kinne and Annika Jahnke
MPI-Meteorology, Hamburg and UFZ, Leipzig

2019

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1 Cruise summary

1.1 Summary

The RV SONNE cruise SO268-3 covered two research projects – MICRO-FATE and MORE-2:

- MICRO-FATE (Characterization of the fate and effects of micro-plastic particles between hotspots and remote regions in the Pacific Ocean) was to characterize distribution, fate and potential effects of plastic debris in the Northern Pacific, with a focus on gradients between hotspots and more remote regions. During SO268-3, probes were collected for extended analyses over the next years. The sampling strategy covered plastic from the sea surface and from selected depths in the water column, down to the seabed. The data from vertical profiling will test the hypothesis that a large part of the plastic emitted to the marine environment sinks to the seabed where it is stored for an undetermined time. The main study area covered the so-called „Great Pacific Garbage Patch", but also three background locations: after leaving the US EEZ, in the central Pacific (i.e. north of Midway) and towards Asia (southern Japanese EEZ).

- MORE-2 (Measuring Ocean References – part 2) collected atmospheric reference data along the way. The focus was on atmospheric data for aerosol, trace-gases to calibrate satellite retrievals, to evaluate model simulations and to constrain with observational associations simulated processes in modeling. In addition 21 ARGO floats were deployed to maintain the monitoring capabilities of the upper ocean state and underway hydro-acoustic data were prepared for the Seabed 2030 project of the Nippon Foundation and GEBCO (for more accurate oceans maps).

1.2 Zusammenfassung

Die SONNE Ausfahrt SO268-3 bediente zwei Fahrtvorschläge: MICRO-FATE und MORE-2.

- MICRO-FATE (Charakterisierung des Verbleibs und der Effekte von Mikroplastikpartikeln zwischen Hotspots und abgelegenen Regionen im Pazifik) hatte die Charakterisierung der Verteilung, des Verbleibs und möglicher Effekte von Plastikmüll im Nordpazifik zum Ziel, insbesondere entlang Gradienten zwischen Hotspots und weniger belasteten Gebieten. Während der SO268-3 Forschungsfahrt wurden Proben für weiterführende Untersuchungen in den kommenden Jahren gesammelt. Die Probenahme betraf dabei Treibgut an der Wasseroberfläche, Wasser aus verschiedenen Tiefen und Ozeanboden-Proben. Ziel dieser Untersuchungen ist es vor allem die Annahme zu bestätigen, dass ein Großteil des in die Meere emittierten Plastikmülls zum Ozeangrund absinkt, wo er auf unbestimmte Zeit verbleibt. Das Schwerpunktgebiet war dabei der sogenannte „große Pazifische Müllstrudel", aber auch drei Hintergrundgebiete: direkt nach dem Verlassen der amerikanischen EEZ, im zentralen Pazifik (nördlich von Midway) und im westlichen Pazifik (im südlichen Teil der japanischen EEZ).

- MORE-2 (Messungen von ozeanischen Referenzdaten Teil 2) sammelte atmosphärische Eichdaten. Der Ziel waren Daten zu Eigenschaften von Aerosolen, Spurengasen und Wolken, um mit diesen die Interpretationen der Satellitendaten zu verbessern, Modell-Rechnungen besser zu beurteilen und durch Zuordnungen verschiedener Eigenschaften simulierte Prozesse einzuschränken. Ausserdem wurden 21 ARGO floats ausgelegt, um die Überwachung-Möglichkeiten des oberen Ozeans aufrechtzuerhalten und hydroakustische Daten für das Projekt Seabed 2030 der Nippon Foundation und GEBCO gesammelt, um verbesserte Karten der Meeresbodenmorphologie zu erstellen.

2 Participants

2.1 Principal investigators

name	institution
Kinne, Stefan, PhD	MPI-M
Jahnke, Annika, Dr.	UFZ

2.2 Scientific party

name	discipline	institute
Kinne, Stefan, PhD	Atmosphere / chief scientist	MPI-M
Weitz, Antje, PhD	Atmosphere	MPI-M
Machnitzki, Tobias	Atmosphere	MPI-M
Menken, Julia	Atmosphere	MPI-M
Ruhtz, Thomas, Dr	Atmosphere	FUB
Kleinschek, Ralph	Atmosphere	U. Hei
Knapp, Marvin	Atmosphere	U. Hei
Welsch, Andreas	Ocean	U. HH
Dufek, Tanja	Ocean	HCU
Schniotalla, Cara	Ocean	HCU
Jahnke, Annika, Dr	Environment	UFZ
Rojo Nieto, Elisa	Environment	UFZ
Rummel, Christoph	Environment	UFZ
Rynek, Robby	Environment	UFZ
Klöckner, Philipp	Environment	UFZ
Lips, Stefan	Environment	UFZ
Schmitt-Jansen, Mechthild, Dr	Environment	UFZ
Caba, Armando, Dr	Environment	UFZ
Abele, Cedric	Environment	UFZ
Schneider, Markus	Environment	IKTS
Moldaenke, Lynn	Environment	U. Bie /IOW
Reichelt, Sophia	Environment	SU
Gerdes, Zandra	Environment	SU
Gaudl, Tatjana	Environment	UFZ M /IHI
Bergmann, Melanie, Dr	Ocean	AWI
Tekman, Mine Banu	Ocean	AWI
Gritta Veit-Köhler, Dr	Ocean	Senck
Bohn, Merten	Ocean	Senck

2.3 Participating institutes

AWI	Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven
FUB	Free University, Berlin
HCU	HafenCity University, Hamburg
IKTS	Fraunhofer Institute for Ceramic Technologies and Systems, Dresden
IOW	Leibniz-Institut für Ostseeforschung, Warnemünde

MPI-M	Max-Planck Institute for Meteorology, Hamburg
Senck	Senckenberg Institute, Senckenberg am Meer, Wilhelmshaven
SU	Stockholm University
U. Bie	University, Bielefeld
U. Hei	University, Heidelberg
U. HH	University, Hamburg
UFZ	Helmholtz Centre for Environmental Research – UFZ, Leipzig
UFZ M	Helmholtz Centre for Environmental Research – UFZ, Magdeburg
IHI	Internationales Hochschulinstitut, Zittau

2.4 Crew

name	rank
Meyer, Oliver	Kapitän / Master
Birnbaum-Fekete, Tilo	Ltd. Off. / Chiefmate
Dugge, Heike	1. NO / 1st mate
Hoffsommer, Lars	2. NO / 2nd mate
Schüler, Achim	Ltd. Ing. / Chief Eng.
Stegmann, Tim	2. Ing / 2nd Eng.
Genschow, Steffen	3. Ing / 3rd Eng.
Leppin, Jörg	Ltd. Sys.Op / Chief Sys.Op
Grossmann, Matthias	2. Sys.Op / 3nd Sys.Op
Plöger, Miriam	3. Sys.Op / 3rd Sys.Op
Schmidt, Hendrick	Elektriker / Electrician
Ulbricht, Martin	Elektriker / Electrician
Kraft, Jürgen	Bootsmann / Bosun
Heibeck, Frank	SM / AB
Ross, Reno	SM / AB
Kruzona, Torsten	SM / AB
Papke, Rene	SM / AB
Hampel, Ulrich	SM / AB
Klemm, Oliver	SM / AB
Koslik, Denis	SM / AB
Lübke, Rene	Motormann / Motorman
Blaurock, Andre	Motormann / Motorman
Blohm, Volker	Fitter / Fitter
Becker, Mario	1. Koch / 1st Cook
Prater, Lars	2. Koch / 2nd Cook
Vogt, Alexander	Ltd. Steward / Chief Steward
Tober, Martina	Stewardess / Stewardess
Kroeger, Sven	Steward / Steward
Yan, Jinhao	Steward / Steward
Mönnich, Niklas	Azubi / Azubi
Schmidt, Rüdiger	Schiffsarzt / Shipsdoctor

3 Research program

3.1 Description of the work area

The RV SONNE 268-3 cruise was a transit cruise from Vancouver (Canada) to Singapore with about 8 full days for station time. The station time was used to survey the Northern Pacific for ocean litter and micro-plastic at the sea surface, in the water column and at the seabed. This work was complemented by continuous “underway” observations (e.g., of atmospheric and oceans floor properties) and the deployment of 21 ARGO floats along the way.

3.2 Aims of the cruise

The SO 268-3 cruise covered goals of two different projects: MICRO-FATE and MORE-2.

The MICRO-FATE project investigated the occurrence, fate and possible effects of plastic in the so-called "Great Pacific Garbage Patch" and along gradients to less polluted areas. The transit from Vancouver to Singapore was an ideal route to investigate this topic. In total, about 8 days of station time were available on this transit. Due to the great depth (mostly 5000-6000 m) and the extensive sampling program, 8 complete profile stations could be covered. According to models, the center of the garbage patch was expected to be in the region between 30 and 35°N and 135 and 145°W, but due to the prevailing sea surface currents in the North Pacific Ocean, increased concentrations of plastic material could also be expected westward of the garbage patch near 30°N. Thus, an important reference station was sampled at 39°N and 135°W at the beginning of the voyage with a presumably low plastic load. This was followed by three stations in the expected center of the garbage patch (at 33°N 144°W, at 30°N 141°W and at 30°N 152°W) and three more sampling locations with likely lower plastic concentrations at 29°N 162°W, at 29°N 175°W (with a permit near the Midway Atoll) and at 29°N 171°E. The final profile was sampled at 22°N 127°E, with a permit in the Japanese EEZ.

The MORE-2 project collected atmospheric properties of aerosols, clouds and trace-gases, because reference data coverage over oceans is sparse – especially over the Pacific. The data will serve as (1) calibration data for satellite remote sensing retrievals and (2) as evaluation data for (global) modeling, and data associations should assist in constraining simulations of atmospheric processes. In addition, 21 ARGO floats were deployed to maintain the monitoring capabilities of the upper ocean (i.e., temperature, salinity) and underway hydroacoustic data were prepared for the Seabed 2030 project.

3.3 Agenda of the cruise

MICRO-FATE activities focused on similar probing activities at 8 stations across the Pacific, with ocean depths always exceeding 5000 m. The depth probing involved (1) vertical profiling with the on-board CTD with water filtering to collect particles larger than 0.45 µm, 10 µm and 35 µm size via attached McLane *in situ* pumps, (2) multi-hour image surveys with the on-board OFOS camera and (3) sampling of 20 sediment cores with a MUC. The near-surface probing involved the sampling of particles in (1) a Neuston catamaran with a 335 µm mesh size net, (2) a cascade filtration unit to collect particles of different sizes (larger than 0.45 µm, 10 µm, 50 µm, 100 µm, 200 µm and 500 µm), (3) a marine snow catcher, (4) a plankton net, (5) a scoop and occasionally (6) a coarse “SONNE” net specifically built by the crew for sampling of large items. Continuous sampling involved (1) enrichment of dissolved organic pollutants in a solid-phase extraction unit, (2) a visual observation-based ocean litter survey and (3) a plastic aging experiment with exposure of plastic items to seawater with or without exposure to solar irradiation.

MORE-2 activities included the deployment of 21 ARGO floats, the analysis of bathymetric data and continuous sampling of atmospheric data via active and passive remote sensing techniques.

During the SO268-3 research cruise, in total 31 stations were assigned and their locations are indicated in the official station map (Figure 3.1). Most of the assigned stations mark only a slowing down of the vessel for the deployment of an ARGO float. The large profile stations are listed in Table 3.1 and are highlighted in Figure 3.2.

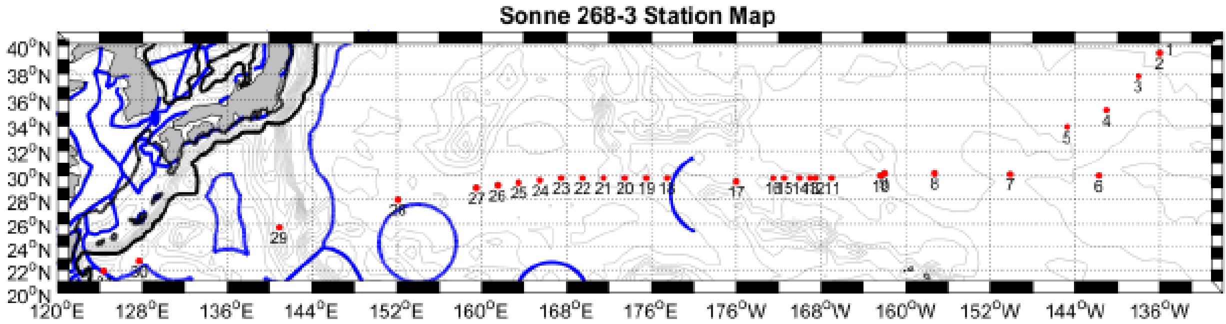

Figure 3.1 Official station map of the R/V SONNE research cruise SO268-3.

Table 3.1 Profile stations on SO268-3.

	#	date	time (UTC)	lat N	lon E	z (m)	
1	3	6/2/2019	03:40-20:38	39.4734	224.0450	5129	CTD, OFOS, MUC
2	5	6/4/2019	15:40-11:50	33.9194	215.2169	5260	CTD, OFOS, MUC
3	6	6/6/2019	10:36-07:37	30.0412	218.2360	5069	CTD, OFOS, MUC
4	7	6/9/2019	00:30-22:41	30.0858	208.0724	5238	CTD, OFOS, MUC
5	10	6/11/2019	17:42-17:08	29.9896	196.3954	5670	CTD, OFOS, MUC
6	17	6/14/2019	22:50-19:39	29.8324	187.5002	5298	CTD, OFOS, MUC
7	21	6/17/2019	20:38-16:25	29.8317	171.4991	5240	CTD, OFOS, MUC
8	30	6/26/2019	15:38-12:01	22.7466	127.7269	5360	CTD, OFOS, MUC
9	31	6/28/2019	01:57-07:29	21.9526	124.4131	5152	CTD

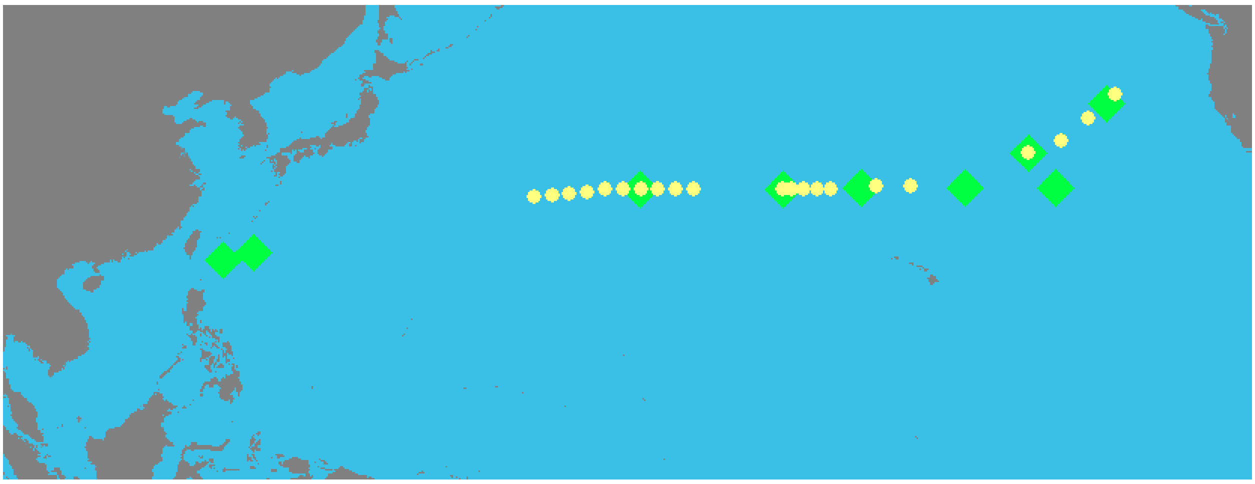

Figure 3.2 R/V SONNE 268-3 track chart displaying the location of the 9 profile stations (green) and the deployment locations of the 21 ARGO floats (yellow, Scripps Oceanic Institute, La Jolla, CA).

4 Narrative of the cruise

The SO268-3 cruise covered the MICRO-FATE and the MORE-2 projects. Under the MICRO-FATE project distributions of oceanic litter across the Pacific were surveyed with a focus on the full range from large pieces (such as barrels) down to micrometer sizes. Central activities were eight stations with three locations near the projected core of the North Pacific Garbage Patch. At each station, the sampling program lasted almost one day due to the great depth. The plastic litter sampled covered material collected at the surface (with nets and filters of various mesh size), the vertical distribution from different depths (snow catcher, plankton net, *in situ* pumps) and material from the seabed (sediment (MUC), visual surveys (OFOS)). These samples were complemented by near-continuous observations of floating litter, plastic aging experiments, water filtering and initial characterization of the biofilm growing on the surface of plastic debris. Under the MORE-2 project atmospheric reference data for satellite remote sensing and modeling data were sampled underway, and recorded ocean floor data were analyzed. Furthermore, for deployments of the 21 US ARGO floats the speed of the vessel was temporarily reduced.

The voyage began in Vancouver, Canada on May 30, 2019. The ship left its north-side quay in the morning at 5 a.m. (3 hours earlier than scheduled to avoid delays by a potential strike by the harbor staff). The pilot stayed until Victoria, BC, and the ship then headed in SW direction as soon as the open Pacific was reached towards the garbage patch area (30-35°N 140-145°W). Once the ocean depths exceeded 5000 m (similar to depths in the garbage patch area) near 39.5°N 135°W on June 1, the “background” profile station #1 was selected to establish a largely litter-free ocean reference. Further proceeding towards the garbage patch area, the frequency of floating litter and plastic increased, as observed in the litter survey. Profile station #2 was picked near the Northern rim of the garbage patch region at 34°N 145.5°W on June 4. Profile station #3 at 30°N 141.5°W on June 6 was at the Southern rim of the garbage patch region. In efforts to capture the longitudinal distribution of floating debris the voyage continued then in a westward direction near 30°N, with profile station #4 at 152°W on June 8 and profile station #5 at 162°W on June 11 (after passing a cold front with considerable rain near 155°W).

Although the floating litter frequency had decreased since the core garbage patch region, there were still occasional patches with very high litter levels, probably related to the dominating mesoscale currents in the Pacific near 30°N. A particular effort was made to catch a large plastic barrel, which was not just filled with seawater but also contained many small fishes, with one of them already too big to escape through the openings; the fish was rescued by opening the barrel with a saw. Several ARGO floats were deployed before the Papahānaumokuākea Marine National Monument (PMNM) zone in the Northwestern Hawaiian Archipelago was entered. Profile station #6 at 175°W on June 15 (as the data of June 14 was skipped in anticipation of the dateline crossing) supported the collection of large litter pieces during the scheduled routine testing of the fast rescue boat. Still, at this stop near the Midway Islands it was easy to collect floating plastic litter with the scoop next to the ship from the lower deck.

The dateline was crossed in the night to June 17 and from now on marine birds had started to compete for the best positions on the front mast and pollute the area below. After the PMNM region the remaining ARGO floats were released every two degrees in longitude with the profile stop #7 on June 17 near 172°E in between. When halting for technical reasons for a couple of hours near 165°E, two passing bigger ships lured some of the birds away. By June 21 all ARGO floats had been deployed just in time for a Swedish-style midsummer night celebration. The EEZ of Japan was entered on June 23, now with warmer temperatures, higher humidity, deep convection, occasional precipitation and hardly any blue skies. After passing a frontal zone with heavy precipitation on June 25, the last profile station # 8 was reached on June 26 near 23°N 127°E. Another CTD-only station on June 28 near 22°N 124°E ended the station work. The rest of the way was a (relative rough) transit through a windy South China Sea, and Singapore was reached late on July 4.

5 Preliminary results

5.1 Hydroacoustics *(T. Dufek, C. Schniotalla)*

Three different hydroacoustic echo sounders were operated during SO268-3 from Vancouver to Singapore: The multi-beam echo sounder Kongsberg EM122, the sub-bottom profiler Teledyne Atlas Parasound P70, and the scientific echo sounder Kongsberg Simrad EK60. The EM122 and the EK60 were continuously recording data from leaving the Canadian EEZ on May 31st, 2019 (16:00 UTC) until June 28th, 2019 (8:00 UTC) before entering the EEZ of the Philippines. The data acquisition continued within the Hawaiian and Japanese EEZ. The P70 was not constantly acquiring data and was mainly switched on before and after stations.

5.1.1 Multi-beam echosounder Kongberg EM122

Technical description The multi-beam echo sounder Kongsberg EM122 was recording bathymetric, backscatter, and water column data during SO268-3. It operates with an acoustic frequency of about 12 kHz, has a beam opening of 0.5° x 1°, and a fan opening angle of up to 150°. During SO268-3 the fan opening angle was set to 130°-140° in dependency of the backscattering characteristics of the seabed resulting in a swath width of about 22 km in 5,000 m water depth. Per ping the EM122 gains up to 432 soundings (in high density mode) which can be increased to 862 in dual swath mode when two signals are emitted into the water column simultaneously with a difference in tilting angle (Kongsberg Maritime AS, 2011). During SO268-3 the high density and dual swath mode were used continuously.

Data acquisition and processing The data acquisition was done by using the Kongsberg SIS (Seafloor Information System) software. The bathymetry and backscatter data was stored in Kongsberg raw file format (*.all) of 60 min duration. The water column data was stored in wcd file format. During SO268-3 nine CTDs (conductivity, temperature, depth) measurements were taken. Eight of them were imported into SIS for improving the quality of the depth measurement. The last CTD was taken just before switching off the hydroacoustic systems and was therefore not used. Before the first CTD was taken, the open-source software “Sound Speed Manager” developed by NOAA Coast Survey and UNH CCOM/JHC was used to generate a synthetic sound velocity profile based on the oceanographic database “World Ocean Atlas 2009” (WOA09) from NOAA. The all-files were imported into QPS Qimera 1.7.2. Erroneous depth measurements were deleted by using the swath and slice editor. Afterwards, the soundings were exported in ASCII and GSF format. The ASCII data was then imported to QPS DMagic 7.8.6 and gridded with the 3x3 weighted moving average gridding methods and a cell size of 60 m. Data gaps were interpolated in QPS Fledermaus 7.8.6 and the models were saved as SD files and exported as GeoTIFF. Additionally, the open-source software tool “Generic Mapping Tools” was used to create grids in grd format with a resolution of 100 m. For backscatter processing the all-files were imported into QPS FMGeocoder Toolbox 7.8.10 and mosaics with a raster cell size of 30 m were generated (with default processing settings) and exported as GeoTIFF.

Preliminary results The EM122 bathymetric data will be contributing into the SEABED 2030 initiative, which aims for 100 percent completion of a map of the world’s ocean floor by 2030. It is a joined project of The Nippon Foundation and the General Bathymetric Chart of the Oceans (GEBCO) Guiding Committee. GEBCO operates under the auspices of the International Hydrographic Organization (IHO) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO. To achieve the goal of a complete mapping of the ocean floor an efficient data collection and the establishment of a cooperative framework across various sectors for accessing existing data is carried out. Completed maps will be published online for everyone to access and also will be made available for online resources. (https://seabed2030.gebco.net/). Within 664 h of EM122 data acquisition a total distance of approximately 6,350 nm was covered and an area of about 258,805 km² was mapped, which corresponds to about 0.072 % of additional bathymetry recorded of an approximate total surface area of 360,570,000 km² covered by oceans and seas. The measured water depths ranged from 7,990 m at extension from the Marianna Trench at 26.717°N 143.340°E to 500 m in the Hawaiian EEZ at 29.802°N 179.051°E. The following figures show some examples of mapped underwater features depicted with the global data set of GEBCO2019 in the background (Sandwell et al., 2002). Figure 5.1.1.1 shows the extensions of the Columbia River on the ocean floor with a river bed depth of 50 m to 100 m and so far unmapped seamounts with a height of around 1,000 m. The figure also shows the differences of quality within the GEBCO2019 grid as the lower resolution satellite data can be clearly distinguished from already implemented high resolution echo sounder data (visible in the bottom left corner).

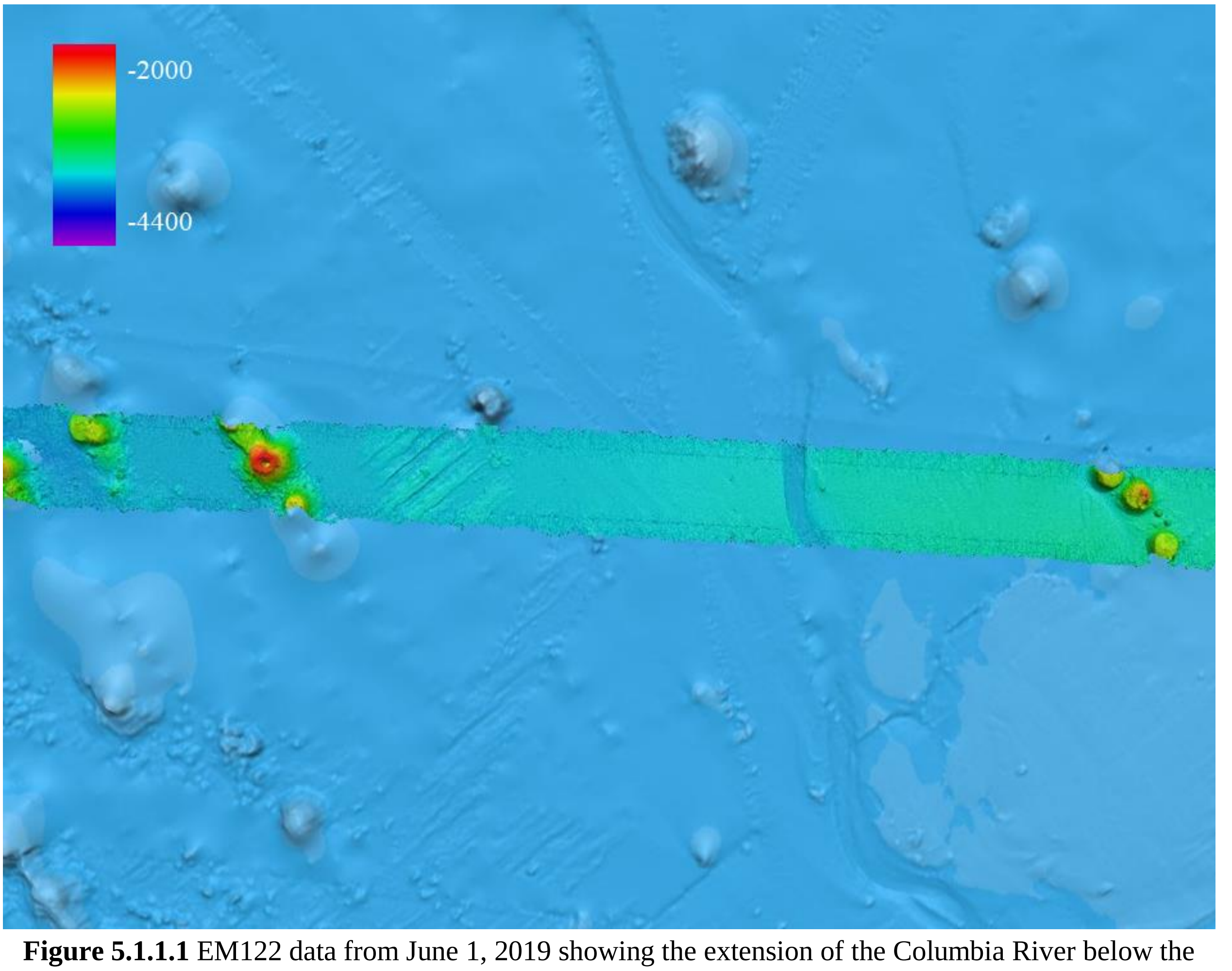

Figure 5.1.1.1 EM122 data from June 1, 2019 showing the extension of the Columbia River below the water surface and seamounts at 43.326°N -131.827°W.

Figure 5.1.1.2 shows an unnamed seamount chain with the height of up to 1,500 m. Furthermore, it shows the GEBCO2019 data set of the same area in the top of the figure, where some of the mountains can be roughly seen but without any details. Figure 5.1.1.3 shows a part of an unmapped ridge with a height of about 800 m.

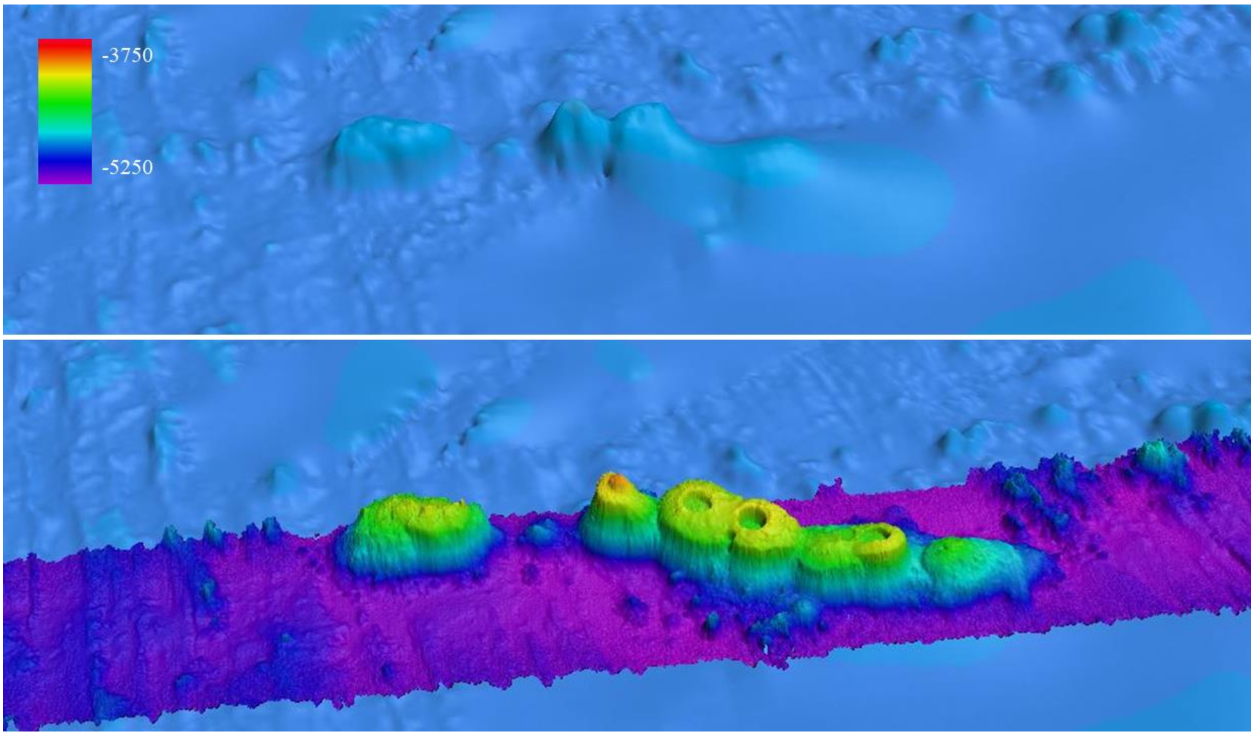

Figure 5.1.1.2 EM122 unnamed seamount chain mapped on June 7, 2019 at 30.123°N -144.039°W.

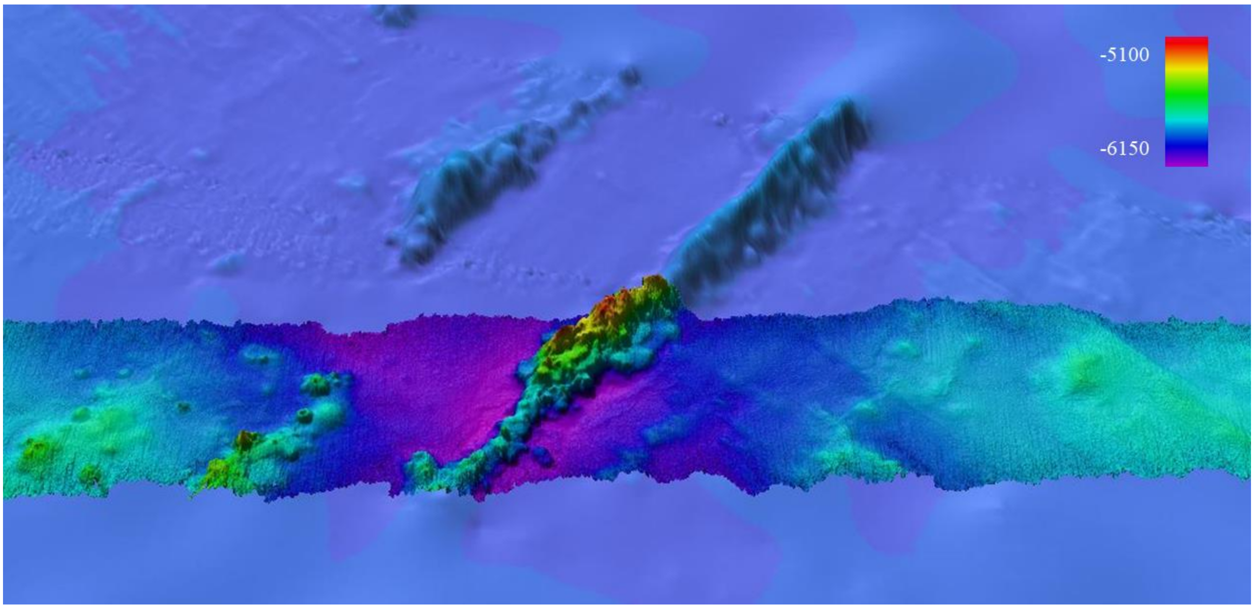

Figure 5.1.1.3 EM122 data collected on June 19, 2019 at 29.791°N 167.126°E**.**

5.1.2 Sub-bottom profiler Teledyne Atlas Parasound P70

Technical description The Teledyne Atlas Parasound P70 is a parametric sub-bottom profiler. The parametric effect utilizes two higher acoustic signals (18-33 kHz), which are emitted vertically downwards into the water and are interacting to create a new parametric signal, with a frequency that equals the difference of the two acoustic waves (0.5-6 kHz). This way the smaller beam opening angle of the higher frequencies is preserved in the parametric signal (4.5° x 5°) and therefore a higher horizontal resolution is obtained than when utilizing the lower frequency directly. On the other hand the signal achieves high bottom penetration (max. >200 m) depending on local bottom and environmental conditions (Atlas Hydrographic, 2010). During SO268-3 the desired PHF (Primary High Frequency) was set to18.8 kHz and the desired SLF (Secondary Low Frequency) was set to 4 kHz.

Data acquisition The P70 data was mainly recorded a few hours before and after stations as with the multi-corer (MUC) and Ocean Floor Observation System (OFOS) ground truthing data was collected at stations. SLF and PHF were recorded in ASD, PS3, and SEG-Y format and the pinging mode was set to quasi-equidistant. As the hydroacoustic systems were not triggered externally, interference could be observed and resulted in wrong depth measurements of the EM122 in the nadir part of the swath which was forwarded to the P70. The amount of such erroneous depth measurements depends on the characteristics of the area of investigation. In areas of low number of wrong depth measurements the depth source for P70 was set to “other” (EM122) and in areas with often occurring false measurements the depth source was set to “manual”. The echogram window height was set to 200 m and was adjusted to the seabed depth variations manually.

Preliminary results During SO268-3 different acoustic seabed types were recorded by the P70 within about 246.5 hours of data acquisition. Figure 5.1.2.1 shows P70 SLF data from June 13, 2019 (2:05-2:45 UTC) at 29.908° N 164.913° W (after station SO268-3/10).

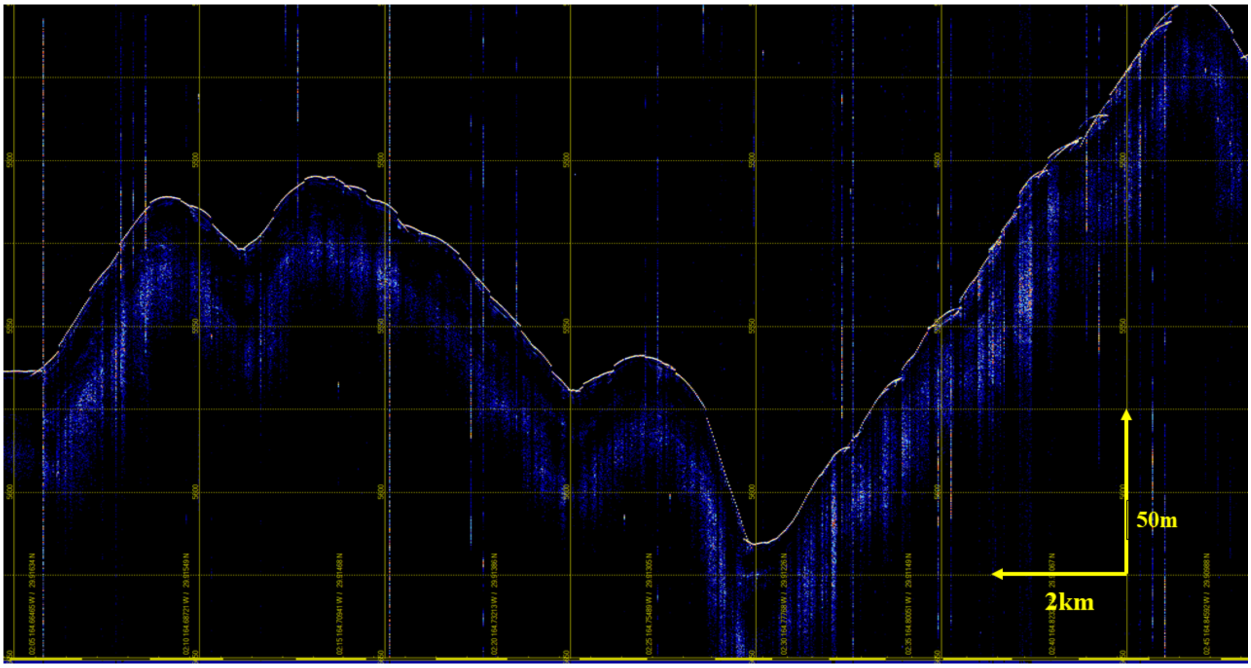

Figure 5.1.2.1 Echogram of the sub-bottom profiler P70 SLF (June 13, 2019 / 2:05-2:45 UTC) west of station SO268-3/10.

The water-seabed interface is clearly visible and a diffuse subsurface reflection can be seen. This is a typical echogram for the areas where manganese nodules were found on the seabed. Figure 5.1.2.2 shows P70 SLF data from June 23, 2019 (3:10-4:00 UTC) at 28.276°N 146.390°E before entering the Japanese EEZ. This echogram shows nicely stratified sediment layers to a depth of up to 50 m. Two of the CTD profiles (SO268-3/6, SO268-3/21) were also entered into P70. Before station SO268-3/6 an average sound velocity of 1,500 m/s was used.

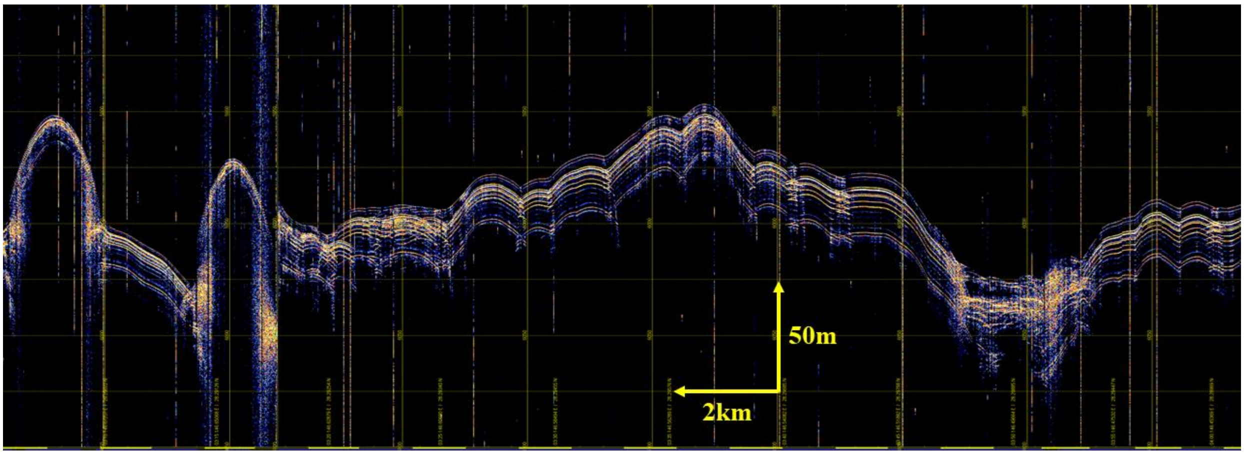

Figure 5.1.2.2 Echogram of the sub-bottom profiler P70 SLF (June 23, 2019 / 3:10-4:00 UTC) before entering the EEZ of Japan.

5.1.3 Scientific echosounder Simrad EK60

Technical description The scientific echo sounder Simrad EK60 from Kongsberg Maritime AS operates with four frequencies (18 kHz, 38 kHz, 120 kHz, 200 kHz) simultaneously and records the backscattered signals from the water column for each frequency. The use of different frequencies allows a more detailed look into different depths and the identification of species as they have different acoustic frequency responses (Kongsberg Maritime AS, 2018). Additionally, the range of utilized frequencies combines the advantages and disadvantages of the range of frequencies: The higher frequencies have a smaller range but a higher resolution than lower frequencies.

Data acquisition and processing The EK60 was running continuously from leaving the Canadian EEZ until entering the EEZ from the Philippines. All four frequencies were recorded in raw format to a depth of about 3,000 m. The data was processed with QPS FMMidwater 7.8.7. After importing the raw files, they were converted to gwc format for each frequency and day individually. Water column images of volume scattering were created for the depth of 1,000 m for the low frequencies and 200 m for the high frequencies. Different color table settings were used for the different data sets:

18 kHz: -80dB / -45dB
38 kHz: -75dB / -45dB
120 kHz: -75dB / -45dB
200 kHz: -70 dB / -45 dB

Preliminary results Within the water column images the movement of zooplankton in correspondence to the sunrise and sunset can be clearly seen. Also objects within the water column like schools of fishes or up- and downgoing instruments such as the CTD during stations can be observed in the data. Figure 5.1.3.1 shows 7 hours of 18 kHz data collected on June 6, 2019 during station SO268-3/6. The downward movement of the zooplankton after sunrise can be seen, as well as the downcast and upcast of the CTD. Figure 5.1.3.2 shows 18 kHz data from June 20, 2019 where schools of fishes can be seen.

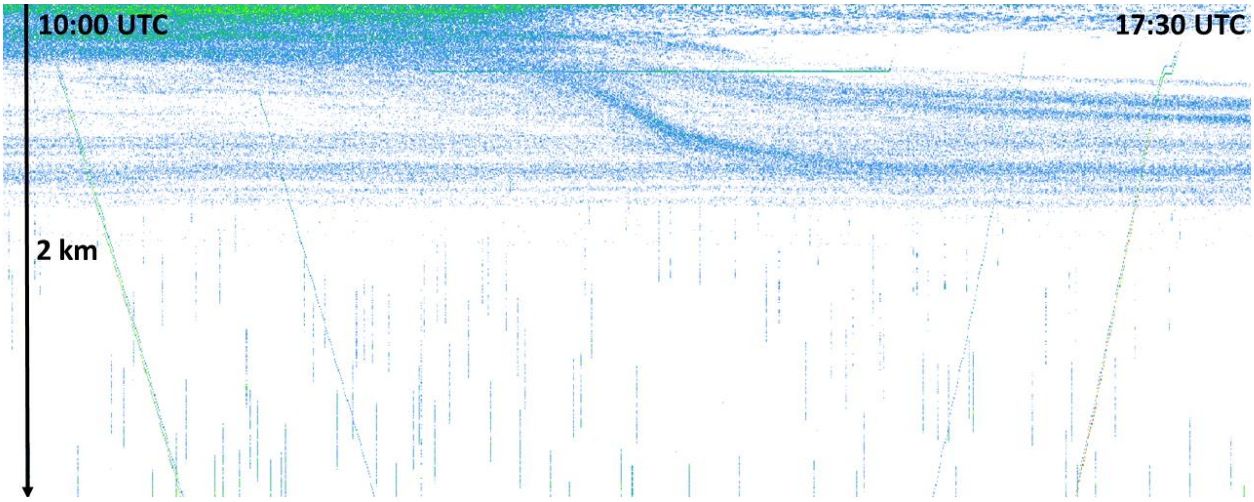

Figure 5.1.3.1 EK60 (18 kHz) data showing CTD downcast and upcast (left and right side) and the movement of zooplankton on June 6, 2019 during station SO268-3/6.

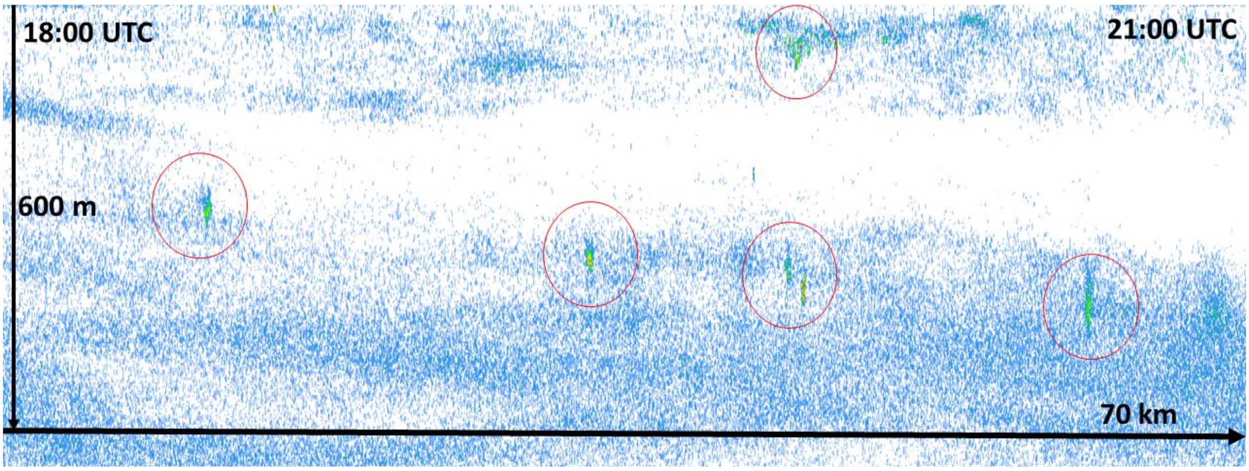

Figure 5.1.3.2 EK60 (18 kHz) data showing some schools of fishes (red circles) within the water column on June 20, 2019.

References

Atlas Hydrographic (2010): *Atlas Parasound Data Sheet*. https://epic.awi.de/id/eprint/26733/7/ATLAS_PARASOUND_2015-02.pdf (accessed 3.7.19)

Kongsberg Maritime AS (2011): *EM 122 Multibeam Echo Sounder - Product description*.

Kongsberg Maritime AS (2018): *Simrad homepage*. https://www.simrad.com/ (accessed 7.1.18).

Sandwell, D.T., Gille, S.T., Smith, W.H.F (Eds.) (2002): *Bathymetry from Space: Oceanography, Geophysics, and Climate*. Geoscience Professional Services, Bethesda, Maryland.

Hydroacoustic data were automatically recorded during the SO 268-3 cruise outside national EEZ regions and over regions of US-PMNM and Japan, where permits were given. The Parasound instrument explored the sediment structure and echo-sounder mapped a ca. 20 km wide path of ocean floor elevations. The hydroacoustic data were harmonized for a contribution to the SEABED 2030 ocean survey initiative.

5.2 Oceanic measurements

The oceanic data involved continuous sampling of surface waters, vertical profiling during station times and the deployment of ARGO floats for continued upper ocean monitoring capabilities.

5.2.1 Surface (*S.Kinne*)

Oceanic surface water properties were continuously recorded with on-board instruments during the cruise. In a summary plot of Figure 5.2.1.1 for the entire SO268-3 cruise, properties and temporal changes for sea salt content, sea surface temperature (SST) and chlorophyll density are presented.

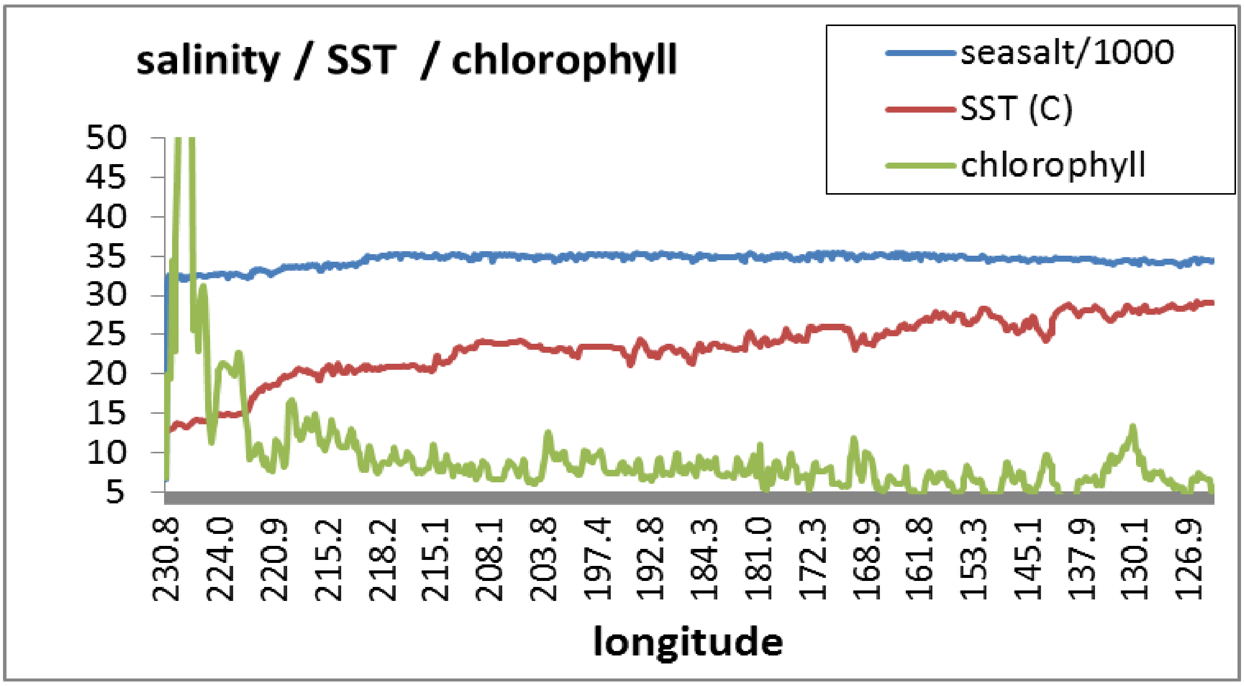

Figure 5.2.1.1 Temporal changes for hourly averages of salinity, SST and chlorophyll as a function of longitude across the Pacific mainly near 30°N from off the US coast to the South China Sea.

Salinity The sea salt content in surface waters increased from 32/1000 at the beginning of the cruise to 35/1000 and then slowly declined to 34/1000 near the South China Sea. Hourly average fluctuations were on the order of 0.5/1000.

SST The water temperature increased steadily with the voyage from 13 °C to about 30 °C near the South China Sea. Some of the temperature increases can be attributed to lower latitudes. However, there was also a significant latitudinal gradient, with increasing temperatures towards the Western Pacific. While the SO 268-3 cruise stayed near 30°N temperatures increased from about 21 °C at 215°E to about 28 °C at 145°E.

Chlorophyll The nutrient content in water is represented by chlorophyll. With the upwelling water off the US coast, the level of nutrients was very high. Proceeding away from that region in a Westward direction the nutrient content sharply declined and often reached values close to zero beyond the dateline. Still in the western Pacific there was a lot of local variability, even though overall values stayed low.

5.2.2 Depth profiling (*A.Welsch, M.Bergmann,G.Veit-Köhler*)

Oceanic state properties down to ocean depths of more than 5,000 m were sampled with the on-board CTD. A CTD measures Conductivity, Temperature and Density and on the on-board system we also included a fluorometer and sensors for turbidity as well as PAR radiation. To the CTD/Rosette, 24 bottles with a volume of 10 liters each permitted water samples at selected ocean depths to be collected. Images of the on-board CTD are given in Figures 5.2.2.1 and 5.2.2.2.

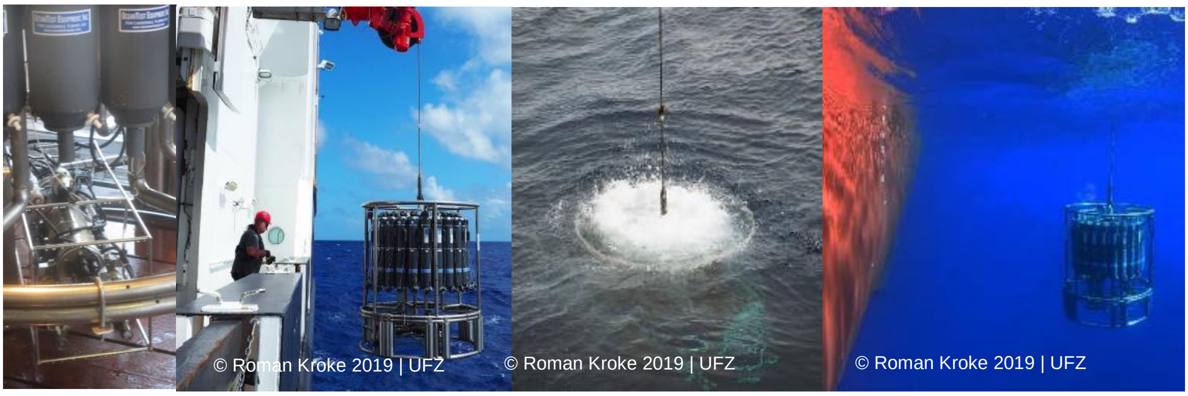

Figure 5.2.2.1 Images of the CTD, before (left), during (center) and after (right) its lowering into the water.

Figure 5.2.2.2 Preparations and deployment of the CTD on board of RV SONNE. Pictures: Roman Kroke 2019, UFZ.

CTD profiles were sampled at nine locations across the northern Pacific (as already shown in Figure 3.2). Time, location and ocean depth of all nine CTD profiles are listed in Table 5.2.2.1. Depth profile data of temperature, salinity, oxygen and density are presented in Figure 5.2.2.3 and for temperature, salinity, fluorescence and turbidity in Figure 5.2.2.4. Since each set for nine profiles are similar, the profiles of June 11, 2019 (in the PMNM zone) are enlarged in those figures and briefly examined.

Table 5.2.2.1 Profiling times with CTD, OFOS and MUC at profile stations.

	#	date	CTD (UTC)	OFOS (UTC)	MUC (UTC)	lat °N	lon °E	z (m)
1	3	6/2	03:40 – 10:14	10:15 – 13:00	16:54 – 20:39	39.5	224.0	5129
2	5	6/4	15:40 – 22:28	22:34 – 05:31	08:06 – 11:50	33.9	215.2	5260
3	6	6/6	10:36 – 17:29	17:38 – 00:40	04:11 – 07:37	30.0	218.2	5069
4	7	6/9	00:30 – 08:11	08:54 – 16:09	18:56 – 22:40	30.1	208.1	5238
5	10	6/11	17:42 – 01:32	04:05 – 11:20	13:03 – 17:08	30.0	196.4	5670
6	17	6/14	22:50 – 05:28	07:27 – 13:17	15:41 – 19:39	29.8	187.5	5298
7	21	6/17	20:38 – 03:16	06:17 – 12:22	12:23 – 16:25	29.8	171.5	5240
8	30	6/26	15:38 – 21:28	21:38 – 04:45	08:06 – 12:01	22.7	127.7	5360
9	31	6/28	01:57 – 07:28	-	-	22.0	124.4	5152

Temperature The surface temperature decreased sharply with depth to about 4 °C at 1,000 m depth with an even colder temperature of about 1.5 °C from about 3,000 m down to the ocean bottom (>5,000 m).

Salinity The salinity shows a minimum of 34.0/1000 at a depth of about 600 m. This minimum is absolute for the larger surface salinity of the central and Western Pacific but only local if the salinity is lower as in the Eastern Pacific. From 3,000 m to the ocean floor (>5,000 m) the salinity is stable at about 34.7/1000.

Oxygen The oxygen content at the surface decreases from the Eastern to the Western Pacific. At each profile station the oxygen content quickly decreased to a minimum at 1,000 m depth and again increases towards the ocean floor, still well below the content at the surface. The oxygen minimum in the Western Pacific is less developed and only near 500 m in depth.

Fluorescence The fluorescence represents biological matter and has a maximum just below the surface and a minimum near 200 m depth. Values towards the ocean bottom are small although slightly elevated between 700 and 1,500 m.

Turbidity The small particle content is largest in near surface waters and pretty much constant from about 200 m down to the ocean bottom.

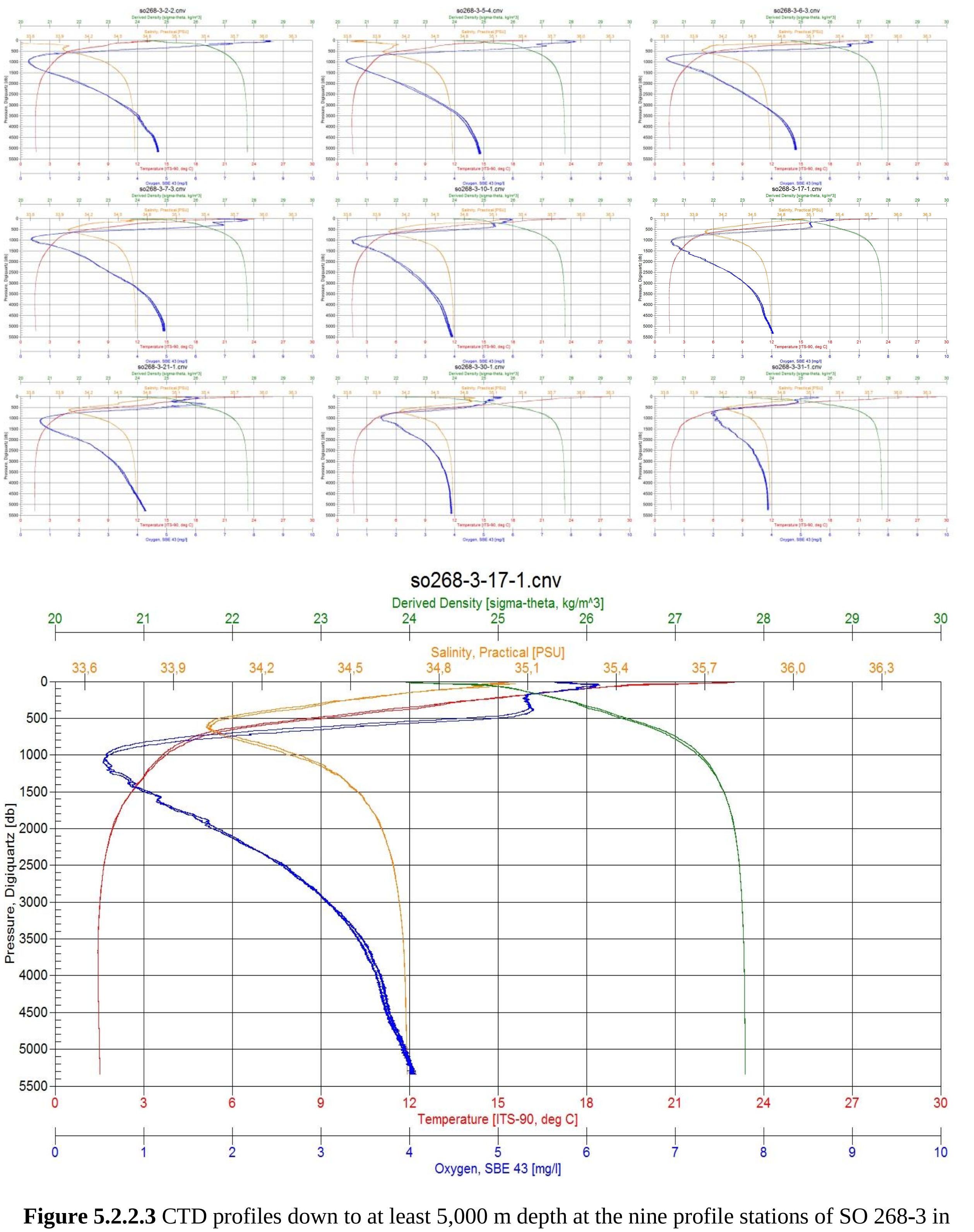

Figure 5.2.2.3 CTD profiles down to at least 5,000 m depth at the nine profile stations of SO 268-3 in temporal order (by row from left to right). Profiles are presented for temperature (red), salinity (orange), density (green) and oxygen (blue). The profile of June 11, 2019 is enlarged for better viewing.

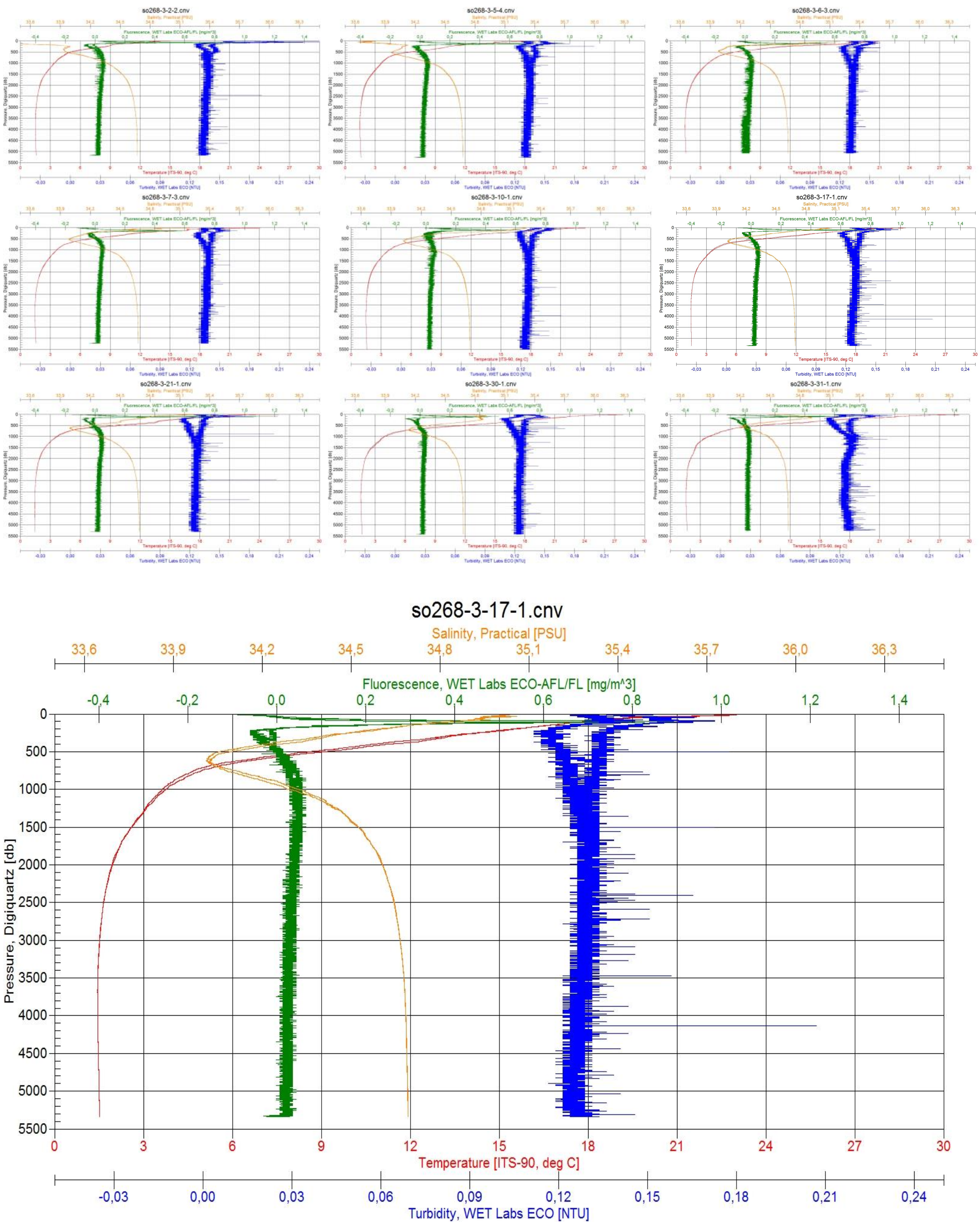

Figure 5.2.2.4 CTD profiles down to at least 5,000 m depth at the nine profiling stations of the SO 268-3 in temporal order (by row from left to right). Profiles are presented for temperature (red), salinity (orange), fluorescence (green) representing biological matter and turbidity (blue) representing small particle content. The profile of June 11, 2019 is enlarged for better viewing.

On the first eight profiling stations also OFOS and MUC were used to inform on ocean floor properties. The on-board underwater camera system (OFOS) investigated the ocean floor for several hours at each station to search for marine life, rocks and debris and the Senckenberg (20 sample) multicorer (MUC) probed sediments for subsequent studies on ocean floor deposition of plastic debris and pollutant concentrations. The instruments are presented in Figure 5.2.2.5 and some images of the camera and a sediment probe sample are presented in Figure 5.2.2.6.

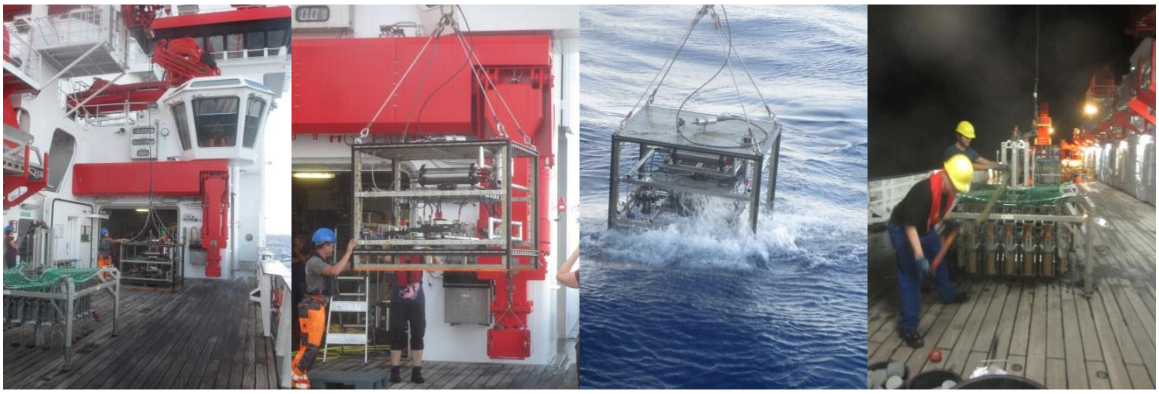

Figure 5.2.2.5 MUC sediment sampler (front) and OFOS camera (back) on the deck (left), the deployment of OFOS (center) and the MUC return with (usually brownish) sediment probes (right).

Figure 5.2.2.6 OFOS camera images at the ocean floor at more than 5,000 m of a 'maze' (top left) , a drawer (top center) ,a 'volcano' (top right) and a (ca 40cm long) fish (bottom left). The manganese nodules frequency was highest in the Eastern Pacific (bottom, center). The rest of a sediment core (bottom, right - one of 20 simultaneous cores taken with the MUC) illustrates the color of the ocean sediments. These sediments seemed to be more clay-like in the Eastern and central Pacific as compared to more sandy in the Western Pacific. Melanie Bergmann (AWI).

5.2.3 ARGO floats (*A. Welsch, S. Kinne, J. Gilson*)

Technical description An ARGO float is a diving robot that regularly takes profiles of temperature, density and pressure of the upper 2,000 m of the ocean. A float usually drifts with the ocean current at a depth of 1,000 m. About every fifth day a float is activated and descends to 2,000 m, then samples a profile up to the surface, there immediately sends the recorded data via satellite to the data center before it descends back to 1,000 m. Currently, there are about 4,000 floats of the international ARGO network operating in all oceans worldwide. However, the (battery) lifetime of these floats is limited to only 3 to 5 years. Thus, to maintain ocean monitoring capability new floats need to be added continuously, preferably in regions where the density of free-drifting ARGO floats is low.

Deployment 21 ARGO floats of the Scripps Institute for Oceanography at La Jolla via John Gilson were shipped to Vancouver for deployment during the SO268-3 cruise. Their deployment locations are summarized in Table 5.2.3.1 and selected images of the deployment are shown in Figure 5.2.3.1.

Table5.2.3.1 Deployment locations of the ARGO floats

		date	time (UTC)	latitude °N	longitude °E	longitude °W
1	s/n 8772	6/1/2019	21:30:40	40.5015	225.0004	-134.9996
2	s/n 8773	6/3/2019	07:46:16	37.8009	222.0000	-138.0000
3	s/n 8774	6/3/2019	23:32:19	35.2073	219.0092	-140.9908
4	s/n 8775	6/5/2019	11:54:08	33.9197	215.2188	-144.7812
5	s/n 8776	6/10/2019	22:37:25	30.2004	202.0045	-157.9955
6	s/n 8777	6/11/2019	14:29:01	30.2168	198.0012	-161.9989
7	s/n 8778	6/13/2019	10:53:10	29.8331	192.9996	-167.0004
8	s/n 8779	6/13/2019	16:39:27	29.8317	191.4996	-168.5005
9	s/n 8780	6/13/2019	23:25:35	29.8334	190.0007	-169.9993
10	s/n 8781	6/14/2019	05:31:38	29.8331	188.5006	-171.4994
11	s/n 8782	6/14/2019	09:27:33	29.8324	187.5002	-172.4998
12	s/n 8783	6/16/2019	20:57:42	29.8334	177.4991	
13	s/n 8784	6/17/2019	04:46:18	29.8336	175.5005	
14	s/n 8785	6/17/2019	12:38:55	29.8336	173.5089	
15	s/n 8786	6/18/2019	16:33:27	29.8333	171.5284	
16	s/n 8787	6/19/2019	00:50:00	29.8333	169.5056	
17	s/n 8788	6/19/2019	08:58:58	29.7996	167.5008	
18	s/n 8789	6/19/2019	17:28:38	29.5997	165.4997	
19	s/n 8790	6/20/2019	06:45:52	29.3997	163.4974	
20	s/n 8791	6/20/2019	14:49:18	29.2001	161.5029	
21	s/n 8792	6/20/2019	23:04:42	29.0018	159.5009	

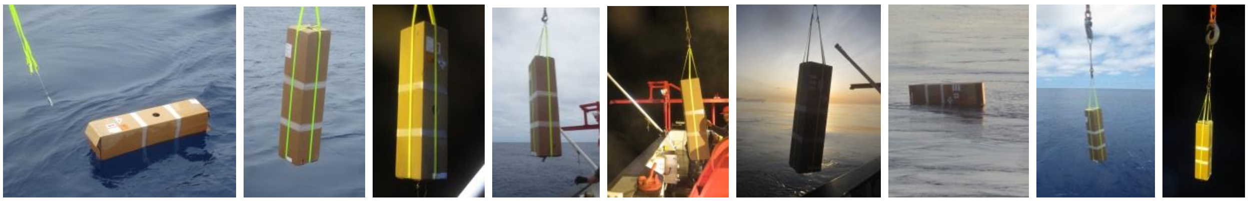

Figure 5.2.3.1 Scripps type ARGO float deployments in the Pacific during the SO268-3 research cruise.

The newly at Scripps developed floats are relatively small and light-weight as shown in Figure 5.2.3.2. The floats are shipped in carton boxes, with a small hole on the side for activation access. For protection, the floats are intended to be launched in their packing cartons. At deployment the carton is lowered with holding straps into the water. The straps open via a water contact release and are recovered while the carton drifts away. Carton and quickly dissolving tape around the carton release the float after about 10 minutes following deployment. At one deployment station, however, the water contact release of the holding straps did not work. At the time the contact release was replaced onboard, the carton had already been soaked so much that the float slipped out for a rare view at the float itself. Thus, in that particular case the float was deployed in the old-fashioned way. At a last check all 21 floats were operating.

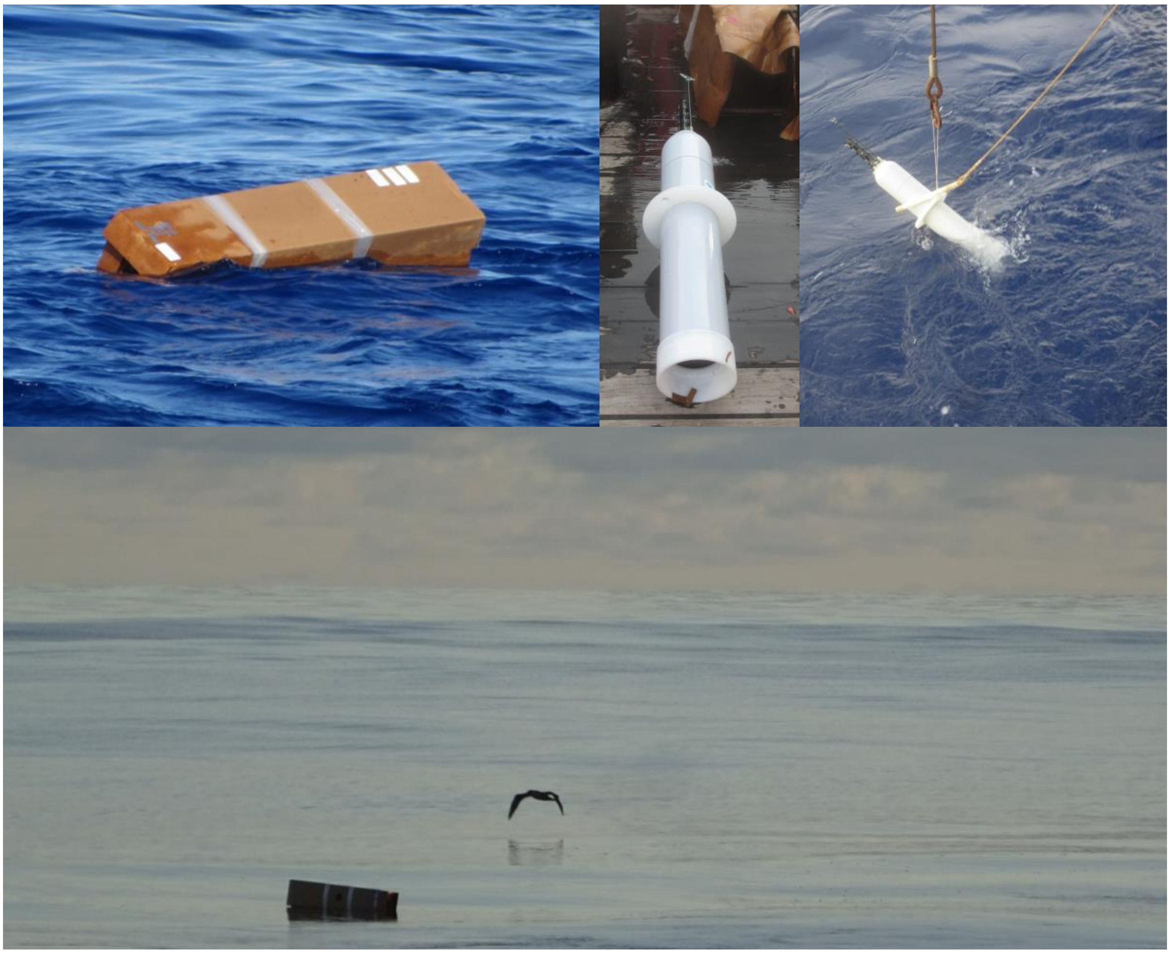

Figure 5.2.3.2 Scripps-built new ARGO float with its carton deployment design.

5.3 Atmospheric measurements

Atmospheric properties were sampled with standard on-board meteorological sensors and extra remote sensing instruments to address properties of aerosols, trace gases, greenhouse gases and clouds. The simultaneous aspect of these measurements also allowed investigations of associations among different atmospheric properties for process understanding.

5.3.1 Surface (*S.Kinne*)

Selected atmospheric *in situ* and remote sensing data of the ship's meteorological instruments are introduced first. Hourly averages of temperatures, relative humidity, wind and radiation over the entire cruise were examined via time series and in the context of daily cycles.

Temperature data are summarized in Figure 5.3.1.1.

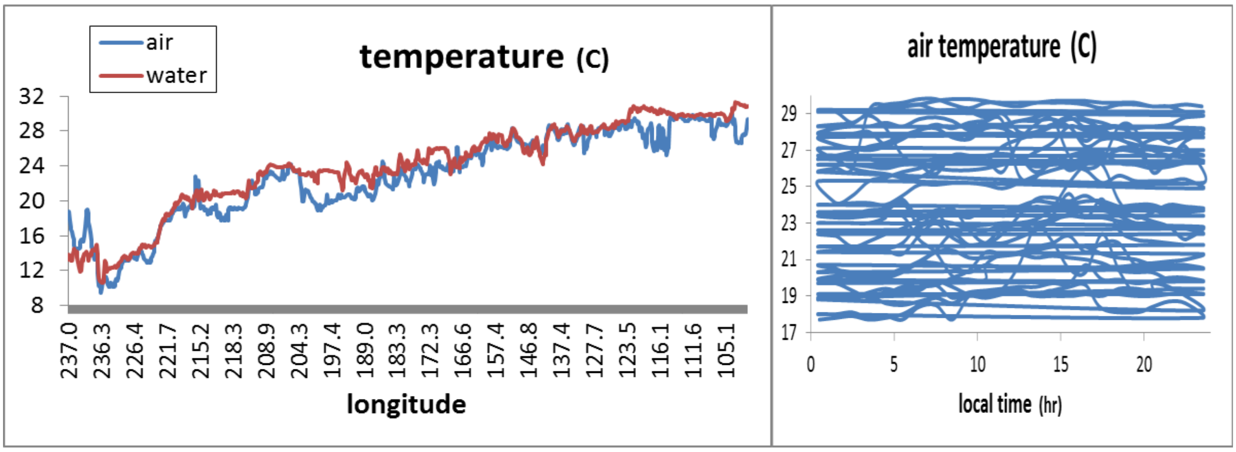

Figure 5.3.1.1 Hourly averages of air temperature and water temperature from Vancouver, Canada to Singapore as a function of time and longitude (left) and a function of local time over oceans (right).

Hourly averages of air and water temperatures near 30 °N (in latitude) steadily increased from about 20 °C in the eastern Pacific (140 °W or 220 °E) to about 28 °C in the Western Pacific (140 °E). The temperatures at lower latitudes towards the end of the cruise did not change much anymore, while temperatures at higher latitudes at the beginning of the cruise were lower and displayed in Vancouver with its continental environment strong daily variations. Over oceans air temperatures were usually lower than water temperatures and especially so during precipitation events via evaporative cooling. Daily variations in air temperature (hourly averages) over oceans were usually small (and intermittent smaller variations were often associated with precipitation).

Relative humidity data and data associated with water vapor are summarized in Figure 5.3.1.2.

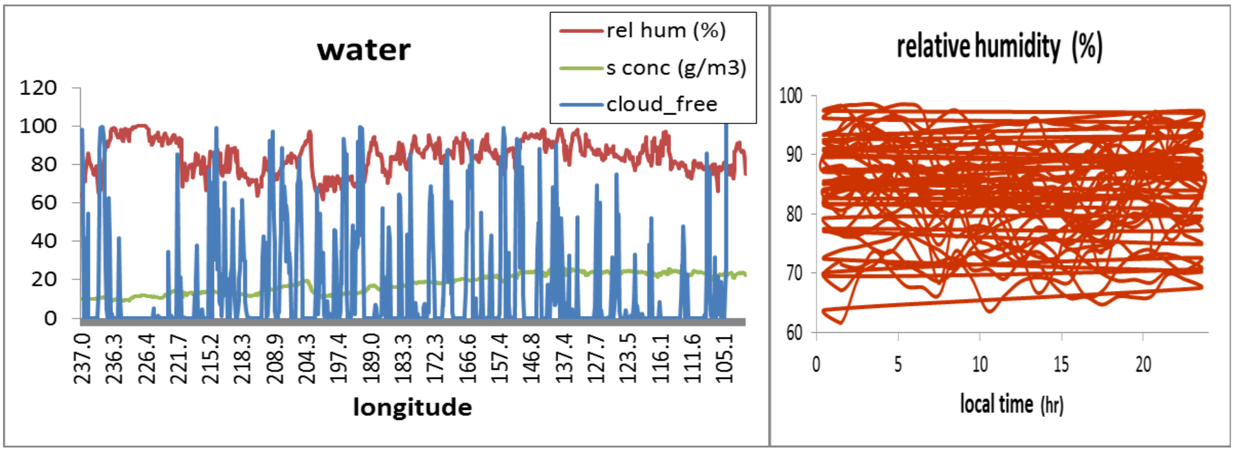

Figure 5.3.1.2 Hourly averages of relative humidity and water vapor concentration at the surface and cloud-free fraction from Vancouver, Canada to Singapore as function of time and longitude (left) and the relative humidity at the surface a function of local time (right).

Hourly averages of the relative humidity were usually between 70 and 80 % but overall varied between 60 and 100 %. Rapid changes were rare and were mainly associated with air mass changes, as with the passing of a frontal system at 202 °E on June 6, 2019. Secondary variations were often correlated with cloud cover.

Wind speed data are summarized in Figure 5.3.1.3.

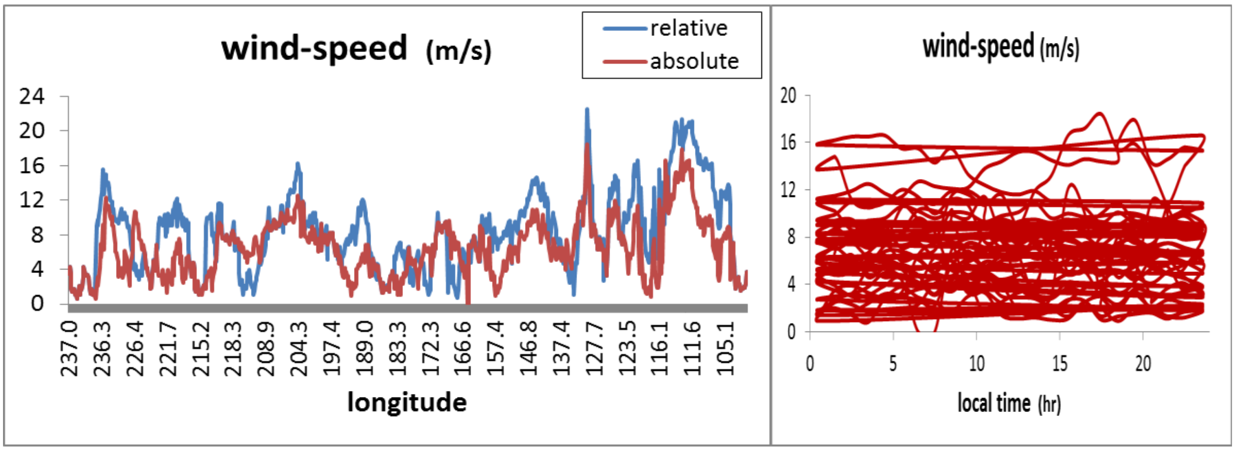

Figure 5.3.1.3 Hourly averages of absolute and relative wind speed from Vancouver, Canada to Singapore as a function of time and longitude (left) and absolute wind speed as a function of local time over oceans (right).

The wind was relatively calm with hourly averages varying between 2 and 10 m/s. Ocassionally, the winds were very calm for almost mirror-like ocean surfaces. Intermittent large windspeeds were assoaciated with passing weather systems, as briefy at 129 °E on June 26, 2019 and near 112 °E for the entire day of July 1, 2019. Also indicated In Figure 5.3.3 are relative wind speeds (adding the speed of the vessel). Hereby maxima exceeded at times 20 m/s, pointing to times of more severe ship rolling movements.

Radiation data for solar and infrared downward fluxes are summarized in Figure 5.3.1.4.

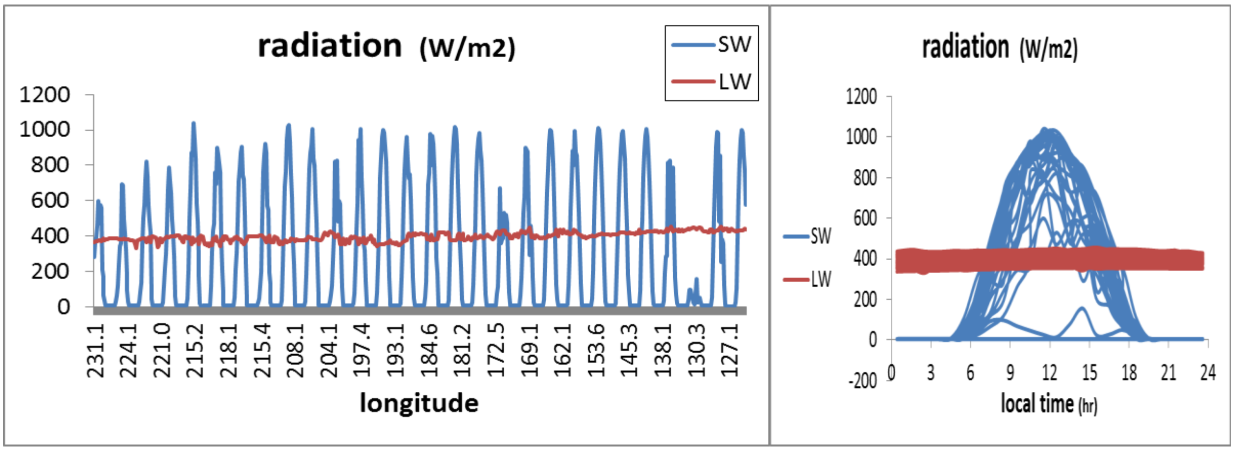

Figure 5.3.1.4 Hourly averages of downward solar and infrared broadband fluxes from outside the Canadian EEZ until entering the EEZ of the Philippines as a function of time and longitude (left) and local time over oceans (right).

Hourly averages of downward solar fluxes show the expected daily cycles, with noon maxima exceeding 1000W/m2 at cloud-free conditions (once 30N was reached). Reductions by cloud cover were persistent and strong during the storm on July 1, with solar insolation hourly averages not even reaching 200W/m2. Downward infrared broadband fluxes increased low altitude cloud cover and with surface temperature.

5.3.2 Column data aerosol *(S. Kinne, T. Machnitzki, J. Menken)*

Direct attenuation measurements of the direct sunlight are highly accurate, unlike interpretations of satellite sensor data with assumption to composition and background. Thus, NASA's AERONET group distributes on an opportunity basis calibrated handheld (MICROTOPS) sun photometer instruments for the sampling of atmospheric aerosol column properties and water vapor content. Solar attenuation is sampled simultaneously at five different solar spectral intervals, to allow the collection of not only information on aerosol amount, but also on aerosol particle size (to distinguish between contributions by pollution, sea salt or mineral dust) and on atmospheric water vapor content. Hereby, the water vapor content (results will be presented later under trace gases) is determined by comparing solar attenuation in the spectral region not affected by trace gases to solar attenuation affected by (known strength) water vapor absorption. The MICROTOPS is paired with a GPS unit, so that with the position information (in combination with the time) the (always) larger incoming reference solar irradiance at the top of the atmosphere is defined - for each of the five solar spectral sub-intervals. Still, note that column data for aerosol and water vapor could only be sampled with a (handheld) sun photometer when views of the sun were not obstructed by clouds. Instrument and sampling method are shown in Figure 5.3.2.1.

Figure 5.3.2.1 The MICROTOPS sun photometer with the GPS (left) and handheld measurements (right).

All aerosol and water vapor data were transferred at the end of each day to NASA's Marine Aerosol Network (MAN) database and the data can serve almost immediately as reference to satellite remote sensing and modeling (https://aeronet.gsfc.nasa.gov/new_web/maritime_aerosol_network.html). With regular and often longer overcast conditions (see cloud cover data below) the aerosol measurements (already limited to daytime) were rather sporadic. For the data presentation below samples were combined into hourly bins, often based on only a single successful sample. Time series and daily cycles are presented in Figure 5.3.2.2 for column data of aerosol amount (AOD at 550 nm), aerosol size (Angstrom parameter and AOD fine-mode fraction) and aerosol potential to modify water clouds (Aerosol Index). The AOD stands for Aerosol Optical Depth, where optical depth is the negative exponential attenuation coefficient normalized with respect to a nadir view. The Angstrom parameter requires AOD data at two different solar wavelengths (here at 440 and 870 nm) to address - via the negative slope in ln(AOD) / ln(wavelength) space - the aerosol particles size. A smaller (<0.5) Angstrom parameter indicates a dominance of super-micrometer sizes, while a larger Angstrom parameter (>1.2) indicate sub-micrometer size presence. A more useful size information is the fractional AOD attribution to sub-micrometer aerosol sizes, the fine-mode fraction, because modeling usually distinguishes aerosol into super- and sub-micrometer size-modes. Finally, the Aerosol Index, as the product of AOD and Angstrom, is a good proxy for aerosol number and a large aerosol number (AI >0.5) is a requirement for potential aerosol effects on clouds.

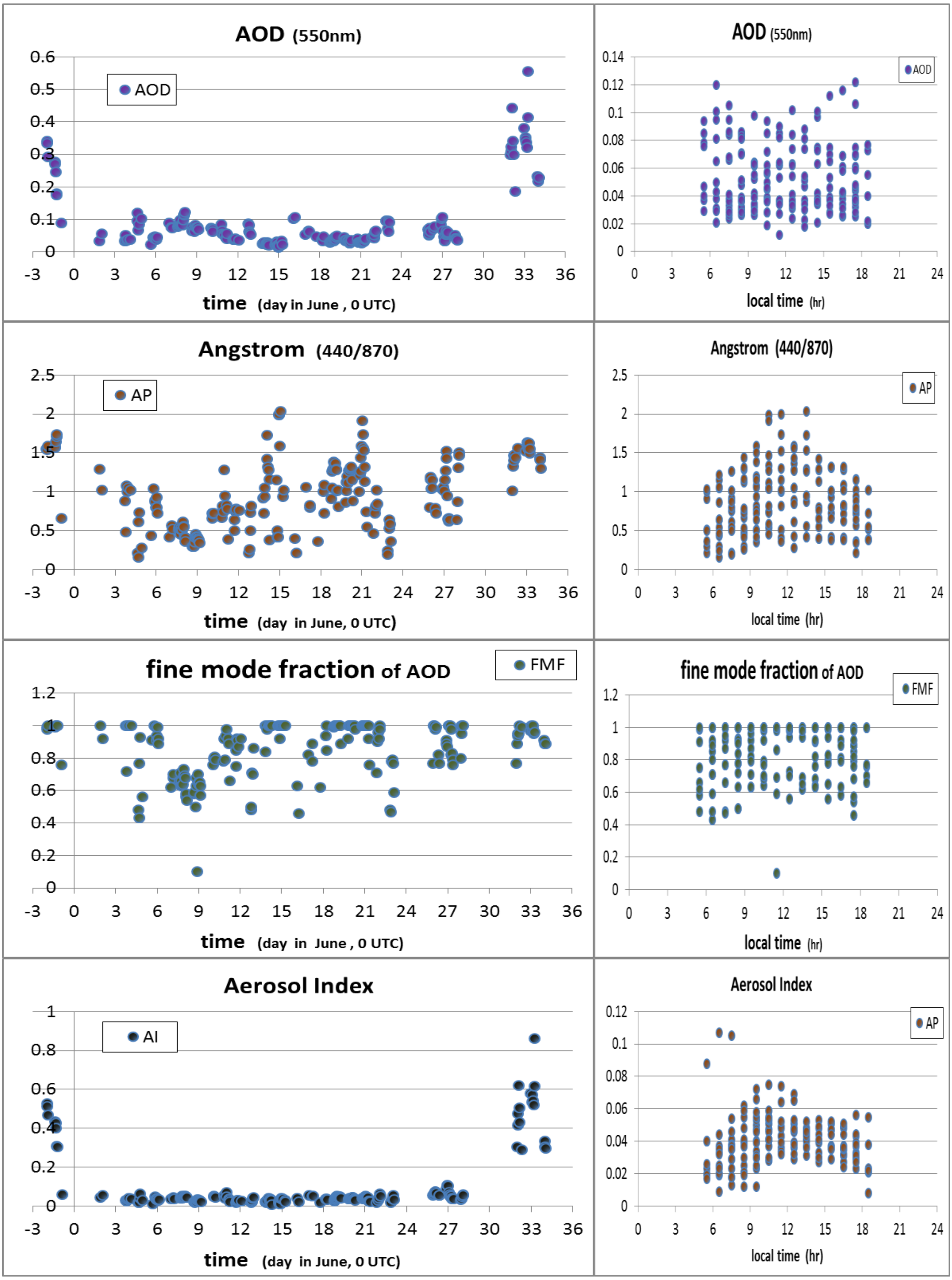

Figure 5.3.2.2 Aerosol column properties for AOD at 550 nm, for Angstrom parameter, for fine-mode AOD fraction and for the Aerosol Index (=AOD*Ang). Presented are time series of samples for the entire cruise (left) and dependencies to local time in June - thus away from urban pollution (right).

The MICROTOPS samples showed very high aerosol loads near the (arrival and departure) ports but very low aerosol loads over oceans. Over oceans (expect for larger values in the South China Sea) the AOD values (at 550 nm) stayed between 0.02 and 0.10 with the highest frequency between 0.03 and 0.04.

These low aerosol concentrations were associated with weak winds and larger aerosol sizes were rare, as fine-mode AOD fractions then stayed usually above 0.8 and Angstrom parameters above 1.0. The aerosol potential to affect the microphysical properties of low altitude clouds was very small, quite is contrast to much higher AI values closer to Vancouver and especially closer to Singapore.

In an application, sun-photometer data were sampled during ocean cruises over the last three years and reported to the MAN databases (as data from this cruise) were compared to retrieved AOD data by MODIS, MISR and VIIRS satellite sensors. MODIS and MISR sensors apply highly mature retrievals and have the longest ongoing AOD retrievals with global coverage. The more recently launched VIIRS sensor is tagged to succeed MODIS in future years and applies now a recently improved AOD retrieval. Only matches in space and time are considered. The match requirements consider 3x3 deg (lat/lon) regions around each MAN reference data and consider (if available) the nearest valid satellite AOD retrieval value within a timespan of plus/minus one day.

Tested **MODIS** data (2015-2018) were provided by Ed Hyer (NRL, Monterey), who had post-processed MODIS v6.1 data for assimilations in NRL's Navy Aerosol Analysis and Prediction System (NAAPS). The analysis is based on 1225 matches over 4 years (2015-2018) and absolute AOD deviations to MAN reference are presented in Figure 5.3.2.3.

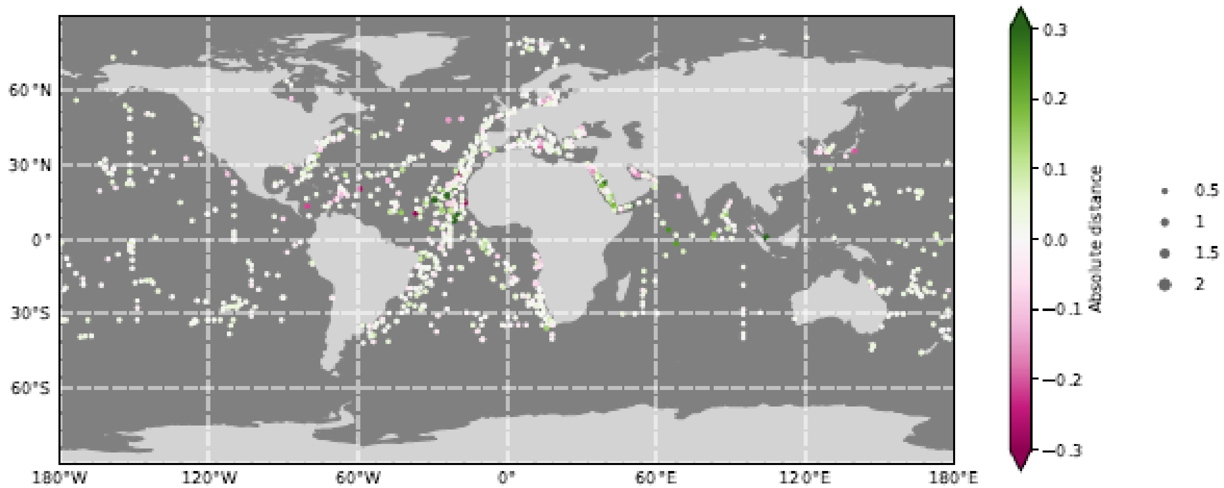

Figure 5.3.2.3 Deviations of MODIS AOD retrievals to MAN data matches, with overestimates displayed in green and underestimates displayed in red.

The MODIS offset to the MAN on average is positive but negative at the very high AOD values. Overall MODIS has a slight positive bias. Against the overall tendency values are too low over the central Atlantic, as if Saharan dust cases are removed.

Tested **MISR** data (2015-2018) were provided by Mike Garay (NASA JPL, Pasadena) who coordinated the recent re-processing for the new MISRv23 product, which is now much improved over oceans. In contrast to the MODIS, MISR retrievals extend further polewards, where AOD retrievals are usually more difficult. The analysis is based on 1002 matches over 4 years (2015-2018) and absolute AOD deviations to MAN reference are presented in Figure 5.3.2.4.

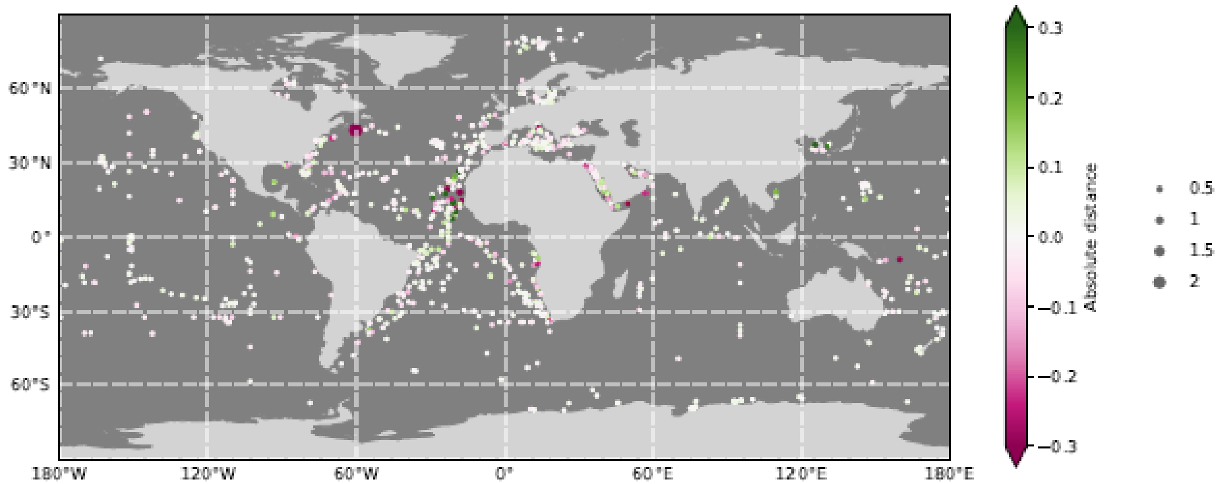

Figure 5.3.2.4 Deviations of MISR AOD retrievals to MAN data matches, with overestimates displayed in green and underestimates displayed in red.

The MISR offset to the MAN on average is slightly negative and more negative at the high AOD values. Similar to MODIS, there are AOD underestimates in the dust outflow regions off Africa and there are a few larger deviations, which need special attention.

Tested **VIIRS** data (2018) were provided by Hongqing Liu (NOAA, College Park) from their newest operational retrieval. The analysis is based on 327 matches over 1 year (2018) and absolute AOD deviations to MAN reference are presented in Figure 5.3.2.5.

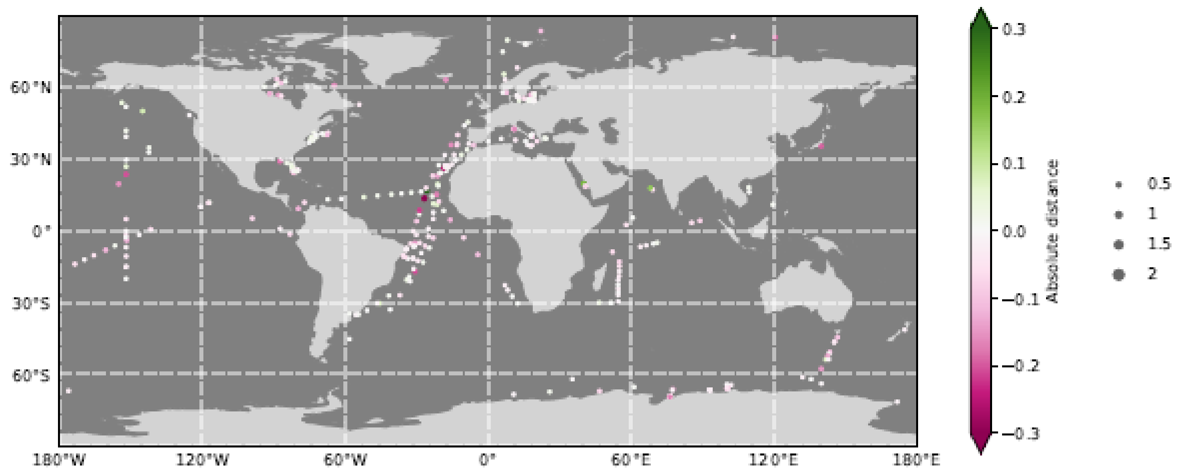

Figure 5.3.2.5 Deviations of VIIRS AOD retrievals to MAN data matches, with overestimates displayed in green and underestimates displayed in red.

The VIIRS offset to the MAN on average is negative.

5.3.3 Column data trace gases *(T. Ruhtz, S. Dörner, O. Tuinder, S. Kinne)*

Atmospheric trace gases were derived by measuring the solar energy (either the direct irradiance or the scattered radiation) in trace gas absorbing spectral regions. During the SO268-3 cruise four different instruments provided data on trace gases. The MICROTOPS sun-photometer (of NASA) provided estimates for water vapor, the MAX-DOAS instruments (of KNMI and MPI-C) provided information on

SO_2 and NO_2 (trace gases associated with pollution) and the Pandora-2s (of FU-Berlin) had the potential capability to mimic both, a sun-photometer and a MAX-DOAS.

MICROTOPS The sun-photometer determines the atmospheric water content from the difference in the solar attenuation in a spectral region with and without water vapor absorption. Combining attenuations at 870 and 940 nm (where water vapor absorbs), the atmospheric water vapor content increased from 20 mm over the Eastern Pacific to about 45 mm over the Western Pacific and larger day-to-day variations were associated with air mass changes (i.e. the June 10 frontal passage) as shown in Figure 5.3.3.1.

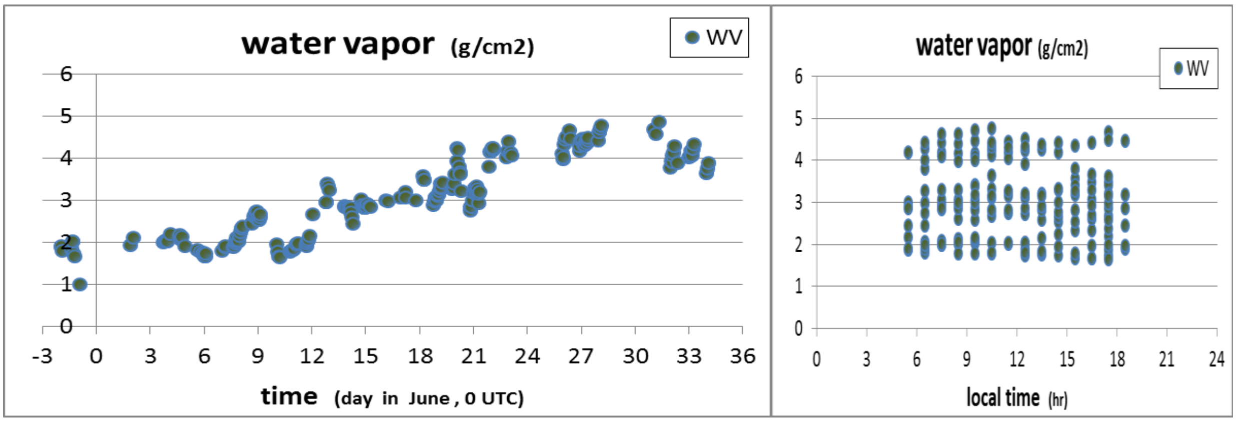

Figure 5.3.3.1 Water vapor column properties as time series of sun-photometer samples over the entire cruise (left frame) and dependencies to local time during June - away from urban pollution (right frame).

MAX-DOAS – KNMI The MAX-DOAS spectrometer of KNMI was onboard the RV SONNE since the cruise SO 267-2 from January 2019 (Fiji). The measurements are intended to validate TROPOMI satellite NO_2 and O_3 retrievals at oceanic background conditions. The MAX-DOAS instrument was mounted on the railing on the observation deck as illustrated in Figure 5.3.3.2.

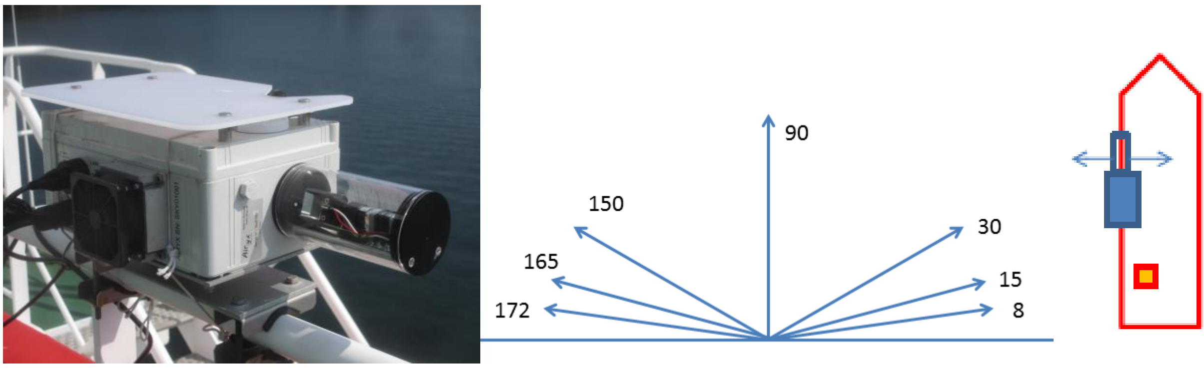

Figure 5.3.3.2 MAX-DOAS of KNMI on the RV SONNE (left), a sketch of the MAX-DOAS (blue box) and the chimney (yellow red-rimmed square) position with line of sight measurement perpendicular to the ship's direction (right) and the elevation angles for the atmospheric probing of scattered sunlight (center).

The azimuth angle of the KMNI MAX-DOAS sampling was perpendicular to the ship's heading direction. At this fixed azimuth angle the MAX-DOAS instrument sequentially scanned at elevation angles of 8°, 15°, 30°, 90°, 150°, 165°, 172° during a measurement cycle (elevation angles larger than 90° refer to the backward direction). One measurement cycle took about 1-2 minutes to complete.

Results The processing of the data is limited as no KNMI staff member participated in SO268-3 and only remote access to the instrument for functioning checks were possible. Some preliminary data, however, for June 8 and June 15, 2019 are already offered and shown in Figure 5.3.3.3.

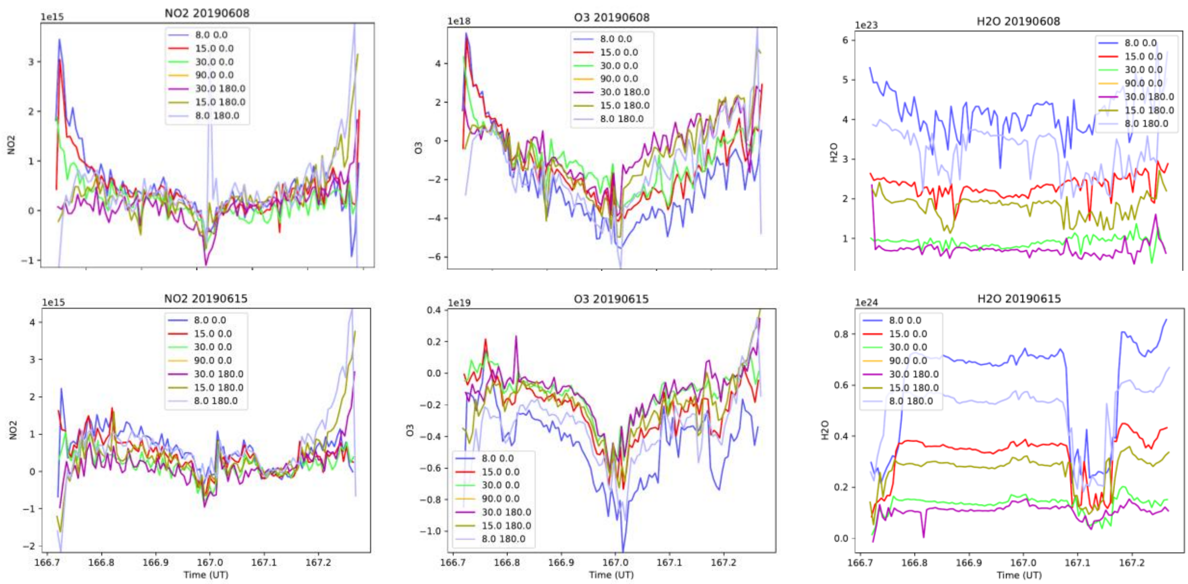

Figure 5.3.3.3 Sample data for NO_2 (left), O_3 (center) and water vapor (right) with the KNMI MAX-DOAS instruments at different elevations during June 8, 2019 (top row) and during June 15, 2019 (bottom row).

After the instrument has been brought back home, co-locations with TROPOMI overpasses will be identified and data will be compared. There are plans to submit a paper about the comparisons from this (and previous) trips to a peer-reviewed journal in 2019.

MAX-DOAS - MPI-C The Tube Multi AXes Differential Optical Absorption Spectrometer (Tube MAX-DOAS) measures spectra of scattered sun light between 303 nm and 465 nm for a series of elevation angles. These measurements are used to derive atmospheric profiles of aerosol extinction and trace gas concentrations. The main focus of the cruises starting with SO267-2 until the end of SO268-3 cruise from Suva, Fiji to Manzanillo, Mexico, Vancouver, Canada until Singapore was to retrieve the following species from the measured spectra: Nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) from (mostly) anthropogenic sources like diesel fuel combustion, formaldehyde (HCHO) from anthropogenic and biogenic sources, water vapor (H_2O) and the oxygen dimer (O_4) with information on the aerosol extinction. These species help to characterize the chemical composition of the atmosphere, the location and strength of emission sources and provide important input for global modeling and comparisons to satellite data. In addition, measured spectra contain information on less abundant species like bromine monoxide (BrO), iodine oxide (IO) and glyoxal (CHOCHO) for which tropospheric abundances especially in marine regions are not well known.

Since the data of the MPI-C MAX-DOAS were not analyzed at the time of this report (as no MPI-C staff was participating on the SO268-3 cruise) Figure 5.3.3.4 shows examples of retrieved profiles for aerosol and water vapor from a previous (SO267-2) cruise are presented for two cloud-free days (February 3 and 4, 2019).

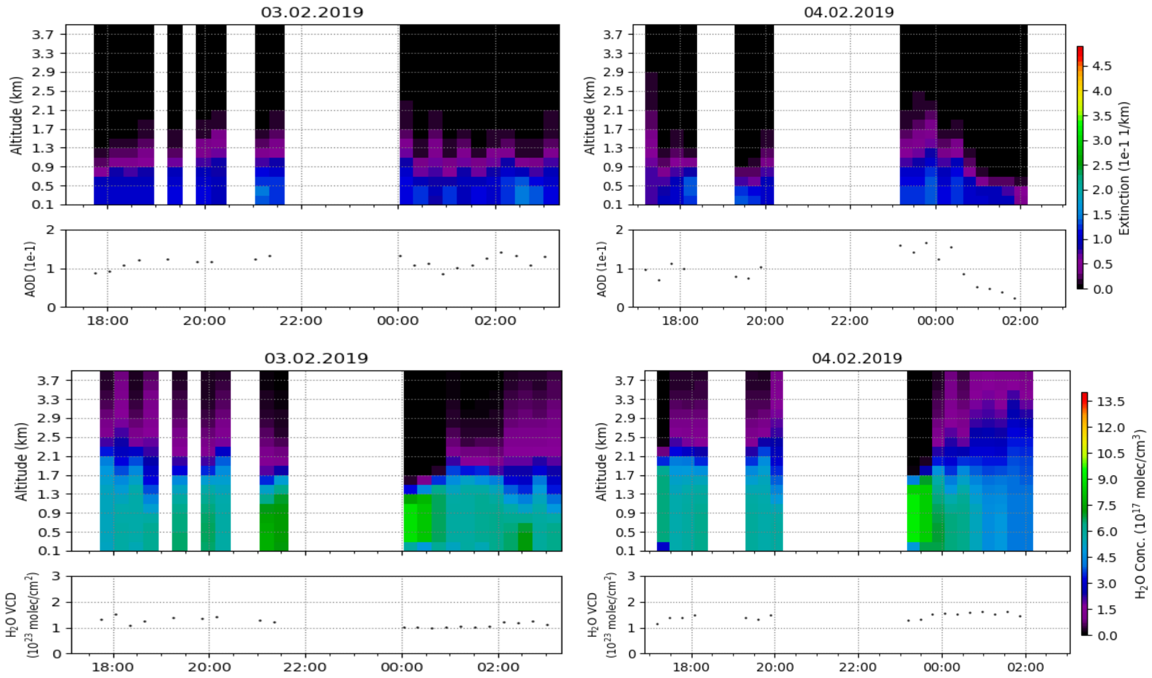

Figure 5.3.3.4 Aerosol extinction profiles and aerosol optical depths at 360 nm (upper panel) as well as water vapor concentration profiles and vertical column densities as retrieved from Tube MAX-DOAS spectra of scattered sunlight for two selected days (Feb 3 and Feb 4) during the SO267-2 cruise. The dates refer to local time, while the time axis is displayed in UTC.

The profiles were retrieved via estimates of the light pass through the atmosphere with the MAinz Profile Algorithm (MAPA) at cloud-free conditions as illustrated for February 4, 2019 in Figure 5.3.3.5.

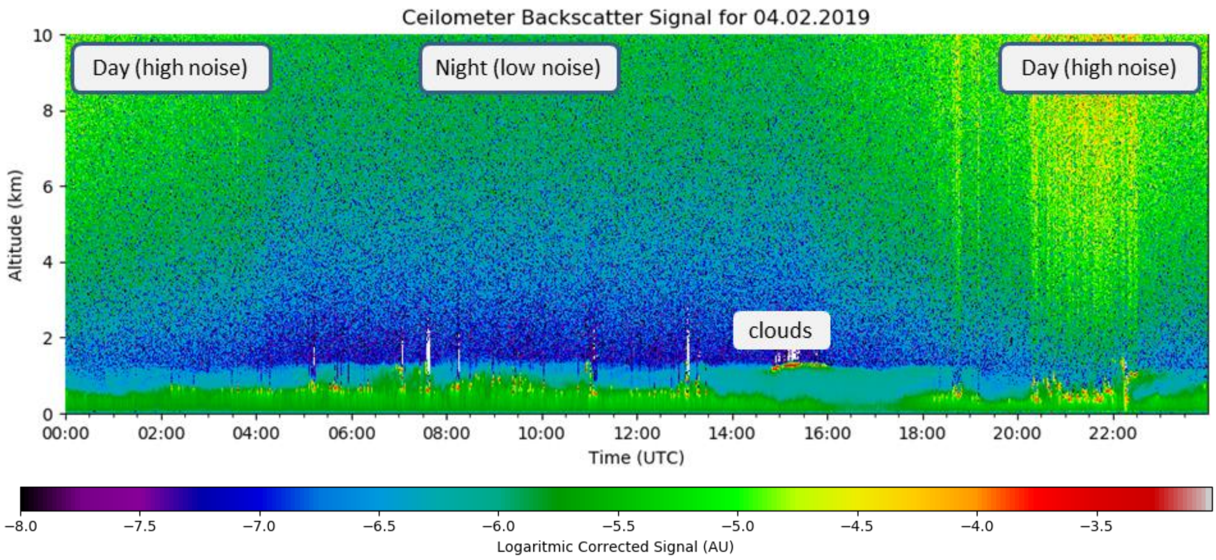

Figure 5.3.3.5 Example for 24 hours of ceilometer measurements: Strong backscatter signals indicate clouds, e.g. only between 15:00 and 16:00 h on February 4, 2019. The strong gradient at about 1 km altitude indicates the top of the planetary boundary layer.

The determined layer height with enhanced aerosol extinction remained almost constant at around 1.1 km. During the afternoon (1 a.m., UTC) the layer height drops to about 500 m while the total AOD decreases. The water vapor column density remains constant while its layer height increases from 1.5 km to 3.0 km.

As the next steps the results of the Tube MAX DOAS measurements will be compared to the MAX DOAS instrument set up by KNMI and the PANDORA instrument set up by FU Berlin in order to identify and solve possible issues with either of these three instruments. Again, all three hyperspectral instruments with MAX-DOAS elevation sampling capabilities are shown in Figure 5.3.3.6.

Figure 5.3.3.6 MPI-C (left), KNMI (center) and FU-Berlin (right) solar hyper-spectral instruments with MAX-DOAS scanning capabilities for the retrieval of atmospheric trace-gases (and aerosol).

Pandora 2S This hyperspectral instrument combines MAX-DOAS measurements at different elevations (above the horizon) with sunphotometer samples of the direct solar attenuation. During SO268-3 the Pandora 2S was installed on a tripod on top of the observation deck as illustrated in Figure 5.3.3.7.

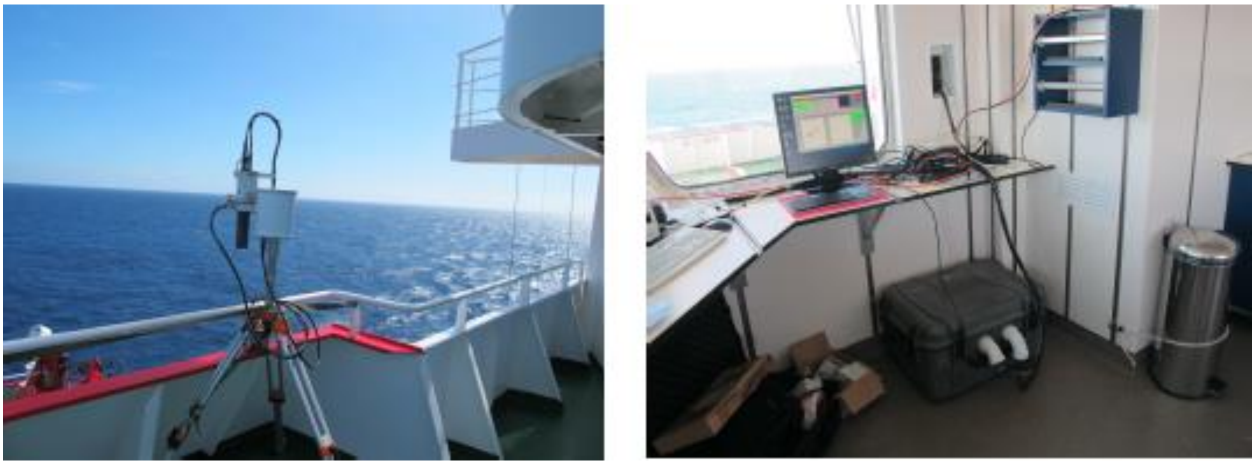

Figure 5.3.3.7 Sensor heads on the Pandora-2s on top of the observation deck during the cruise (left) and the data display unit and instrument control box inside the observation deck (right).

With this instrument lower atmospheric profiles of trace gases such as NO_2, O_3, H_2O and SO_2 via the MAX-DOAS technique can be determined. In addition, direct attenuation data in a sun photometer mode can determine column properties of aerosol and trace gases. And in a CIMEL mimicking mode, in theory, even aerosol size distribution and aerosol absorption could be determined with AERONET type inversion methods. In a NASA- and ESA-initiated effort to provide trace gas reference data for satellite retrievals of trace gases, almost 100 instruments have been distributed worldwide at continental and island sites under the umbrella of the Pandonia Network.

The Pandora-2S unit operated on the ship is an attempt for an operation as a mobile unit (e.g., for ship-based measurements). Unfortunately the direct sun orientation - even with available data for the ship (roll and pitch) movements - failed due to software issues. Thus, only trace gas data from the MAX-DOAS sampling at different zenith angles (of 0°, 60°, 75°, 80°, 82°, 85°, 86°, 87°, 88°, 89°) could be reported. Data from two relatively cloud-free days (June 8 and June 15, 2019) are presented in Figure 5.3.3.8.

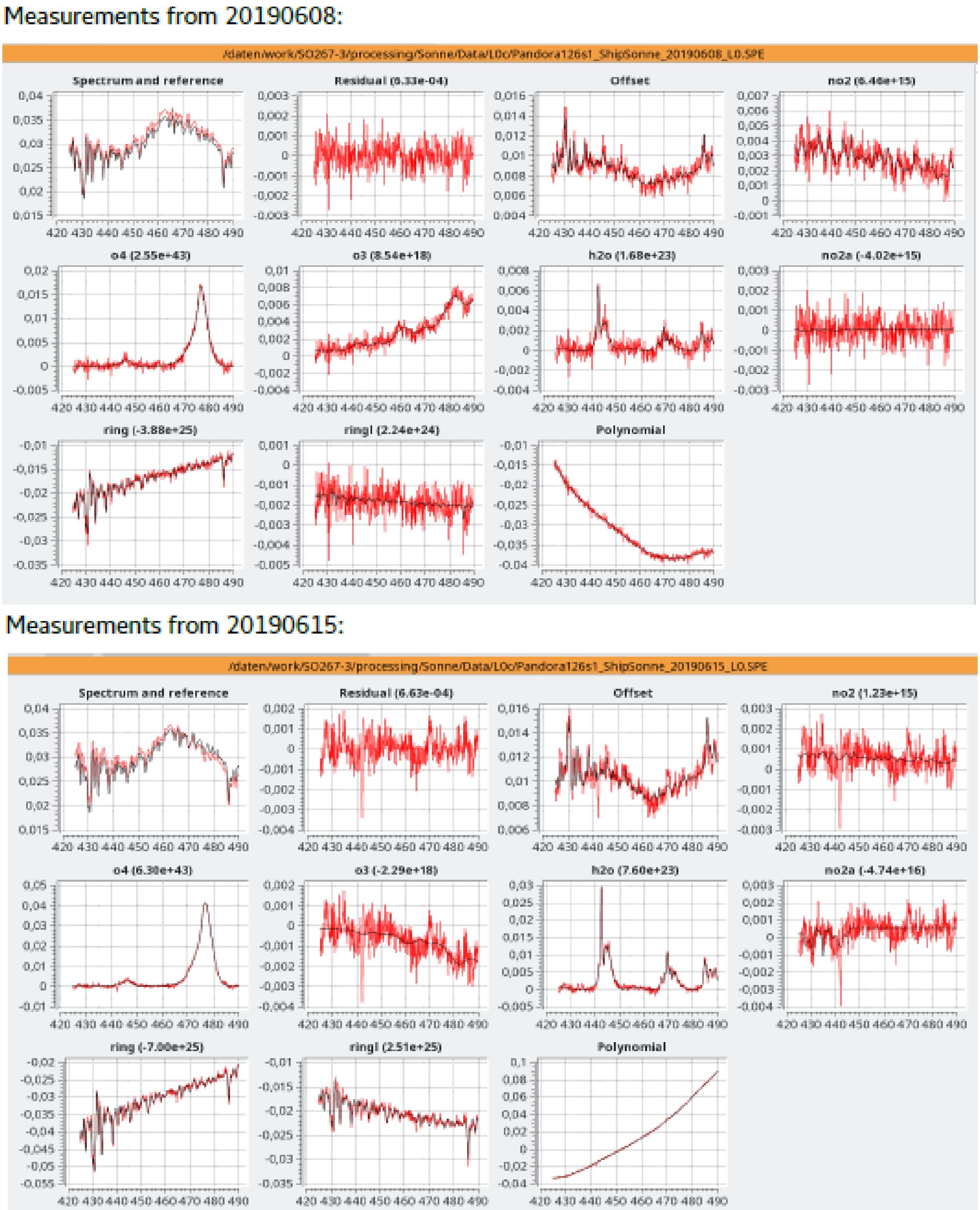

Figure 5.3.3.8 Sample measurements with Pandora-2S on June 8 and on June 15, 2019.

5.3.4 Column data greenhouse gases *(R. Kleinschek, M. Knapp)*

Background The Total Carbon Column Observation ground Network (TCCON) is intended to monitor concentrations of atmospheric greenhouse gases and provide reference data for satellite remote sensing. TCCON sites are land-based, but a few islands-based sites (none in the Pacific) cannot offer over-ocean conditions. The BRUKER EM27/SUN Fourier Transform Spectrometer measures direct solar absorption spectra in the shortwave infrared spectral range. From those spectra, a retrieval algorithm calculates the total column concentrations of the trace gases CH_4, CO, and CO_2 in the atmosphere. CO_2 and CH_4 are major greenhouse gases and CO represents pollution. In order to perform direct sunlight measurements, a sun tracker is used to have the sensor follow the sun. The tracker compensates for the movement of the ship sufficiently under typical conditions (i.e., the tracker keeps the spectrometer sensor fixed on the solar disk with a precision of about a tenth of the apparent sun diameter).

Measurements An improved instrument setup was used for the ship deployment of the spectrometer. Several electric compartments were added to automatize the measurement process. Furthermore, an enclosure box was built to protect all parts (i.e., the optics) from the environment. The box has dimensions of approximately 0.5 x 0.5 x 1.0 m and weighs 80 kg. It consumes 400 W via a regular 230 V line. This allows easy transportation and setup on field campaigns. In order to provide sufficient calibration data, the spectrometer has been deployed side-by-side with the TCCON station in Karlsruhe, Germany, before the cruise. This allows to trace its results to the World Meteorological Organization (WMO) standard. The setup was outside during the whole cruise on the uppermost possible level of the ship as illustrated in Figure 5.3.4.1.

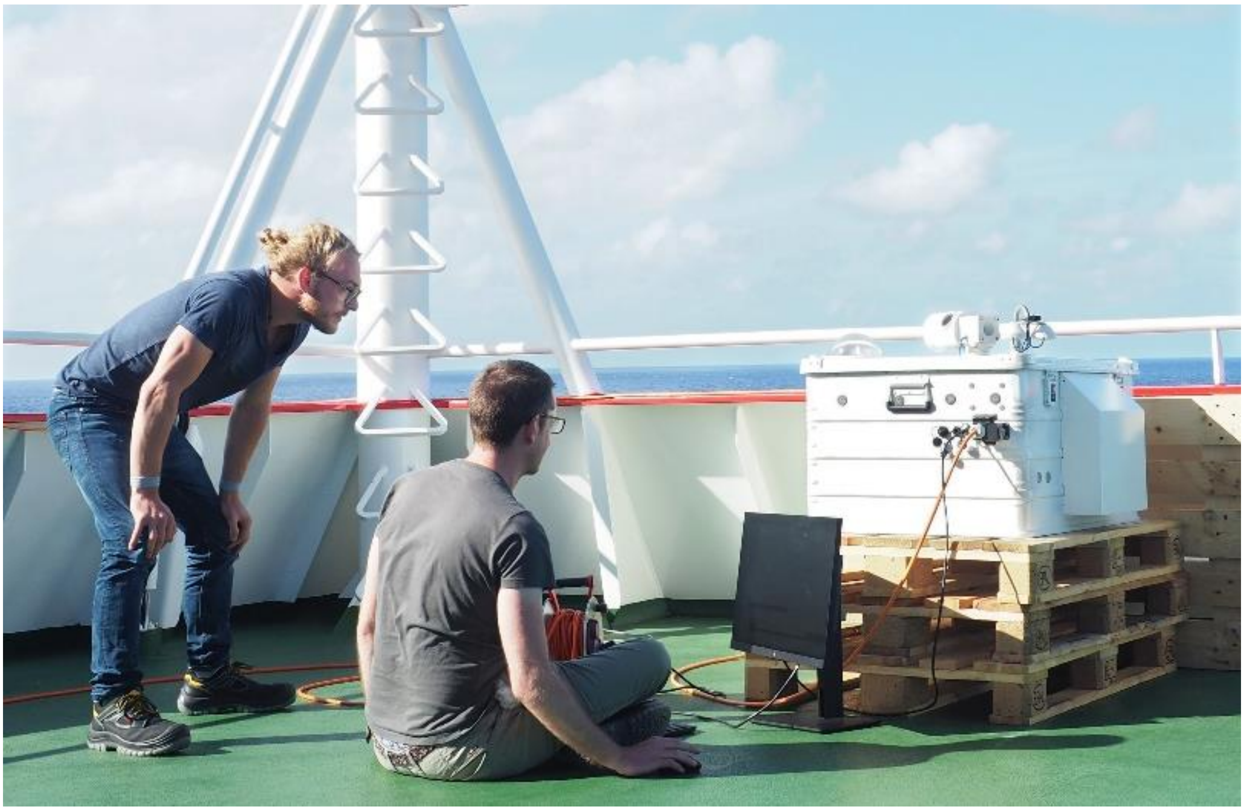

Figure 5.3.4.1 The instrument set-up on the observation deck of the RV SONNE.

After four weeks, the instrument showed little to no damage from rain, wind, or corrosion from sea salt. Despite very humid tropical air and heat inside the box, it was always possible to take measurements. These are not affected by the shielding, especially by the wedge window in the enclosure of the sun tracker. Therefore, we were able to collect more than 65,000 spectra on 20 days.

Results All sampled spectra need to undergo several quality filters before passing the retrieval algorithm. Most frequent causes for failure were optically too thick cloud within the direct light path of the sun or substantial deviations in the tracking of the solar disk. Applying data filters for these cases preliminary results of three consecutive sunny days at the end of June 2019 are presented in Figure 5.3.4.2.

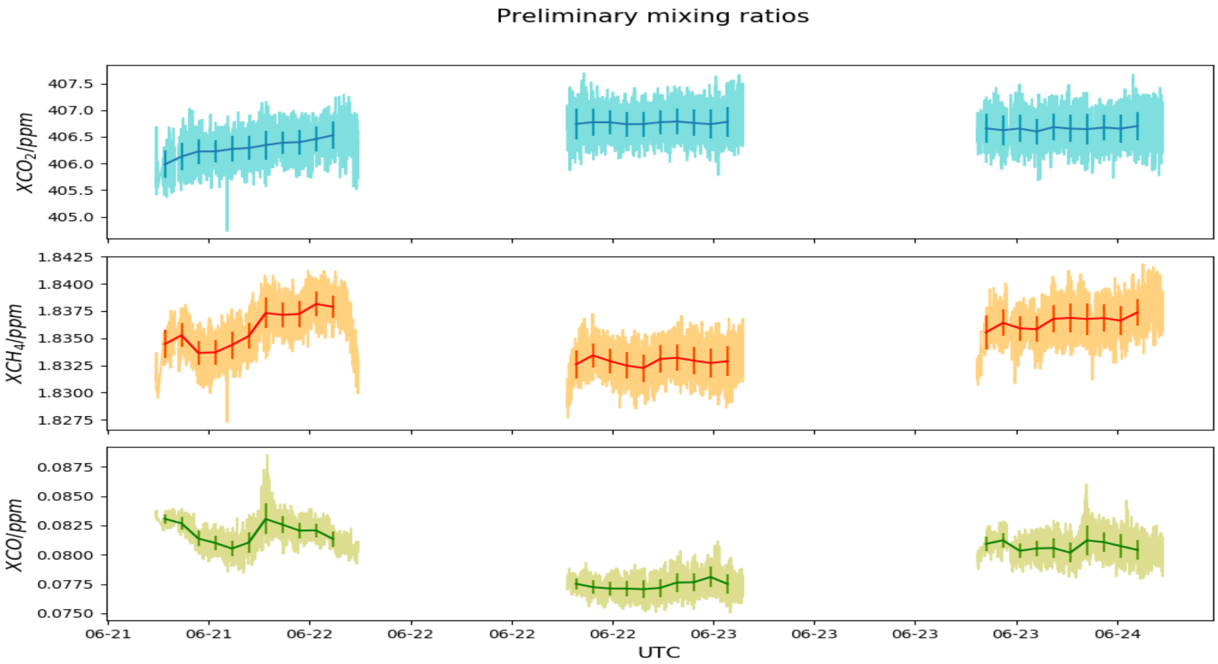

Figure 5.3.4.2 Atmospheric column data for CO_2, CH_4 and CO on three sunny days over the Pacific.

Note, that the data presented in Figure 5.3.19 are not fully post-processed. The post-processing includes a filter for false measurements due to spectroscopic shortcomings, the removal of a spurious solar zenith angle (SZA) dependency and the scaling of the retrieved mixing ratios on WMO standard. From these steps, only the latter two have been applied to the data shown in Figure 5.3.4.2. While the SZA-correction should be based on the whole data set, here it was applied on a daily basis. Furthermore, only preliminary TCCON data were available at the time of this report, so the scaling factors on WMO standard are likely to cause small changes. Nevertheless, the data give a first glimpse into mixing ratios and detection limits for the measured greenhouse gas species.

Future work The final data set of the SO268/3 cruise will be filtered and processed. Another side-by-side deployment at the TCCON station in Karlsruhe is planned to validate our calibration factors to assure instrument stability during the cruise.Then the samples are ready for comparison to satellite and model data. A long-term goal is the unattended deployment of the EM27/SUN on non-research vessels to produce an extensive validation data set in the notoriously thin covered areas above water for satellites like OCO-2/3, TROPOMI, and GOSAT(-2). Upcoming steps are the improvement of the tracking accuracy, especially for low SZA, and an independent start of measurements as soon as the sky conditions allow.

5.3.5 Clouds

Clouds were observed with a ceilometer, nadir viewing laser, and with a camera system with a visible and a thermal imager. In the context of cloud base as a function of altitude, the accuracy of the ceilometer and the spatial context of the thermal images complement each other. Both instruments are illustrated in Figure 5.3.5.1.

Figure 5.3.5.1 Ceilometer (left) and the camera system with a visible frog-eye and a thermal sensor (right).

Ceilometer The Lufft CHM-8k ceilometer repeatedly sends laser beams at a non-visible wavelength (905 nm) upward in the nadir direction and waits for backscattered signal returns. The time that had passed provides information on atmospheric particle density and size. As the laser is quickly attenuated in optically denser media (optical depths >2) water clouds are usually indicated by a strong return signal, which represent the cloud base altitude and no further signal above that altitude. Figure 5.3.3.5 already showed ceilometer data for an entire day. As sunlight provides an additional source of radiance at 905 nm, daytime measurements are typically more noisy than nighttime measurements. Also with increasing altitude the uncertainty of the backscatter signal increases.

Daily time series of ceilometer backscatter profile up to 10 km in altitude during the SO268-3 cruise from May 31 to June 30, 2019 are illustrated in Figure 5.3.5.2. Hereby being on the other side of the globe with respect to Greenwich, UK nighttimes with less solar scatter noise at higher altitudes are in the center of each UTC day. Cloud base altitudes show that most days had significant cloud cover. This limited the opportunities to collect reference data for aerosol and trace gases. Clouds in the Eastern and central Pacific (until June 20, 2019) were mainly at lower attitudes (below 2 km). Towards the Western part of the Northern Pacific convective clouds increased, also indicated by cloud bases that are detected at higher altitudes.

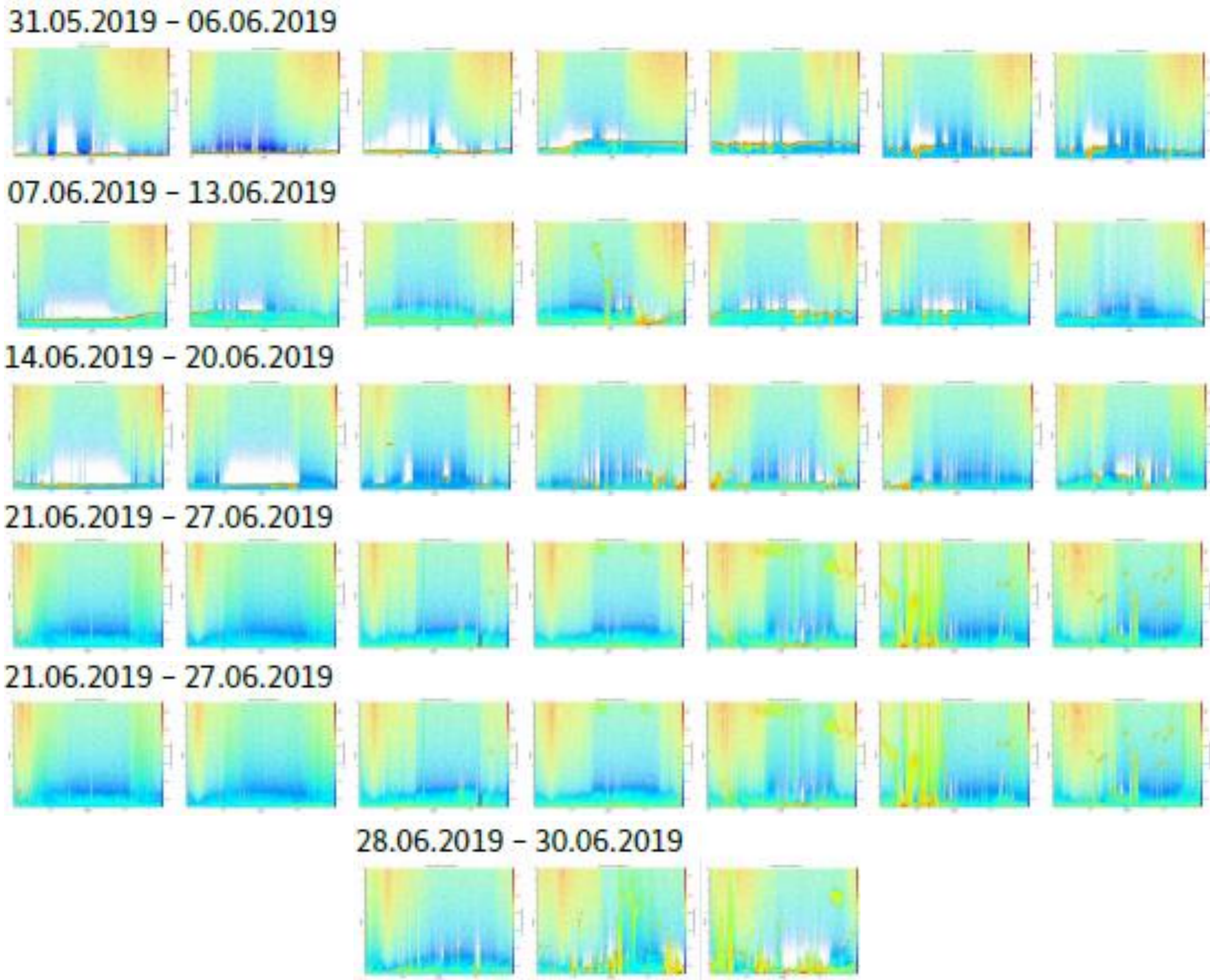

Figure 5.3.5.2 Ceilometer data from May 31 to June 30, 2019. Daily time-series are presented in UTC time.

Cloud camera The analysis of clouds with the camera system focuses on thermal imager data, because information on cloud presence, cloud structure and cloud altitude are quasi continuously (every 10 s) offered, during day and night. Compared to the surface temperature the sensed blackbody temperature is lower as a function of altitude and coldest in cloud-free conditions. First the total cloud cover is determined by counting the pixels in all images that are warmer than the cloud-free sky temperature. This sky temperature is defined by the 5 % pdf value of all (300 x 200) pixels of all (8640) images during a day. If this 5 % pdf value is relatively warm (in the case of overcast conditions lasting all day) then the clear-sky threshold temperature of a previous day is prescribed. The next step is to assign cloud base altitude. Since the difference between sky and surface temperature is usually near -60 °C at high latitudes (in the absence of radiosonde soundings) a simple temperature decrease with respect to the hourly average surface temperature is assumed: -4.5 K ~ 500 m, -9 K ~ 1 km, -13 K ~ 1.5 km, -17 K ~ 2 km, -24 K ~ 3 km and -40 K ~ 6 km. This lapse rate (temperature decrease with altitude) assumption is complicated in warmer climates, when water vapor continuum absorption (proportional to the square of the water vapor concentration) in effect reduces the prescribed lapse rate attributed to each altitude. In an approximation a lapse rate reduction factor is applied based on the reduced difference between surface temperature and sky temperature (Factor = $[T_{surf} – T_{sky}] / 60$). Then based on the temperature assigned altitudes of 0.5, 1.0, 1.5, 2.0, 3.0, 6.0 and 10 km cloud cover and cloud homogeneity (based on cloud boundary lengths) are determined. Thermal camera-based hourly averages for cloud cover as function of altitude for the Pacific crossing near 30 °N (between 28 and 32 °N) is presented in Figure 5.3.5.3.

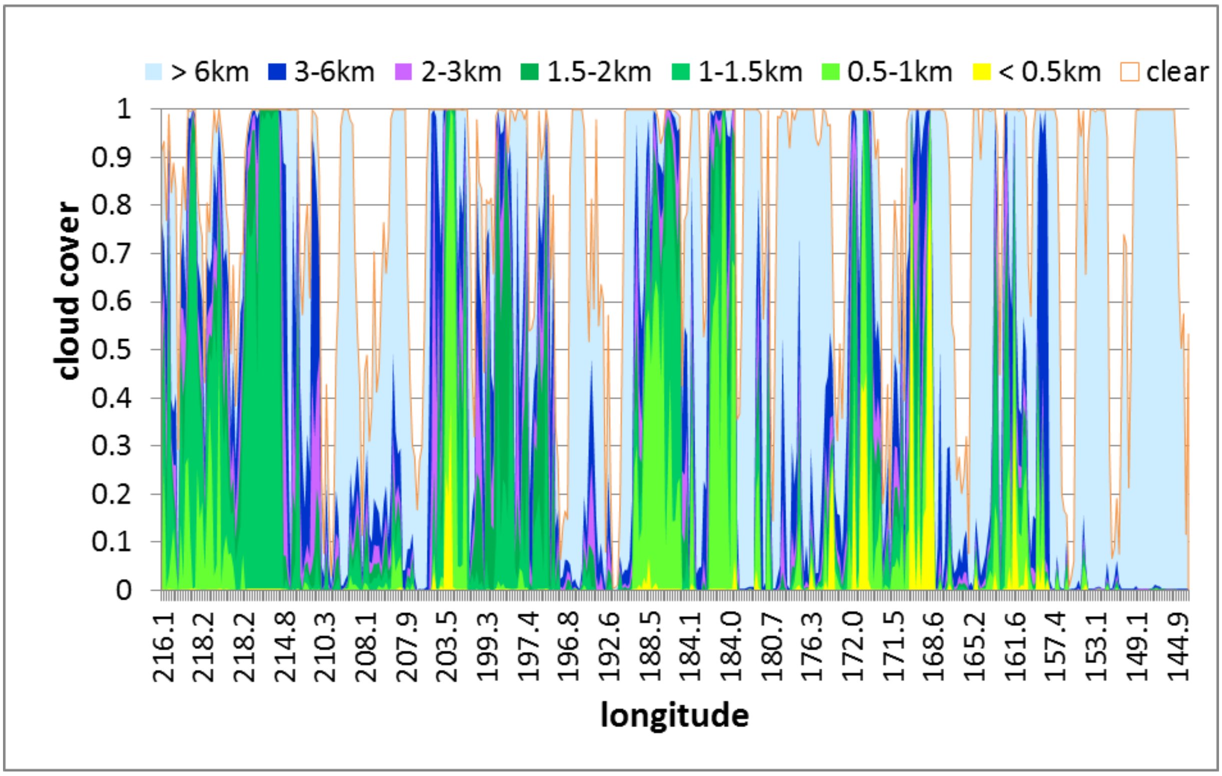

Figure 5.3.5.3 Cloud base cover hourly averages as function of longtiude/time and altitude based on hourly averages of thermal camera images for the crossing of the Pacific near 30 °N during June 2019.

With warmer surface temperatures from the Eastern Pacific to the Western Pacific the frequency of higher altitude clouds and convection increased. During the Pacific crossing there were extended regions with significant periods of large cloud cover, which restricted the sampling of aerosol and trace gases. Thus for comparison time and values of the retrieved AOD values are presented in Figure 5.3.5.4.

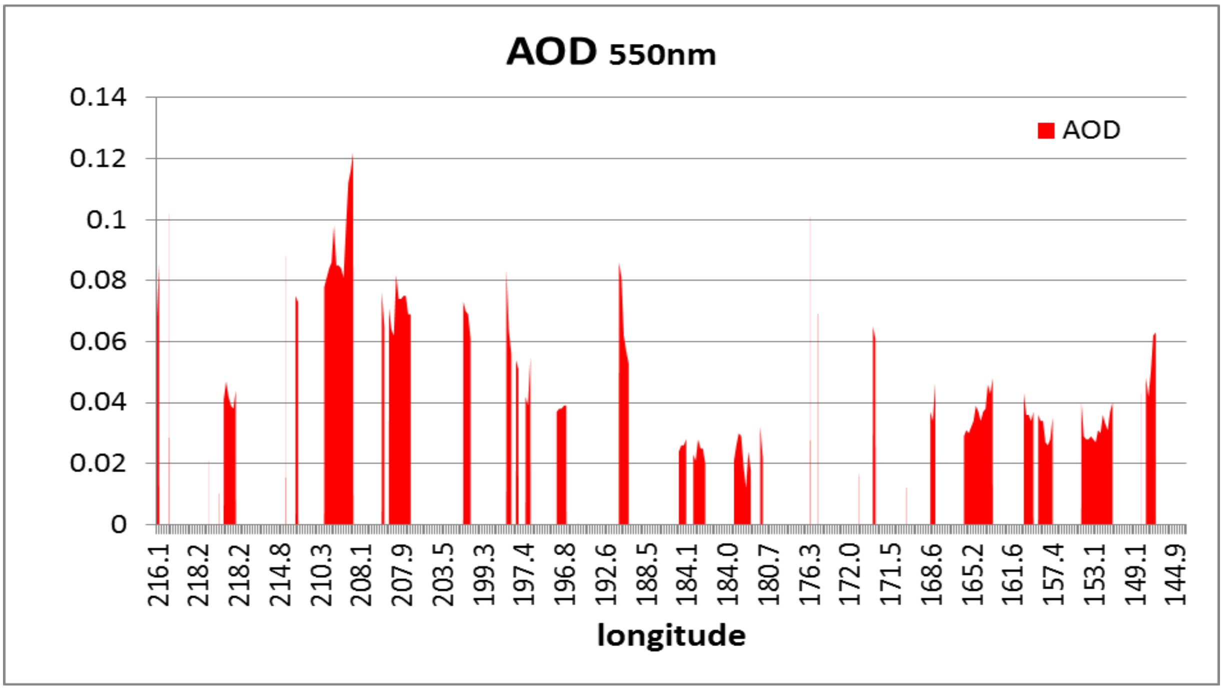

Figure 5.3.5.4 Successful AOD retrievals (cloud-free views at the sun) as function of longtiude/time.

The comparison between cloud cover and successful AOD data indicates that there are times, when (admittedly – only when including estimates for very high altitude clouds) when a 100 % cloud cover contradicts successful aerosol sampling. This indicates that assigned cloud temperature in the cloud base altitude assignment are probably too cold. This is also confirmed by binning the (trusted) ceilometer altitudes on a hourly basis in a similar plot in Figure 5.3.5.5.

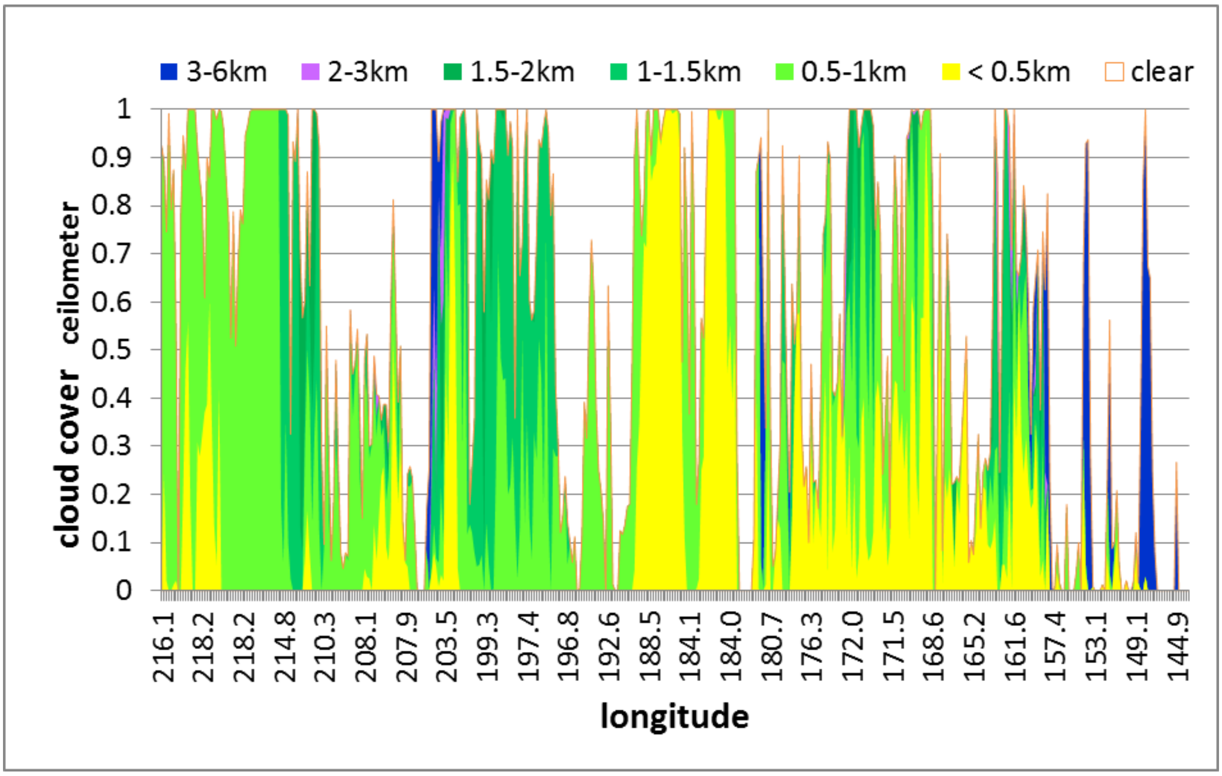

Figure 5.3.5.5 Cloud base cover hourly averages as function of longtiude/time and altitude based on hourly averages of nadir viewing ceilometer for the crossing of the Pacific near 30 °N during June 2019.

Having these reference altitude distribution data available, now lapse rate assumptions can be revisited (and reduced), such that with reprocessing a better fit to the ceilometer statistics is achieved so that the thermal cloud camera altitude distribution becomes more quatitative. Another thermal camera element are investigations of the cloud inhomogeneity, which is compared at different altitudes in Figure 5.3.5.6.

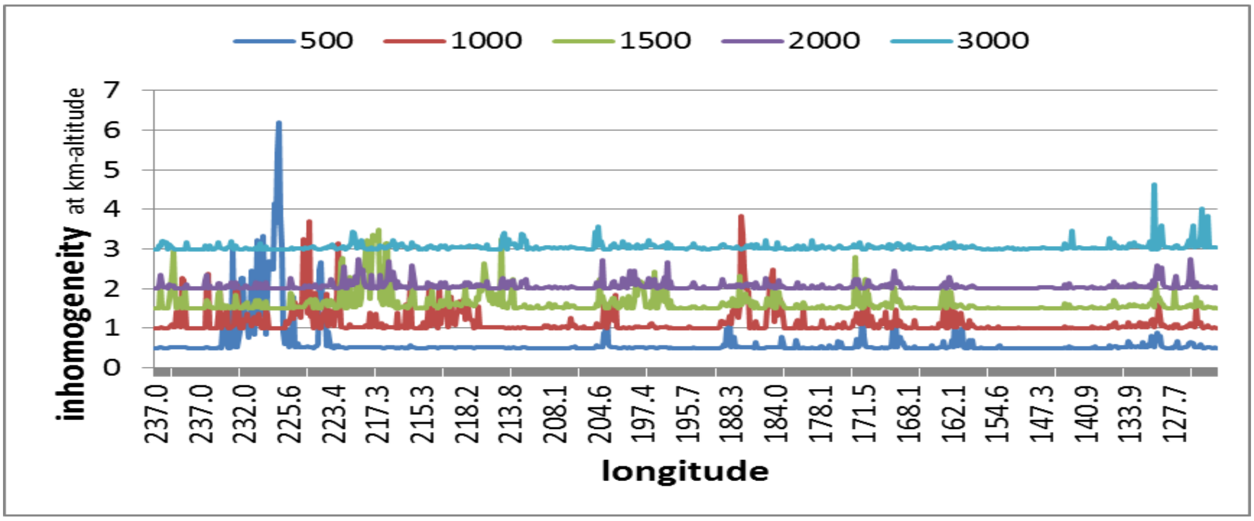

Figure 5.3.5.6 Comparison of inhomogeneity strength at different cloud altitudes (0.5, 1, 1.5, 2, 3 km).

Daily cycles with respect to low altitude cloud cover and total cloud cover based on the cloud camera analysis is presented in Figure 5.3.5.7. In that figure the missing low cloud cover fractions for total cloud cover during local noon seem strange and should be revisited after reprocessing.

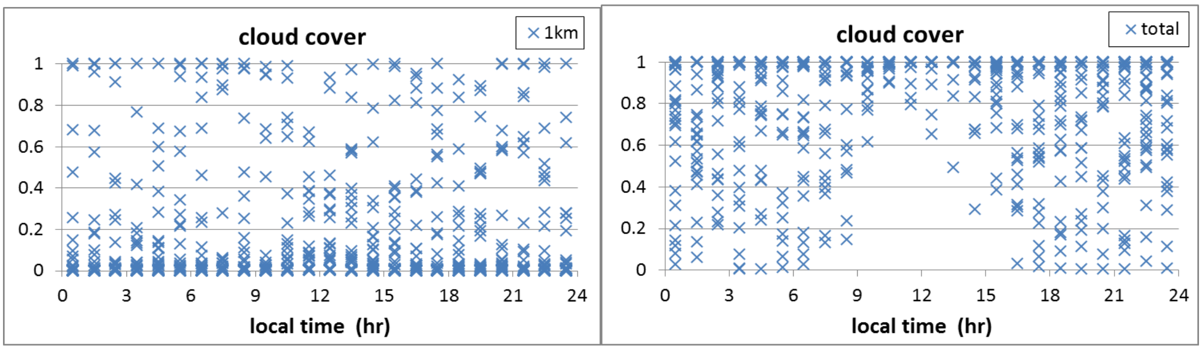

Figure 5.3.5.7 Comparison of daily cycles for low altitude (left) and total (right) cloud cover.

5.3.6 Associations (*S. Kinne*)

In this section relationships between different atmospheric properties are examined. Hereby associations of hourly averages are compared. Selected atmospheric variables are examined for their relationships to (1) surface wind speed, (2) water-minus-air temperature differences at the surface, (3) sea surface temperature and (4) aerosol properties.

Wind-speed dependencies Aerosol and cloud properties to wind speed are examined in Figure 5.3.6.1.

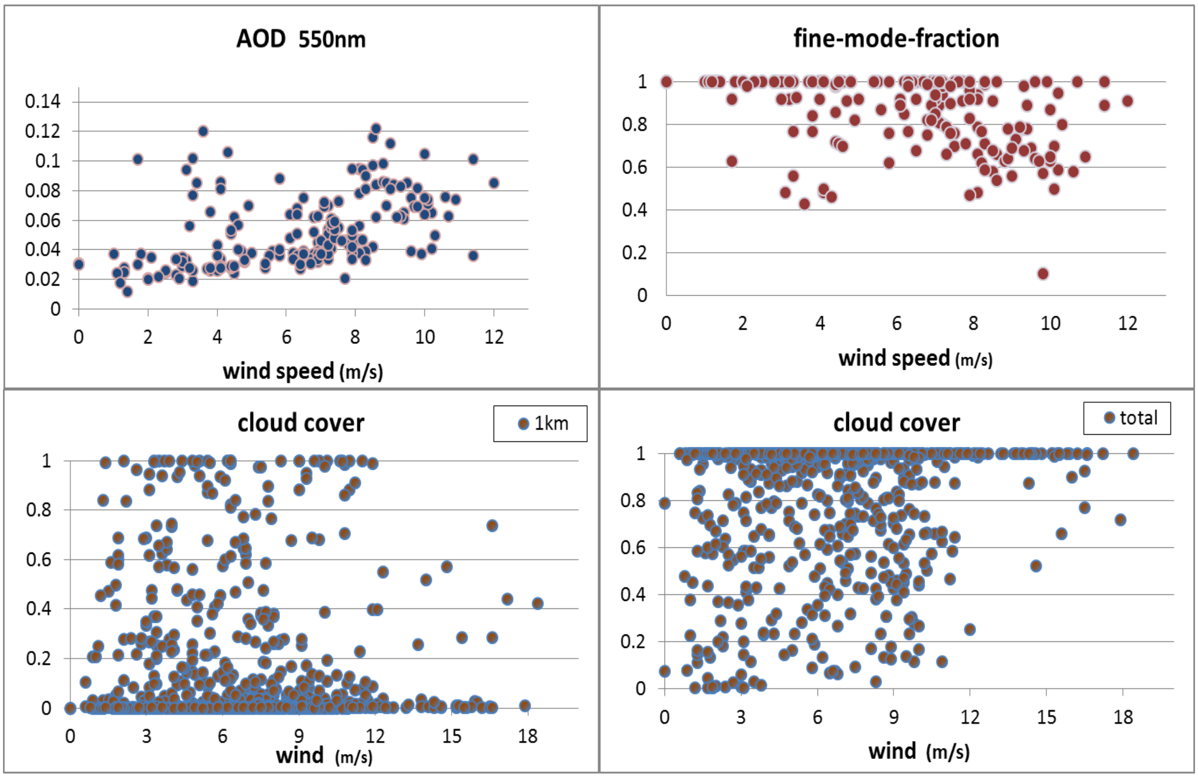

Figure 5.3.6.1 Hourly average associations of AOD (upper left), AOD fine mode fraction (upper right), cloud cover near 1 km (lower left) and total cloud cover (lower right) as function of surface wind speed over the Northern Pacific in June, 2019.

Stronger wind speeds are expected to raise AOD values and lower fine-mode AOD fractions, as with sea spray relatively large sea salt particles are released into the atmosphere. Expected relationships are reproduced, although the scatter is significant. Quite relevant are the low AOD boundary at a particular surface wind speed and the wind speed when the fine-mode AOD fractions start to deviate significantly from 1.0 (~ at 8 m/s). Wind-to-cloud cover associations demonstrate that low cloud overcast conditions are only supported up to 12 m/s and that for the highest wind speeds the total cloud cover is usually high.

Surface temperature difference dependencies Associations of hourly averages between cloud cover and air-minus-water temperatures over the Northern Pacific are examined in Figure 5.3.6.2. With precipitation overcast conditions and evaporative T_{air} cooling (thus more negative T_{air}-T_{water} differences) are expected. However, such a dependency is weak for low and total cloud cover.

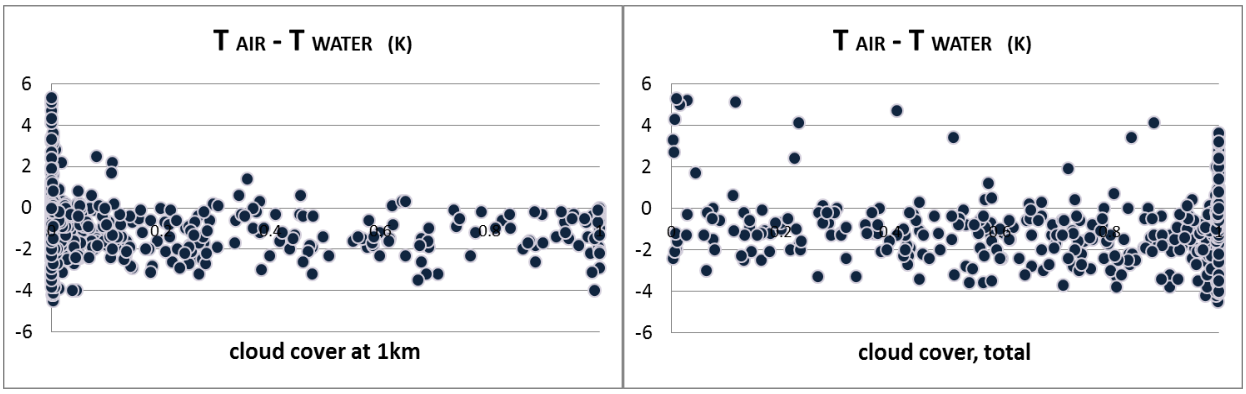

Figure 5.3.6.2 Hourly average associations of cloud cover to water-air temperature difference.

Sea surface temperature dependencies Associations of hourly averages of water vapor and cloud cover as a function of the sea surface temperature (SST) are examined in Figure 5.3.6.3.

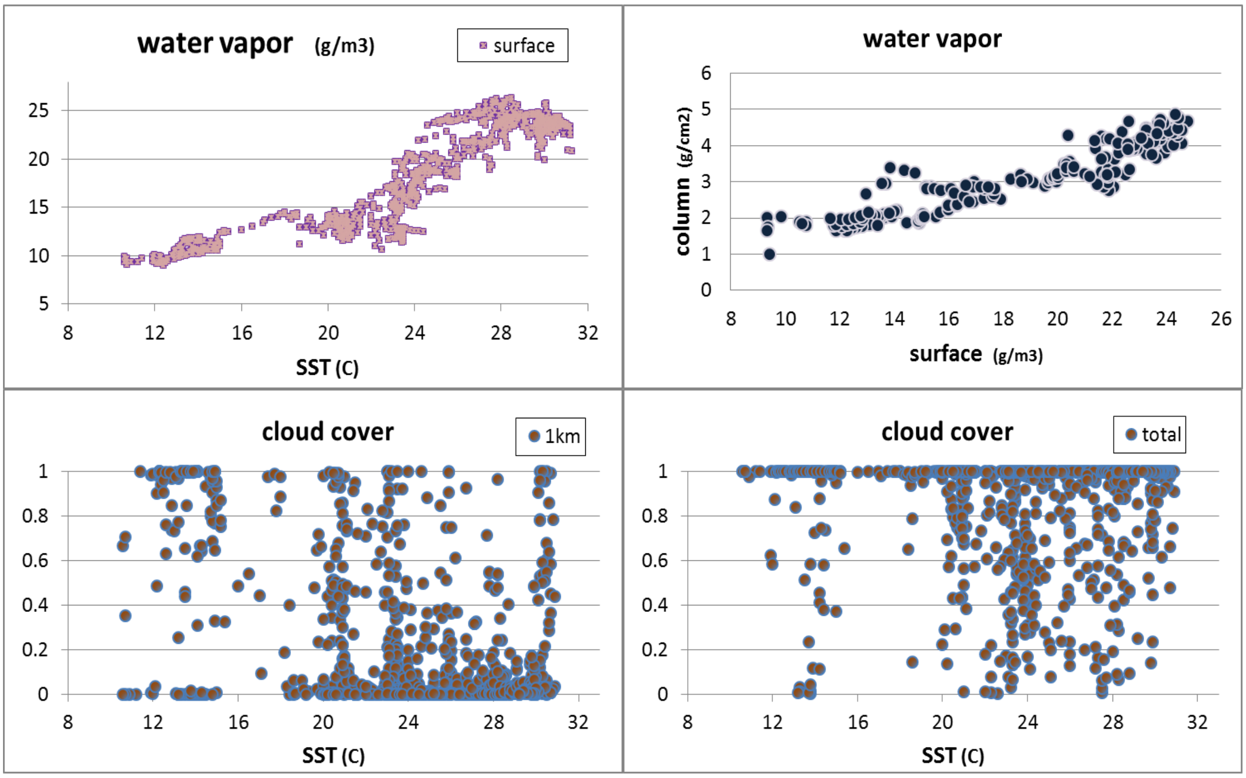

Figure 5.3.6.3 Hourly average associations of water vapor and cloud cover as function of the SST.

The water vapor concentration increases with the surface temperature weakly exponentially – similar to the saturation curve. Interestingly, the ratio between column water vapor and water vapor concentration at the surface is much larger at higher SST. Cloud cover dependencies on SST suggest that at very warm surface temperatures the low cloud altitude coverage is relative low, while total cloud cover is relatively high – something to expect from unstable and convective atmospheres.

Aerosol dependencies Associations of hourly averages of cloud properties to aerosol properties are examined in Figure 3.5.6.4 and associations among aerosol properties in Figure 3.5.6.5.

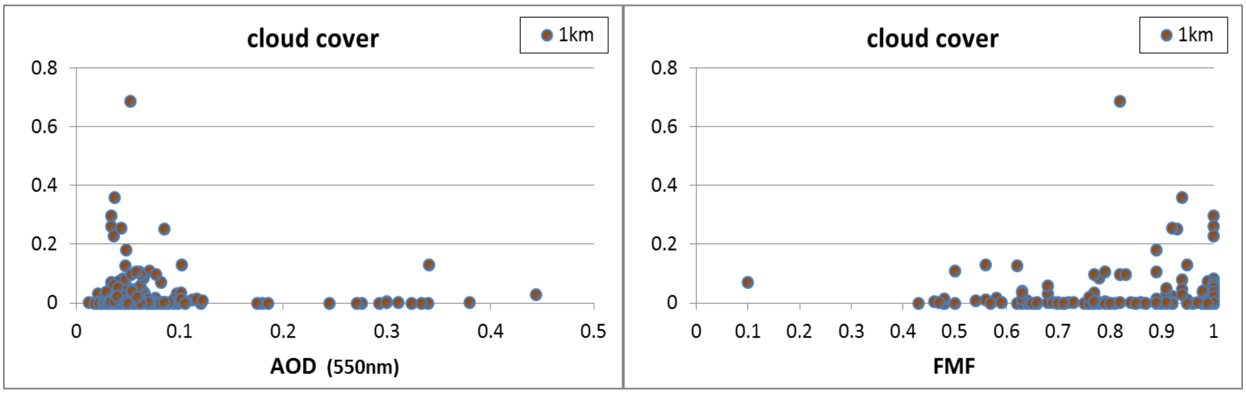

Figure 5.3.6.4 Hourly average associations of low cloud cover as function of AOD and AOD fine-mode fraction over the northern Pacific in June 2019.

Usually high AOD values are assocaited with low cloud cover (e.g., low potential for wet deposition).

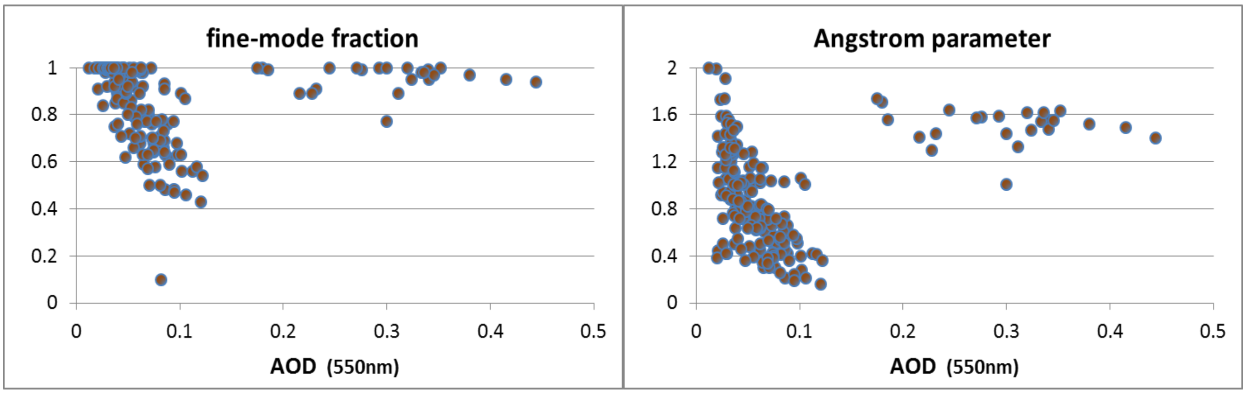

Figure 5.3.6.5 Hourly average associations of fine-mode AOD fraction or Angstrom parameter to AOD over the northern Pacific in June 2019.

AOD data over ocean associated larger AOD with larger particles (e.g. lower fine-mode fractions and lower Angstrom parameters). The large AOD values with low particles are associated with pollution close to the departure and arrival ports and are not typical for ocean regions.

5.4 Plastic pollution

An extensive sampling programme was carried out at the profile stations to characterize the distribution and fate of plastic material at the sea surface, but also to investigate biofilm formation on the plastic surface and formation of aggregates as possible mechanisms leading to sinking of the particles in the water column down to the seabed. According to a current hypothesis, only a small proportion of the plastic emitted into the marine environment remains floating at the surface, while up to 99 % sink to deeper layers or the ocean floor, and we will assess this hypothesis with the field material collected on SO268-3. The large-scale equipment used for this purpose included:

- Neuston Catamaran (CAT) to collect plastic particles >335 µm at the sea surface
- McLane *in situ* pumps (McL) to sample particles >35 µm, >10 µm and >0.45 µm at up to four depths throughout the water column
- Cascade filtration (CAS) for sampling of particles of different sizes close to the sea surface
- Multiple Corer (MUC) to collect up to 20 sediment cores with 10 cm diameter
- Large-volume solid-phase extraction (SPE) unit to sample organic pollutants from water (at the sea surface and at the deployment depths of the McL)
- CTD Rosette for recording different profiles such as temperature from the surface to the sea floor and to sample 24 x 10 L water at various depths
- Marine Snow Catcher (MSC) for collection of aggregates down to 400 m depth and plankton nets (NET) to sample plastic and other material at the sea surface and down to 130 m depth
- „SONNE net" that was built by the SONNE crew specifically for this expedition and scoop sampling for sampling of large plastic debris
- Ocean Floor Observation System (OFOS) for photographs of the seabed
- Mesocosms to investigate plastic weathering with/out UV irradiation

At each of the eight profile stations (see above), the entire range of samples was collected, while certain types of sampling were also carried out "underway" while steaming: SPE and CAS and partly CAT. The following sections describe the relevant research questions or hypotheses, the number and characteristics of the sample material collected and the analyses that have already begun, while the majority of the investigations will be carried out subsequently in the home laboratories of the participating institutes.

The MICRO-FATE project is coordinated by the Helmholtz Centre for Environmental Research - UFZ in Leipzig, with partners from the Leibniz Institute for Baltic Sea Research - IOW in Warnemünde, the Fraunhofer Institute for Ceramic Technologies and Systems (IKTS) in Dresden and Stockholm University (SU), Sweden. Also involved are scientists from the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (AWI), Bremerhaven, and from Senckenberg am Meer Research Institute (Senck), Wilhelmshaven, as well as an interdisciplinary artist, amongst others for photo documentation of the ongoing research work and for the creation of a blog about this expedition: blogs.helmholtz.de/on-tour.

With some of the collected material, extensive work to characterize the biofilm growing on the plastic surface was carried out. Furthermore, visual observations of the sea surface in so-called flotsam surveys were done with contributions of most of the scientists, which allowed a large part of the cruise track to be monitored. In the following sections, the scientific work, the obtained material and a preview of the first results are presented, grouped according to the large equipment used.

5.4.1. Neuston Catamaran (CAT) *(C. Rummel, M. Banu Tekman, M. Bergmann, A. Jahnke)*

Background We used CAT at each profile station to determine the concentration of microplastic (<5 mm) in the superficial water in the North Pacific Ocean. It allowed the sampling of the neuston, i.e., the fraction of floating organisms directly underneath the water surface. The neuston contains plastic fragments which are collected using a net with a mesh size of 335 µm.

Sampling Once deployed, the CAT trawls alongside the ship to avoid contamination by ship-bourne particles for 45 minutes at about 4 knots, with the net attached close to the sea surface. Hereby it collects the organisms and particles from the top layer of water. In order to allow for extrapolations of the amount of microplastic present in the surface layer, a flowmeter was used to determine the flow rate. As soon as the CAT was lifted to the deck, we exchanged the net and deployed the CAT a second time to maximize the amount of material collected for the different analyses. At station SO268/3_7, we deployed the CAT four times to generate replicates for plastic and biofilm analysis. In addition to the profile stations, we deployed the CAT twice underway (stations SO268/3_28 and SO268/3_29) to increase the spatial resolution of the obtained data set. Additional material for pollutant determination was collected using a scoop, and at one station using a boat (see below). All deployments are listed in Table 5.4.1.1., and the device and selected samples are displayed in Figure 5.4.1.1.

Table 5.4.1.1. Details of CAT deployments during SO268/3

station no.	timestamp	latitude	longitude	remarks / info on sea state
SO268/3_2-4	02.06.2019 13:20	39° 28,592'	135° 57,323' W	calm sea, no wind, no waves
SO268/3_2-5	02.06.2019 14:04	39° 29,520'	135° 57,407' W	
SO268/3_5-6	05.06.2019 05:37	33° 53,894'	144° 47,435' W	calm sea, no wind, no waves
SO268/3_5-7	05.06.2019 06:32	33° 53,983'	144° 45,659' W	
SO268/3_6-5	07.06.2019 00:49	30° 02,509'	141° 43,955' W	1.5 m wave, wind 3 m/s
SO268/3_6-6	07.06.2019 01:47	30° 03,213'	141° 41,307' W	
SO268/3_7-1	08.06.2019 22:30	30° 10,126'	152° 01,767' W	1.5 m waves, wind 8-9 m/s. CAT drifting close to the ship
SO268/3_7-2	08.06.2019 23:22	30° 07,744'	151° 58,950' W	
SO268/3_7-7	09.06.2019 16:14	30° 05,133'	151° 55,646' W	1.5 m waves, wind 8-9 m/s. CAT drifting close to the ship
SO268/3_7-8	09.06.2019 17:11	30° 03,549'	151° 54,292' W	
SO268/3_10-2	12.06.2019 01:44	29° 59,690'	162° 36,275' W	1 m wave, windy
SO268/3_10-3	12.06.2019 02:36	30° 03,234'	162° 35,646' W	
SO268/3_17-3	15.06.2019 05:37	29° 33,280'	175° 58,084' W	totally flat sea, no wind, no waves, a lot of macroplastic, net opening around 3-4 cm above water line
SO268/3_17-4	15.06.2019 06:25	29° 30,953'	175° 56,054' W	
SO268/3_21-4	18.06.2019 04:24	29° 50,117'	171° 30,153' E	2 m waves, windy, rough sea, 10 m/s wind speed, trawl against waves
SO268/3_21-5	18.06.2019 05:18	29° 51,719'	171° 32,858' E	as above, trawl with the waves
SO268/3_28-1	22.06.2019 04:33	28° 01,119'	152° 04,671' E	calm, almost no waves, construction works on deck
SO268/3_28-2	22.06.2019 05:22	28° 01,271'	152° 01,259' E	
SO268/3_29-1	24.06.2019 05:30	25° 42,052'	140° 56,497' E	0.5 m waves, windy (7 m/s)
SO268/3_29-2	24.06.2019 06:22	25° 41,366'	140° 52,410' E	
SO268/3_30-3	27.06.2019 04:57	22° 42,372'	127° 43,589' E	sampling was one day after 2 m waves and 7 bf (26/06/19), at 0.5 m waves, windy
SO268/3_30-4	27.06.2019 05:55	22° 38,890'	127° 43,060' E	

Ongoing work and planned analyses The analyses done/planned with the CAT material were diverse, and in many cases, the work on board only comprised the conservation of the sample for future work in the laboratories of the participating individual institutes: Some of the plastic samples went to a group of researchers for biofilm analysis to carry out functional and structural analyses of the superficial community (see chapter 5.4.10). Another group received an undisturbed CAT sample which was frozen for the detection, characterization and quantification of the plastic particles. Finally, some larger particles were dried and stored frozen for future determination of the concentrations of environmental pollutants sorbed to the plastic material (see chapter 5.4.5). The sampling cups with the valuable material were distributed directly amongst scientists, and different analyses are scheduled to maximize the analyses done successively with each single particle.

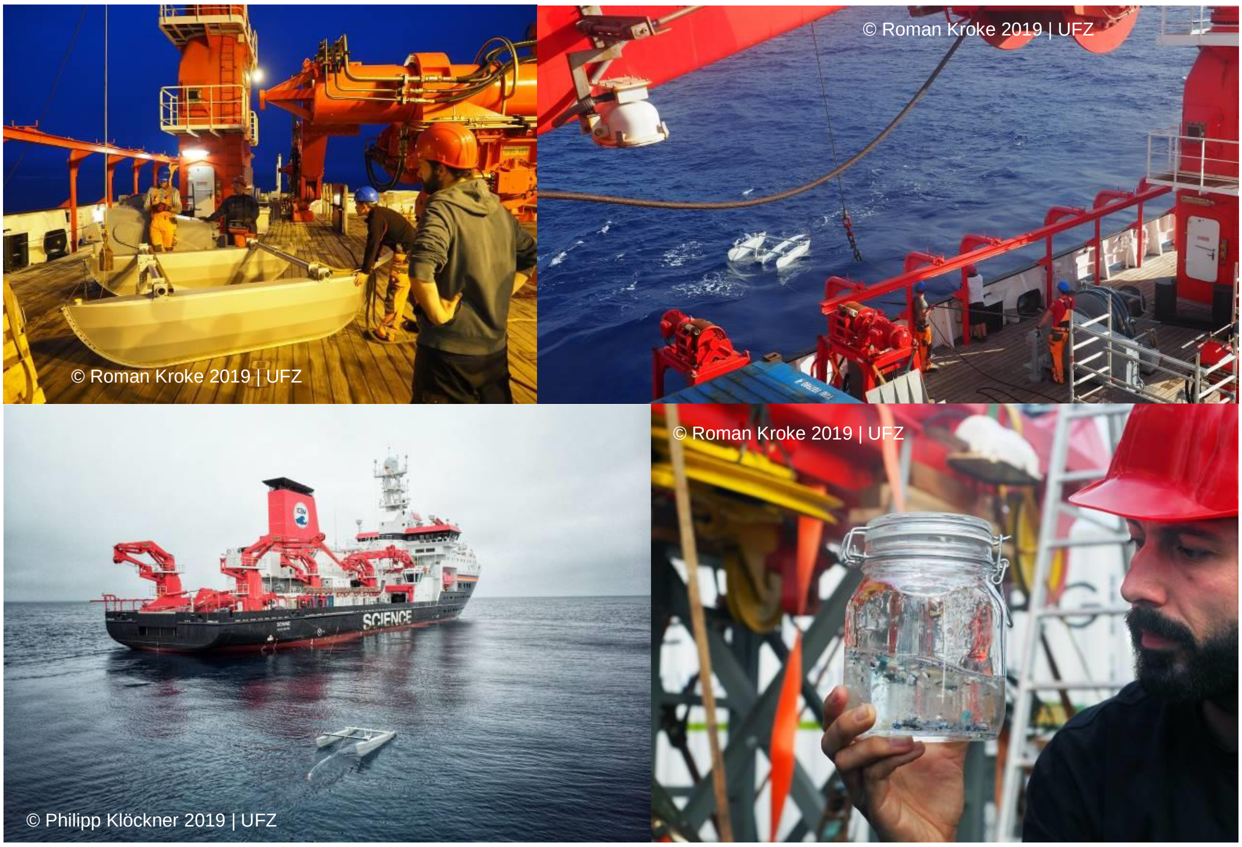

Figure 5.4.1.1 Nighttime deployment of the CAT and sampling with trawling next to the SONNE. An example of a sample collected from the North Pacific Garbage Patch (lower right).

5.4.2. McLane *in situ* pumps (McL) *(M. Banu Tekman, A. Jahnke)*

Background The McL were used to determine the particle distribution between the ocean surface and the seabed. With the help of McL, we sampled particles >35 µm, >10 µm and >0.45 µm at up to four depths in the water column to obtain comparable data to published data generated during past campaigns. At the final stations (SO268/3_30 and SO268/3_31), we continuously sampled replicates of the entire profile from the surface to the deep sea, in order to explore a new sampling design that allows for integration of the entire water column.

Sampling The McL were mounted on the 11 mm CTD cable as part of the CTD deployments. They were usually mounted and programmed in a way that they started sampling at their designated depths: bottom (about 70 m above the sea floor), 2500 m, 300 m, chlorophyll maximum (between 50 and 140 m, info from CTD sensor). At these depths, they were allowed to sample particles for 60-120 min. During the final two stations, another sampling strategy was followed: The pumps were mounted directly above the CTD and pumped continuously to characterize the profile from the sea surface to about 5000 m depth, while lowering down the equipment at a speed of 0.5 m/s. The samples collected are listed in Table 5.4.2.1., and impressions of the sampling are demonstrated in Figure 5.4.2.1.

Table 5.4.2.1 Details of McL deployments during SO268-3.

station no.	timestamp	latitude	longitude	depths, pumping time
SO268/3_2-2	02.06.2019 04:02	39° 28,403' N	135° 57,298' W	bottom, 2500 m, 300 m, chl. A max., 60 min
SO268/3_5-4	04.06.2019 15:47	33° 55,223' N	144° 46,938' W	bottom, 2500 m, 300 m, chl. A max., 120 min
SO268/3_6-3	06.06.2019 10:45	30° 02,474' N	141° 45,843' W	bottom, 2500 m, 300 m, chl. A max., 120 min
SO268/3_7-3	09.06.2019 01:14	30° 05,145' N	151° 55,655' W	bottom, 2500 m, 300 m, chl. A max., 120 min
SO268/3_10-1	11.06.2019 17:49	29° 59,375' N	162° 36,275' W	bottom, 2500 m, 300 m, chl. A max., 120 min
SO268/3_17-1	14.06.2019 23:05	29° 33,421' N	175° 58,224' W	bottom, 2500 m, 300 m, chl. A max., 90 min
SO268/3_21-1	17.06.2019 20:46	29° 50,008' N	171° 29,966' E	bottom, 2500 m, 300 m, chl. A max., 120 min
SO268/3_30-1	26.06.2019 15:42	22° 44,795' N	127° 43,598' E	continuous profile to 4975 m depth (*n* = 3), immediate hoisting
SO268/3_31-1	28.06.2019 02:03	21° 57,150' N	124° 24,789' E	continuous profile to 5127 m depth (*n* = 2), immediate hoisting

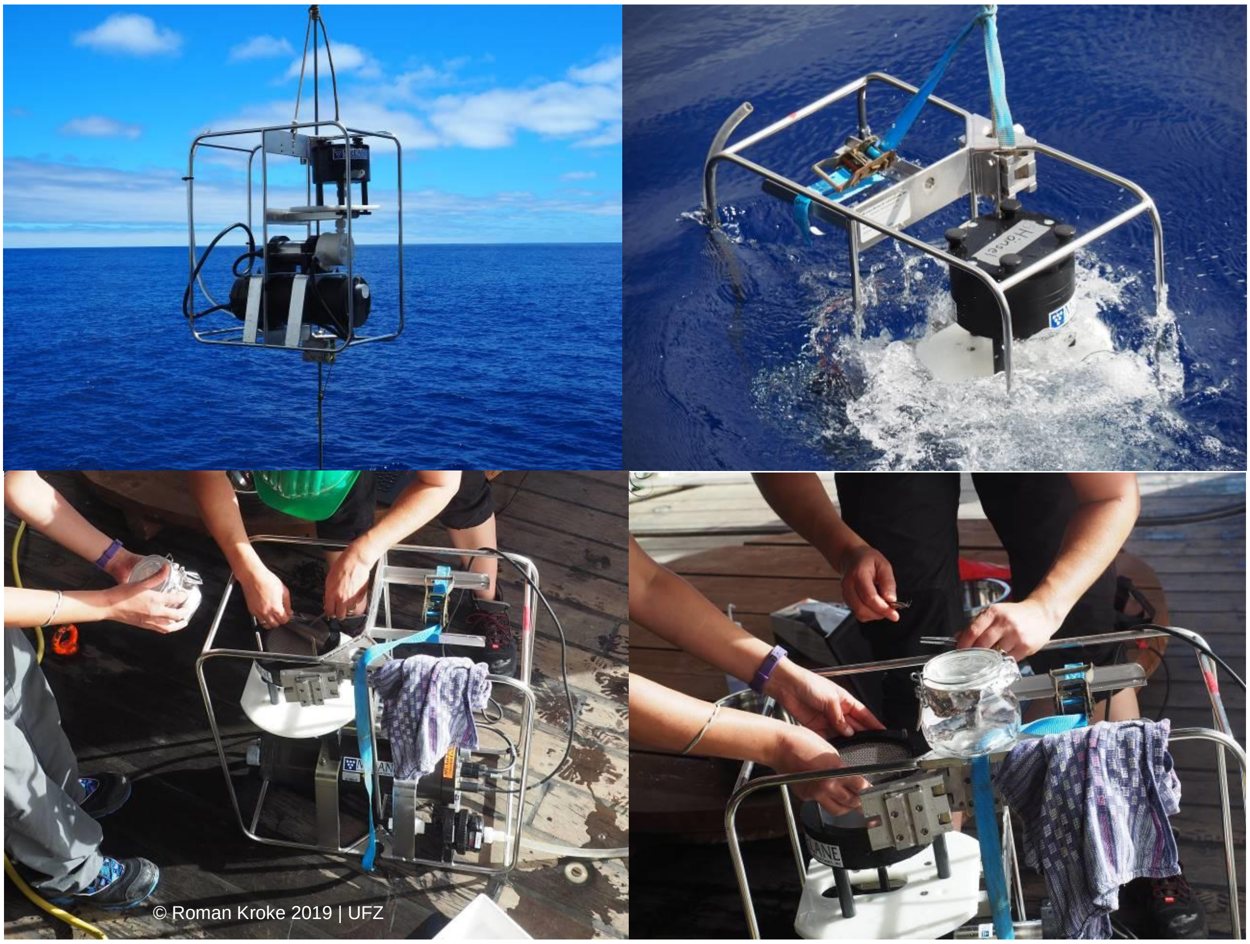

Figure 5.4.2.1 McLane *in situ* pumps during deployment and sample collection after taking them on board after successful sampling. Pictures: Roman Kroke 2019, UFZ.

Planned analyses The stainless steel and cellulose acetate filters containing the particles were stored in 500 mL jars and frozen until analysis for their plastic particle content at UFZ. If the mass of particles allows, we will attempt to quantify their concentrations of environmental pollutants, but this analysis is unlikely to be possible due to the scarcity of the material.

5.4.3. Cascade filtration (CAS) *(R. Rynek, P. Klöckner)*

Background CAS was used „underway“ while the SONNE was steaming to sample particles of different sizes close to the sea surface. The microplastic particle number is expected to increase dramatically with reduced particle sizes, as single large plastic items break down to many small fragments. With increasing distance to land-based sources, the size distribution of plastic particles may thus shift towards smaller size ranges due to their larger degree of weathering and hence fragmentation status. The smaller the particles are, the lower their buoyancy is and as such, particles in the size range below 100 µm may be more locally dispersed than larger fragments. The CAS is complementary to the CAT since particles with a size of <330 µm cannot be sampled with the CAT net. For this work, our hypotheses were: (a) The composition and microplastic concentration changes with increasing distance to land-based sources (North-America, East-Asia) or hotspots (North Pacific Garbage Patch). (b) The concentration of small microplastic (<100 µm) is correlated with the concentration found in the CAT samples. (c) Comparison of microplastic concentrations in different water depths (CAT, McL) and in sediment (MUC) allows identification of plastic sinks and assessment of microplastic transport.

Sampling The CAS system allowed the sampling of micro-plastic particles that are <100 µm in size and dispersed in the upper 10 m of the ocean. The CAS unit was run daily for 7-9 h. Sampling was conducted during station time as well as “underway” during transit. The total water volume sampled was approximately 3000 L per day (Table 5.4.3.1). Mesh sizes used were 500, 100, 50, 10 and 0.45 µm. Due to one leaking cascade unit and due to minor particle load on the 500 µm mesh, this mesh size was omitted after 5 sampling days. Since the membrane pump of the ship failed after 4 sampling days and could not be repaired, an alternative peristaltic pump was used. This pump allowed sampling of water from the ship’s hull at around 7 m depth. However, this pump could not be operated 24/7, and as such, was limited to sampling times of 7-9 h per day and a maximum volume of 3000 L per sample. Since the 0.45 µm filter generated a high back pressure and severely reduced flow-through of the whole system, it was omitted as well. A blank sample was prepared for each day of sampling, allowing the assessment of contamination during sampling and further sample treatment. This is a prerequisite to correctly assess microplastic particle concentrations. Samples were taken for a total number of 25 days, resulting in 104 samples. The samples that were collected are summarized in Table 5.4.3.1., and some impressions of the sampling on board are given in Figure 5.4.2.1.

Table 5.4.3.1: Overview of samples taken with the cascade filtration system.

number of sampling days	25
number of samples per sampling day	(5) 3 different mesh sizes + 1 blank
total number of samples taken	104
mesh sizes	(500), 100, 50, 10, (0.45) µm
average volume pumped through filtration unit per day	3360 L
total water volume sampled	83400 L

Figure 5.4.3.1 Operation of CAS on board of RV SONNE and sample collection. Pictures: Roman Kroke 2019, UFZ.

Planned analyses The samples were stored in glass jars and shipped frozen at -20 °C for analysis at UFZ using FT-IR and Raman spectroscopy. Before analysis, samples will be treated with an enzymatic cleanup protocol and hydrogen peroxide oxidation, in order to reduce the mass of matrix components, and filtrated on membrane filters. This requires a clean-bench and a range of chemicals which were not available on board. Samples will be analyzed with respect to polymer type of the enriched particles, number of plastic particles and the respective particle size distribution. Similarly as described above, if the mass of particles allows, we will attempt to quantify their concentrations of environmental pollutants, but this analysis may not be possible due to the scarcity of the material.

5.4.4. Multiple Corer (MUC) *(G. Veit-Köhler, M. Bohn, M. Banu Tekman, A. Jahnke)*

Background The MUC was used to sample up to 20 undisturbed sediment cores per deployment from the seabed (inner diameter of plexiglass core liners 9.6 cm, sampled sediment surface 72.4 cm^2). During SO268/3, we often deployed the MUC after the OFOS images were recorded, such that we could use them for selection of the MUC sampling locations. There were many manganese nodules visible at the first stations, and hence the OFOS images were very valuable for site selection to maximize the chances for successful MUC deployments.

Sampling The MUC was operated at every large profile station towards the end of the sampling program, since the choice of the location for the sediment sample was in part based on the OFOS imagery. While a MUC collects undisturbed sediment cores, the sampling itself disturbs the sediment, leading to turbid water conditions which may interfere with other sampling methods. Times of the MUC deployments are listed in Table 5.4.4.1 and images are offered in Figure 5.4.4.1.

Table 5.4.4.1: Details of MUC deployments during SO268/3.

station No.	timestamp	latitude (N)	longitude	depth [m]
SO268/3_2-8	02.06.201918:59:26	39° 28,402'	135° 57,296' W	5128.7
SO268/3_5-9	05.06.201910:03:08	33° 55,194'	144° 46,878' W	5214.7
SO268/3_6-8	07.06.201906:01:21	30° 02,470'	141° 44,442' W	5274.3
SO268/3_7-10	09.06.201920:56:20	30° 05,759'	151° 55,699' W	5238.1
SO268/3_10-7	12.06.201915:07:46	29° 59,371'	162° 36,288' W	5665.0
SO268/3_17-8	15.06.201917:42:50	29° 33,408'	175° 58,212' W	5300.3
SO268/3_21-7	18.06.201914:36:11	29° 50,008'	171° 31,686' E	5241.7
SO268/3_30-7	27.06.201910:02:21	22° 44,560'	127° 43,633' E	5370.0

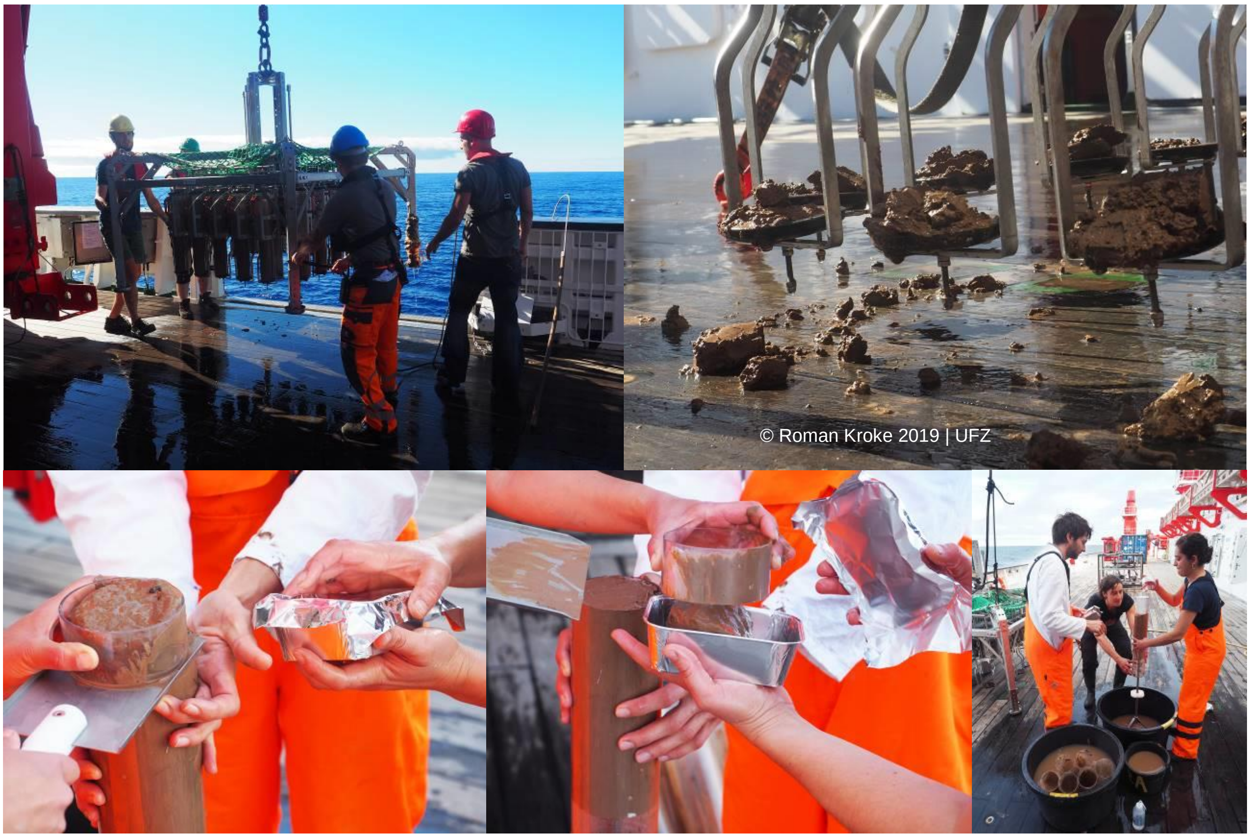

Figure 5.4.4.1 Operation of MUC and sampling of the sediment on board of RV SONNE. Pictures: Roman Kroke 2019, UFZ.

Planned analyses There is a multitude of analyses foreseen with this material. The 20-corer proved to be very efficient and successful in retrieving up to 20 intact cores, with only few exceptions where, e.g., the presence of mangenese nodules prevented undisturbed sampling of some of the cores. The upper 5 cm of each core for microplastic analysis (*n* = 6) were stored and shipped frozen at -20 °C for further processing in the home instutions; triplicates were sent to AWI and UFZ each for this purpose. The remaining cores will be analyzed for environmental pollutants at UFZ (see chapter 5.4.5), and used for the characterization of the sediment in terms of total organic carbon content and grain size distribution. Another set of samples (n = 6) were taken and conserved for abyssal meiofauna determination at Senckenberg am Meer (see chapter 5.5 below).

5.4.5. Solid-phase extraction (SPE) *(E. Rojo Nieto, C. Abele, C. Rummel, A. Jahnke)*

Background The plastic material collected during the sampling campaign has been exposed to the environment (water or sediment) for a certain time. During this time, it has on the one hand been in contact with the pollutants present in water and sediment, and on the other hand may have released some additives. Assuming that 80 % of all marine plastic is older than 4 years (Koelmans et al. 2016, *doi.org/10.1021/acs.est.5b06069*), pollutants in the polymer should be close to equilibrium with the freely dissolved chemicals present in the surrounding seawater or sediment. The aim of this work was to determine whether the plastic floating at the sea surface and that present in the sediment represents a sink or source of environmental pollutants relative to the surrounding water or sediment.

Sampling During the transit of RV SONNE, we enriched the pollutants present in the pre-filtered seawater on large-volume solid-phase extraction (SPE) cartridges, for further chemical analysis in the UFZ laboratory. The method provides on-site extraction of 50-100 L of water, avoiding common limitations due to small sample volumes or the need to transport huge amounts of water. During SO268/3, seawater samples were collected (i) using surface water from the membrane/rotary pumps, at the same stations where the Rosette was deployed or "underway"; or (ii) using the Niskin bottles of the CTD for deep water from the same depths as the McL were deplyed (bottom, 2500 m, 300 m, chlorophyll maximum). In addition, macro- and microplastic have been sampled at the same sampling locations using CAT, SONNE net or the scoop. The concentrations of pollutants in the SPE cartridges and plastic samples will be determined and compared to elucidate whether plastic debris has enriched pollutants relative to the surrounding seawater. Analogously, the pollutant concentrations will be determined in the sediment for similar comparisons. Optionally, we will submit selected extracts to cell-based bioassays to describe the mixture effects of the unknown mixtures of pollutants present in the extracts. Table 5.4.5.1 lists all the LV-SPE samples collected on SO268-3, with Figure 5.4.5.1 showing some impressions of the work on board.

Planned analyses The future work at UFZ will encompass the solvent extraction of the pollutants from the cartridges, the up-concentration of these extracts and the subsequent chemical analysis. The analysis and quantification of a wide range of compounds, including traditional and emerging pollutants such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polybrominated diphenylethers (PBDEs), pesticides, musk compounds, sunscreens and antioxidants, will be carried out using a gas chromatograph coupled to a high-resolution mass spectrometer (GC-HRMS Orbitrap Q-Exactive, Thermo Fisher). Selected sample extracts may optionally also be tested in cell-based bioassays for their mixture effects. In parallel, plastic material sampled at the same stations as the water samples as described below (chapter 5.4.8) will be extracted and analyzed for the identical compounds, in order to elucidate if the plastic is a sink or source of the studied chemicals from the surrounding seawater and sediment. This knowledge is of interest to see if *in situ* plastic litter that has been long-term exposed to the seawater can act as passive samplers and hence serve as a tracer of oceanic pollution.

Table 5.4.5.1. details of SPE samples collected during SO268-3

date	place	sample code	vol (m^3)	D (m)
5/31/2019	Transit 1	SO268/3_SPE_190531_surface_transit 1_sp 1	0.1	6
6/2/2019	Station 2	SO268/3_SPE_190602_surface_st 2_sp 1	0.1	6
6/2/2019	Station 2	SO268/3_SPE_190602_bottom_st 2_sp 2	0.06	5060
6/2/2019	Station 2	SO268/3_SPE_190602_2500_st 2_sp 3	0.06	2500
6/2/2019	Station 2	SO268/3_SPE_190602_300_st 2_sp 4	0.0605	300
6/3/2019	Station 2	SO268/3_SPE_190602_max Chl (50)_st 2_sp 5	0.058	50
6/4/2019	Station 5	SO268/3_SPE_190604_surface_st 5_sp 1	0.1	6
6/4/2019	Station 5	SO268/3_SPE_190604_bottom_st 5_sp 2	0.06	5155
6/4/2019	Station 5	SO268/3_SPE_190604_2500_st 5_sp 3	0.06	2500
6/4/2019	Station 5	SO268/3_SPE_190604_300_st 5_sp 4	0.06	300
6/4/2019	Station 5	SO268/3_SPE_190604_max Chl (140)_st 5_sp 5	0.056	140
6/6/2019	Station 6	SO268/3_SPE_190606_surface_st 6_sp 1	0.1	6
6/6/2019	Station 6	SO268/3_SPE_190606_bottom_st 6_sp 2	0.06	4980
6/6/2019	Station 6	SO268/3_SPE_190606_2500_st 6_sp 3	0.06	2500
6/7/2019	Station 6	SO268/3_SPE_190606_300_st 6_sp 4	0.06	300
6/7/2019	Station 6	SO268/3_SPE_190606_max Chl (130)_st 6_sp 5	0.0575	130
6/8/2019	Station 7	SO268/3_SPE_190608_surface_st 7_sp 1	0.1	6
6/8/2019	Station 7	SO268/3_SPE_190608_bottom_st 7_sp 2	0.06	5123
6/8/2019	Station 7	SO268/3_SPE_190608_2500_st 7_sp 3	0.0599	2500
6/8/2019	Station 7	SO268/3_SPE_190608_300_st 7_sp 4	0.0602	300
6/8/2019	Station 7	SO268/3_SPE_190608_max Chl (130)_st 7_sp 5	0.0585	130
6/11/2019	Station 10	SO268/3_SPE_190611_surface_st 10-sp 1	0.1	6
6/13/2019	Transit 2	SO268/3_SPE_190613_surface_transit 2-sp 1	0.1	6
6/15/2019	Station 17	SO268/3_SPE_190615_surface_st 17-sp 1	0.1	6
6/15/2019	Station 17	SO268/3_SPE_190615_bottom_st 17-sp 2	0.06	5235
6/15/2019	Station 17	SO268/3_SPE_190615_2500_st 17-sp 3	0.06	2500
6/15/2019	Station 17	SO268/3_SPE_190615_300_st 17-sp 4	0.06	300
6/15/2019	Station 17	SO268/3_SPE_190615_max Chl (110)_st 17-sp 5	0.05	110
6/17/2019	Transit 3	SO268/3_SPE_190617_surface_transit 3_sp 1	0.1	6
6/18/2019	Station 21	SO268/3_SPE_190618_surface_st 21-sp 1	0.1	6
6/18/2019	Station 21	SO268/3_SPE_190618_bottom_st 21-sp 2	0.06	5200
6/18/2019	Station 21	SO268/3_SPE_190618_2500_st 21-sp 3	0.06	2500
6/18/2019	Station 21	SO268/3_SPE_190618_300_st 21-sp 4	0.06	300
6/18/2019	Station 21	SO268/3_SPE_190618_max Chl (105)_st 21-sp 5	0.051	105
6/20/2019	Transit 4	SO268/3_SPE_190620_surface_transit 4_sp 1	0.1	6
6/22/2019	Transit 5	SO268/3_SPE_190622_surface_transit 5-sp 1	0.1	6
6/23/2019	Transit DOM	SO268/3_SPE_190623_surface_transit P&R-sp 1	0.1	6
6/24/2019	Transit 6	SO268/3_SPE_190624_surface_transit 6-sp 1	0.1	6
6/26/2019	Station 30	SO268/3_SPE_190626_surface_st 30-sp 1	0.1	6
6/26/2019	Station 30	SO268/3_SPE_190626_bottom_st 30-sp 2	0.06	5264
6/26/2019	Station 30	SO268/3_SPE_190626_2500_st 30-sp 3	0.06	2500
6/26/2019	Station 30	SO268/3_SPE_190626_300_st 30-sp 4	0.06	300
6/26/2019	Station 30	SO268/3_SPE_190626_max Chl (…)_st 30-sp 5	0.051	~100

Figure 5.4.5.1 Water was submitted to the LV-SPE either from the ship's seawater supply of from the CTD/Rosette to process deep sea samples. The pollutants from 50-100 L of seawater were enriched on a sorptive phase. Pictures: Roman Kroke 2019, UFZ.

5.4.6. Marine Snow Catcher (MSC) and plankton nets (NET) *(S. Reichelt, Z. Gerdes)*

Background Marine snow is a generic category including aggregates of primarily organic detritus of varying origin, such as dead organisms and fecal matter, but also live microorganisms and inorganic particles. These aggregates vary in size and composition, which affects their sinking rate, nutrient value, and colonization by microbes. The transfer of marine snow from the surface waters, i.e., the area of primary photosynthetic activity, to deeper layers of the ocean provides food and nutrients to low-light environments. Only a small proportion of the sinking matter reaches the ocean floor since most of it is already consumed on its way down. In the area of the North Pacific Garbage Patch, microplastic accumulates driven by the currents. Plastic items are colonized by different organisms, and can rapidly become incorporated into marine snow aggregates during algal blooms. It has been hypothesized that floating microplastic can be exported from the surface waters to the bottom via marine snow but we know little about how the addition of microplastic particles to the marine snow changes its composition. Whether microplastic affects the microbial composition of aggregates and their sinking rates is of great importance for the export of organic matter from the surface to the sea floor and for the fate of microplastic in the ocean. During this cruise, we aimed to sample marine snow and study its composition and activity as well as determine the presence and nature of its microplastic content.

Sampling We used the Marine Snow Catcher (MSC) sampler designed to retrieve 50 L of water from any desired depth and collect intact aggregates. During the cruise, we initially sampled at two depths, below and above the chlorophyll maxima, to collect aggregates with contrasting contribution of primary producers. In addition to the MSC, we also deployed a plankton WP2 net (200 µm mesh size) to collect pelagic consumers of the microplastic and aggregates. Figure 5.4.6.1 gives impressions of the sampling with the MSC and NET during SO268-3.

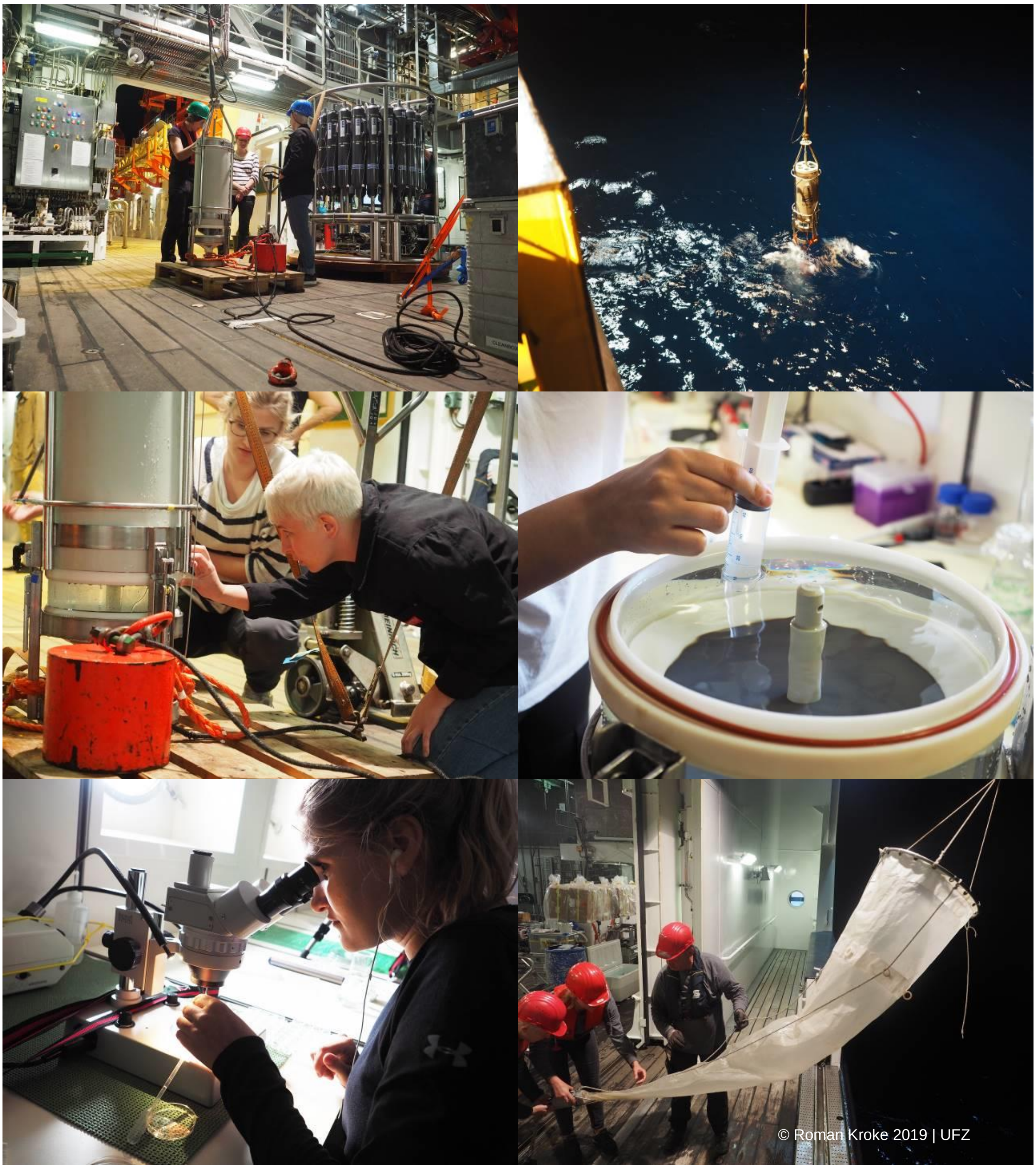

Figure 5.4.6.1. Nighttime deployment of the MSC, search for "marine snow" and nighttime NET deployment. Pictures: Roman Kroke 2019, UFZ.

Planned analyses Earlier studies (e.g., Piskaln et al. 2005, *doi.org/10.1016/j.dsr.2005.08.004*) have shown relatively high abundance of marine snow in the epipelagic North Pacific Garbage Patch considering its highly oligotrophic state. We were, however, not able to collect similar quantities with similar sampling effort by MSC. No typical (>200 µm) aggregates were retrieved, except one station, where some instable aggregates were collected. These aggregates appeared to be discarded appendicularia houses, a common component of marine snow. Yet, at each station and every sampling depth, the water collected by MSC was used to sample the pelagic microbial community. These samples will be used for microscopy and metagenomics analyses. The collections made by the WP2 net also reflected the oligotrophic environment with diverse zooplankton, but also algal colonies that varied across the stations. The organisms were sorted and preserved for later analysis for presence of microplastic.

5.4.7. „SONNE net“ and scoop sampling of large plastic debris *(C. Rummel, C. Abele, S. Lips, M. Bohn, E. Rojo Nieto, A. Jahnke et al.)*

Background Since the CAT sampling provided limited amounts of plastic, we collected large plastic debris using a scoop and the so-called „SONNE net" that was specifically made by the crew during the expedition to allow for sampling of large plastic debris such as a barrel as shown in Figure 5.4.7.1.

Figure 5.4.7.1 The "SONNE net", specifically built by the crew to capture large marine litter, was used to capture a barrel. Pictures: Roman Kroke 2019, UFZ.

Sampling We deployed the SONNE net twice to collect a fishing buoy and to sample a large plastic container. The scoop was used for extended time periods, in particular during stations or when moving slowly, e.g. to operate OFOS or CAT. It proved to be very efficient at collecting plastic debris from the ocean surface, incl. both intact items, but largely fragments of weathered plastic items. This material was used by all the different groups, e.g. to investigate the biofilm from the plastic surface or to take subsamples for culturing. The remainder was dried and shipped to UFZ for pollutant analysis.

Planned analyses In addition to the biofilm analysis, the material obtained by the SONNE net and scoop will be characterized in terms of polymer composition and surface characteristics, and it will be extracted and analyzed for its pollutant content as described above (chapter 5.4.5). The work related to chemical pollutant characterization and their mixture effects is illustrated in Figure 5.4.7.2.

Figure 5.4.7.2. Large, still identifiable plastic debris is collected to investigate pollutants and their mixture effects, in field-weathered plastic as opposed to the pristine material. Pictures: Roman Kroke 2019, UFZ.

5.4.8. Ocean floor observation system (OFOS) *(M. Bergmann, M. Tekman Banu)*

Background Plastic debris contamination of the oceans is a global problem of growing environmental concern. Analyses of camera footage from the seafloor of the HAUSGARTEN observatory in the Arctic (2500m depth) revealed substantial quantities and a significant increase of litter between 2002 and 2011 (Bergmann and Klages 2012, *doi.org/10.1016/j.marpolbul.2012.09.018*; Tekman et al. 2017, *doi.org/10.1016/j.dsr.2016.12.011*). Comparison with data from the sea surface (Bergmann et al. 2016, *doi.org/10.1007/s00300-015-1795-8*) revealed 300 times higher quantities on the seafloor indicating that the seafloor is a sink for plastic pollutants. Although a number of previous studies have shown high densities of plastic debris in the North Pacific Subtropical Gyre (Pichel et al. 2007, *doi.org/10.1016/ j.marpolbul.2007.04.010*; Lebreton et al. 2018, *doi.org/10.1038/s41598-018-22939-w*), research has focused largely on floating debris. Here, we aim to apply the same approach used in the Arctic to assess plastic quantities on the deep Pacific seafloor underneath projected plastic accumulation zones. Comparison with plastic densities obtained in flotsam surveys from the sea surface will allow us to verify if the deep Pacific seafloor is a sink for marine debris, too.

Sampling Plastic densities on the seafloor were assessed using RV SONNE’s Ocean Floor Observation System (OFOS), a camera system which is towed behind the ship at 0.5-0.7 knots at a target altitude of 1.5 m. Still images were taken automatically at 20 second-time intervals along with video footage. Additional photos were taken manually when specific objects or organisms occurred in the field of view. Seven transects with a profile length of 2-3 h bottom time were undertaken at the stations selected for detailed survey. Water depths varied between 5145 and 5914 m. The images were uploaded to an offline version of the image analysis tool BIIGLE and analysis begun (Bergmann & Klages, 2012). The OFOS deployment are summarized in Table 5.4.8.1 and displayed in Figure 5.4.8.1.

Table 5.4.8.1: Details of OFOS deployments made during SO268/3

Station No.	timestamp	action	latitude	longitude	D (m)
SO268/3_5-5	05.06.2019 00:48	start	33° 55,199'	144° 46,890' W	5211
SO268/3_5-5	05.06.2019 03:50	end	33° 53,899'	144° 47,551' W	5234
SO268/3_6-4	06.06.2019 19:46	start	30° 02,473'	141° 45,842' W	5145
SO268/3_6-4	06.06.2019 22:50	end	30° 02,474'	141° 44,122' W	5265
SO268/3_7-6	09.06.2019 11:16	start	30° 05,342'	151° 55,685' W	5191
SO268/3_7-6	09.06.2019 14:18	end	30° 06,841'	151° 55,749' W	5245
SO268/3_10-4	12.06.2019 06:23	start	30° 00,698'	162° 35,320' W	5662
SO268/3_10-4	12.06.2019 09:24	end	29° 59,422'	162° 36,248' W	5914
SO268/3_30-2	27.06.2019 02:52	start	22° 42,671'	127° 43,613' E	5453
SO268/3_30-2	26.06.2019 23:47	end	22° 44,794'	127° 43,612' E	5354
SO268/3_21-6	18.06.2019 08:24	start	29° 50,006'	171° 30,011' E	5243
SO268/3_21-6	18.06.2019 10:32	end	29° 50,006'	171° 31,682' E	5223
SO268/3_17-5	15.06.2019 09:32	start	29° 33,403'	175° 58,219' W	5298
SO268/3_17-5	15.06.2019 11:32	end	29° 33,403'	175° 56,654' W	5283

Preliminary results Litter was encountered during all transects conducted albeit at densities lower than expected given the large quantities of debris floating at the sea surface. It comprised mostly plastic and possibly timber. Most items were very small. Although image analysis was started whilst onboard, definite numbers for all transects are subject to ongoing analyses. The seafloor of most stations harbored manganese nodules, sometimes at very high densities. This hard substratum may retain less plastic debris compared with the stickier surface of low-energy soft-bottom environments. Fig 5.4.8.2 shows some examples of images showing plastic debris.

Data management All OFOS images, videos and metadata will be uploaded to the PANGAEA archive. In addition, all images have been uploaded to the online image data base BIIGLE to enable online image analysis.

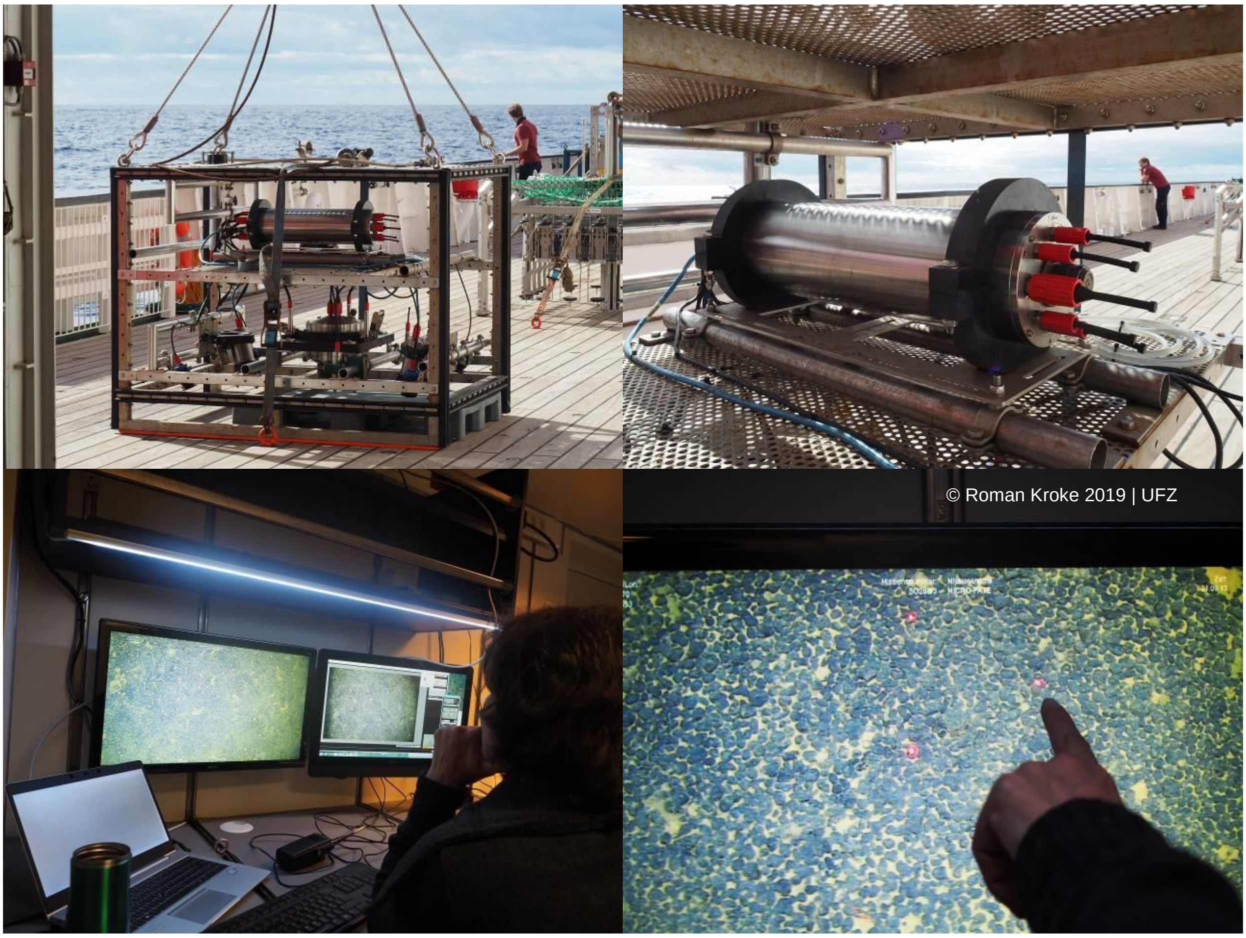

Figure 5.4.8.1 The OFOS system on the working deck (top) and evaluation of the resulting pictures by Melanie Bergmann in the laboratory (bottom). Pictures: Roman Kroke 2019, UFZ.

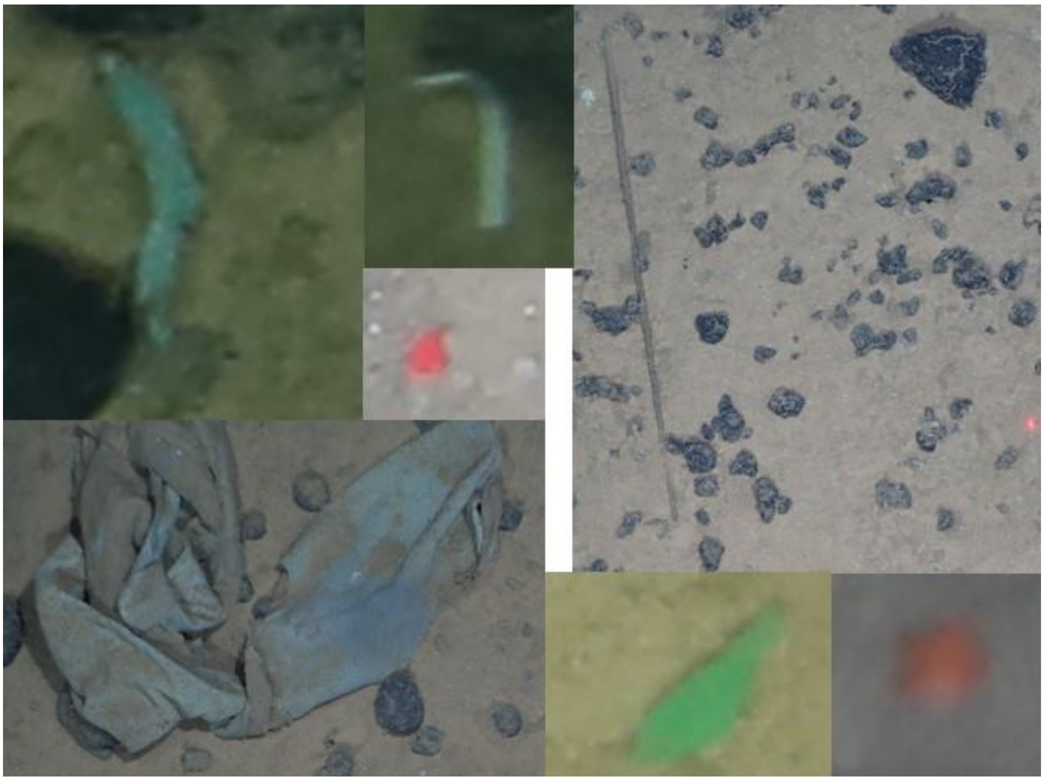

Figure 5.4.8.2 Examples of marine debris observed on the deep Pacific seafloor. Melanie Bergmann.

5.4.9 Mesocosms *(M. Schneider, R. Rynek, C. Rummel)*

Background The aim of the work performed on board the RV SONNE was to better understand the weathering of polymers in the marine environment with and without exposure to UV radiation and to sensitively detect the changes in material properties during weathering. The expedition was hence used to weather known polymer samples under controlled natural conditions.

Sampling Two steel tanks, so-called mesocosms, were operated during the entire transit to weather a range of samples. The polymers varied in their shape (slides and granules) and type. The main polymers studied were those already detected in the environment: Polyethylene (PE), polyethylene terephthalate (PET), polystyrene (PS) and a commercial product consisting mainly of PET. The samples were deployed in the mesocosm and exposed to seawater, solar radiation (for the UV treatment) and fluctuating temperatures (day/night). A continuous supply of seawater was realized with the help of the SONNE's rotary pump system. Decisive for the initiation of the degradation of the material was the UV radiation in the sunlight spectrum. Its intensity depends on the time of day, the position of the sun and the weather (cloudless sky/overcast). Considering environmental samples, the water depth is also crucial with regard to the UV intensity that occurs. Seawater acts as a natural UV filter and reduces the UV intensity with increasing depth. Data on UV intensity were recorded by SONNE sensors and by a water sensor. The mesocosms enabled us to weather samples under different UV conditions and thus to investigate the influence of UV light on the degradation of different polymer types and shapes. An initial visual examination of the polymers proved that they had changed due to weathering, for example biofilms were visible on the polymer surface. In addition to the polymers, water samples were taken and examined on board for pH, conductivity, and density, amongst others. The water parameters in the mesocosm were compared to the water parameters recorded by the SONNE systems. So far no substantial differences could be found. An overview of the activities carried out in the mesocosm and in the following on board is given in Figure 5.4.9.1.

Figure 5.4.9.1 Installation of the mesocosms and the exposed plastic. Pictures: Roman Kroke 2019, UFZ.

Planned analyses Following the expedition, all samples will be analyzed in the laboratories of IKTS in Dresden. A detailed characterization will be carried out on land since many of the measuring devices were sensitive and could not provide reliable data under the given conditions. At IKTS, the samples will be examined with regard to their surface properties and physical properties. The results of the analyses will be shared with all project partners, ensuring comprehensive results. The investigation of biofilms, for example, is carried out in cooperation between material scientists and biologists. Finally, the collected data on the samples generated on the research vessel will not only provide us with information on the differences between unweathered and weathered samples, but will also enable us to compare natural weathering with weathering under laboratory conditions. For this purpose, a weathering chamber was set up at IKTS in which polymer samples can be exposed to UV light and continuous movement. The findings - based on the samples generated during the research expedition - will help us to further optimize the laboratory setup, so that in the future an approach for the weathering of polymer samples under near-natural conditions will be possible in the laboratory.

5.4.10. Biofilm characterization *(M. Schmitt-Jansen, S. Lips, C. Rummel, L. Moldaenke, T. Gaudl, A. Caba et al.)*

Background Floating plastic polluting the ocean is heavily covered by heterotrophic and autotrophic microorganisms embedded in a matrix of extracellular polymeric substances, which makes them stick to the plastic surface. This newly introduced habitat may be colonized by unique microbial communities which contribute to elemental ecosystem functions, especially due to the stable environmental conditions that the plastic surface offers. We studied the early biofilm formation on artificial substrates in on-board mesocosms (chapter 5.4.9) to characterize the so-called eco-corona. We hypothesized that environmental gradients along the cruise influence the organic matter composition and early bacterial colonization in a material-dependent way. Therefore, lab-aged polymers (beads and sheets: LDPE, PET, PS and glass as a control) were exposed for 3 days in the mesocosm and sampled after 1 h, 6 h, 24 h and 3 d. Samples were shock-frozen in liquid nitrogen for later DNA-analysis and preserved for microscopic analysis.

Additionally, a long-term colonization experiment was performed over 23 days. We aimed at studying the structural and functional characteristics of biofilms on environmental plastic sampled from the Pacific Ocean by CAT and scoop sampling. We hypothesized that plastic-specific microbial communities settle on the field-aged material and contribute to important functions in the marine ecosystem like organic matter turnover. Therefore, samples for DNA analysis and pigment profiling were taken from biofilms of net samples and shock-frozen. For functional characterization, several methods were used to address primary production and respiration. As primary production rests upon photosynthesis, Pulse-Amplitude Modulation (PAM) fluorescence-based methods were used to quantify the photosynthetic capacity of autotrophic biofilms. Dissolved oxygen concentrations were monitored via contactless optical sensors on undisturbed plastic particles sampled either by CAT or scoop sampling. They were placed into gas-sealed oxygen chambers (Figure 5.4.10.1) and incubated in light incubators under dark/light illumination. Furthermore, stable isotopes were used as tracers to quantify metabolism. Finally, water samples from surface water and CTD/Rosette sampling were taken to compare biofilm-related communities and processes to the pelagic environment. The samples taken for in-depth biofilm analysis are listed in Table 5.4.10.1.

Finally, we addressed the question if microorganisms that form biofilms on plastic have different life strategies in comparison to water-derived communities. We hypothesized that due to the high abundance of plastic in the North Pacific Garbage Patch, microbial communities adapt to life on these substrates. Therefore, biofilms from scoop-sampled plastic were suspended in sterile sea water and transferred into liquid media. These media were complemented by natural material (Chitin) and polymers (polyamide

(PA), PE and PET), respectively. Additional samples were plated on solid media comparable to the liquid media and filtered Pacific seawater media, respectively (Figure 5.4.10.2). Additionally, suspensions have been fixed in Lugol solution for microscopic analysis. Finally, small plastic items from CAT were added to the media to characterize non-extractable biofilm communities.

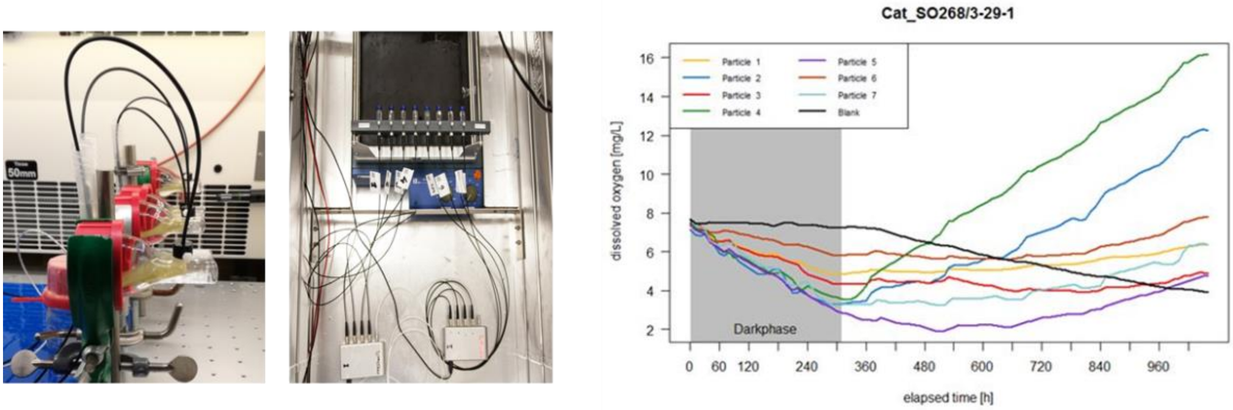

Figure 5.4.10.1 Gas-sealed Oxygen chambers (left panel) and oxygen profile after incubation of plastic-colonizing biofilms for 10 h in light/dark phases (right panel).

Table 5.4.10.1 Samples taken for in-depth biofilm analysis

device	samples	sample storage	analysis, done	analysis, planned
CAT	40	Fixed in Formol at 4°C	PAM, Primary Production	Microscopy
	70	Liquid media and plates	-	Cultivation and genetic characterization
	3	Lugol solution	-	Microscopy
Scoop	30	Frozen at -80°C	PAM, Primary Production	Dry weight and pigment analysis Genetic characterization
	65	Liquid media and plates	-	Cultivation Genetic characterization
	17	Lugol solution	-	Microscopy
	196	Biofilm solution		Genetic characterization
Mesocosm	361 samples from 6 short-term tests	Frozen at -80°C	-	Genetic characterization, microscopy
	2x 24 + 1x8 samples from 1 long-term test	Frozen at -80°C	-	Genetic characterization, microscopy
Water samples for comparison	10	Frozen at -80°C after filtration	-	Pigment analysis
	50	Filtrated and frozen at -80°C	-	DNA analysis

Further impressions on the biofilm-related work are given in Figures 5.4.10.3 and 5.4.10.4.

Figure 5.4.10.2 Plastic items in liquid media and cultivation plates for selection of plastic-specific microbial communities.

Figure 5.4.10.3 Sampling of biofilm on board of RV SONNE. Pictures: Roman Kroke 2019, UFZ.

Figure 5.4.10.4 Processing of the biofilm-coated plastic debris on board of RV SONNE. Pictures: Roman Kroke 2019, UFZ.

5.4.11. Flotsam surveys *(M. Bergmann, M. Banu Tekman, A. Weitz et al.)*

Background Plastic litter contamination of the oceans is a global problem of growing environmental concern. Previous research has highlighted that plastic is accumulating at sea surfaces of the North Pacific subtropical gyre, the so-called garbage patch (Lebreton et al. 2018, *doi.org/10.1038/s41598-018-22939-w*). To assess the distribution of plastic debris, we carried out qualitative assessments of floating debris near 30N along the cruise track of SO268-3 across the Pacific Ocean. This 'flotsam counting' (*flotsam refers to a sunken vessel whose goods float to the surface of the sea, or any floating cargo that is cast overboard*) across the Pacific adds to the survey aspect of the MICRO-FATE project. The litter count activity was initiated by Melanie. Bergmann (AWI) and carried out as a joint effort of volunteering scientists of the MICRO-FATE and MORE-2 projects. For comparability, the method of an earlier study in the Arctic was followed.

Sampling Observational surveys of floating oceanic litter were performed at day-light hours between MICRO-FATE profiling stations to inform on spatial context (i.e. the longitudinal distribution near 30N across the Pacific). The daily sequence of hourly surveys started at 8:30 and ended at 19:30, interrupted by a 1-hour break for lunch and dinner each. Surveys stopped during rainy hours but continued while the vessel slowed down to release ARGO-floats (Chapter 5.2). During each survey, a team of two scientists stood for an hour at the ship's rail in the front section of the vessel and scanned the ocean surface visually for floating objects in a 10-m stripe next to the ship, as shown in Figure 5.4.11.1.

Figure 5.4.11.1 Pairs of volunteers counting the debris and plastic floating near the ocean surface.

When spotting an object the researchers set a waypoint using a hand-held GPS device and protocolled material, shape, size and color as well as the appearance of the object (submerged, aggregated, fouled). Using a counter, clearly identifiable objects <5 cm were counted as 'bits'. Seaweed was also recorded and note taken of observed animals. In addition, weather, sea state and other observations were reported. Individual survey results were digitalized by the teams and merged into one larger database for further processing. The surveys started on May 31, shortly after the research vessel had left Vancouver and ended on June 29, when the ship reached the EEZ of the Philippines.

Preliminary results Between May 31 and June 29, a total of 151 surveys were performed and148 of those had been digitalized by July 1. Figure 5.4.11.2 presents the preliminary data as sum of marine debris objects (> 5 cm) that were spotted per survey hour. Times during which the vessel was stationary to run the major measurement program or while the vessel was moving at a slower speed to release ARGO floats or to employ a neuston catamaran are indicated, too.

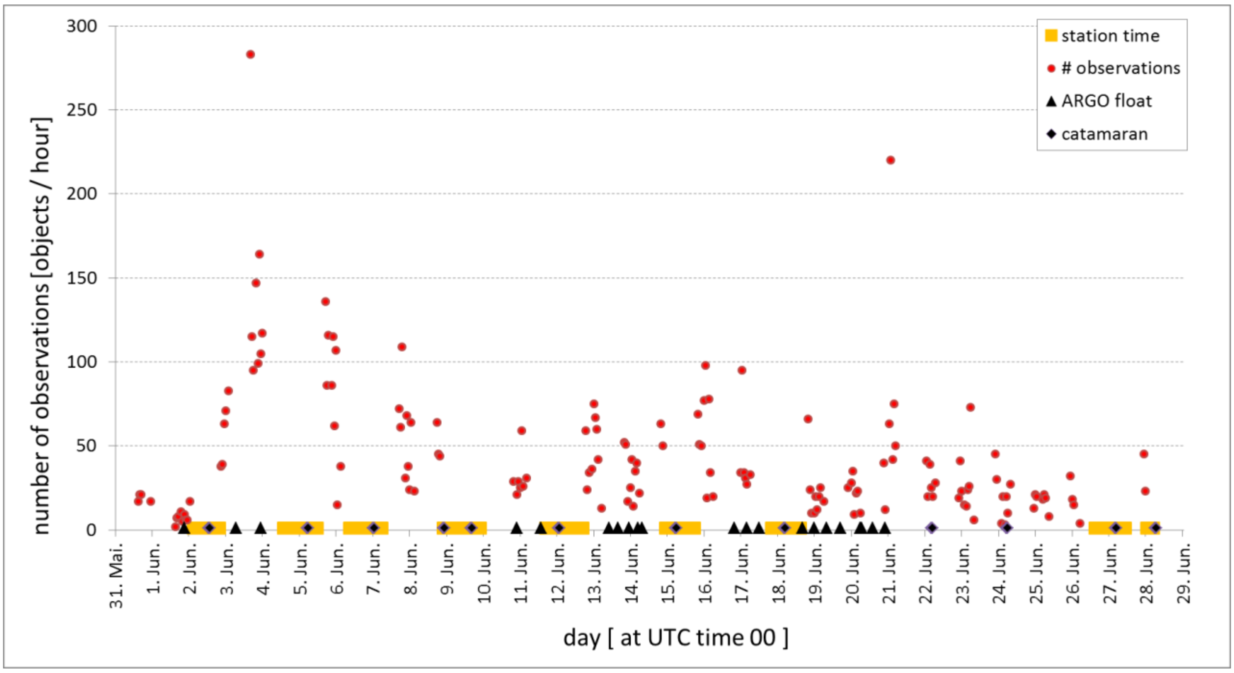

Figure 5.4.11.2 Number of objects spotted during an hourly survey (red dots). Stationary time periods (yellow bars), during which the major measurement program was conducted, and short phases of slow vessel progress (diamonds and triangles) are marked at the base of the Figure.

The raw data showed considerable variability in the number of spotted objects per hour. High variability is observed throughout the overall survey period as well as within individual survey days. Even within survey hours, we noticed substantial variability indicating a very patchy distribution of plastic debris. Figure 5.6.2 shows that the vessel passed through a region of higher litter pollution between June 3 and June 9. During that time (at or in the garbage patch region) on average about 60 objects per hour (or one per minute) were counted, with maximum hourly counts above 250 objects. Westward of eastern Pacific central garbage patch region average counts and maxima were about half as large, thus still significant.

In a first rough assessment of raw data we observed quite some variation in the recording of objects, e.g. a ‘piece of rope’ and ‘fragment of rope’ are similar kind of objects, as are ‘net’ and ‘fragment of fish net’. Such inconsistencies in characterization were to be expected given the large number of survey participants. Hence prior to a final data assessment work on the reports is needed to increase data consistency. The results of Figure 5.4.11.2 therefore have to be understood as a very first coarse assessment.

Overall a total of 6,436 objects were spotted (this accounts for digitalized data only) of which only 1.8 % was recorded as ‘natural’. Since some reports also counted animals we expect that the total number of observations is larger than the final number will be after scrutinizing and ‘cleaning’ of raw data. As to be expected, seaweed was observed in coastal regions only, thus before June 2 and after June 23, 2019. The vast majority of spotted objects were some kind of plastic debris (including Styrofoam) of various sizes. Some of the larger fragments could be identified as e.g. piece of a bucket or a rope or other parent material. Comparatively few intact objects were spotted such as e.g. container and plastic bottles - the latter accounting for ~1.6 % of total recorded objects. Throughout the survey a total of 12 glass bottles were spotted plus one light bulb. Roughly 18 % of the spotted objects clearly originate from marine industry (sections of rope, strings, nets, buoys, fish boxes), even 4 intact fish boxes were recorded. About 7 % of the objects were submerged and ~16 % of the objects were recorded as bio-fouled to some degree. During the last surveys, we noticed that some of the plastic bottles and packaging seemed to be ‘young’ litter judging from its clean look and the presence of colorful printing.

As mentioned, the figures we provide above are to be understood as very first and rough assessment of the raw data. Given the survey conditions concerning vessel speed, the actual ocean surface, light and weather conditions etc. we assume that the recorded data deliver a lower estimate of the actual amount of garbage that passed the vessel. Even though such qualitative survey has some shortcomings it still contributes valuable information to the Micro-fate research project.

Future analyses Back at the AWI, Mine Banu Tekman and Melanie Bergmann will carry out more detailed analyses. Links of the counts to the speed of the vessel will be considered and consistent classification of debris in oceans will be applied for geo-referencing of survey locations. This enables conversion to number of objects km^{-2} and thus comparison with previous data or those from other regions, e.g. the Arctic. It will also allow us to study the variation within and between survey days and the spatial distribution of pollution density along the cruise track. In addition, superimposing the latter on published garbage distribution maps that were simulated by different mathematical models offers a way to appraise model performance. Comparison with data from the seafloor obtained through the use of a towed camera system (OFOS, Chapter 5.4.8) will allow us to detect accumulation zones. Data from this survey will be discussed with data derived from earlier surveys that AWI scientists performed on different research voyages in the Arctic and North Sea. For detailed information please contact Melanie Bergmann (Melanie.bergmann@awi.de).

Participating scientists C. Abele, M. Tekman, M. Bergmann, M. Bohn, A. Caba, T. Gaudl, Z. Gerdes, A. Jahnke, R. Kleinschek, P. Klöckner, M. Knapp, S. Lips, T. Machnitzki, J. Menken, L. Moldaenke, S. Reichelt, E. Rojo Nieto, C. Rummel, R. Rynek, M. Schmitt-Jansen, M. Schneider, A. Weitz.

5.5. Abyssal meiofauna

Background Our knowledge of meiofauna communities of the central Pacific and their connectivity and diversity across this ocean is scarce. Sampling during SO 268/3 was carried out in order to fill the gap between earlier cruises to eastern and western Pacific areas. A 20-core multiple corer (MUC) was provided by the German Centre for Marine Biodiversity Research (DZMB, Senckenberg am Meer, Wilhelmshaven). This device is used to retrieve undisturbed sediment cores from the sea floor and hence it is especially suited for collecting meiofauna. Organisms of the meiofauna size class (32 µm – 1 mm) inhabit all kinds of marine sediments. Nematodes, copepods, kinorhynchs, ostracods, tardigrades, small polychaetes and small other crustaceans are the main groups forming meiofauna communities. At the deep-sea floor where food is scarce, most of the meiofauna live in the first centimetre or even the first millimetres of the sediment.

Sampling The MUC was operated at every large profile station (for station information see chapter 5.4.4). At each station 6 sediment cores were collected for meiofauna investigations. The overlying water of each core was sieved over a 32-µm sieve. The withheld particles and organisms were transferred to a plastic container as were the upper 5 cm of the sediment. Three samples were fixed with denatured ethanol (99.6%), three were stored in DESS (Dimethyl sulfoxide 20%, EDTA, saturated NaCl solution). After 24 h the fixatives were exchanged with fresh ethanol and DESS, respectively. Ethanol samples were stored at -20 °C (transport to the home institute with reefer container), DESS samples at 4 °C until shipment. Some images are offered in Figure 5.5.1.

Planned analyses Meiofauna will be analyzed in different ways. By sieving and centrifugation of the samples the organic material will be separated from the sediment. The organisms will be counted for quantitative analyses which will give an overview over the different taxa and the composition of the communities. Ethanol-fixed hand-picked individuals can be used for MALDI-TOF analyses of the proteome and to build up a genetic barcoding library of meiofaunal organisms. The samples stored in DESS are suitable for meta-barcoding, where the whole community will be analyzed at once.

Figure 5.5.1 A. The Multiple Corer comes back from the deep sea. **B.** Retrieval of core liner. **C.** Cores with undisturbed sediment surface. **D.** Sediment with manganese nodules. **E.** Slicing of sediment.

6. Ship's Meteorological Station

There was no meteorologist on board during the cruise.

7 Station list (SO268-3)

station - No.	date, time	device	latitude	longitude	d (m)	remarks
SO268-3/1	2019/06/01 21:30:40	FLOAT in water	40° 30.088' N	134° 59.977' W	4204.8	
SO268-3/2	2019/06/02 03:53:37	CTDin water	39° 28.403' N	135° 57.298' W	5131.6	CAT, OFOS, MUC, …
SO268-3/3	2019/06/03 07:46:17	FLOATin water	37° 48.054' N	137° 59.947' W	5254.8	
SO268-3/4	2019/06/03 23:32:19	FLOATin water	35° 12.473' N	140° 59.447' W	5213.8	
SO268-3/5	2019/06/04 15:42:39	CTDin water	33° 55.180' N	144° 46.977' W	5212.3	CAT, OFOS, MUC, …
SO268-3/6	2019/06/06 10:38:21	CTDin water	30° 02.473' N	141° 45.843' W	5029.5	CAT, OFOS, MUC, …
SO268-3/7	2019/06/09 00:34:10	CTDin water	30° 05.145' N	151° 55.655' W	5178.7	CAT, OFOS, MUC, …
SO268-3/8	2019/06/10 22:37:25	FLOATin water	30° 12.021' N	157° 59.729' W	5831.9	
SO268-3/9	2019/06/11 14:29:01	FLOATin water	30° 13.006' N	161° 59.431' W	4255.6	
SO268-3/10	2019/06/11 17:44:08	CTDin water	29° 59.375' N	162° 36.275' W	5664.3	
SO268-3/11	2019/06/13 10:53:10	FLOATin water	29° 49.983' N	167° 00.024' W	5451.0	
SO268-3/12	2019/06/13 16:38:27	FLOATin water	29° 49.900' N	168° 30.007' W	5465.1	
SO268-3/13	2019/06/13 18:58:01	NETin water	29° 49.783' N	168° 57.670' W	5350.3	
SO268-3/14	2019/06/13 23:25:35	FLOATin water	29° 50.005' N	169° 59.956' W	5312.8	floating barrel
SO268-3/15	2019/06/14 05:31:38	FLOATin water	29° 49.984' N	171° 29.966' W	5364.5	
SO268-3/16	2019/06/14 09:27:33	FLOATin water	29° 49.946' N	172° 29.986' W	5371.1	
SO268-3/17	2019/06/14 22:58:13	CTDin water	29° 33.429' N	175° 58.232' W	5299.4	boat, CAT, O, M, …
SO268-3/18	2019/06/16 20:57:42	FLOATin water	29° 50.002' N	177° 29.981' E	5305.9	
SO268-3/19	2019/06/17 04:46:18	FLOATin water	29° 50.014' N	175° 30.032' E	5224.4	
SO268-3/20	2019/06/17 12:39:55	FLOATin water	29° 50.013' N	173° 30.542' E	3955.3	
SO268-3/21	2019/06/17 20:40:34	CTDin water	29° 50.012' N	171° 29.956' E	5255.4	CAT, OFOS, MUC, …
	2019/06/18 16:33:27	FLOATin water	29° 49.997' N	171° 31.701' E	5233.3	
SO268-3/22	2019/06/19 00:50:05	FLOATin water	29° 49.994' N	169° 30.335' E	5672.9	
SO268-3/23	2019/06/19 08:58:58	FLOATin water	29° 47.977' N	167° 30.047' E	5865.3	
SO268-3/24	2019/06/19 17:28:48	FLOATin water	29° 35.980' N	165° 29.980' E	5958.5	
SO268-3/25	2019/06/20 06:45:52	FLOATin water	29° 23.980' N	163° 29.842' E	5976.8	
SO268-3/26	2019/06/20 14:59:18	FLOATin water	29° 12.008' N	161° 30.174' E	5889.3	
SO268-3/27	2019/06/20 23:04:42	FLOATin water	29° 00.005' N	159° 30.051' E	6134.6	
SO268-3/28	2019/06/22 04:33:53	CAT in water	28° 01.119' N	152° 04.671' E	6026.3	
SO268-3/29	2019/06/24 05:30:29	CAT in water	25° 42.052' N	140° 56.497' E	2100.4	
SO268-3/30	2019/06/26 15:38:47	CTDin water	22° 44.794' N	127° 43.612' E	5360.4	CAT, OFOS, MUC, …
SO268-3/31	2019/06/28 01:57:54	CTDin water	21° 57.156' N	124° 24.785' E	5200.0	CTD

CAT	catamaran nemicat
OFOS	OFOS underwater camera
MUC	20 sample Multi-Coarer
CTD	Conductivity-Temperature-Depth ocean profiling sonce
FLOAT	ARGO float deployment
NET	fishing net for large litter collection
boat	outside boat for litter collection

8 Data and sample storage and availability

HYDRO-acoustic data will be archived at BSH and HCU-Hamburg (Harald.sternberg@hcu-hamburg.de).
OFOS ocean floor images will be uploaded in the PANGAEA data base (Melanie.Bergmann@awi.de)
MICROTOPS will be at http://aeronet.gsfc.nasa.gov/new_web/maritime_aerosol_network.html
CEILOMETER will be at ftp://ftp-projects.zmaw.de/aerocom/ships/ceilometer_sonne19
CLOUD-CAMERA will be at MPI-M by request (Stefan.Kinne@mpimet.mpg.de)
MAX-DOAS will be at KNMI and MPI-C by request (Ping.Wang@knmi.nl , Steffen.Doerner@mpic.de)
PANDORA will be at FU-B by request (Thomas.Ruhtz@fu-berlin.de)
BRUKER EM27/SUN Fourier Transform Spectrometerby request (andre.butz@iup.uni-heidelberg.de)

If interested in any atmospheric data sampled during the SO268-3 cruise it is also recommended to contact stefan.kinne@mpimet.mpg.de to be informed on updates and to avoid data misinterpretations.

If you are interested in the sampled oceanic plastic debris and the analyses of the polymers, their surface properties, associated biofilms and sorbed environmental pollutants during the SO268-3 cruise, please contact annika.jahnke@ufz.de.

9 Acknowledgements

The scientific staff of RV SONNE Cruise SO268/2 gratefully acknowledges the friendly and enjoyable atmosphere and the helpful assistance of Captain Meyer and his crew. Also the support of the Leitstelle Deutsche Forschungsschiffe (German Research Fleet Coordination Centre) at the University of Hamburg was highly appreciated. The expedition was funded by DFG and BMBF (MICRO-FATE project, project no. 03G0268TA).

10 Appendix – Outreach

10.1 Blog and Artistic Activities *(R. Kroke)*

background Roman Kroke accompanied the SO 268/3 cruise as an artistic mediator mandated by the UFZ, Leipzig. (http://roman-kroke.de/research-expedition-pacific-crossing-mexico-via-sinapour-2/) .
His tasks consisted, in particular, in the following:

- Documenting the entire expedition for the scientific archive of the UFZ (photos/videos)
- Helping the research team to disseminate the contents of the expedition via diverse channels of communication (web, blogs, social media), in particular by writing the official UFZ Travel Blog
- Developing an interdisciplinary workshop concept allowing participants of diverse backgrounds (general public, students, …) to learn about the scientific topics dealt with during SO 268/3; after the return to Germany: Leading the pilot-workshop at the UFZ student lab in Leipzig (until July 2020)
- Creating artworks (drawings, paintings, installations etc.) which will mediate the research topics of the SO 268/3 to a broader scientific and non-scientific public of all ages. Roman Kroke will accomplish this goal according to his practice and network already established during the last years: organising exhibitions, giving lectures, workshops, teacher-trainings, …; his artworks will be developed with an interdisciplinary approach, thus establishing links between the scientific research topics and other disciplines, in particular: contemporary *philosophical* concepts about sustainable development and ecological consciousness; *pedagogical* concepts as part of the national educational systems; *literary* sources dealing with the elements of water and air from a poetical perspective.

first results

The video material during the expedition allowed the ARD (Mittagsmagazin 5.Juli 2019) to broadcast a documentation about the SO 268/3 which also included live-feeds of sampling methods.
https://www.daserste.de/information/politik-weltgeschehen/mittagsmagazin/videos/forschungsschiff-mikroplastik-ard-mittagsmagazin-video-100.html

The article includes an interview on MDR-Wissen (8.Juli, 2019) where Kroke explains his artistic approach to the SO 268/3 expedition and also sensitizes the public with respect to his blogs on the UFZ website and Instagram account.
http://roman-kroke.de/press-article-in-mdr-wissen-about-pacific-expedition/

An official Helmholtz Blog during and after the SO268-3 cruise (in German)
https://blogs.helmholtz.de/on-tour/
The goals determining the writing style and storylines which Roman Kroke chose for the blog intended:

Introducing the readers back in Germany to the scientific research realised on board of the SONNE just as well as to the work of the ship's crew (bridge, machine room, kitchen, bosun, fitter etc.).

Building bridges between the scientists and the ship's crew: The blog has not only served to bring the manifold working universes closer to its readers back in Germany. From the feedback he got from diverse scientists as well as members of the ship's crew it also helped the different people on board of the SONNE to learn about each other's fields of expertise. As everyone on the ship had been quite busy with his/her own daily tasks and challenges, it is entirely understandable that sometimes scientists knew quite little about their colleagues' field of research or the work achieved by the ship's crew – and vice versa. The stories in the blog therefore also aimed at contributing to an interdisciplinary exchange in this regard.

By integrating topics into the blog which – at first glance – may not directly seem to be related to our expedition I managed to establish links towards societal players which normally would not have learned about the SO 268/3. For instance, by weaving into one of the storylines a fragment about Germany's very first deep sea expedition on board of the VALDIVIA under the direction of the Leipzig zoologist Carl Chun (1898) – see at the end of https://blogs.helmholtz.de/on-tour/2019/07/ein-lego-baukasten-fuer-ozeanographen/ – I got into contact with Dr. Leder, Director of the Museum of Natural History in Leipzig (Germany, https://naturkundemuseum.leipzig.de/), who plans to devote one of the museum's upcoming exhibitions to the topic of scientific research in the deep sea; this entry may lead to an opportunity to spread the experience of the SO 268/3 to an entirely new public. The same applies to other interdisciplinary fragments integrated into the blog – in particular those of a *philosophical* and *pedagogical* nature. Like in the past, these thematic bridges will allow me to present the research topics related to the SO 268/3 on occasion of international conferences related to philosophy (UNESCO, Paris, http://roman-kroke.de/lecture-at-the-17th-international-colloquium-on-new-practical-methods-in-philosophy-unesco-house-paris-fr/) or as part of teacher trainings (in Germany, France, Switzerland, Belgium).

an overview article by the Wilhelmshavener Zeitung (20April 2019)
http://roman-kroke.de/wp-content/uploads/2019/04/Presse_WZ_20.-April-2019_Roman-Kroke.pdf

Instagram As a complement to the rather text-oriented travel blog for the UFZ Kroke also set up an Instagram account on which he documented the SO 268/3 expedition. Starting with the departure from Vancouver harbour, this blog gained around 150 followers, among which private people as well as institutions working in the domain of ocean preservation, sustainable development, science etc. Via instragram Kroke also documented how he has been preparing artistic materials as a basis for his future drawings/paintings. For instance, he let a linen canvas travel down to the bottom of the ocean by attaching it to one of the "legs" of the MUC deep sea sampler (see Figure A1) and let it hang in the chimney of the SONNE with the air of the engine room passing through it. The underlying idea of this approach has been to impregnate the canvas with intimate stories and traces (salt crystals, sediments etc.) bearing witness about the different working universes of the SO 268/3. It is quite understandable that to people who are not acquainted with the current vivid discourse about art as means of fostering interdisciplinary exchange and responsible citizenship such an approach might appear as nothing but a "fun game". The underlying concepts of his artistic approach run far deeper and concern basic questions of our societal values.

Figure A.1 TOP/LEFT: Preparation of the canvas (for future paintings) to travel with the MUC deep sea sampler down to the seabed of the Pacific Ocean. BOTTOM/LEFT: canvas recovery after the return with the sediments from the ocean floor with traces of this journey (salt crystals, sediments etc.) in its linen matrix.TOP/RIGHT: Canvas during the drying process being attached to one of the SONNE's antennas, getting thus impregnated with the sun and atmosphere symbolizing the universe of our MORE-2 scientists. BOTTOM/RIGHT: The remnants of a paper recycling-process (by an on-board shredder and compactor) to be integrated into Kroke's future artworks thus informing the public about the ecological concepts on the research vessel SONNE.

planned activities Roman Kroke firstly would like to express his gratitude to all the people and institutions which have been advocating and supporting his participation and work during the SO 268/3 expedition – in particular the Helmholtz Centre for Environmental Research UFZ (Leipzig/Germany) with its project coordinator Annika Jahnke, the cruise leader Stefan Kinne, the master of the SONNE Oliver Meyer, the German research Fleet Coordination Center as well as all scientists and crew members. He very much hopes that he will have the opportunity to embark on similar research travels in the future. Selection of some upcoming projects/events in which Kroke will integrate his interdisciplinary artwork based on the SO 268/3 expedition:

Pilot-Workshop for the UFZ student laboratory (until July 2020, exact dates not yet determined)

Developing an interdisciplinary workshop concept allowing participants of diverse backgrounds (general public, students, …) to learn about the scientific topics dealt with during SO 268/3; after the return to Germany: Leading the pilot-workshop at the UFZ student lab.

Lecture and exhibition at LA FESTA DEL PAESAGGIO, Montalcino/Italy (September 2019)

OCRA Montalcino (https://www.ocramontalcino.it/), organised by the architectural office of Edoardo Milesi & Archos, has invited Kroke for the interdisciplinary festival LA FESTA DEL PAESAGGIO which is dedicated the topic of climate change.

Lecture and exhibition at the Museum of Contemporary Art, Novi Sad/Serbia (September 2019)
http://www.novisad.rs/eng/museum-contemporary-art-vojvodina

Publication edited by the Berlin University of the Arts (October 2019)
http://roman-kroke.de/publication-microplastics-and-medusae-expeditions-into-h%e2%82%82o/

Teacher Trainings at the HEP Lausanne and HEP Fribourg/Switzerland (October/November 2019)
Teacher-Trainings at the Teacher Training Colleges in Lausanne and Fribourg for pedagogues of diverse disciplines (art, science, literature, philosophy, geography) about how to teach about the topic of plastic pollution of the oceans and sustainable development with an interdisciplinary approach.

Follow-up meetings with the University of Siegen and the Museum of Natural Sciences Leipzig
A first contact has also been made with the staff of the FUTURIUM Berlin. The Futurium unites under the same roof a museum of the future with vivid scenarios, a laboratory of the future in which visitors can make their own explorations and a forum of the future for dialogue between players from different spheres (https://futurium.de/en/).

resources
www.Roman-Kroke.de (homepage)
https://www.instagram.com/roman.kroke/ (Instagram-account)