



Helmholtz-Zentrum für Ozeanforschung Kiel

RV SONNE
Fahrtbericht / Cruise Report
S0235

23.07.-07.08.2014
Port Louis, Mauritius to Malé, Maldives



Berichte aus dem GEOMAR
Helmholtz-Zentrum für Ozeanforschung Kiel

Nr. 21 (N. Ser.)

Oktober 2014



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RV Sonne cruise SO235: Port Louis-Malé, July 23 to August 07, 2014

Introduction

Within the frame work of the BMBF-project OASIS (“**O**rganic very short lived substances and their **Air Sea Exchange** from the **I**ndian Ocean to the **S**tratosphere”) the research cruise SO235 of the German research vessel SONNE was organized and conducted by the University of Oslo, Norway (www.uio.no) together with the GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany (www.geomar.de) from July 23 to August 07, 2014 in the tropical West Indian Ocean (Figure 1). The SO235 cruise was planned as a pilot study to the tropical West Indian Ocean. 23 scientists from Germany, Austria, China, Italy, Malaysia, UK and USA and one observer from Mauritius took part. The research covered oceanic sources, air-sea gas exchange between the atmosphere and the ocean, and the transport of ocean trace gases from the Indian Ocean to the stratosphere during the southwest Monsoon. This research was funded from the BMBF with the project SO235-OASIS (Grant: 03G0235A).

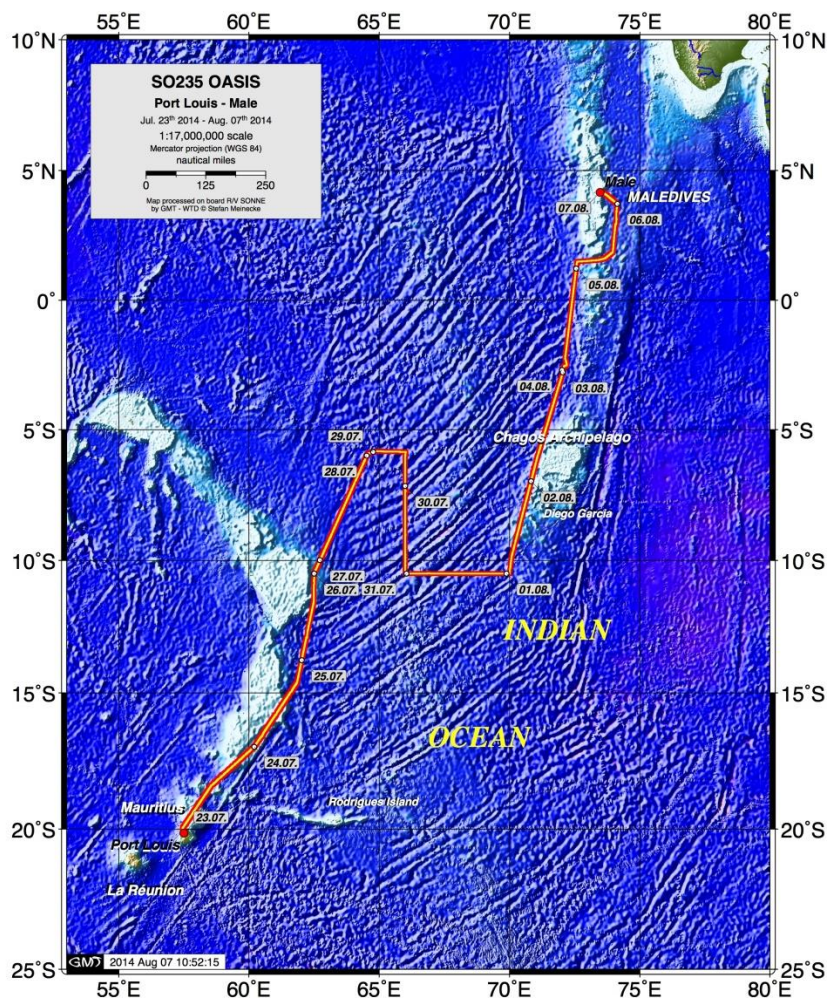


Figure 1: SO235 OASIS cruise track of RV Sonne: Port Louis-Malé (July 23 to August 07, 2014).

Scientific background

Trace gases, containing halogens like chlorine and bromine are broken down by solar radiation in the stratosphere, where the halogens are highly efficient at destroying ozone. Increasing emissions from human activities have led to depletion of global stratospheric ozone over the last three decades. Whereas the chlorine supply is dominated by anthropogenic compounds, a major part of the bromine is supplied by natural, short-lived compounds with oceanic sources. The importance of sulphur compounds emitted from the ocean for the middle atmosphere relates to their role as precursors for the stratospheric aerosol layer. Recently, an increase of the stratospheric aerosol background level since 2000 has been observed. However, the origin of this elevated Junge layer, made either anthropogenically or naturally, is still under investigation. The tropical oceans are a known source of reactive halogen and sulphur compounds to the atmosphere in the form of short-lived brominated and iodinated methanes, as e.g. bromoform (CHBr_3), methyl iodide (CH_3I), dimethyl sulphide (DMS) and COS (carbonyl sulphide). Elevated atmospheric concentrations above the oceans are related to oceanic super saturations of the compounds, and to natural photochemical and biological production. Macro algae in coastal regions, as well as regionally enhanced phytoplankton, coral reefs, photochemical reactions and local anthropogenic sources all contribute to marine and atmospheric concentrations.

Trace gases enter the stratosphere principally in the tropics, where ascending warm air carries them rapidly from the ocean surface to the tropical tropopause layer. The intense vertical transport of the tropical atmosphere implies that the oceanic sources supply significant amounts of halogens and sulphur to the upper troposphere/ lower stratosphere where they contribute to the observed halogen content and ozone changes. The subtropical and tropical Indian Ocean is a largely uncharacterized region for oceanic compounds and a projected hot spot, especially in coastal regions for their emissions and transport pathways into the stratosphere during southwest monsoon.

Spatial and temporal variability in production and sea-to-air flux of short-lived halogenated and sulphuric trace gases creates strongly varying oceanic distributions and thus also varying atmospheric contributions. The current impact of the natural ozone depleting substances is still uncertain and future changes in the mechanisms, that regulate their emissions to the atmosphere, their transport, and their chemical processing are largely unknown. Therefore the oceanic emissions have the potential to cause surprises in the evolution of the stratospheric ozone and aerosol layer in a changing climate, unless they are better understood. The tropical Indian Ocean measurements are thus needed to improve the understanding of future stratospheric halogen and sulphur loading and therewith on the ozone depletion and the radiative forcing of the future climate. The results of the SO235 campaign will contribute to new scientific insights of the United Nations Montreal Protocol on Substances that Deplete the Ozone Layer, to the United Nations Framework Convention on Climate Change, and to global climate change research in general.

Objectives and measurements

The SO235 cruise was primarily planned as a pilot study to characterize the oceanic sources and emissions of natural halogenated and sulphuric gases in the tropical West Indian Ocean and their delivery to the stratosphere during Southwest Monsoon. The western tropical Indian Ocean experiences the Somali current, which reverses with the different monsoon systems, the Agulhas current, open ocean denitrification and high rates of nitrogen fixation in the Arabian Sea, and a large area in the western equatorial region of high carbon dioxide drawdown. All these phenomena make the tropical Indian Ocean an excellent laboratory for ocean biogeochemical and physical processes, atmosphere-ocean interactions and for global climate change studies with a special focus on anthropogenic versus natural effects.

Of particular scientific relevance during SO235 were oceanic and atmospheric measurements of a suite of short-lived trace gases containing bromine, iodine and sulphur in various marine biogeochemical regimes like close to the coasts, in regions of high chlorophyll, close to coral reefs (as the Cargados Carajos Shoals and Maldives) and sea banks (i.e. Saya de Malha bank), and open ocean conditions. From these measurements the climate-sensitive oceanic emission strengths and their contribution to stratospheric halogen and sulphur aerosol abundances will be deduced by high resolution transport modelling.

The atmospheric structure was determined by frequent radio and ozone soundings during the cruise. Other marine trace gases as e.g. nitrous oxide (N_2O), dimethyl sulphide (DMS), oxygen (O_2) and carbon dioxide (CO_2) were investigated as well. In situ and satellite measurements of phytoplankton groups, obtained by special retrieval methods from the SCIAMACHY and GOME-2 instruments gave further information about biogeochemical conditions during the cruise. Atmospheric concentrations of a variety of long-lived anthropogenic and natural trace gases were also determined. These measurements will help to identify transport pathways of the tropospheric trace gases to and away from the ship.

Quasi-continuous measurements of a set of halocarbons, DMS, COS and CO_2 in both seawater and air were carried out in order to determine actual sea to air fluxes. Additionally, we conducted direct flux measurements of CO_2 , DMS, isoprene and acetone with the eddy covariance technique. In order to understand seasonal and spatial fluctuations of the oceanic trace gases emissions and to project their future development, microbial production and removal processes in the surface ocean with emphasis on the turnover of organic matter during production and decomposition processes, as well as phytoplankton pigments, species and size distribution, radiation and absorption spectra of seawater and plankton content were characterized.

The participants were grouped into 10 working themes, which are further outlined below (see also Table 1). The detailed research questions and first preliminary results are given in the Working groups reports (PP. 13-57).

Working groups

1.) HALOCARBONS: Atmospheric and oceanic concentrations of bromine, iodine and chlorine containing halocarbons, in order to calculate their air-sea fluxes.

2.) OCEANIC TRACE GASES: Oceanic concentrations of DMS, COS, CO₂, isoprene, CO, nitrous oxide and methane, in order to understand their distribution in the different biogeochemical regimes of the western Indian Ocean and to gain new insights into halocarbon sources.

3.) EDDY COVARIANCE: Direct measurements of DMS, CO₂, isoprene, and acetone air-sea exchange. When combined with bulk concentration measurements the in-situ gas transfer coefficient is derived, which can be used for other gases measured on-board as well.

4.) OCEAN SENSORS: Identification of carbon dioxide and oxygen sources and sinks, separation of physical and biological factors for observed sources and sinks by CTD data temperature and salinity, joint evaluation with halocarbons, in order to understand more about their sources and sinks.

5.) BIOLOGICAL PARAMETERS Characterisation of the community structure and physiological conditions of phytoplankton, phytoplankton pigments, species and size distribution, radiation and absorption spectra of seawater and plankton content. Genetic analyses of functional genes involved in halocarbon cycling. Photosynthetic production and heterotrophic respiration. Turnover of organic matter during production and decomposition processes.

6.) RADIOSOUNDING: Identification of meteorological vertical profiles, including relative humidity and ozone, in order to evaluate the marine atmospheric boundary layer and tropopause height, to calculate the air mass origins of sampled air masses by trajectory calculations and to validate transport model simulations above the tropical Indian Ocean atmosphere.

7.) AIR-SAMPLING: Determination of anthropogenic and natural trace gas concentrations by flask sampling, to identify regional and diurnal gradients of some compounds and for intercalibration of different instruments

8.) REACTIVE HALOGENS: Identification of reactive trace gases BrO and IO with Multi-Axis Differential Optical Absorption Spectroscopy in a three dimensional field and Cavity Ring Down Spectroscopy as possible decomposition products of organic trace gases and for validation of satellite-data.

9.) GHG: Continuous measurements of the atmospheric mixing ratios of a suite of pollution indicators and greenhouse gases (e.g. CO, CH₄, O₃, CO₂) in order to investigate their spatial and temporal variability in the lower tropical marine boundary layer.

10.) AEROSOL: Major ions and halogens in aerosol samples, in order to identify their sources and quantify the halogen budget. Total aerosol optical thickness for cloud-free conditions to complement the radiation measurements.

Participants

Nr.	First / Sure Name	Institute/ Country	Position	Working Group
1.	Kirstin Krüger	UiO, Oslo, Norway	Chief Scientist	6.), 7.)
2.	Birgit Quack	GEOMAR, Kiel, Germany	Project PI	1.), 7.), 10.)
3.	Christa Marandino	GEOMAR, Kiel, Germany	Co-Chief	2.), 3.), 9.)
4.	Tobias Steinhoff	GEOMAR, Kiel, Germany	Scientist	2.), 3.), 4.), 9.)
5.	Susann Tegtmeier	GEOMAR, Kiel, Germany	Scientist	6.), 7.), 8.), 10.)
6.	Matthias Krüger	GEOMAR, Kiel, Germany	Scientist	4.)
7.	Henning Finkenzeller	Uni Heidelberg, Germany	PhD Student	8.), 9.)
8.	Helmke Hepach	GEOMAR, Kiel, Germany	Scientist	1.), 5.)
9.	Gert Petrick	GEOMAR, Kiel, Germany	Technician	1.)
10.	Matt Patey	University of Las Palmas, Spain	Scientist	5.)
11.	Sonja Endres	GEOMAR, Kiel, Germany	Scientist	5.), 1.)
12.	Luisa Galgani	GEOMAR, Kiel, Germany	Scientist	5.)
13.	Rudolf Link	GEOMAR, Kiel, Germany	Technician	4.)
14.	Sinikka Lennartz	GEOMAR, Kiel, Germany	PhD Student	1.), 2.), 3.)
15.	Martina Lohmann	GEOMAR, Kiel, Germany	Technician	5.)
16.	Xioa Ma	GEOMAR, Kiel, Germany	PhD Student	2.)
17.	Chea Wee	Academia Sinica, Taiwan	Scientist	5.)
18.	Sonja Wiegmann	AWI, Bremerhaven, Germany	Technician	5.)
19.	Danishta Dumur	Mauritius	Observer	5.)
20.	Gesa Eirund	GEOMAR, Kiel, Germany	Student	2.), 9.)
21.	Alina Fiehn	GEOMAR, Kiel, Germany	PhD Student	6.), 7.), 8.)
22.	Alex Zavorsky	GEOMAR, Kiel, Germany	PhD Student	3.)
23.	Dennis Booge	GEOMAR, Kiel, Germany	PhD Student	2.)
24.	Steffen Fuhlbrügge	GEOMAR, Kiel, Germany	PhD Student	6.), 7.), 8.)

Table 1 Participants, institutions and working groups.

Work program SO235

During the SO235 cruise of 'RV Sonne' from July 23 to August 07, 2014 in the tropical West Indian Ocean from Port Louis, Mauritius to Malé, Maldives a variety of chemical, biological and physical parameters within the surface waters as well as between the atmospheric boundary layer and the stratosphere have been examined with different frequencies. Data and samples were obtained using various analytical instruments and sampling devices (Tables 2 and 3). Regular surface water samples were collected from pumps submersed in the hydrographic shaft of the ship (Appendix A). Depth profiles (Appendix B) were undertaken at selected locations to investigate the vertical hydrographic structure of the water column and to obtain trace gas profiles. Additionally, a Lagrangian drifter following the water masses at the surface was employed. Several trace gases from sea water and surface air as well as biological parameters were analysed directly on board the ship.

In total 48 instruments and sampling devices were employed to analyse the samples during the cruise (Table 2). Routinely three hourly surface water and air samples were taken with the submersed pumps respectively metal bellows pumps on the monkey deck (Working Groups 1, 2, and 7).

Halogenated hydrocarbons, oxygenated trace gases and dimethyl sulphide from sea water and surface air were analysed directly on board using six different gas chromatography and mass spectrometry systems (Working Groups 1, 2, and 3). Carbon dioxide and oxygen were measured immediately with sensors within the upper oceanic layer (Working group 4). More trace gases in sea water (N_2O , CH_4) will be analysed by gas chromatography post-cruise in the laboratory. Oxygen was measured on board directly by the Winkler method and nutrient samples were analysed with micro-molar and nano-molar auto analysers. Biological sampling included parameters of organic carbon and nitrogen as well as DNA, pigments, cell sizes, the amount of small cells and the composition and activity of the phytoplankton and zooplankton (Working Group 5).

Atmospheric profiles of temperature, humidity and different kinds of trace gases (e.g. ozone, nitrous oxide, bromine oxide) were examined on the basis of optical measurements, and by rises of research balloons to the stratosphere (up to 30 km height) (Working Groups 6, 7, 8, 9). Optical sensors and continuous instruments were installed in the beginning of the cruise on the monkey deck, the bow and in a research container (Working Groups 3, 8, and 10). Discrete air samples were taken for partners of the "Rosenstiel School of Marine and Atmospheric Sciences" in Miami and of the University of East Anglia (Working Groups 7 and 10). In the respective home laboratories more than 70 anthropogenic and natural trace gases and elements in aerosols within the marine boundary layer shall be analysed following the cruise.

Frozen water and filter samples of chemical and biology parameters, taken during the cruise, were sent by air freight and are currently analysed in the respective home laboratories, while the containers with equipment reach Kiel by beginning of October 2014. The analysis of the extensive dataset from the ocean and the atmosphere collected during SO235 will bring first results in summer 2015. The new insights into the interaction of ocean and atmosphere from the tropical West Indian Ocean will be published in peer reviewed scientific journals.

Instruments:

Nr.	Working group	Instrument/ Method	Parameter	Duration (hr)
1	Halocarbons	GC/MS1	Halocarbons	354
2		GC/ED1	Halocarbons	354
3		GC/ED2	Halocarbons	354
4	Oceanic Trace Gases	GC/MS2	DMS	354
5		Mini-CIMS	DMS/ Isoprene / Acetone	354
6		MICA/CRDS	COS	354
7		GC/ED	N2O	354
8	Ocean sensors	Drifter with sensors	O2/CO2/fluorometer	74
9		ADCP	Currents	354
10		CTD	Salinity, Temperature, Depth	44
11	Biological param.	Auto-analyzer	nmolar-nutrients (uw)	354
12		Auto-analyzer (Seal Quattro)	μmolar-nutrients (from CTD)	354
13		Cell counter	Flow-Cytometrie	354
14		HPLC	Pigments	354
15		Sequencing	RNS	354
16		TOC-Analyzer	DOC/TDN	354
17		MS	¹⁵ N	354
18		X-ray fluorescence	Halogen POC	354
19		Adsorbable Organic Halogens	Halogen DOC	354
20		Ion chromatograph	I-/IO3-	354
21		Microscopy	Phytoplankton community	30
22		Slides	TEP/CSP	120
23		Photometrie	PAB	120
24		LWCC	CDOM	120
25		Winkler Titration	oxygen	120
26		Light sensor	radiation	11
27		FRRF	plankton physiologie	11
28	Eddy Covariance	APCIMS	DMS, acetone, isoprene	354
29		Licor	CO2/ Water vapor	354
30		Campbell Sonic Anemometer	3D-wind speed and dir (2x)/ T-flux	354
31		IMU	Motion sensor (pitch and roll)	354
32		GPS/ Kompass	Lat /long/ speed over ground	354
33	Radiosounding	Radiosondes	T, Td, w	198
34		Ozonesondes	Ozone	16
35		Disdrometer	Precipitation/ raindrop size	354
36		RAMSES	Radiation	354
37		weather-station	T, Td, rain, radiation	354
38	Air-sampling	Denuders	Iodide	45
39		Canister samples (MS)	long- and short lived trace gases	24
40	Reactive Halogens	MAX DOAS	BrO/ Nox/ Aldehyde	354
41		CES-DOAS	IO	354
42	GHG	Horiba ozone monitor	Ozone	354
43		OA-ICOS	N2O/CO2/CO	354
44		GC	CH4	354
45	Aerosols	Aeronet/ microtop	Aerosol	8
46		Cascade impactor	Aerosol Ions	354
47	DSHIP	Ship sensors	u,v, T, P, U	354
48		Thermo salinograph	surface salinity, temperature	354

Table 2: Installed and operating instruments on SO235 (Port Louis-Malé, July 23-August 07, 2014).

Measurement plan

Group	Time of day in UTC																							
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	w			w			w			w			w			w			w			w		
2	w			w			w			w			w			w			w			w		
3	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c
4											as necessary													
5	r			(r)			r			(r)			r/o			(r)			r			(r)		
6	a			a			a			a			a			a			a			a		
7						c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c
8	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c
9	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c

c: continuous
w: water sample
r: radiosonde
a: air sample
o: ozonesonde

Table 3: Underway measurement plan and sampling strategy on SO235.

Working groups reports

1.) HALOCARBONS

2.) OCEANIC TRACE GASES

3.) EDDY COVARIANCE - TRACE GASES

4.) OCEAN SENSORS

5) BIOLOGICAL PARAMETERS

6.) RADIOSOUNDING

7.) AIR-SAMPLING

8.) REACTIVE HALOGENS

9.) GHG

10.) AEROSOL

1) Halocarbons in surface and deep water

Helmke Hepach, Gert Petrick, Sinikka Lennartz, and Birgit Quack (PI) (GEOMAR, Kiel, Germany)

Background

Halocarbons are hydrocarbons in which one or more hydrogen atoms are replaced by one or more halogens. Some halocarbons are produced naturally in the oceans. Although it is commonly acknowledged that many of these compounds have a biological origin with distinct maxima in the subsurface chlorophyll *a* (Chl *a*) maximum, their cycling within the water column is still poorly understood. Other production pathways such as photochemical formation might play a significant role. Once the halocarbons are transported into the troposphere from the sea surface by air-sea gas exchange, they have very short lifetimes of less than 180 days. Bromoform (CHBr_3) and dibromomethane (CH_2Br_2) are together the biggest carriers of organic bromine into the atmosphere, while CH_3I is the most abundant organoiodine. The tropical ocean is a key region with respect to atmospheric transport processes: tropical deep convection can carry these compounds despite their short lifetimes into the stratosphere where they can deplete ozone much more effectively than chlorine. Additionally, diiodomethane (CH_2I_2) and chloriodomethane (CH_2ClI) have recently been suggested to be similarly important for the organic iodine loading of the troposphere as CH_3I . These compounds are involved in numerous chemical cycles within the atmosphere with iodinated compounds even participating in aerosol formation.

So far, large data gaps with respect to halocarbons exist in the tropical Indian Ocean. Very few studies have focused on this region, although it might be of large importance for convective transport processes in to the stratosphere. The measurements of halocarbons during the OASIS SONNE cruise are the first measurements of these compounds in the tropical Indian Ocean. They will help to characterize this area with respect to the global oceanic distribution of these compounds, and the contribution of the Indian Ocean to the stratospheric organic halogen loading.

Material and methods

Halocarbons on-board the RV Sonne were measured directly after sampling. Discrete samples were collected both from the continuously working pump located in the ship's moon pool (underway) every three hours, and from the Niskin bottles attached to the CTD. Each CTD was sampled for five to eight different depths. The water was analyzed for ten brominated, chlorinated and iodinated compounds including CH_3I , dichloromethane (CH_2Cl_2), chloroform (CHCl_3), tetrachloromethane (CCl_4), CH_2Br_2 , CH_2ClI , bromiodomethane (CH_2BrI), dibromochloromethane (CHBr_2Cl), CHBr_3 , and CH_2I_2 . 50 mL of the sampled water was introduced into a purge chamber. The water was purged with a stream of helium of 30 mL min^{-1} while it was concurrently heated up to 70°C . The purged gas was trapped in stainless steel tubing hanging in liquid nitrogen for 50 min. The trap was desorbed at 100°C and the sample was injected into a gas chromatograph. CTD samples were measured using combined

gas chromatography and mass spectrometry (GC-MS), while underway samples were analysed using a gas chromatograph equipped with an electron capture detector (ECD). Calibration was conducted using volumetrically prepared standards in methanol. In total, 15 CTD casts were measured, rounding up to a total of 105 samples that were measured from the CTD, while 190 samples were taken from the underway pump system, making a total of 295 halocarbon water samples during OASIS-Sonne. Additionally, air samples were measured. For these measurements, 500 mL of air was sucked from a sampling line located at the ship's main deck into a cooled trap, and then injected into a third GC-ECD for quantification.

In cooperation with the Working Group 5B (Sonja Endres and Luisa Galgani), additional incubation experiments were carried out. Water samples were taken from above, within and below the subsurface chlorophyll maximum, and from the sea surface micro layer during one experiment. Half of the samples were filtered through 0.2 μm filters, while the other half was left unfiltered. Half of the filtered and half of the unfiltered samples were spiked with ^{13}C -Bromoform to investigate possible transformation of CHBr_3 into CH_2Br_2 . Three experiments were carried out incubating only dark samples, in order to investigate heterotrophic processes while in two incubation experiments, samples were also incubated in light, in order to observe autotrophic production processes.

Preliminary results

Halocarbon data of our target compounds CHBr_3 and CH_2Br_2 were very variable during the cruise in the surface waters of the Indian Ocean. While CHBr_3 was often elevated during the previous cruise SO234-2 and especially in waters near Madagascar, the concentrations in the blue waters of the tropical Indian Ocean of SO235 appear a magnitude lower. While the high wind speed during SO235 obviously met low oceanic concentrations, the variations of the two brominated compounds and also the variation of CH_2ClI and CH_2I_2 will give new insights into the sources of these compounds. Incubation experiments were conducted (Working group 5B), to see whether a fast production may lead to increased emissions, while there also appear to be diurnal variations between the compounds.

Halocarbon concentrations within the CTD profiles were larger during the SO235-cruise than during the SO234-2 cruise (Figure 1). Similarly to the first cruise leg, CH_2Br_2 concentrations were elevated in comparison to CHBr_3 , which could be an indication for bromocarbon cycling (Quack et al., 2007, Hughes et al., 2013) investigated during the incubation experiments. Overall, both CHBr_3 and CH_2Br_2 had similar average preliminary concentrations of 5.4 (0 – 32.1) and 5.3 (0 – 60.9) pmol L^{-1} with the largest overall concentrations of the SO235 cruise at the first 24-h-station (Figure 1c – d). The first 24-h-station during the SO235-cruise was also characterized by higher fluorescence values than the 48-h-station during SO234-2, which could be an indicator for the (biological) origin of these larger bromocarbon concentrations.

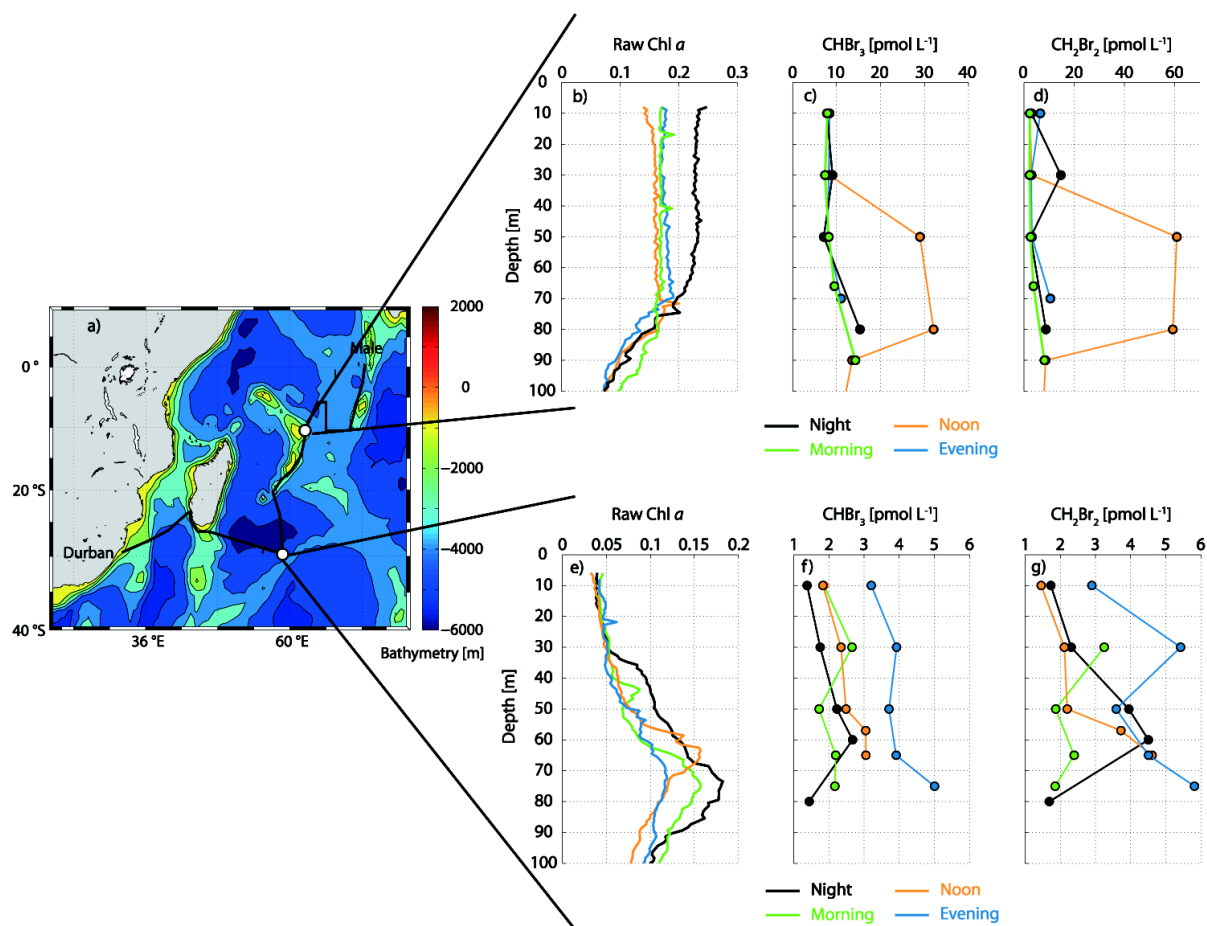


Figure 1 (a) Cruise map with bathymetry [m], and b-d) examples for CTD profiles during SO235 (first 24-h-station, and e-g) SO234-2 (first day of the 48-h-station, showing fluorescence (raw Chl *a*), CHBr₃ and CH₂Br₂).

Outlook

Further analysis of the data will be performed in Kiel. Once the data are fully analysed, they will be compared to biological and physical parameters. Emissions will be calculated using discrete atmospheric samples that were taken at the same time as the water samples, and using several parameters from the DSHIP data and the continuously measuring thermosalinograph (e.g. wind speed, air pressure, water temperature, density). Furthermore, the data will be compared to pigment data, nutrients, CDOM, and iodide and iodate, which were all sampled in parallel to elucidate sources of halocarbons in the Indian Ocean and learn more about their biogeochemical cycling. The final evaluation of the 48h-station will reveal possible diurnal variability of these compounds within the water column. Sea-to-air fluxes from the Indian Ocean will be used to calculate the entrainment of halocarbons into the stratosphere.

Furthermore, the incubation experiments will be evaluated with respect to bromocarbon cycling. The results will be compared to the biological measurements during the experiments, which include measurements of heterotrophic activity.

References

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Quack, B., Peeken, I., Petrick, G., and Nachtigall, K.: Oceanic distribution and sources of bromoform and dibromomethane in the mauritanian upwelling, *J. Geophys. Res.-Oceans*, 112, C1000610.1029/2006jc003803, 2007b.

2) OCEANIC TRACE GASES

2A) Underway measurements of CO₂, CO, and N₂O

Gesa Eirund, Xiao Ma, Tobias Steinhoff and Damian Arevalo-Martinez (GEOMAR, Kiel, Germany)

Method and measurements

Oceanic and atmospheric measurements of CO₂, CO and N₂O were carried out by means of a continuous system based upon the off-axis integrated cavity output spectroscopy technique (RMT-200 N₂O/CO Analyser, Los Gatos research Inc.) coupled to a CO₂ detector based upon non-dispersive infrared detection (LICOR, USA; LI-6252). Water was drawn on board by using a submersible pump installed in the ship's moonpool at 6 m depth and was subsequently conducted at a rate of about 5 L min⁻¹ through the equilibrator. Sample air from the headspace of the equilibrator was continuously pumped through the instruments and then back to the equilibration chamber forming a closed loop. The air stream was dried before being injected into the analysers in order to diminish interferences due to the water vapour content of the sample. In order to correct for potential warming of the seawater between intake and equilibrator the water temperature at the equilibrator was constantly monitored by means of a digital thermometer and at the intake by a Seabird SBE37 thermosalinograph. Ambient air measurements were accomplished by drawing air into the system from a suction point located at the ships mast at about 30 m high. Control measurements and calibration procedures were performed every ~8 and 24 h respectively, by means of 3 standard gas mixtures.

Discrete comparison samples for N₂O, CH₄ and CO₂ were carried out in 6-12 h intervals by sampling from the same water stream that fed the underway setup. N₂O samples were measured on board (together with the N₂O CTD samples on a gas chromatograph (GC HP 5890 series 2)) while CH₄ and DIC/TA samples were collected and stored to be measured at the Chemical Oceanography Department of the GEOMAR in Kiel.

Preliminary results

Figure 1 shows the surface temperature during the SO235 cruise. In figure 2 the underway measurements of N₂O and CO are shown. Presented results are not calibrated and show one lack of measurements due to a failure of the pump.

SST are coldest off the coast of Mauritius and increase northward. Peak SST are found close to the equator. In the N₂O distribution two areas with higher concentrations can be seen at approximately 10° S. In this region the ocean is slightly oversaturated while everywhere else atmosphere and ocean are in equilibrium. CO values vary along the cruise track with higher concentrations in the ocean than in the atmosphere. The CO₂ data were not processed by the end of the cruise. This will be done directly after the cruise.

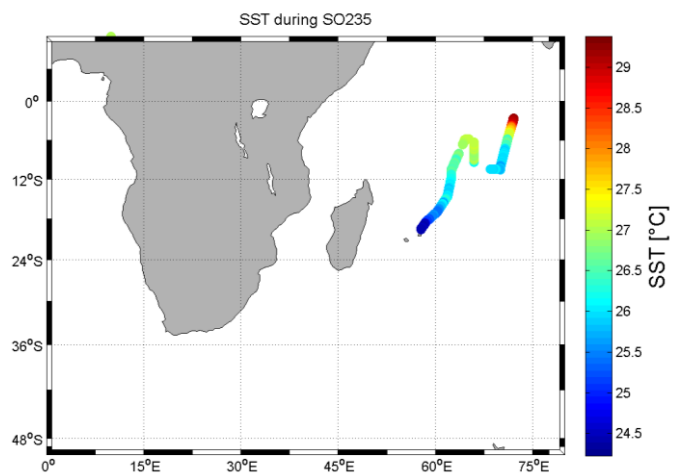


Figure 1 SST (°C) measurements along cruise track.

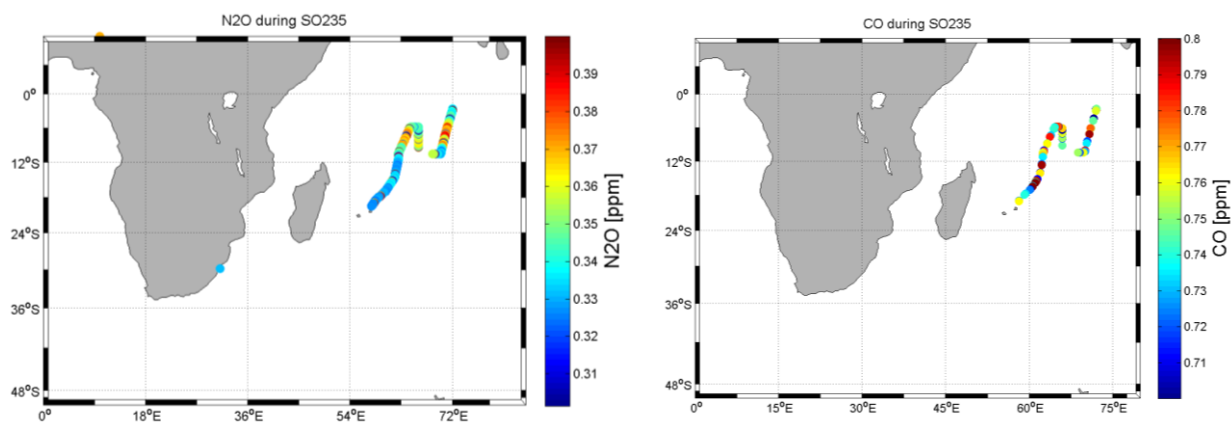


Figure 2 Surface water N₂O and CO concentrations (ppm) along cruise track.

2B) CH₄, N₂O and hydroxylamine in the Indian Ocean

Xiao Ma (GEOMAR, Kiel, Germany)

Background

Methane (CH₄) and nitrous oxide (N₂O) are important greenhouse gases which, directly or indirectly, influence global climate. N₂O has great global warming potential with a life time of 131 years. Due to the decreasing of chlorofluorocarbons (CFCs) and the continuous increase of N₂O in the atmosphere, the contributions of N₂O to both the greenhouse effect and ozone depletion are expected to be even more pronounced in the 21st century. CH₄ is a strong greenhouse gas as well. In the stratosphere, photo-oxidation of CH₄ is a major source of stratospheric H₂O, which influences stratospheric cooling.

Open oceans are considered as important sources of atmospheric N₂O, but oceans contribute only a relatively small amount to global CH₄ budget. Many projects were carried out in different scales and areas, and a lot of studies about CH₄ and N₂O distributions and emissions were reported, but their formation and cycling are still poorly understood. CH₄ is produced by microbial methanogenesis in anoxic environments. Since the majority of the ocean water column contains oxygen, methane maximum at surface mixed layer presents “the ocean methane paradox”. Oceanic N₂O is produced as a by-product during microbial nitrification and as an intermediate during denitrification, but the exact formation path remains unclear. In the open ocean, where oxygen widely exists, nitrification is considered as the main process for N₂O production. Hydroxylamine is mainly produced in the first step of nitrification, when ammonium is oxidized to nitrite by ammonium-oxidizing bacteria (AOB). Hydroxylamine is also found during dissimilatory nitrate reduction to ammonium (DNRA) and anammox, which take place in anoxic conditions. Researchers have made great break through by proving the extensive existence of ammonium-oxidizing archaea (AOA) and their significant contributions on nitrification. However, genes encoding the NH₂OH oxidoreductase have not been identified in AOA yet. Thus, the measurement of hydroxylamine can give us a clue to distinguish the respective contributions by AOA and AOB.

Our measurement can help fill out the blank of our database on CH₄ and N₂O in the Indian Ocean, and it is the first time to measure hydroxylamine in this area. This cruise will help to identify the global CH₄ and N₂O distribution and estimate their emissions from tropical Indian Ocean.

Methods and measurements

Dissolved CH₄ samples were just collected and sealed. They will be measured in GEOMAR with a gas chromatograph (GC) equipped with FID as soon as possible. Dissolved N₂O was measured directly after sampling with a GC using head-space equilibrium method. ECD response toward N₂O concentration was calibrated with different standard gases.

Hydroxylamine was measured with a ferric ammonium sulphate (FAS) conversion method (A. Kock and H. Bange, 2013). Hydroxylamine was oxidized into N_2O followed by removing nitrite. Samples were measured within 48 hours after sampling. Conversion factor was also measured with different hydroxylamine standard solution.

We took triplicate samples for CH_4 , N_2O and hydroxylamine. 441 CTD N_2O samples were collected and measured from every station (except for the last station, samples were just sealed and will be measured in GEOMAR). 213 CTD CH_4 samples were collected from 5 selected stations and will be measured in GEOMAR. 120 hydroxylamine samples were collected and measured from 4 selected stations. Zodiac samples were also collected ($\text{CH}_4 \times 9$, $\text{N}_2\text{O} \times 9$) from boat to look into the surface gradient.

Besides, samples were also collected from underway (UW) system in order to make comparison. N_2O samples were collected once a day (39 samples) and CH_4 samples were collected every 6 hours (~120 samples).

Work plan

CH_4 measurement will be conducted in GEOMAR. N_2O and hydroxylamine samples were just measured and will be calculated and analysed as soon as possible. According to our GC peaks, it seems that there is no surface gradient for N_2O from Zodiac samples. As soon as we get the data, we will compare them with oxygen, salinity, temperature and other related parameters. GC results will be used to calibrate UW data. Air-sea fluxes can be calculated with different models and will be compared with published results.

3) EDDY COVARIANCE – trace gases

Christa Marandino (PI), Alex Zavarisky, Dennis Booge, Sinikka Lennartz (GEOMAR, Kiel, Germany)

Motivation

Despite their low abundances, short-lived trace gases produced in the oceans play an important role in biogeochemical cycling and atmospheric processes. Some examples of such climate active gases that are measured on board the SO235 cruise are dimethyl sulphide (DMS), isoprene, acetone, and carbonyl sulphide (OCS). These gases react rapidly when emitted to the atmosphere, with lifetimes between 1 hour and 1 month. They participate in ozone and hydroxyl radical cycles and in the formation of aerosols and cloud condensation nuclei. The biogeochemical and physical factors influencing the production and destruction of these compounds in the surface ocean are only marginally constrained for gases such as DMS, OCS, and acetone, while very little information about isoprene cycling is known. In addition, quantifying the air-sea exchange of these compounds is further hindered by the lack of direct flux measurements and poor constraints on the factors controlling their fluxes (e.g. the gas transfer coefficients, presence of vertical gradients, etc.). The goal of this cruise is to understand what controls the biogeochemical cycling of these gases in the surface ocean, in depth profiles, and their exchange with the atmosphere.

In order to investigate the ocean's role in the atmospheric budget of these trace gases, bulk atmospheric and oceanic concentration measurements and ancillary data (such as coloured dissolved organic matter, cell counts, and DNA), as well as direct air-sea exchange, have been measured. We deployed three different instruments to measure underway and CTD seawater samples for trace gas concentrations and three instruments to measure air concentrations. An eddy covariance (EC) direct flux measurement system has also been deployed, which can be used to perform biogeochemical cycling measurements without typical pitfalls associated with bulk flux calculations, as well as to constrain the main forcings on air-sea gas exchange. Measurements of the precursors and sinks of these trace gases were measured in order to better understand and quantify surface ocean cycling. The main factor thought to influence these gases is biological activity. Therefore, samples for DNA and cell counts (i.e. flow cytometry) were taken for later analysis. Because the degradation of CDOM by UV light results in the formation of trace gases, such as OCS, acetone, and isoprene, CDOM quantities were also measured.

Methods

The Marandino working group is responsible for the following measurements:

1. Continuous eddy covariance fluxes of DMS, isoprene, acetone using atmospheric pressure chemical ionization mass spectrometry (AP-CIMS).
2. Continuous eddy covariance fluxes of CO₂ using infrared absorption (LICOR 7200).
3. Three hourly underway and CTD water concentrations of DMS (and related compounds such as DMSP, DMSO), and isoprene with purge and trap gas chromatography-mass spectrometry (GC-MS).

4. Continuous underway water concentrations of DMS, isoprene, and acetone using an equilibrator coupled to AP-CIMS.
5. Continuous underway water levels of OCS using an equilibrator coupled to a cavity ring down spectrophotometer (MICA), with hourly valve switches to measure air mixing ratios for 15 minutes.
6. Quantification of CDOM (both underway and at depth with the CTD) using UV-visible absorption (qualification may be attempted with a fluorescence spectrophotometer, but this has not yet been accomplished).
7. Sampling and preparation of flow cytometry samples for identifying types and amount of biological activity.

Eddy covariance

The eddy covariance direct flux (F) is computed with the following equation,

$$F = \rho \langle w'c' \rangle$$

where ρ is the density, w' are the vertical wind fluctuations, and c' are the concentration fluctuations (brackets denote time average). Using this technique, we can attempt to improve the gas transfer parameterization (k) used in the commonly employed bulk formula,

$$F = k(HC_w - C_a),$$

where C_w and C_a are water and air concentrations, respectively, and H is the Henry's law solubility constant. The goal was to measure dimethylsulphide (DMS), isoprene and acetone flux with the AP-CIMS and CO_2 flux with the LICOR 7200. Measurements started at Port Louis and continued until two days outside of Male.

Air was sampled through a $\frac{1}{2}$ " tube from a mast welded to the bow (approximately 10 m above the sea surface) at a flow rate of 70 l min^{-1} to the AP-CIMS and approximately 25 l min^{-1} to the LICOR. To obtain turbulent wind speed measurements and sensible heat flux, a sonic anemometer was placed at the bow mast, which measured three dimensional wind speed and the speed of sound. A GPS and inertial navigation system (INS) was used for motion correction (Figure 1). The AP-CIMS can discriminate gases using a single quadrupole mass spectrometer. The gases are ionized at atmospheric pressure using H_3O^+ as the reagent gas and electrostatically steered to the quadrupole. The ions are detected using a counting electron multiplier. The LICOR measures CO_2 and H_2O using infrared absorption.



Figure 1 Eddy covariance setup on the R/V Sonne.

Purge and trap GC-MS

We improved a purge and trap technique coupled with a GC-MS (Figure 2) to measure different non-methane hydrocarbons (NMHCs) in seawater. In addition, we developed a method to quantify different NMHCs (e.g. isoprene, dimethylsulphide (DMS)) in one measurement using isotopically labelled internal standards. A 40 ml discrete water sample was taken, bubble free, and purged with approximately 30 ml min^{-1} of helium for 15 minutes and trapped with liquid nitrogen on an empty u-shaped trap. The frozen gas was then injected with boiling water into the GC. Each analysis took approximately 13 minutes.



Figure 2 Purge and trap GC-MS aboard R/V Sonne.

AP-CIMS coupled to an equilibrator

A miniature AP-CIMS was coupled to a membrane equilibrator to measure DMS and isoprene. The equilibrator had approximately 5 l min^{-1} water flow and a counterflow of purified air of $\sim 300 \text{ ml min}^{-1}$. The air stream was dried with a Nafion dryer and diluted with dry purified air with a flow of 1100 ml min^{-1} . All gas flows were controlled with mass flow controllers and all liquid flows were measured and recorded.

OCS measurements

OCS in the gas phase is determined with an OCS Analyser (Los Gatos Research, California, Model 907-0028), which was sent by Mr. von Hobe (Forschungszentrum Jülich, Germany). The analyzer technique is off-axis integrated-cavity output spectroscopy (ICOS), using laser absorption according to the Lambert-Beer-Law to determine the volume mixing ratio of the gas in the measurement cell. The effective path length of the laser is about 2.5 km, as the gas is led into a cell between two 99.99% reflectivity mirrors. Besides OCS, the ICOS also measures CO, CO₂ and water vapour with a temporal resolution of 1 Hz. It has to be noted however that during transport, the mirrors of the ICOS became dirty, resulting in an offset to the accurate concentration. This offset will be corrected by a calibration after the cruise in Jülich.

In order to measure also the water concentrations of OCS in the surface ocean, the ICOS is connected to a Weiss-type equilibrator with a water flow of $\sim 2 \text{ L/min}$. The seawater is pumped from 5 m depth. The set-up is shown in Figure 3. The Weiss-type equilibrator enables effective equilibration, as the gas is circulated through the ICOS back to the equilibrator, ensuring that the gas concentration is always close to equilibrium to enable fast equilibration. Two electric valves were programmed to switch between outside air (10 min) and water (50 min) sampling every hour. Outside air was drawn with a chemically inert pump (KNF Neuberger) from the top of the monkey deck.

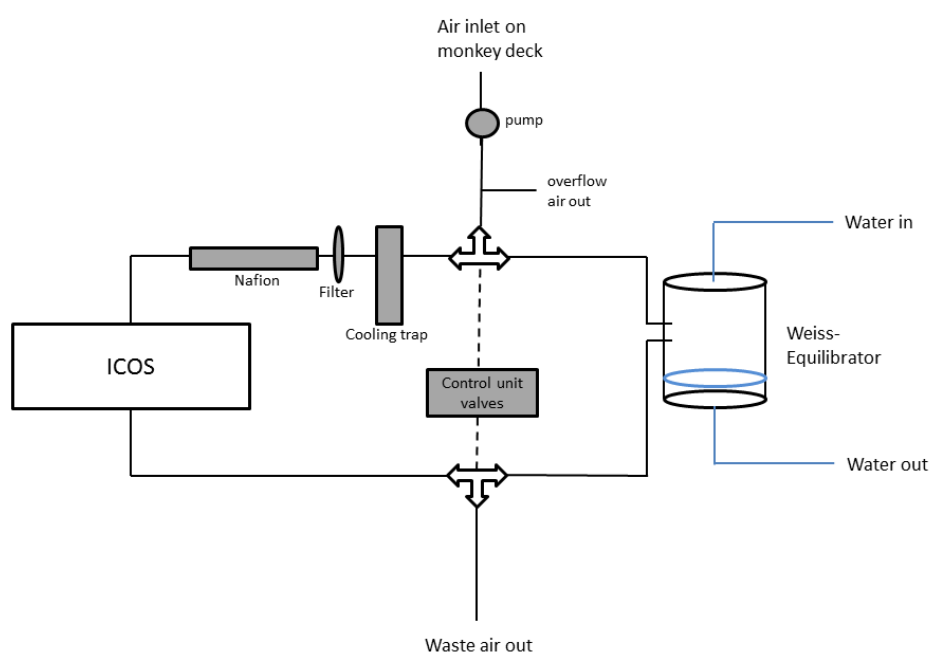


Figure 3 Set-up of the continuous underway measurement system for OCS.

Ancillary measurements

Samples for cell counts and CDOM were also taken from both the underway system and the CTD and preserved for later analysis. 4.5 ml of water were taken for phytoplankton and bacteria cell counts, each, and were preserved with GDA (20 and 200 microliters, respectively) before final storage in the -80C freezer. The samples will be shipped to Kiel for flow cytometry analysis. 50 ml of water was filtered through 0.2 micron filters for CDOM quantification. The samples were stored in the refrigerator until shipboard analysis, between 1 and 48 hours. Measurements were made using a UV-visible spectrophotometer. MilliQ water was used as a reference. The CDOM value was computed by subtracting the absorbance at approximately 700 nm from that at 350 nm. All values are reported in absorbance units and reflect relative amounts.

Results

Bulk air values – Eddy covariance system

Figure 4 shows the bulk air mixing ratios of isoprene, DMS, and acetone measured with the AP-CIMS during the first 24 hour station. DMS and isoprene show slightly elevated values, while acetone levels are low in accordance with typical marine air. A daily cycle in the DMS levels can be seen, which is due to photolysis (sunlight creates OH which destroys DMS).

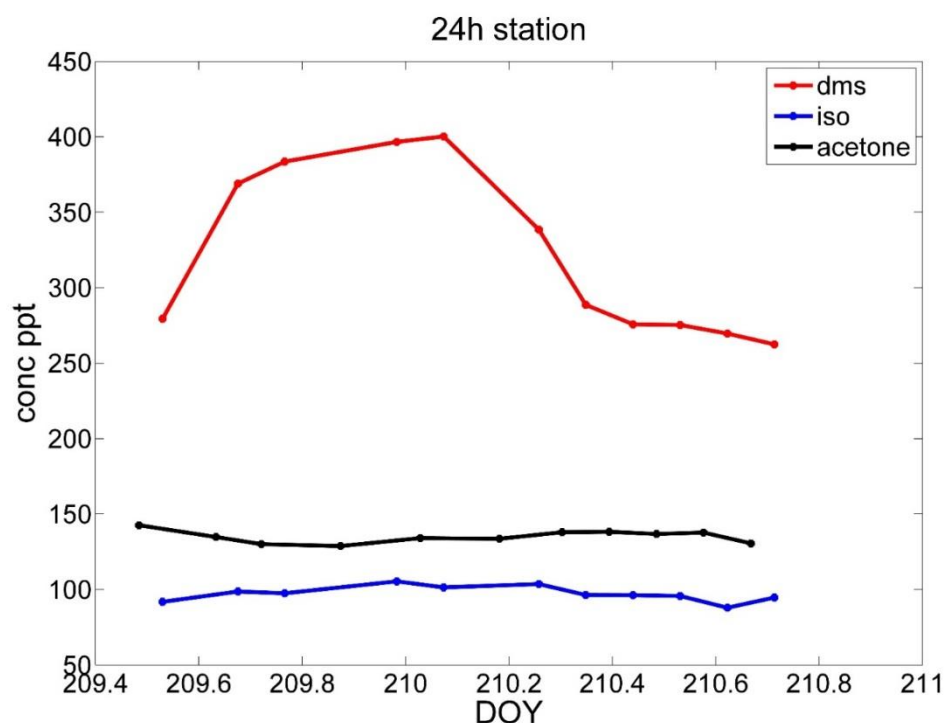


Figure 4 DMS, isoprene, and acetone atmospheric mixing ratios during the first 24 hour station.

Eddy covariance wind measurements

Vertical wind speed power spectra are in good agreement with the empirically determined Kaimal turbulent wind spectrum (Kaimal et al., 1972; Figure 5), which is used as the standard for all turbulence measurements. The peak at around 0.1 Hz in the green line is due to the motion of the ship. This must be removed from the wind data in post processing, using the data from the IMU situated on the mast. The black and the blue lines show the correction using the data from IMU and an additional multi regression analysis, respectively.

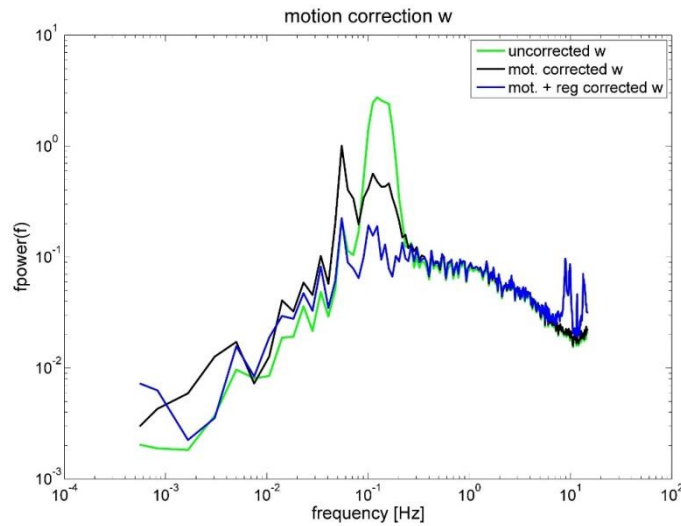


Figure 5 Sample power spectrum of vertical wind speed showing two different types of motion correction.

Eddy covariance trace gas measurements

It is clear that trace gas spectra show the same features as the wind spectrum, in accordance with the Kaimal curve (Figure 6). Therefore, the trace gas measurements can be correlated with the vertical wind speed measurements to obtain the eddy covariance flux. However, this data must be post processed to correct for high and low frequency interferences and the possibility of flow distortion.

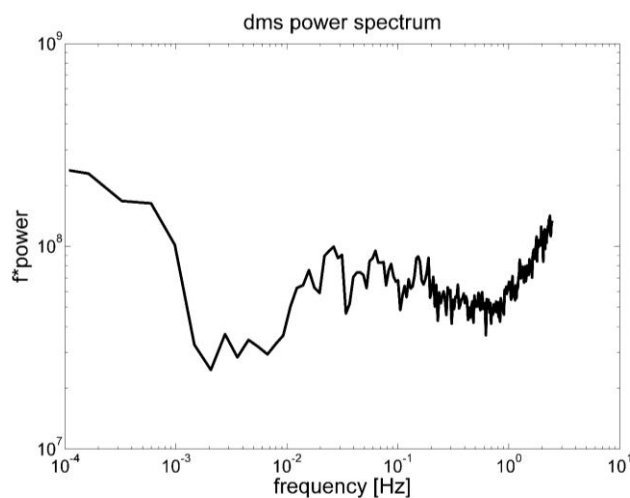


Figure 6 Sample power spectrum of DMS turbulent fluctuations.

GC-MS measurements

We took underway samples every 3 hours from a submersible pump which was located in the ship's moonpool at 6m depth. In total about 100 underway samples were taken during 13 days on the ship. Isoprene concentrations were very low ($<20 \text{ pmol L}^{-1}$) south of 8°S . Between 0°S and 8°S the concentrations increased slightly due to different water masses, but stayed at generally low levels (Figure 7 left).

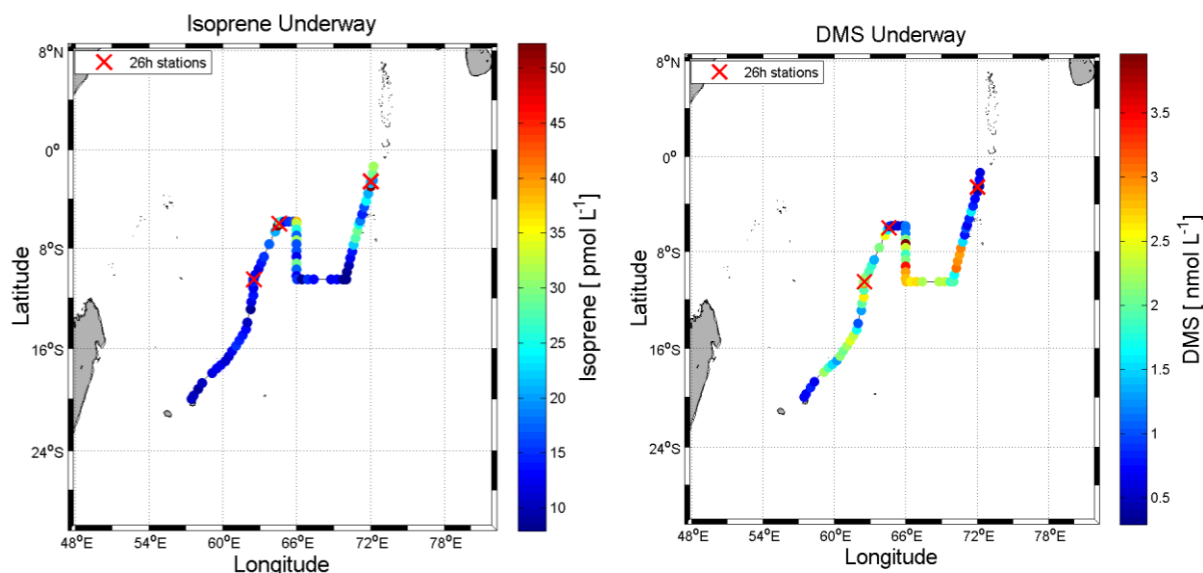


Figure 7 Underway surface water concentrations of isoprene (pmol L^{-1}) and DMS (nmol L^{-1}).

DMS exhibited different trends than isoprene. In a band of about 8°S to 10°S the concentrations were the highest on the cruise, about $2.5\text{--}3.0 \text{ nmol L}^{-1}$ then decreasing sharply when going north to $0.5\text{--}1 \text{ nmol L}^{-1}$ (Figure 7 right). During three 24+ hour stations (red crosses in Figure 7) with 3 hourly underway sampling and 6 hourly CTD-casts, it could be shown, that concentrations of isoprene were highest in the same depth as the $\text{chl}a$ -maximum, while DMS concentrations always peaked slightly above the $\text{chl}a$ -maximum. No diurnal cycle in either isoprene or DMS could be detected.

OCS measurements

With a mixing ratio of 400-500 ppt, carbonyl sulphide (OCS) is the most abundant organic sulphur compound in the atmosphere. OCS is involved in formation of aerosols and cloud condensation nuclei as it can be oxidized to SO_2 . Therefore, it has the ability to alter the radiative budget of the earth and influences the climate.

OCS has anthropogenic sources, such as biomass or fuel burning, but is also emitted naturally by volcanoes or the ocean. Oceanic emissions originate from either direct OCS emissions or emission of the gases DMS and CS_2 that then quickly react to OCS in the atmosphere. Global OCS sinks besides atmospheric OH-radical reactions are mainly uptake by vegetation during photosynthesis and uptake by soils (Watts et al., 2000). Recent studies that used global models to calculate a global OCS budget discovered a missing source of OCS and located it in the tropical ocean (Berry et al. 2013). However, the spatial coverage of OCS

measurements in the surface ocean and marine boundary layer is sparse, especially in the tropical regions.

The OCS measurements on RV SONNE SO235 are the first measurements in this part of the Indian Ocean (IO). So far, OCS measurements in the southeastern IO have only taken place during the 38th Japanese Antarctic Research Expedition Cruise in 1996 (Inomata et al., 2006). Besides temporal and spatial variations of surface concentration and oceanic OCS emissions, we aim to adapt existing OCS 1D models from the Atlantic Oceans to this cruise's data, to compare source and sink processes and rates.

OCS volume mixing ratios (vmr) were measured in both outside air and with seawater equilibrated air during 28 July to 5 August 2014. OCS values in the air were relatively constant throughout the whole cruise in an average range of 350-400 ppt. After offset-calibration, the values are expected to be 30-40 % higher, which would fit to previously reported ranges over the Pacific/Atlantic Ocean.

The equilibrium vmr in the equilibrator is a first approximation to the water concentration, the latter has to be calculated using the Henry constant

$$H = c_a / c_g$$

corrected for the temperature of the seawater. Vmr of OCS in equilibrated air had a regular diurnal cycle with highest concentrations in the afternoon (local time) and lowest during night, very similar to the diurnal cycle of global radiation (shown in Figure 8). In general, surface waters were supersaturated during noon and afternoon and undersaturated during nighttime. Averaged over the day, the surface was undersaturated in OCS during SO235. Figure 9 illustrates the equilibrated seawater OCS values over the cruise track.

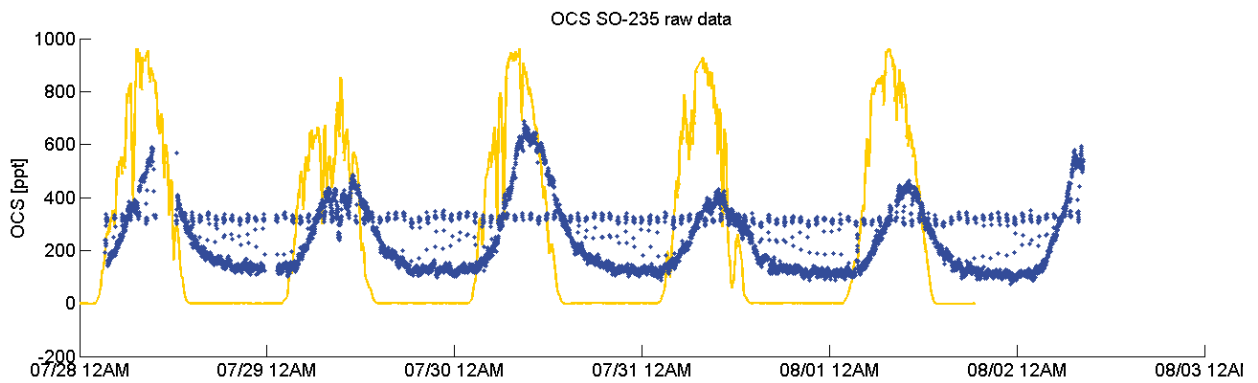


Figure 8 Volume mixing ratio (vmr) of air (straight blue line at ~350 ppt) and vmr of seawater equilibrated air (blue, diurnal cycles). The global radiation in W/m² is indicated in yellow. Note that absolute values might shift after calibration (expected ~40%).

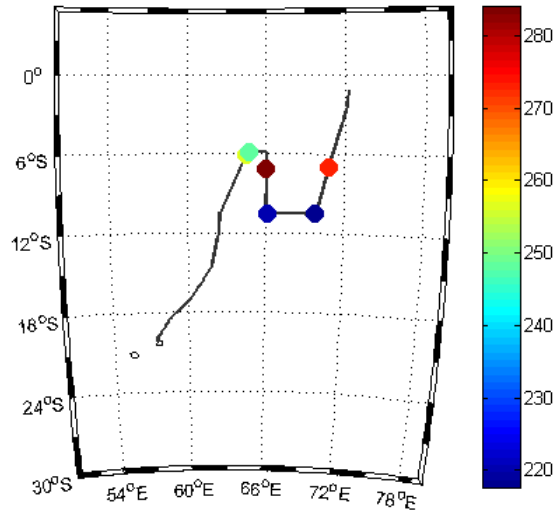


Figure 9 Daily averages of OCS in with seawater equilibrated air (ppt) on the cruise track of SO 235 (black line). Note that absolute values might shift after calibration (expected ~40%).

CDOM measurements

The abundance of CDOM in terms of absorption has been determined for most underway samples from SO235 (Figure 10). The values measured here were much lower than values found on the previous cruise SO234-2 (Krüger et al., 2014). Future data workup will determine if these values correlated with any of the trace gases measured underway. In addition, the CDOM values in all CTD casts were also measured and will be used to investigate trace gas profiles in the ocean.

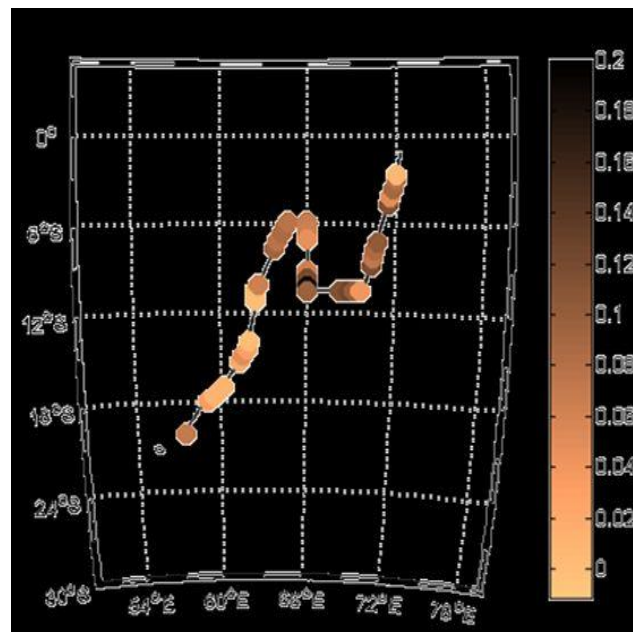


Figure 10 CDOM absorbance values over the SO235 cruise track.

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4) OCEAN SENSORS

4A) Conductivity Temperature Density (CTD)

Matthias Krüger and Rudolf Link (GEOMAR, Kiel, Germany)

During SO235, 22 profiles of pressure (P), temperature (T) and conductivity (C) were recorded. These CTD profiles usually ranged to 750 m, on some stations the profiles ranged to the bottom. We used a Seabird Electronics (SBE) 9plus system, attached to the water sampler rosette, and the latest Seabird Seasave software. The system had the following sensors: p #64860, T #2135, C #1854, Oxygen (O) #1902 and a Dr. Haardt Fluorometer. Conductivity will be calibrated using a linear relation in p , T and c . This relation will be obtained by fitting the according CTD salinity to 41 water samples, which will be analysed with a salinometer later on. Oxygen will be calibrated using a linear relation in p , T and O . Winkler titration of 87 triplets bottle samples gives the accurate value of absolute oxygen in the water.

During the cruise we did 24 hour stations, the potential temperature – salinity diagrams (Figure 1 and 2) show the occurrence of different water masses especially in the upper layers of the oceans. The water at the second 24 hour station is saltier than at the first station, which can be clearly seen in Figures 1 and 2.

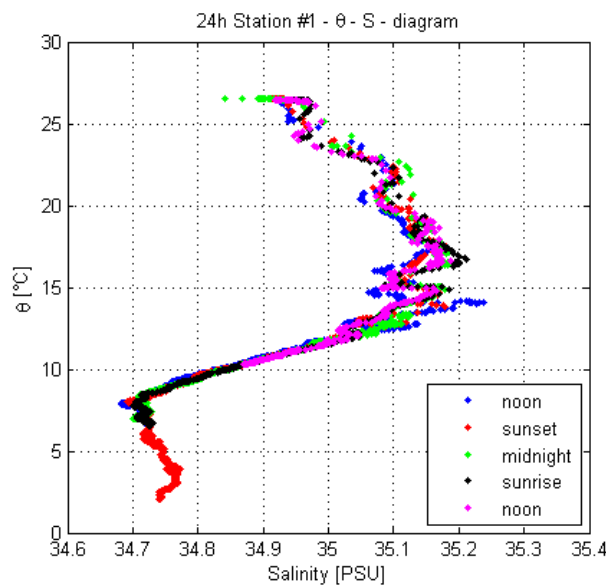


Figure 1 Potential temperature - salinity diagram of the first 24 hour station, different colours show different profiles.

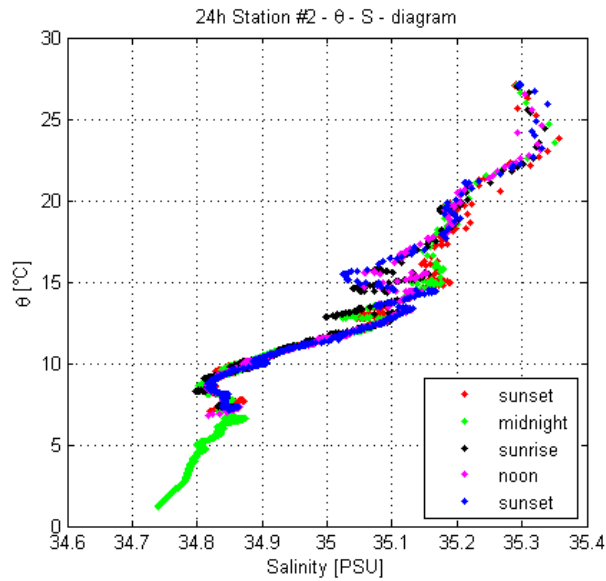


Figure 2 Potential temperature - salinity diagram of the second 24 hour station, different colors show different profiles.

4B) ADCP underway measurements

Matthias Krüger (GEOMAR, Kiel, Germany)

A vessel mounted Acoustic Doppler Current Profiler (ADCP) continuously recorded current velocities. We used a 38kHz RDI Ocean Surveyor (OS38) mounted in the ship's hull. It is possible to run the instrument in two configurations: one in broadband mode (BB) and one configuration in narrowband mode (NB). Usually NB is for the deeper regions of the ocean. The main reason to choose the less robust BB mode was the higher possible resolution in space and time. So the BB mode was used with 40 bins of 24m and a range of 800m. Acoustic interference from other shipboard acoustic devices was avoided by switching these off whenever possible. One exception was the echosounder EM120 which continuously delivered high quality bathymetry without considerable interference.

4C) Surface drifter

Tobias Steinhoff (GEOMAR, Kiel, Germany)

During Sonne cruise SO235 two (Lagrangian) drift experiments (each approximately 24 h) were conducted. In order to follow a water parcel in a quasi-Lagrangian approach a surface drifter was used to mark a water patch and follow it with the ship. The drifter was further equipped with autonomous instrumentation at approx. 15 m water depth for in situ measurements of Salinity and Temperature (Seabird MicroCat), $p\text{CO}_2$ (Contros HydroC), O_2 (Aanderaa Oxygen Optode, Model 4330), Chlorophyll (Trios Micro flu) and Nitrate (Trios Props). The continuously recorded data need to be processed and will be available after the cruise. During the drift experiment the ship approached the drifter every 6 hours in order to conduct a CTD hydrocast (750 m max. depth) next to it. Samples were taken and analysed for various parameters. Most of sampling and measurement procedures are described in the cruise report of other groups.

Preliminary results

Figure 1 shows the track of the drifter for the first drift experiment during SO235. Figure 2 show the data for the drifting period. All data show a clear seasonal cycle even if it's not very pronounced. Using the data of CO_2 and oxygen a rough estimation of primary production yields in $1.2 \text{ g C m}^{-2} \text{ d}^{-1}$ during the 24 h period.

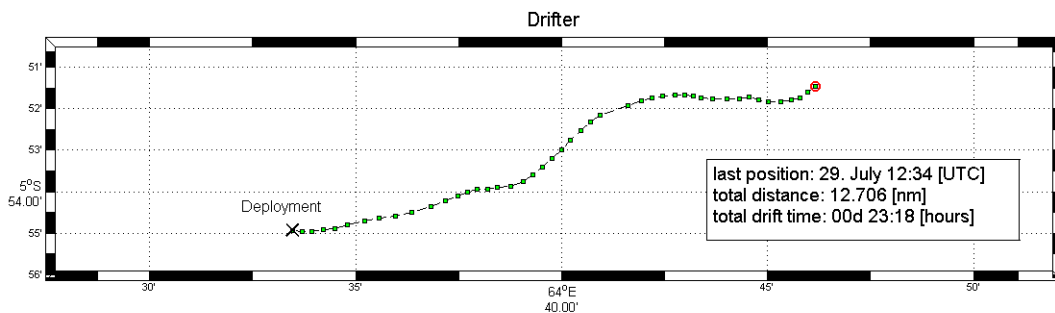


Figure 1 Track of the surface drifter during the first deployment on July 29, 2014.

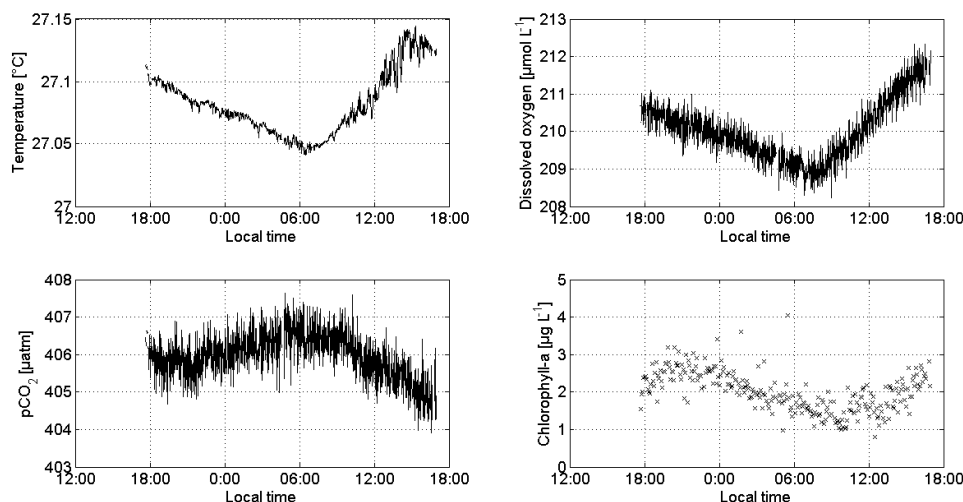


Figure 2 Preliminary data of the first drift experiment for temperature, dissolved oxygen, $p\text{CO}_2$ and chlorophyll-a in approximately 15 m depth.

5) BIOLOGICAL PARAMETERS

5A) Phytoplankton composition and optical properties in the Indian Ocean

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(Collaborators: Isaac Shun-Yan Cheung⁴, Hongbin Liu⁴)

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Objectives

Field measurements of phytoplankton pigment, community structure, and optical characteristics are scarce in the Indian Ocean. The primary objective of this study is to characterise the community structure and physiological conditions of phytoplankton in the Indian Ocean. The information of phytoplankton composition and physiological characteristics will be utilised to investigate the link between phytoplankton and biogenic trace gases in the Indian Ocean.

It is widely believed that phytoplankton and other marine primary producers contribute to the production of biogenic trace gases in both coastal waters and the open ocean. However, the mechanisms in the production and release of these halogens into the atmosphere are largely unknown. Further field studies are required if we are to better estimate the contribution of these halogens in the atmosphere, especially ozone depletion. This study was carried out along a transect from Port Louis, Mauritius to Male, Maldives on-board R.V. Sonne from 23 July to 7 August 2014 as part of the SO235-OASIS campaign.

Work at sea

Water samples

Discrete surface seawaters were collected every 3 hours from ship's moonpool during the cruise transect from Port Louis, Mauritius to Male, Maldives. At CTD stations, water samples from six different depths were collected from the CTD/Rosette Niskin Bottle. Collected water samples were (1) filtered onto GF/F filters for high performance liquid chromatography (HPLC) and particulate absorption (PABS) for later analyses in the laboratory at Alfred-Wegener-Institute for Polar and Marine Research at Bremerhaven, Germany; (2) filtered onto 0.2 µm membrane filter later analyses of DNA and RNA at Hong Kong University of Science and Technology.

In-situ optical and fluorescence measurements

(1) A Fast Repetition Rate Fluorometer (FRRF) (Chelsea Technology Group) was used in a flow-through system to provide continuous surface (~5 m) measurement of phytoplankton

photosynthetic performance (e.g. F_v/F_m) during the entire cruise; (2) A second FRRF was deployed in the water down to ~150 m during CTD stations to obtain the vertical profiles of phytoplankton photosynthetic performance; (3) Total incoming irradiance was measured with another TriOS's RAMSES sensor mounted on the helideck during the entire cruise.

Below is the list of parameters that were measured during the cruise and data that will be obtained after the cruise:

1. Phytoplankton pigment concentration (mg/m^3)
2. Particulate absorption (m^2)
3. Phytoplankton photosynthetic parameters (e.g. F_v/F_m)
4. Downwelling irradiance at the surface, E_0 [$\text{mW}/(\text{m}^2 \text{ nm})$]
5. Photosynthetic active radiation in water, PAR ($\mu\text{mol quanta}/\text{m}^2/\text{s}$)

Preliminary results

Underway FRRF measurements overall show low values of maximum fluorescence and maximum photochemical efficiency of photosystem II (F_v/F_m) along the cruise transect. F_v/F_m represents the potential photochemical efficiency of photosystem II and is interpreted as a diagnostic of the overall health or competency of phytoplankton. F_v/F_m has been shown to response to varying physical and chemical regimes, especially nutrient and light intensity (Kolber et al., 1994). Low F_v/F_m values measured in this study indicate phytoplankton were in poor physiological state, probably due to low nutrient concentrations (Figure 1).

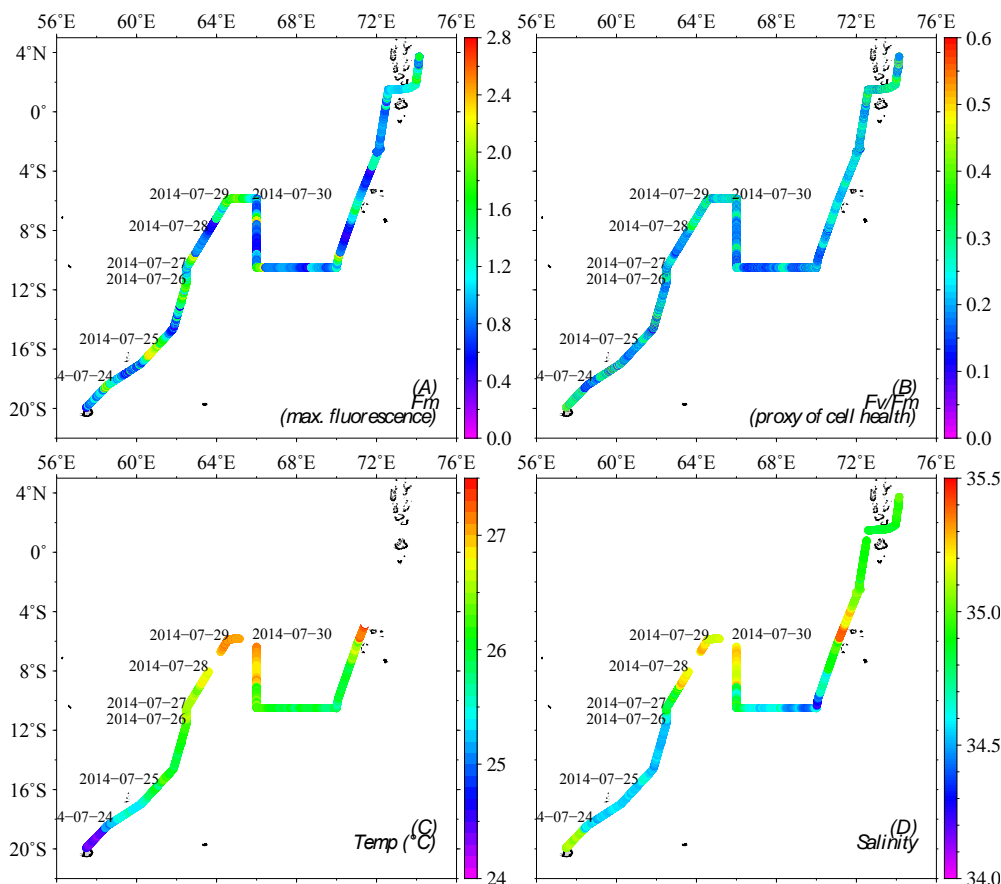


Figure 1 Surface measurements of (A) maximum fluorescence, (B) maximum photochemical efficiency of photosystem II (Fv/Fm), (C) temperature, and (D) salinity measured during SO235-OASIS.

Data management

All data obtained from this cruise will be uploaded to Pangea.

References

Kolber ZS, Barber RT, Coale KH, Fitzwater SE, Greene RM, Johnson KS, Lindley S, Falkowski PG (1994). Iron limitation of phytoplankton photosynthesis in the equatorial Pacific Ocean. *Nature*, 371, 145-149.

5B) Biological cycling of organic matter and atmospheric trace gases in the surface ocean

Sonja Endres and Luisa Galgani (GEOMAR, Kiel, Germany)

Introduction

High sea-air fluxes of bromocarbons and other trace gases in the tropical ocean have been related to biological cycling in the surface ocean, mainly due to phytoplankton and bacteria, but the underlying processes and magnitude of the biogenic sources in the diverse marine environments are poorly known. In order to understand seasonal and spatial fluctuations of oceanic trace gases emissions and to project their future development, we study microbial production and removal processes in the surface ocean and combine them with observational data of trace gases concentrations in the water and atmosphere.

Based on the awareness that marine ecosystems are being increasingly influenced by global changes, we also intend to examine the 'present day' situation of pelagic micro-biogeochemistry in the Indian Ocean, with emphasis on the turnover of organic matter during production and decomposition processes.

Work on sea during SO235

Measurements of underway samples from shipboard surface pump (approx. 6m depth)

55 samplings were conducted along the cruise track, during which seawater was sampled from the shipboard underway pump every six hours:

- a) determination of biogeochemical parameters
 - dissolved organic carbon (DOC)
 - dissolved organic nitrogen (DON)
- b) determination of biological parameters
 - phytoplankton and bacterial cell numbers by flow cytometer
 - genetic analyses of functional genes involved in halocarbon cycling (cooperation with Christian Stolle, IOW), every 12 hours.

Measurements of CTD samples

Seawater was collected by CTD/rosette sampler at 22 stations along the cruise track to determine the impact of microbial processes on organic matter cycling and, more specifically, on trace gases cycling in the surface ocean. Water was sampled from about 7-9 depths.

- a) determination of biogeochemical parameters
 - dissolved organic carbon (DOC)
 - dissolved organic nitrogen (DON)

- transparent exopolymer particles (TEP), only at stations with deep CTD cast (>800m depth)
- Coomassie stainable particles (CSP), only at stations with deep CTD cast (>800m depth)

b) determination of biological parameters

- phytoplankton and bacterial cell numbers by flow cytometer
- composition of key phytoplankton species by microscopic analysis, only at three depths
- genetic analyses of functional genes involved in halocarbon cycling (cooperation with Christian Stolle, IOW) (samples from three depths only)
- photosynthetic production and heterotrophic respiration via dissolved oxygen measurements (using optode technique) during incubation experiments in samples from three depths

Measurements of surface water samples by boat

A boat was used to access one station (2° 40' S, 72° 5' E), where the upper surface ocean was sampled to determine the concentrations of trace gases, organic matter, microbial abundances and phytoplankton composition at the ocean-atmosphere interface (0-5 cm depth), the underlying water (~50 cm depth), and below (2 and 5 m depth). Water samples of the upper two depths were also used for incubation experiments.

Incubation experiments

Water samples from selected depths (usually, surface (~30 m), chlorophyll *a* maximum (50-70 m) and oxygen minimum zone (80-150 m) were taken at all stations and incubated in gas-tight bottles under *in-situ* light and temperature conditions for 22 hours (Figure 1). After successive periods (11 hours) of light and dark phases, oxygen, bromocarbon production and consumption rates were determined. The rates estimated from the incubation experiments will then be compared to measured depth profiles of bromocarbon concentrations. Control experiments comprising of 0.2 µm-filtered seawater, that excludes bacterial activity, were also conducted in parallel, in order to differentiate between biological and chemical processes. Additional water samples from four different sampling stations along the cruise track were incubated to determine uptake rates of added ¹³C-labelled bromoform substrate.

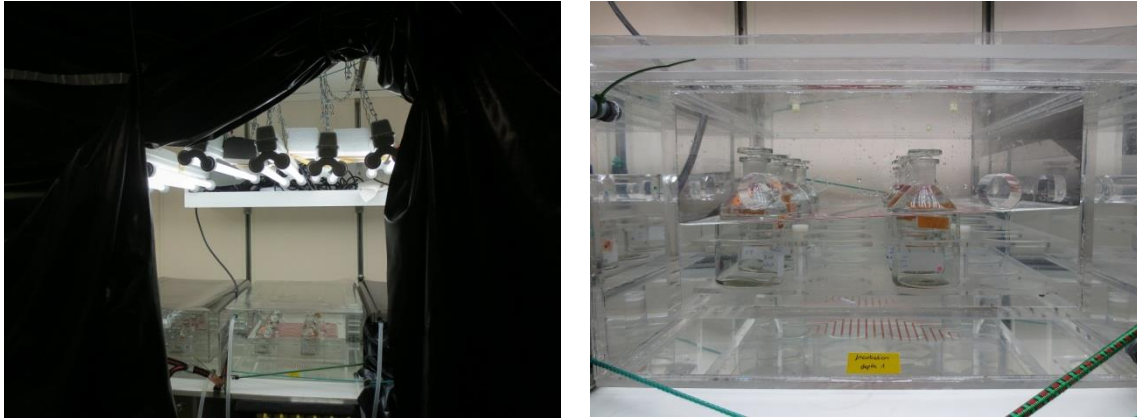


Figure 1 Incubation experiments onboard of SO235.

Sample storage and analyses

All samples were preserved or frozen at -20°C and partly at -80°C and were transported from Colombo for further analyses in the home laboratory at GEOMAR.

5C) Micro nutrients and oxygen measurements

Martina Lohmann (GEOMAR, Kiel, Germany)

Nutrients

Nutrients were measured on-board of SO235 with a QuAAtro auto-analyser from SEAL Analytical (Figure 1). The following methods from SEAL analytics were used:

- Nitrite (Q-068-05 Rev 7) and Nitrate (Q-070-05 Rev 4): The nitrate is determined as nitrite after reduction on a cadmium coil. The nitrite is determined with a colorimetric metric method where sulphanilamide is forming a diazo compound.
- Phosphate (Q-064-05 Rev 4): this is the colorimetric method based on reaction with molybdate and antimony ions.
- Silicate (Q-066-05 Rev 3): this is the colorimetric method where a silico-molybdate complex is reduced to molybdenum blue.

434 samples were measured from 22 CTD casts during the SO235 cruise.

The precision of the nutrient measurements were determined from triplicate samples taken at three varying depths at every station. The precisions of the measurements are determined to be: 0.09 $\mu\text{mol/L}$ for nitrate, 0.003 $\mu\text{mol/L}$ for nitrite, 0.01 $\mu\text{mol/L}$ for phosphate and 0.18 $\mu\text{mol/L}$ for silicate.

In addition to the CTD casts, nutrient concentrations were analysed from 208 underway samples taken every three hours.

Oxygen

Samples for oxygen determination were taken from every CTD for calibration of the oxygen sensor of the CTD. The oxygen was determined with Winkler titration. The precision of the measurements (1σ) of the oxygen concentration determined from the titration is 0.47 $\mu\text{mol/l}$, based on 87 triplicate measurements from CTD samples of varying depths. Additionally, oxygen concentrations were measured for 44 underway samplings. The standard solution for the titration was found to be accurate to better than 0.01% based on comparison to an independent reference material from WAKO inc. (USA).

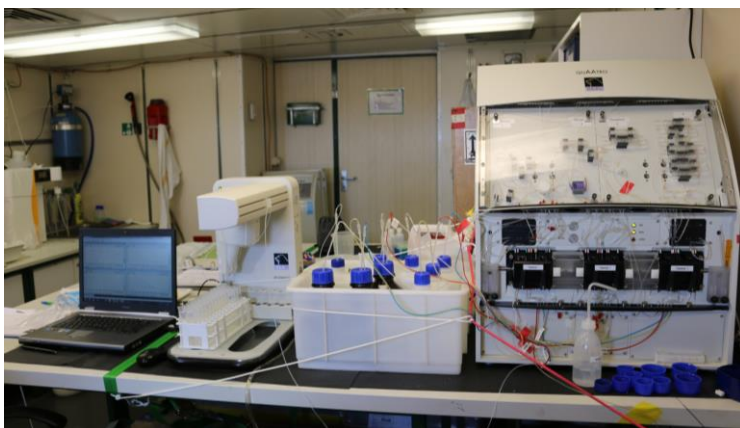


Figure 1 QuAAtro auto-analyser set up on-board of SO235.

5D) Dissolved inorganic nutrients – nanomolar nitrate and phosphate

Matthew Patey (GEOMAR and University of Las Palmas, Spain) and Eric Achterberg (GEOMAR, Kiel)

Method and measurements

Analysis for dissolved nitrate + nitrite (NO_{2+3}^-) (hereinafter nitrate) and dissolved phosphate (PO_4^{3-}), or soluble reactive phosphate (SRP - the phosphorus fraction measured by the Molybdenum Blue technique), at nanomolar concentration were undertaken on a purpose-built, segmented-flow autoanalyser following a method described in Patey et al. (2008) with some changes to reagent flow rates (Figure 1). Two liquid waveguide capillary flow cells (LWCCs) were used to provide a two-metre path-length, enabling the detection of nanomolar concentrations. A single tungsten-halogen lamp (HL2000-HP, Ocean Optics) provided illumination for both LWCCs, with a bifurcated fibre-optic cable being used to divide the light between the two channels. Two Ocean Optics USB spectrometers monitored the absorbance in each cell (USB2000 for phosphate and a USB4000 for nitrate / nitrite).

Samples were introduced manually by switching a sample line between a reference solution (low nutrient surface seawater) and sample or standard solution and the resulting change in absorbance was monitored. Absorbance versus time was continuously recorded for each channel and stored electronically in a plain text format. Calibration curves and results were generated manually from the peak heights using spreadsheet software.

Note: throughout this report (and for all the results generated) molar concentrations are reported in concentrations per unit volume (i.e. nM, μM and mM refer to nmol.l^{-1} , $\mu\text{mol.l}^{-1}$, mmol.l^{-1} , respectively).

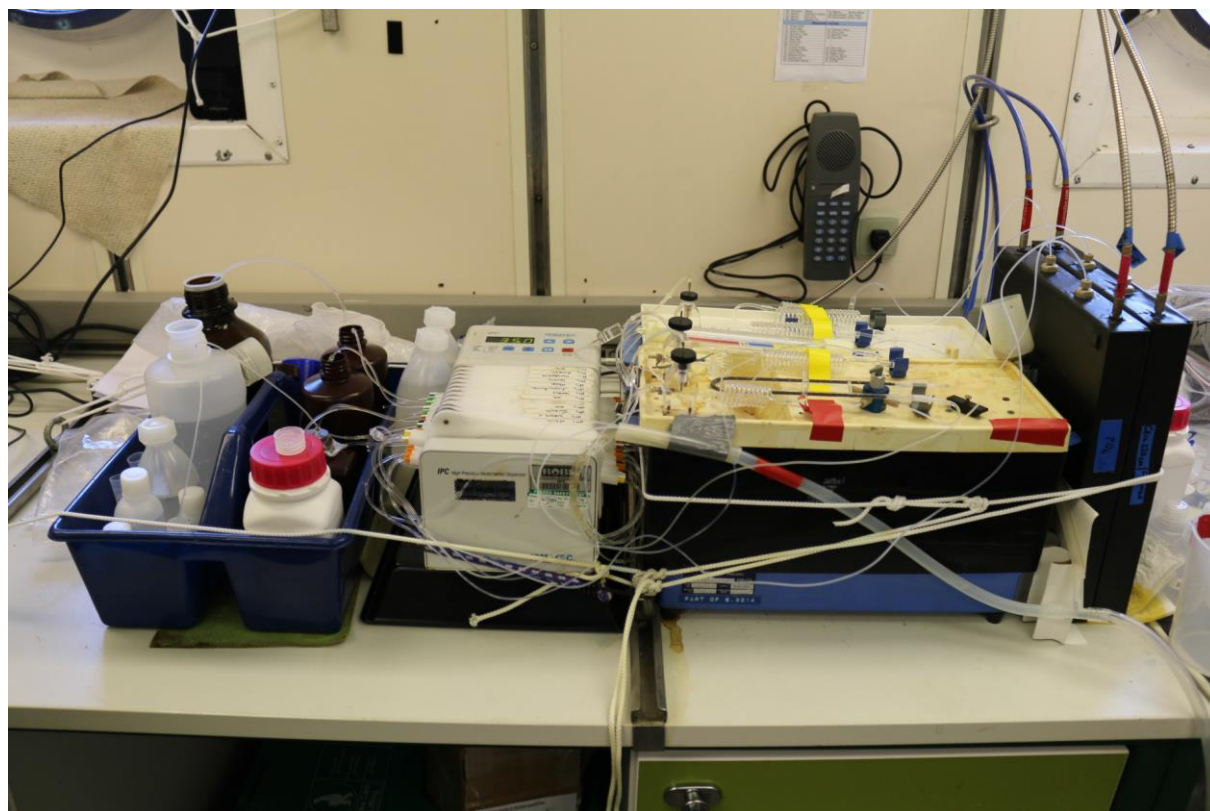


Figure 1 Nanomolar nutrient analysis set-up on-board of SO235.

Sampling approach

All apparatus coming into contact with the samples or reagents was cleaned by soaking in 1M HCl and rinsing thoroughly with ultrapure water from a MilliQ system (hereafter referred to as MQ). Samples were taken from the CTD rosette using 60 ml acid-washed LDPE bottles, rinsing three times before filling, and were stored in the fridge until analysis. Analysis was typically undertaken within 12 hours, although some samples collected during the night were not measured until the following afternoon (typically 18 – 20 hours later).

For each CTD profile, typically 4 to 5 samples were taken from the uppermost depths. Additionally, a sample was taken from the pumped underway system (from approximately 5 metres depth) every three hours.

Wash solution

In order to avoid refractive index changes and other effects resulting from mixing solutions of different salinity, low nutrient seawater was used as a wash solution (to form the baseline from which all sample and standard peaks are measured) and standard matrix. For the wash solution, filtered surface seawater was collected from the CTD during the previous cruise (SO234-2). Knowledge of the nutrient concentration in this seawater is critical for accurate sample determination (particularly for nitrate and nitrite measurements) and its concentration was measured (relative to MQ water) at the beginning of each day's analysis.

Standard matrix and salt-effect correction

Calibration of the instrument was performed by the preparation of standard additions. The same surface seawater is used for the standards as is used for the wash solution in order to match the sample matrix as closely as possible. As part of the calibration, it is necessary to calculate the nutrient concentration in the seawater used to prepare the standards. This is done by making a comparison with purified water (MQ) with the assumption that the purified water is completely free from nutrients. As a result of the different refractive index of seawater and pure water, and also due to solution turbidity it is necessary to apply a salt-effect offset to the calibration of a seawater solution relative to pure water. This offset is measured in accordance with a method described by Zhang and Chi (2002), whereby one of the colour-producing reagents is replaced with a blank, so that the refractive index effects can be measured in the absence of any generation of the coloured reaction products. In place of the ascorbic acid reagent for phosphate analysis, a blank solution containing SDS, acetone and MQ water was used, while purified (MQ) water was used in place of the NED reagent for nitrate analysis.

Calibration

Due to a problem with the packed nutrient standards, the same stock standards as used for micromolar nutrient analysis were used. Intermediate stock standards of 50 μ M were prepared by diluting the 10 mM stock solutions for each of the three nutrients in MQ water. These three solutions were kept refrigerated and used for the duration of the cruise.

Working standard solutions were prepared freshly every day. Mixed nitrate and phosphate standards were prepared using phosphate stripped seawater as the standard matrix. For phosphate, 5 working standards were prepared in the range 25 – 200 nM, giving a 6-point

calibration with the inclusion of the zero standard. For nitrate, 4 working standards were prepared in the range 50 – 300 nM, with the 5th standard being used for a 100 nM nitrite standard to check the performance of the Cd reduction column. Calibration was performed each day prior to measuring any samples. All standards were re-measured as samples at the end of the day in order to verify the precision of the technique and to check for baseline drift.

Preliminary results

The nutrient content of the tropical Indian Ocean surface water was generally below 0.1 μmol for nitrate and generally below 0.2 μmol for phosphate. Some regions with higher nitrate ($>1 \mu\text{mol}$) accompanied by a smaller increase in phosphate ($>0.2 \mu\text{mol}$) were observed between 10° and 5° S, likely due to the wind driven entrainment of upper thermocline water, which will be analysed in detail after the cruise.

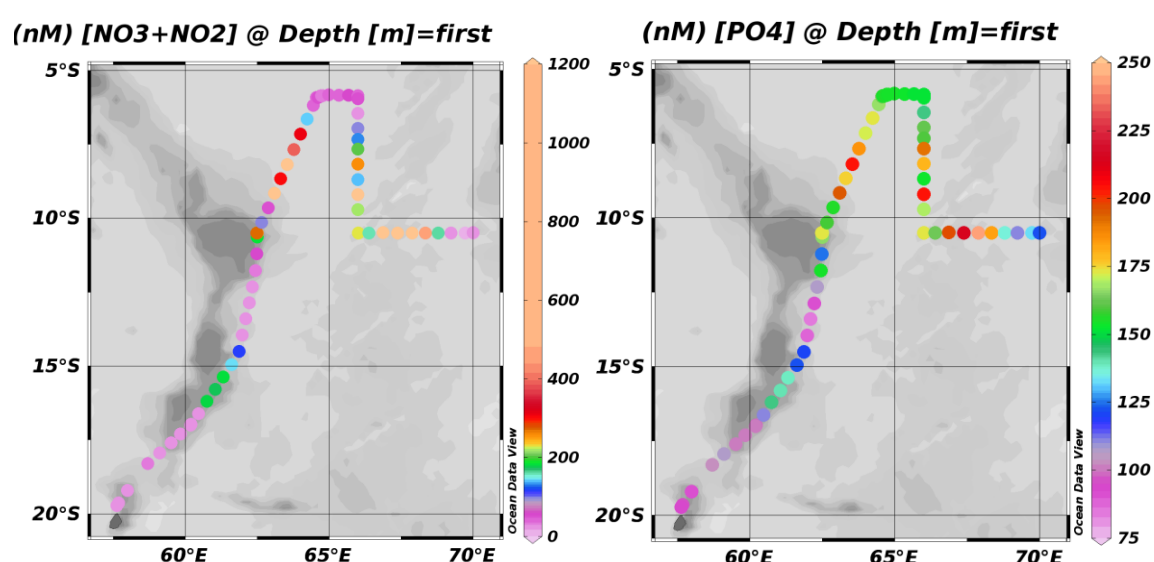


Figure 2 Surface water nitrate and phosphate measurements along the SO235 cruise track, preliminary data.

References

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- Patey, M. D., et al. (2008). Determination of nitrate and phosphate in seawater at nanomolar concentrations. *TrAC Trends in Analytical Chemistry* 27(2): 169-182.
- Zhang, J. Z. and Chi, J. (2002). Automated analysis of nanomolar concentrations of phosphate in natural waters with liquid waveguide. *Environmental Science & Technology* 36(5): 1048-1053.

6) RADIOSOUNDING - meteorology measurements

Susann Tegtmeier, Steffen Fuhlbrügge, Alina Fiehn (GEOMAR, Kiel, Germany) and Kirstin Krüger (PI, University of Oslo, Oslo, Norway)

Introduction

In order to determine the air-sea gas exchange it is important to know about the meteorological condition of the atmosphere. During the cruise the atmospheric structure was determined by frequent radio and ozone soundings on weather balloon launches. After the launches, the radiosonde measurements were directly send to the Global Telecommunication System (GTS) of the World Meteorological Organization (WMO) to improve global meteorological assimilations over the tropical Indian Ocean, which will be used as input data for high resolution transport modelling. Additionally, a disdrometer collected information on precipitation occurrence and intensity and two radiometer measured atmospheric longwave (LW) and solar shortwave (SW) radiation. Furthermore, ship measurements of wind speed, wind direction, temperature, humidity and air pressure were recorded.

Results

66 radiosondes were launched in total during the cruise, switching between 6- and 3-hour intervals. Relative humidity and zonal wind speed measured by the radiosondes are shown in Figure 1.

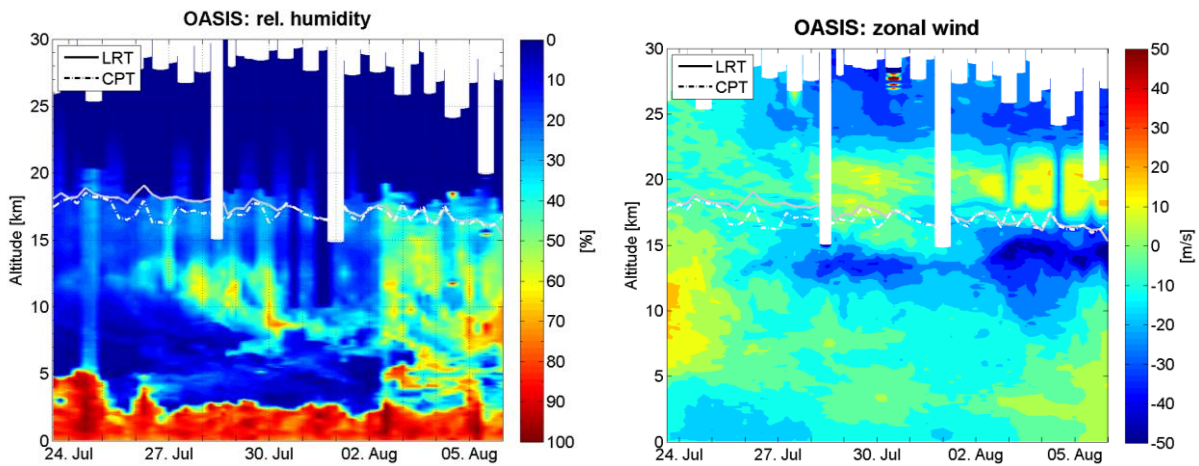


Figure 1 Relative humidity (left) and zonal wind speed (right) as a function of launch date and altitude derived from the radiosonde launches. In addition, the lapse rate tropopause (LRT, solid line) and the cold point tropopause (CPT, dashed line) are shown.

A sharp gradient in the relative humidity profiles is found between 2-5 km height. Here, the relative humidity decreases from > 80% to 15 - 30%. However, this gradient does not mark the upper limit of the atmospheric boundary layer per se. The moist layers up to 5 km are air masses that have been advected and do not interact with the surface by turbulent mixing processes. The mean atmospheric boundary layer height determined from the radiosonde

profiles of temperature, humidity and wind is ~ 0.8 km during the cruise, nevertheless on July 24th we identified a preliminary boundary layer height of about 5 km coinciding with high relative humidity. During the cruise with increasing latitude the relative humidity in the mid to upper troposphere increased, too.

The tropical cold-point tropopause has been identified at around 17 km (temperature profiles not shown here). Maximum zonal wind speeds are found a few km below the tropopause, and show a strong gradient with respect to the latitude of launch. Close to Mauritius we find northward zonal winds of ~ 20 -30 m/s at the edge of the subtropical jet stream. Northward of this threshold, we find weaker southward zonal wind speeds with a maximum of 50 m/s which might be caused by the anti-trades.

Four ozonesonde launches have been performed. Ozone mixing ratio profiles are shown Figure 2. Due to transmission and GPS problems only one ozonesonde retrieved data in the stratosphere. However, all sondes were able to observe the full tropospheric profiles. With

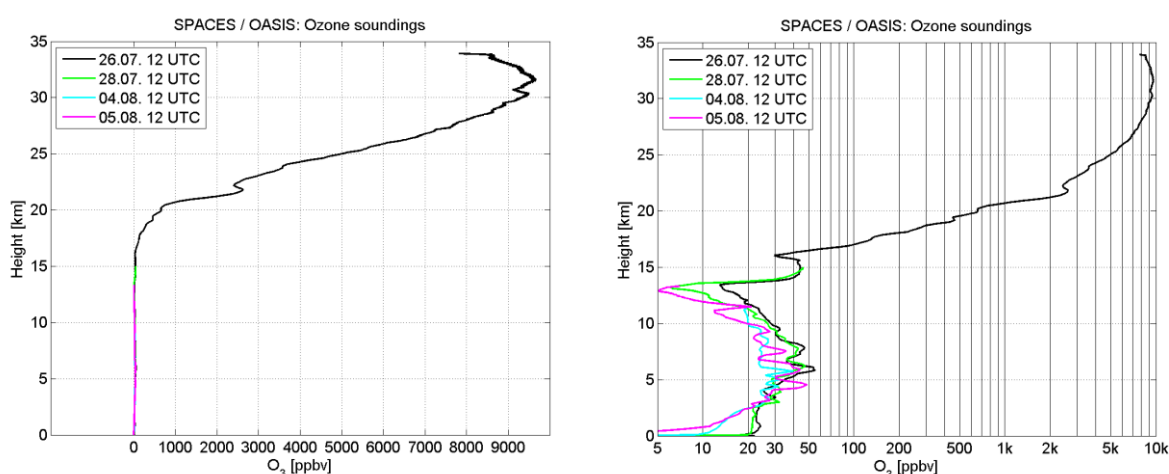


Figure 2 Preliminary ozone profiles from ozonesonde launches on 26.07.2014, 28.07.2014, 04.08.2014 and 05.08.2014. Ozone values shown in (left) linear and (right) log scales to highlight stratospheric and tropospheric values, respectively.

increasing latitude, a level of very low ozone established at around 13 km height with mixing ratios below detection limit for the launches on July, 28 and August, 5, 2014. Low ozone values imply low OH concentrations which will impact the lifetimes of the very-short lived halocarbons.

Surface meteorological fields measured by the ship's instruments are being collected and archived. Surface pressure, temperature, wind speed and wind direction averaged over 10 min for a portion of the cruise are shown in Figure 3. Strongest surface winds were observed during the beginning of the cruise with maximum wind speed of up to 20 m/sec.

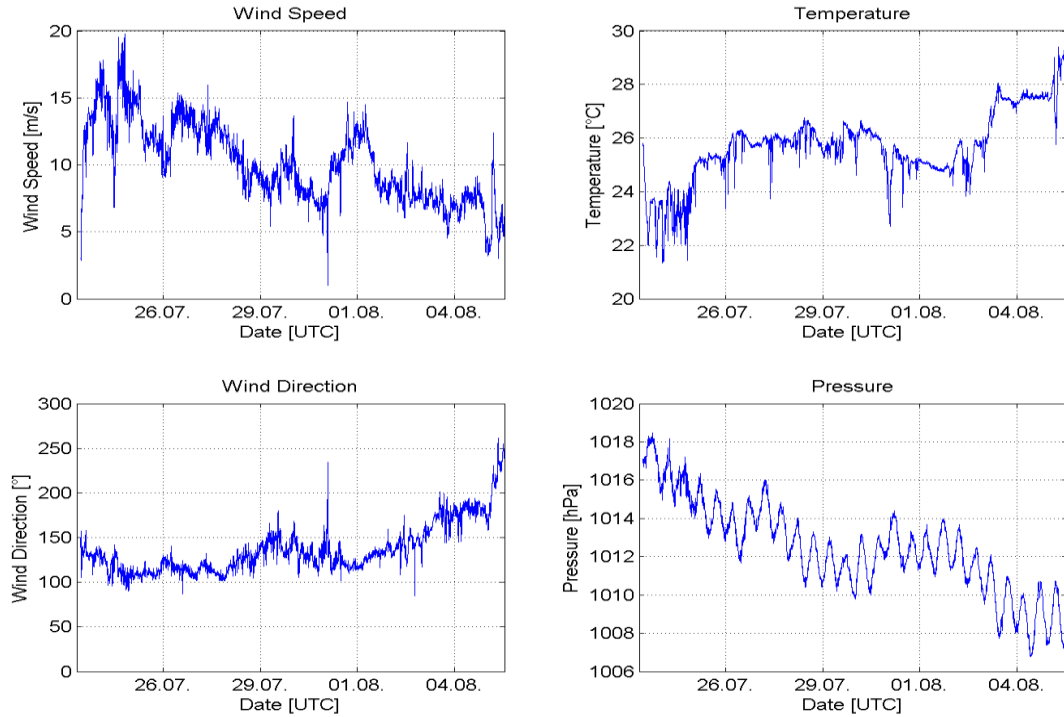


Figure 3 Surface meteorological fields as measured and archived by the Sonne systems.

The pyrgeometer and pyranometer were measuring atmospheric longwave (LW) and solar shortwave (SW) radiation, respectively, and the disdrometer was measuring precipitation continuously over the whole cruise. Figure 4 shows preliminary data.

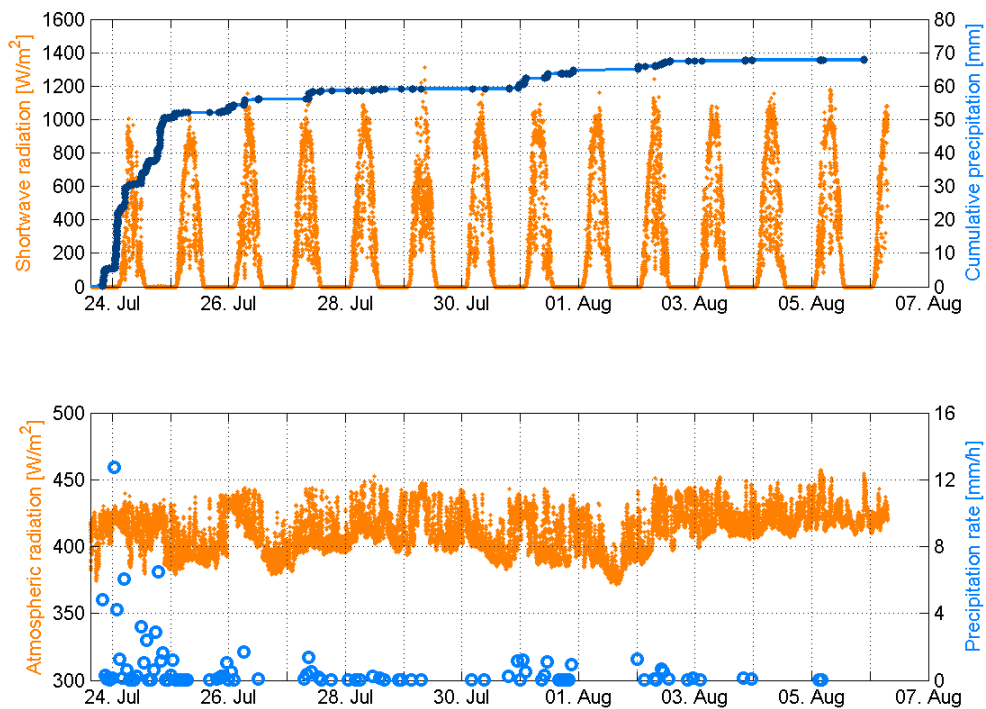


Figure 4 Radiative and precipitation quantities measured by the radiometers and disdrometer.

7) AIR-SAMPLING - for atmospheric trace gases

Elliot Atlas (RSMAS, Miami, USA), and Birgit Quack (GEOMAR, Kiel, Germany)

Introduction

Long lived anthropogenic gases producing halogen radicals can account for about 3400 ppt of chlorine and about 15-16 ppt of bromine in the stratosphere, leading to man-made ozone depletion. Other halogen compounds with shorter lifetimes, the so-called very short-lived substances (VSLS, chemical lifetimes shorter than 6 months) like bromoform (CHBr_3) or dibromomethane (CH_2Br_2) as well as iodinated methanes, originating from the ocean, have an additional impact on the stratospheric halogen loading and on the ozone budget. Deep tropical convection provides a fast pathway for these substances to be transported in significant amounts into the stratosphere. The quantification VSLS contribution of the Indian Ocean to the stratospheric halogen budget during southwest monsoon is the major objective of this cruise. It will give information about natural background halogen loading of the stratosphere and improve the projections of future stratospheric ozone concentrations.

Method and measurements

96 canister samples of air were collected in 2 L stainless steel tanks, being pressurized to 2 bar for RSMAS with a metal bellows pump and will be analysed for a variety of trace gases as natural and anthropogenic hydrocarbons and halocarbons, DMS, N_2O , alkyl nitrates, CO and other long-lived anthropogenic and natural trace gases on different instruments at the Rosenstiel School of Marine and Atmospheric Sciences in Miami.

Outlook

After the analyses of the atmospheric trace gases, in particular of the VSLS, the oceanic emissions can be calculated together with the Working Group 1 (Birgit Quack et al.). These observation based emissions will then be used as input data for the high resolution transport modelling of Working Group 6 (Kirstin Krüger et al.). With the help of the anthropogenic and terrestrial trace gases distributions terrestrial, anthropogenic and open ocean sources and possibly source strengths can be determined using backward trajectory calculations.

8) REACTIVE HALOGENS

8A) MAX-DOAS

Folkard Wittrock (IUP, University of Bremen, Germany)

During the SO235 cruise in the Indic from July 23 to August 07, 2014, measurements of different reactive trace gases were carried out using the Multi-Axis Differential Optical Absorption Spectroscopy (MAX-DOAS) technique (Figure 1). The Bremen MAX-DOAS setup was running continuously for the whole cruise without having any serious problems (starting early in the morning on July 23 in the port of Port Louis). Since the MAX-DOAS technique is based on solar stray light, measurements were only possible during daytime short before sunrise until sunset (96° SZA). In addition some complementary parameters were obtained: surface ozone with an in situ ozone monitor (Horiba), meteorological parameters (wind speed and direction, total solar radiation, UV radiation, precipitation, humidity, pressure and temperature).

The MAX-DOAS setup used on the ship was covering a wavelength range of approximately 300 to 470 nm with a medium resolution (FWHM 0.8 nm). This enables us to retrieve the following trace gases: IO, BrO, CHOCHO, HCHO, H₂O, O₃, NO₂, and SO₂. From O₄ measurements the aerosol extinction profile and the AOD can be derived. The telescope was installed on the starboard side of the ship and was collecting spectra toward three different azimuth angles possibly identifying horizontal gradients of trace gases. In addition the water-leaving radiance was measured once per measurement cycle.

A detailed analysis of the whole data set taking into account detailed radiative transfer calculations will be done at the IUP Bremen as soon as possible.



Figure 1 MAX-DOAS telescope on RV Sonne heading to starboard. During SO235 the telescope was scanning different azimuth angles to identify spatial inhomogeneities in trace gas distributions.

8B) Iodine Monoxide: Open Path CEDOAS

Henning Finkenzeller (IUP, University Heidelberg, Heidelberg, Germany)

The DOAS (Differential Optical Absorption Spectroscopy) method is well established to determine column densities of airborne halogens along a given light path. While passive DOAS methods use naturally present light sources (most often sun light), CEDOAS (Cavity Enhanced DOAS) uses a built in lamp. The effective path length of about 5 km is established in an optical resonator. The usable wave length range with the optics used was about 420 nm to 460 nm. This design allows detection limits for iodine of about 0.5 ppt.



Iodine monoxide is highly reactive and therefore cannot be sucked into a closed path cavity. Thus, an open path cavity was used. Due to the open design the instrument is fairly sensible to aerosols that settle on the highly reflective mirrors and make measurement impossible. The instrument was set up on the upwind side of the pilot deck to get as unbiased air as possible. During the first days

with very heavy swells and winds a continuous operation was not possible; the quality of the acquired data may vary here. However, care was taken to perform quasi continuous measurements starting July 23rd 2014.

In total about 100 GB of data and more than 1 million spectra were recorded. As the iodine monoxide concentrations are of the same magnitude as the detection limit a detailed and careful data evaluation has to be done in Heidelberg, Germany.

8C) Molecular Iodine: Denuder tubes

Henning Finkenzeller (IUP, University Heidelberg, Heidelberg, Germany)

Denuder tubes were used for determination of airborne molecular iodine (I_2) mixing ratios. A known amount of air is sucked through the denuder tubes. These are coated with a special powder to which molecular iodine is absorbed. By the ratio of adsorbed iodine and air mass the mixing ratio of airborne iodine is calculated. Mass spectrometric analysis of the powder will take place in Mainz, Germany, as soon as possible. Hence, no preliminary data are available yet.

Sampling started July, 25th 2014 and was conducted every morning on the pilot deck before sunrise, in order to access the spatial distribution. Additionally, two nocturnal cycles were carried out to capture the chemical dynamics during night. In total 45 denuder tubes were sampled.



9) GHG (see working group reports 2 and 3)

10) AEROSOL

10A) Alex Baker (UEA, Norwich, UK)

Aerosols play a key role in halogen cycling in the marine atmosphere, with Cl being transferred to the gas phase by acid displacement reactions, Br release being induced by reaction of ozone on sea salt particles and iodine chemistry promoting transfer of Cl, Br and I to the gas phase via halogen activation reactions. Ultimately aerosols appear to be net sources for Cl and supermicron Br and net sinks for I and submicron Br.

During the SO235 cruise two day aerosol samples were collected for determination of Cl⁻, Br⁻ and iodine speciation, as well as a number of other aerosol ionic components which will provide us with useful information on aerosol background chemistry. Five two stage forty-eight hour aerosol samples of about 600 L of air and 1 six stage seventy two hour aerosol sample were collected with a multistage aerosol impactor.

The data obtained will allow us to examine the potential strength of the aerosol Br source along the transect and investigate the role of iodine chemistry in halogen activation, as well as providing a unique opportunity to compare atmospheric iodine source (trace gas) and sink (aerosol) strengths in the Indian Ocean for the first time.

10B) Susann Tegtmeier (GEOMAR, Kiel, Germany)

The microtops sunphotometer (Figure 1) was used to measure aerosol optical thickness (AOT) for cloud-free conditions. Based on satellite AOT retrievals, we expect weak aerosol levels during the first part of the cruise, with values below 0.2 and often below 0.1. Larger AOT values are expected in the later portion of the cruise as the ship gets in closer proximity to India.



Figure 1 Microtops sun photometer.

Acknowledgements

I would like to thank the scientific team on board for their extra-ordinary hard work to set-up and operate the instruments during the 16 days of SO235. Thanks to all of your hard work during day and night, that you looked after several measurement and sampling devices, carried out the measurements as long as possible close to Malé and of course the super-efficient container packing. Thanks also that you wrote and delivered the working group reports in time, volunteered with writing the ocean blogs, managed to show first preliminary results on-board of SO235 next to many other duties. Despite these tough times, all of you together created a pleasant, enthusiastic and professional working environment. Next to an inspiring and fruitful exchange we were also able to gain a great and unique data set of the tropical West Indian Ocean. The analysis and evaluation of the data are still ongoing for the next months and I am very much looking forward to see and exchange the scientific results with all of you.

During our SO235 cruise we managed to operate our instruments 24/7, supported also by the expertise of the professional ship's crew, who was there, when we faced technical problems. The ships' crew was always helpful and we had the best cooking team on board. Special thanks go to the WTD and the electrician, who rapidly repaired our breakdowns with insight and care. Thanks also to the decks crew for all helping hands and friendly support of our activities and the machinery for the smooth maintenance of all technical details of this fine ship. SO235 succeeded not last due to the good cooperation between the captain, the crew and the scientists, so we were able to carry out all of our work together during SO235 to the best results. I would like to especially thank the captain of RV Sonne for his careful and considerate navigation through the sometimes rough tropical West Indian Ocean.

Finally, I would like to thank my colleagues Birgit Quack and Christa Marandino for their collaboration and support with the OASIS SONNE project and ship cruise. I am in particular grateful for Birgit Quack's readiness to be co-chief scientist of SO235, for her valuable input and advice before during and after the cruise, and for her help to compile this cruise report next to many more things. Our successful and exciting collaboration has always been challenging and a great pleasure for me. I am looking forward for further inspiring collaborations with you in the future.

All together you were a wonderful, hard-working and successful team; thanks for sharing this experience with me!

At the final end, I would like to thank the BMBF for funding the OASIS SONNE project (BMBF grant 03G0235A) and the OASIS SONNE SO235 cruise, Dr. Barbara Tanner and the PTJ for taking care of the project and the ship cruise administration and the Geoscience Department at University of Oslo and GEOMAR Kiel for supporting our SO235 activities.

Yours Kirstin Krüger (SO235 Chief Scientist, UiO)

Appendix A: Sample lists for underway samples

OASIS-SONNE (ISO235) Samples from Underway system (approx. 5m)																																								
Campaign	Event label	Label	Time UTC	Time Local	Time UTC	System	System	System	System	System	System	System	System	Thermo	Thermo	Thermo	Thermo	Thermo	Thermo	Thermo	Thermo	Thermo	Thermo	Thermo	Thermo	Thermo	Thermo	Thermo												
		Speed				Course	Depth	Heading	Position lat (deg/s)	Position lon (deg/s)	Speed	True wind direction	True wind speed	Conductivity	Safety	Temperature	Weather station pressure	Weather station Air	Weather station Humidity	Weather station (Feet)	Weather station Wind direction	Weather station Wind gale	Weather station Wind	O2	N2O	CH4	DMS +	H2S	CO2	COOH	Li2O2 Br	TDN	Chlorophyll	Microscopic	PARS	DNA	Proteomes	SR		
ISO235	ISO235-LW-170-2021-18	202118	02:08:2014.05:00:00	10:00	05:00	13.80	203.72	21.3	-8.35540	70.6730	12.23	133.90	8.48	53.611	34.442	25.985	1013.8	26.70	73.00	72.70	10.60	9.25																		
ISO235	ISO235-LW-172-2021-18	202118	02:08:2014.08:00:00	13:00	08:00	10.42	203.64	24.2	-7.70940	70.6880	10.14	109.54	8.82	53.801	34.495	26.868	1013.8	26.70	83.00	83.00	10.70	10.70																		
ISO235	ISO235-LW-174-2021-18	202118	02:08:2014.11:00:00	16:00	11:00	30.438	193.84	4.4	-7.16790	70.7040	10.92	98.63	9.03	54.443	34.887	35.848	1013.2	26.30	83.00	83.00	15.40	10.70																		
ISO235	ISO235-LW-176-2021-18	202118	02:08:2014.14:00:00	19:00	14:00	22.08	193.77	17.2	-6.66930	70.6930	11.68	150.82	7.49	54.720	34.842	35.848	1011.1	24.80	83.00	83.00	15.40	10.70																		
ISO235	ISO235-LW-178-2021-18	202118	02:08:2014.18:00:00	22:00	17:00	16.04	207.74	131.2	-6.06930	71.0630	0.46	146.01	7.47	54.560	34.973	35.848	1012.5	26.80	83.00	83.00	9.60	8.10																		
ISO235	ISO235-LW-179-2021-18	202118	02:08:2014.20:00:00	01:00	20:00	15.98	205.15	17.6	-5.89940	71.14210	11.48	148.17	7.45	54.598	35.174	35.848	1011.3	25.70	83.00	83.00	7.50	7.50																		
ISO235	ISO235-LW-180-2021-18	202118	02:08:2014.23:00:00	04:00	23:00	19.49	204.54	17.9	-5.24650	71.31290	11.84	138.44	8.42	54.890	35.387	35.848	1010.7	25.90	83.00	83.00	9.90	7.70																		
ISO235	ISO235-LW-181-2021-18	202118	02:08:2014.05:00:00	10:00	05:00	22.89	206.23	16.5	-4.16100	71.61810	12.85	148.79	8.01	56.484	35.204	35.848	1011.9	26.70	83.00	83.00	6.80	6.80																		
ISO235	ISO235-LW-182-2021-18	202118	02:08:2014.08:00:00	13:00	08:00	15.46	202.66	14.9	-3.57520	71.61830	12.46	161.79	6.83	57.254	35.103	35.848	1008.8	27.40	77.00	77.00	8.20	8.20																		
ISO235	ISO235-LW-183-2021-18	202118	02:08:2014.11:00:00	16:00	11:00	15.15	203.75	14.9	-2.98150	71.60200	12.46	172.56	6.97	57.467	35.033	35.848	1009.0	27.50	77.00	77.00	5.80	2.70																		
ISO235	ISO235-LW-184-2021-18	202118	02:08:2014.14:00:00	19:00	14:00	11.340	206.83	17.85	-2.86070	72.07290	0.88	184.76	8.06	57.651	35.068	35.848	1009.0	27.50	77.00	77.00	5.30	3.80																		
ISO235	ISO235-LW-185-2021-18	202118	02:08:2014.17:00:00	22:00	17:00	78.23	206.80	192.9	-2.69540	72.07290	0.77	193.51	5.99	57.633	35.078	35.848	1011.1	27.50	77.00	77.00	29.70	7.10																		
ISO235	ISO235-LW-186-2021-18	202118	02:08:2014.20:00:00	01:00	20:00	268.65	207.12	195.6	-2.66950	72.04570	0.91	157.68	6.07	57.611	35.078	35.848	1010.5	27.40	80.00	80.00	30.40	7.80																		
ISO235	ISO235-LW-187-2021-18	202118	02:08:2014.23:00:00	04:00	23:00	222.78	207.14	151.7	-2.66660	72.03520	1.11	172.64	6.66	57.698	35.078	35.848	1008.5	27.20	77.00	77.00	8.20	6.40																		
ISO235	ISO235-LW-188-2021-18	202118	02:08:2014.05:00:00	07:00	02:00	200.35	209.55	192.4	-2.67990	72.03910	0.99	174.44	7.92	57.692	35.074	35.848	1009.5	27.40	77.00	77.00	7.80	7.10																		
ISO235	ISO235-LW-189-2021-18	202118	02:08:2014.08:00:00	10:00	08:00	133.93	212.14	154.7	-2.67190	72.06030	1.33	211.67	9.20	57.722	35.064	35.848	1009.4	27.50	77.00	77.00	29.60	8.10																		
ISO235	ISO235-LW-190-2021-18	202118	02:08:2014.11:00:00	14:00	11:00	21.20	212.52	177.0	-2.68210	72.06460	0.36	187.62	7.42	57.734	35.062	35.848	1008.6	27.40	77.00	77.00	9.80	7.40																		
ISO235	ISO235-LW-191-2021-18	202118	02:08:2014.14:00:00	17:00	14:00	296.11	210.93	194.5	-2.71590	72.01460	0.53	189.11	7.17	57.695	35.062	35.848	1009.0	27.40	77.00	77.00	35.70	8.70																		
ISO235	ISO235-LW-192-2021-18	202118	02:08:2014.17:00:00	20:00	17:00	70.80	207.23	75.8	-2.53470	72.01820	10.93	187.17	6.89	57.597	35.062	35.848	1009.0	27.40	77.00	77.00	11.90	10.80																		
ISO235	ISO235-LW-193-2021-18	202118	02:08:2014.20:00:00	23:00	20:00	5.27	203.20	78.6	-1.97160	72.17020	11.15	178.13	6.80	57.704	34.989	34.989	1009.0	27.50	77.00	77.00	10.50	8.80																		
ISO235	ISO235-LW-194-2022-01	202201	02:08:2014.23:00:00	01:00	23:00	9.43	203.74	12.7	-1.38690	72.24100	11.40	168.27	3.63	57.655	34.989	34.989	1007.6	27.50	77.00	77.00	31.00	3.40																		
ISO235	ISO235-LW-195-2022-01	202201	02:08:2014.05:00:00	07:00	02:00	9.43	203.74	15.9	-1.38690	72.24100	11.40	168.27	3.63	57.655	34.989	34.989	1009.5	27.50	77.00	77.00	35.50	3.10																		
ISO235	ISO235-LW-196-2022-01	202201	02:08:2014.08:00:00	10:00	05:00	8.57	209.16	14.7	-0.20370	72.26560	11.94	242.14	12.07	57.715	34.895	34.895	1010.7	28.00	77.00	77.00	35.60	8.10																		
ISO235	ISO235-LW-197-2022-01	202201	02:08:2014.11:00:00	13:00	08:00	5.38	204.72	10.5	-0.42250	72.26180	12.35	242.77	7.26	57.900	34.899	34.899	1008.8	28.80	74.00	74.00	6.80	5.40																		
ISO235	ISO235-LW-198-2022-01	202201	02:08:2014.14:00:00	16:00	11:00	9.30	217.15	10.0	-1.48190	72.53430	11.36	251.64	7.56	57.900	34.899	34.899	1009.2	28.00	74.00	74.00	27.90	6.80																		
ISO235	ISO235-LW-199-2022-01	202201	02:08:2014.17:00:00	19:00	14:00	195.89	207.73	161.4	-1.48190	72.53430	11.36	251.64	7.56	57.900	34.899	34.899	1009.2	28.00	74.00	74.00	80.70	5.60																		
ISO235	ISO235-LW-200-2022-07	202207	02:08:2014.20:00:00	22:00	17:00	90.01	210.93	89.6	1.56550	72.86990	0.66	251.64	5.64	57.517	34.833	34.833	1010.2	28.50	74.00	74.00	92.50	3.40																		
ISO235	ISO235-LW-201-2022-07	202207	02:08:2014.23:00:00	01:00	20:00	74.98	210.93	78.2	1.56550	72.86990	0.66	251.64	5.64	57.517	34.833	34.833	1010.2	28.50	74.00	74.00	22.80	3.40																		
ISO235	ISO235-LW-202-2022-09	202209	02:08:2014.23:00:00	04:00	23:00	4.42	229.21	4.4	-1.87740	73.96710	11.91	273.23	3.48	57.466	34.866	29.342	1009.0	28.50	75.00	75.00	32.90	8.40																		
ISO235	ISO235-LW-203-2022-10	202210	02:08:2014.05:00:00	07:00	02:00	5.27	225.66	5.3	-2.45570	74.02960	12.53	291.37	4.82	57.614	34.852	29.411	1008.8	27.60	75.00	75.00	33.40	9.60																		
ISO235	ISO235-LW-205-2022-11	202211	02:08:2014.05:00:00	10:00	05:00	3.37	233.66	1.7	-3.04690	74.10540	12.51	291.37	4.82	57.686	34.846	29.443	1010.0	28.50	76.00	76.00	30.10	10.60																		

Appendix B: Sample lists for CTD samples

[illegible]

[illegible]

OASIS-Sonne (SO235) Samples taken from CTD casts (preliminary

GEOMAR Reports

No.	Title
1	FS POSEIDON Fahrtbericht / Cruise Report POS421, 08. – 18.11.2011, Kiel - Las Palmas, Ed.: T.J. Müller, 26 pp, DOI: 10.3289/GEOMAR_REP_NS_1_2012
2	Nitrous Oxide Time Series Measurements off Peru – A Collaboration between SFB 754 and IMARPE –, Annual Report 2011, Eds.: Baustian, T., M. Graco, H.W. Bange, G. Flores, J. Ledesma, M. Sarmiento, V. Leon, C. Robles, O. Moron, 20 pp, DOI: 10.3289/GEOMAR_REP_NS_2_2012
3	FS POSEIDON Fahrtbericht / Cruise Report POS427 – Fluid emissions from mud volcanoes, cold seeps and fluid circulation at the Don-Kuban deep sea fan (Kerch peninsula, Crimea, Black Sea) – 23.02. – 19.03.2012, Burgas, Bulgaria - Heraklion, Greece, Ed.: J. Bialas, 32 pp, DOI: 10.3289/GEOMAR_REP_NS_3_2012
4	RV CELTIC EXPLORER EUROFLEETS Cruise Report, CE12010 – ECO2@NorthSea, 20.07. – 06.08.2012, Bremerhaven – Hamburg, Eds.: P. Linke et al., 65 pp, DOI: 10.3289/GEOMAR_REP_NS_4_2012
5	RV PELAGIA Fahrtbericht / Cruise Report 64PE350/64PE351 – JEDDAH-TRANSECT –, 08.03. – 05.04.2012, Jeddah – Jeddah, 06.04 - 22.04.2012, Jeddah – Duba, Eds.: M. Schmidt, R. Al-Farawati, A. Al-Aidaros, B. Kurten and the shipboard scientific party, 154 pp, DOI: 10.3289/GEOMAR_REP_NS_5_2013
6	RV SONNE Fahrtbericht / Cruise Report SO225 - MANIHIKI II Leg 2 The Manihiki Plateau - Origin, Structure and Effects of Oceanic Plateaus and Pleistocene Dynamic of the West Pacific Warm Water Pool, 19.11.2012 - 06.01.2013 Suva / Fiji – Auckland / New Zealand, Eds.: R. Werner, D. Nürnberg, and F. Hauff and the shipboard scientific party, 176 pp, DOI: 10.3289/GEOMAR_REP_NS_6_2013
7	RV SONNE Fahrtbericht / Cruise Report SO226 – CHRIMP CHatham RIse Methane Pockmarks, 07.01. – 06.02.2013 / Auckland – Lyttleton & 07.02. – 01.03.2013 / Lyttleton – Wellington, Eds.: Jörg Bialas / Ingo Klauke / Jasmin Mögeltönder, 126 pp, DOI: 10.3289/GEOMAR_REP_NS_7_2013
8	The SUGAR Toolbox - A library of numerical algorithms and data for modelling of gas hydrate systems and marine environments, Eds.: Elke Kossel, Nikolaus Bigalke, Elena Piñero, Matthias Haeckel, 168 pp, DOI: 10.3289/GEOMAR_REP_NS_8_2013
9	RV ALKOR Fahrtbericht / Cruise Report AL412, 22.03.-08.04.2013, Kiel – Kiel. Eds: Peter Linke and the shipboard scientific party, 38 pp, DOI: 10.3289/GEOMAR_REP_NS_9_2013
10	Literaturrecherche, Aus- und Bewertung der Datenbasis zur Meerforelle (<i>Salmo trutta trutta</i> L.) Grundlage für ein Projekt zur Optimierung des Meerforellenmanagements in Schleswig-Holstein. Eds.: Christoph Petereit, Thorsten Reusch, Jan Dierking, Albrecht Hahn, 158 pp, DOI: 10.3289/GEOMAR_REP_NS_10_2013
11	RV SONNE Fahrtbericht / Cruise Report SO227 TAIFLUX, 02.04. – 02.05.2013, Kaohsiung – Kaohsiung (Taiwan), Christian Berndt, 105 pp, DOI: 10.3289/GEOMAR_REP_NS_11_2013

No.	Title
12	RV SONNE Fahrtbericht / Cruise Report SO218 SHIVA (Stratospheric Ozone: Halogens in a Varying Atmosphere), 15.-29.11.2011, Singapore - Manila, Philippines, Part 1: SO218- SHIVA Summary Report (in German), Part 2: SO218- SHIVA English reports of participating groups, Eds.: Birgit Quack & Kirstin Krüger, 119 pp, DOI: 10.3289/GEOMAR_REP_NS_12_2013
13	KIEL276 Time Series Data from Moored Current Meters. Madeira Abyssal Plain, 33°N, 22°W, 5285 m water depth, March 1980 – April 2011. Background Information and Data Compilation. Eds.: Thomas J. Müller and Joanna J. Waniek, 239 pp, DOI: 10.3289/GEOMAR_REP_NS_13_2013
14	RV POSEIDON Fahrtbericht / Cruise Report POS457: ICELAND HAZARDS Volcanic Risks from Iceland and Climate Change: The Late Quaternary to Anthropogene Development Reykjavík / Iceland – Galway / Ireland, 7.-22. August 2013. Eds.: Reinhard Werner, Dirk Nürnberg and the shipboard scientific party, 88 pp, DOI: 10.3289/GEOMAR_REP_NS_14_2014
15	RV MARIA S. MERIAN Fahrtbericht / Cruise Report MSM-34 / 1 & 2, SUGAR Site, Varna – Varna, 06.12.13 – 16.01.14. Eds: Jörg Bialas, Ingo Klaucke, Matthias Haeckel, 111 pp, DOI: 10.3289/GEOMAR_REP_NS_15_2014
16	RV POSEIDON Fahrtbericht / Cruise Report POS 442, "AUVinTYS" High-resolution geological investigations of hydrothermal sites in the Tyrrhenian Sea using the AUV "Abyss", 31.10. – 09.11.12, Messina – Messina, Ed.: Sven Petersen, 32 pp, DOI: 10.3289/GEOMAR_REP_NS_16_2014
17	RV SONNE, Fahrtbericht / Cruise Report, SO 234/1, "SPACES": Science or the Assessment of Complex Earth System Processes, 22.06. – 06.07.2014, Walvis Bay / Namibia - Durban / South Africa, Eds.: Reinhard Werner and Hans-Joachim Wagner and the shipboard scientific party, 44 pp, DOI: 10.3289/GEOMAR_REP_NS_17_2014
18	RV POSEIDON Fahrtbericht / Cruise Report POS 453 & 458, "COMM3D", Crustal Structure and Ocean Mixing observed with 3D Seismic Measurements, 20.05. – 12.06.2013 (POS453), Galway, Ireland – Vigo, Portugal, 24.09. – 17.10.2013 (POS458), Vigo, Portugal – Vigo, Portugal, Eds.: Cord Papenberg and Dirk Klaeschen, 66 pp, DOI: 10.3289/GEOMAR_REP_NS_18_2014
19	RV POSEIDON, Fahrtbericht / Cruise Report, POS469, "PANAREA", 02. – 22.05.2014, (Bari, Italy – Malaga, Spain) & Panarea shallow-water diving campaign, 10. – 19.05.2014, Ed.: Peter Linke, 55 pp, DOI: 10.3289/GEOMAR_REP_NS_19_2014
20	RV SONNE Fahrtbericht / Cruise Report SO234-2, 08.-20.07.2014, Durban, South Africa - Port Louis, Mauritius, Eds.: Kirstin Krüger, Birgit Quack and Christa Marandino, 95 pp, DOI: 10.3289/GEOMAR_REP_NS_20_2014

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