MARIA S.MERIAN - Berichte

Submesoscale Dynamics in Fram Strait

Cruise No. MSM93 (GPF 18-1_33)

June 26 – July 30, 2020,
Emden (Germany) – Emden (Germany)
SDFS

AUTHORS

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Table of Contents

1 Cruise Summary

1.1 Summary

The cruise started in Emden followed by transit to the working area: Fram Strait between Greenland and Svalbard. Moorings observing long-term changes in the northward flowing Atlantic Water in the West Spitsbergen Current were exchanged first. Next, a process study in central Fram Strait at the transition between open water and the ice-covered ocean quantified physical and biological gradients due to submesoscale dynamics at a front where Atlantic Water was subducting along with the temporal evolution of that front. Heavy sea ice conditions near the end of the cruise prohibited RV MERIAN to enter Scoresby Sund where moorings were supposed to be recovered. While waiting for more favorable sea ice conditions, towed sections across the East Greenland Current measured submesoscale variability at the transition from Polar to Atlantic conditions there. A final deep station in the Norwegian Sea during the transit back to Emden concluded the cruise.

1.2 Zusammenfassung

Die Reise startete in Emden mit der Überfahrt in das Arbeitsgebiet: die Fram-Straße zwischen Grönland und Spitzbergen. Verankerungen, die Langzeitänderungen in dem nordwärtsfließenden Atlantik Wasser im West Spitzbergen Strom messen, wurden zuerst ausgetauscht. Als nächstes vermaß eine Prozessstudie in der zentralen Fram-Straße an der Übergangszone vom offenen Ozean zum eisbedeckten Ozean die physikalischen und biologischen Gradienten, die aufgrund von submesoskaligen Dynamiken an einer Front auftraten, weil dort Atlantik Wasser abtauchte, und zusätzlich die zeitliche Veränderung dieser Front. Schwere Meereisbedingungen zum Ende der Reise verhinderten FS MERIAN das Einlaufen in den Scoresby Sund wo zwei Verankerungen aufgenommen werden sollten. Während des Wartens auf bessere Meereisbedingungen erfassten geschleppte Schnitte quer zum Ostgrönlandstrom die dortige submesoskalige Variabilität am Übergang von polaren zu atlantischen Bedingungen. Eine letzte tiefe Station in der Norwegischen See auf der Rückfahrt nach Emden beendete die Reise.

2 Participants

2.1 Principal Investigators

Name	Institution
von Appen, Wilken-Jon, Dr.	AWI
Iversen, Morten, Prof. Dr.	MARUM/AWI
Kanzow, Torsten, Prof. Dr.	AWI/UniHB
Bracher, Astrid, Prof. Dr.	AWI/UniHB
Walter, Maren, Dr.	UniHB

2.2 Scientific Party

Name	Discipline	Institution
von Appen, Wilken-Jon, Dr.	Physical Oceanography / Chief Scientist	AWI
Hagemann, Jonas	Physical Oceanography	AWI
Engicht, Carina	Physical Oceanography	AWI
Kuhlmey, David	Physical Oceanography	AWI
Hofmann, Zerlina	Physical Oceanography	AWI
Mathieu, Laura	Physical Oceanography	AWI
Iversen, Morten, Prof. Dr.	Biological Oceanography	AWI/MARUM
Konrad, Christian	Biological Oceanography	AWI/MARUM
Ramondenc, Simon, Dr.	Biological Oceanography	AWI/MARUM
Hufnagel, Lili	Biological Oceanography	MARUM
Oelker, Julia	Ocean Optics	UniHB
Körtke, Wiebke	Noble Gases	UniHB
Kalvelage, Tim, Dr.	Journalist	Self-employed

2.3 Participating Institutions

AWI	Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research
MARUM	Center for Marine Environmental Sciences
UniHB	University of Bremen

3 Research Program

3.1 Description of the Work Area

The cruise took place in Fram Strait between Greenland and Svalbard and near the shelfbreak offshore of Scoresby Sund in East Greenland. Fram Strait is the only deep connection between the Arctic Ocean and the Nordic Seas and world oceans beyond. The West Spitsbergen Current transports relatively warm and salty water (so-called Atlantic Water) northward in the eastern part of the strait. The East Greenland Current transports cold and much fresher water (so-called Polar Water) as well as sea ice southward in the western part of the strait as well as along the East Greenland shelfbreak. As a result, the central part is a transition region between ice-free Atlantic Water at the surface and ice-covered Polar Water at the surface. This causes vigorous dynamics on scales from 100km down to 100m. Scoresby Sund is one of the largest fjord systems of the world. Atlantic Water flows into the fjord and contributes to melting of several marine terminating glaciers.

3.2 Aims of the Cruise

The cruise MSM93 had three goals: A process study in the Fram Strait between Greenland and Svalbard, the support of long-term observations in the Fram Strait and at the end of the cruise the recovery of four moorings in and in front of a fjord in East Greenland. For the long-term measurements of temperature and velocity of the northward flowing water in the Fram Strait, at the beginning of the cruise five moorings were supposed to be recovered and four moorings were supposed to be deployed. The process study was supposed to quantify the interaction between physics and biology in the upper ocean in the vicinity of the marginal ice zone on horizontal scales of hundreds of meters to several kilometers. To achieve this, station work was supposed to be combined with data acquisition by a system towed behind the ship.

3.3 Agenda of the Cruise

The first 6 days of the cruise were transit to the working area. Then 5 days were spent in the West Spitsbergen Current for mooring exchange and a CTD section. Next, a process study of 10 days duration took place at a front in central Fram Strait where Atlantic Water subducted below Polar Water. 9 days of transit followed including an attempt to get into Scoresby Sund which failed due to heavy sea ice conditions. During this time period, towed sections across the East Greenland Current were occupied for 4 days. The cruise concluded with 5 days of transit to port.

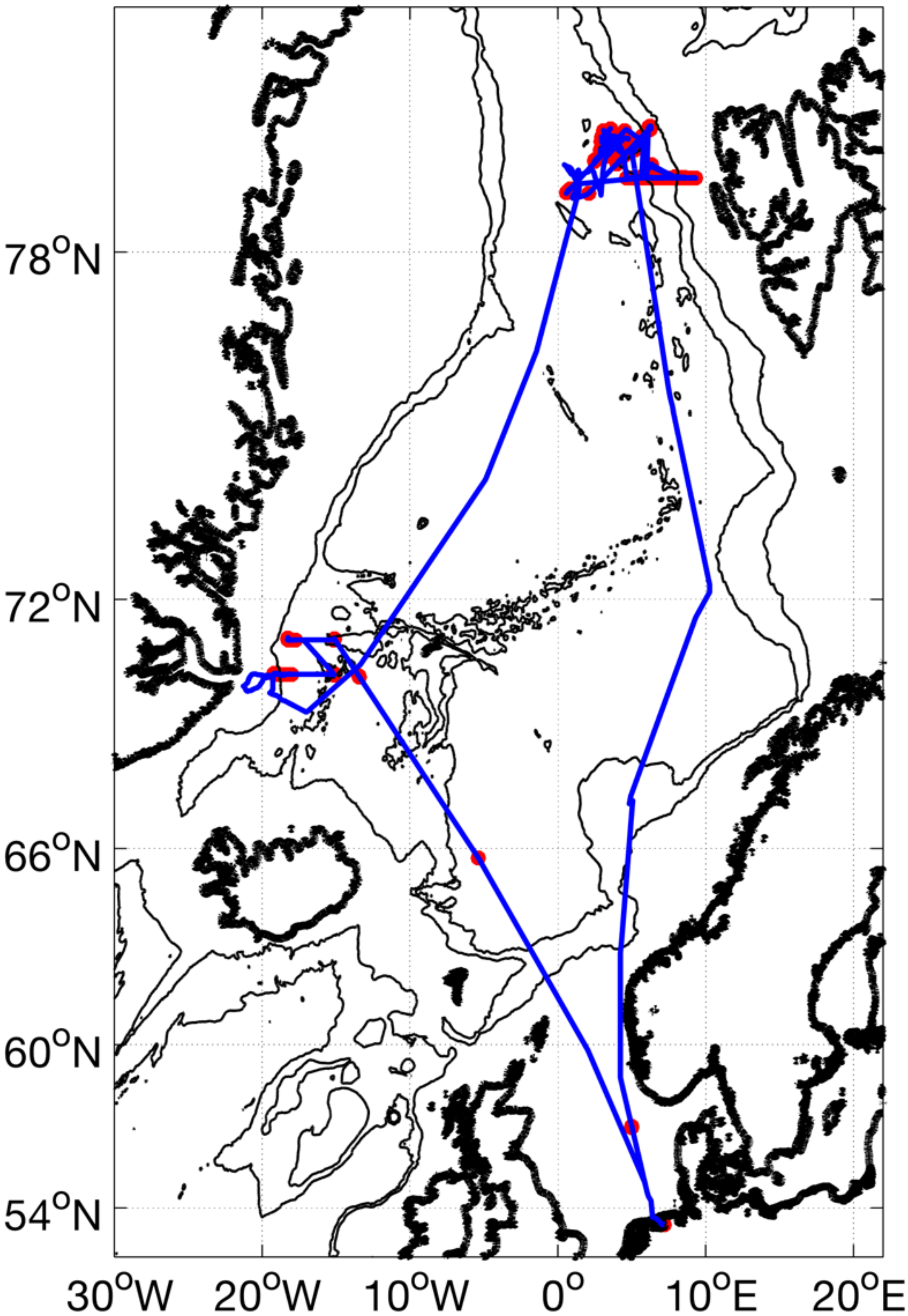

Fig. 3.1 Track chart of RV MERIAN Cruise MSM93. Bathymetry from GEBCO. Stations in red with two main working areas in Fram Strait and offshore of Scoresby Sund.

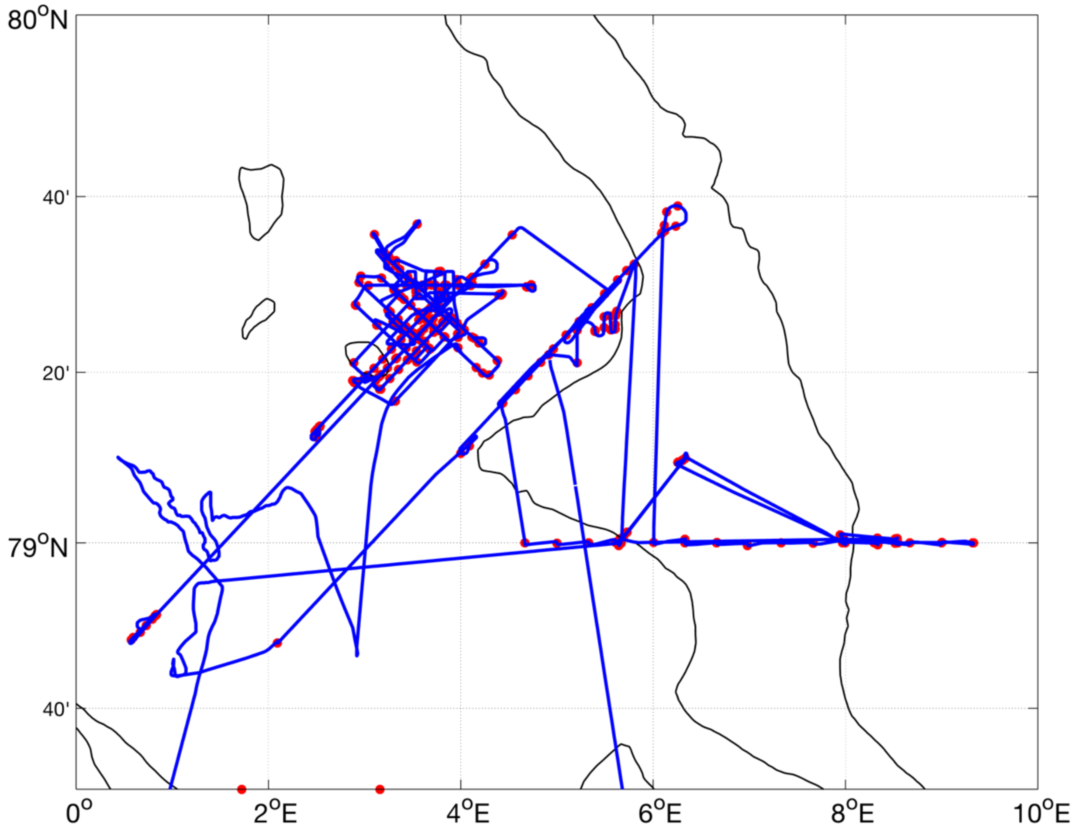

Fig. 3.2 Track chart of RV MERIAN Cruise MSM93 in Fram Stait.

4 Narrative of the Cruise

Due to Corona, all participants of MSM93 had to stay in a hotel in Leer from 21 June onwards and get tested. After the negative test results had arrived, we were taken to RV MERIAN in the port of Emden by bus on 24 June. Our containers and non-containerized cargo were loaded and we were able to set up some of our equipment and start testing it. On June 26 we departed Emden and started the 6-day transit to the working area. Most of the transit was smooth, but on one day most scientists were sea-sick.

July 2 to July 6 constituted the first part of the cruise in the eastern Fram Strait. We used it for the testing of various instrument and laboratory procedures and we completed a CTD section across the West Spitsbergen Current. But the majority of that time was dedicated to mooring work. We recovered 5 moorings that are part of a long-term observation program of the AWI to monitor the warm Atlantic Water which flows into the Arctic Ocean. The recoveries went well and even included a so-called trawl resistant bottom mount, something which had eluded us in previous years for a multitude of different technical reasons. After the recoveries, we deployed 4 moorings. On one day we even had perfect sunny calm summer weather.

July 7 and July 8 marked the transition to the small-scale work that was the second part of the cruise. We occupied an in-situ camera transect parallel to the ice-edge comprised of 10 stations at a 4km horizontal resolution. This was followed by the first extensive deployment of the Triaxus towed system. A 100km section was occupied three times with measurements at three different constant depths. During this transect we identified a region of extremely strong horizontal gradients: a front.

We returned to that front near the ice-edge and sampled it extensively from July 9 to July 16. At that front warm salty Atlantic Water was subducted below cold fresh Polar Water. The goal of the survey was to map the front's complete spatial structure and how it evolved over time. For this we deployed all our gears with a rough separation of towed observations during night-time and stations during day-time. We towed the Triaxus as well as the underway CTD and observed the currents with the vessel mounted ADCP. We made profiles with the CTD-rosette, in-situ camera, and light optical package. Water was collected from the CTD-rosette, marine snow catcher and the ship's sea water intake and samples were collected for nutrient concentrations, primary production, particle properties (e.g. sinking speed and oxygen consumption), phytoplankton concentrations and functional group composition, CFCs, noble gases, and tritium. We deployed surface drifters and drifting sediment traps. During transit, optical properties of the surface water were also measured and we monitored the ship's radar which showed the line at which the subduction took place.

After completion of the front study, we celebrated the cruise's half time (Bergfest) and left Fram Strait. July 17 to July 19 was a transit to the shelf in front of Scoresby Sund in eastern Greenland. Unfortunately, those days were also marked by a storm which did not play out as forecast. Rather it pushed thick multi-year sea ice in front of the entrance of Scoresby Sund. We attempted to get into the fjord on July 19 and July 20. But at nearly 100% concentration the ice was too thick for RV MERIAN and we had to abort late on July 20. Therefore, we were not able to recover two oceanographic moorings deep in Scoresby Sund, one oceanographic mooring at the entrance of Scoresby Sund, and one passive acoustics mooring in front of the fjord.

By the end of July 21 we were back at the shelfbreak and until July 25, while waiting for better ice conditions, we proceeded to occupy two transects somewhat longer than 100km from the ice-edge across the East Greenland Current to the open ocean. We periodically returned to the ice-edge to check whether the ice conditions had improved which they however had not.

On July 25 we started the transit home and occupied a last deep station in the international waters east of Iceland. Parts of the remainder of the transit home were windy enough to cause some sea-sickness again, but we were able to store all our equipment and samples and to save and document the collected data. On July 30 the cruise successfully commenced in the port of Emden.

5 Preliminary Results

5.1 Physical Oceanography

W.-J. von Appen (AWI), J. Hagemann (AWI), C. Engicht (AWI), D. Kuhlmey (AWI), Z. Hofmann (AWI), L. Mathieu (AWI), H. Becker (AWI, not on board), T. Kanzow (AWI/UniHB, not on board)

Moorings

Five moorings were deployed in Fram Strait by RV MERIAN in 2018 during MSM76 and three moorings were deployed in Scoresby Sund by RV MERIAN in 2018 during MSM76, see Tab. 5.1.1. Furthermore, one mooring was deployed by the Greenland Institute of Natural Resources in front of Scoresby Sund in 2018. All of those moorings were supposed to be recovered during MSM93. However, difficult sea ice conditions precluded RV MERIAN from reaching the mooring positions in and in front of Scoresby Sund. Therefore, those moorings could not be recovered. The five recoveries in Fram Strait were successful. Mooring F1-17 was a trawl resistant bottom mount (TRBM). After a number of failed attempts with this technology in previous years, the TRBM recovery of F1-17 during MSM93 was the first successful recovery in Fram Strait. The data return as judged by a preliminary analysis of the recovered sensors was mostly good, but a number of instruments, specifically current meters and ADCPs also terminated their measurements prematurely.

The four regular moorings in Fram Strait were successfully redeployed (Tab. 5.1.1). Only minor modifications in the instrument and depth setups of those moorings were implemented compared to the recovered moorings.

Tab. 5.1.1: List of mooring recoveries and deployments.

Name	Longitude		Latitude		Depth	Top	Deployment time UTC					Recovery time UTC					Deployment station	Recovery station
	Degrees	Minutes	Degrees	Minutes	Meters	Meters	Year	Month	Day	Hour	Minute	Year	Month	Day	Hour	Minute		
Recoveries																		
F1-17	8	32.55 E	79	0.00 N	343	342	2018	9	7	12	58	2020	7	3	15	35	MSM76/205-1	MSM93/008-1
F2-19	8	19.73 E	78	59.99 N	784	26	2018	9	7	14	50	2020	7	4	8	47	MSM76/206-1	MSM93/013-1
F3-18	7	59.72 E	78	59.99 N	1073	41	2018	9	9	6	16	2020	7	3	13	1	MSM76/225-1	MSM93/007-1
F5-18	5	40.08 E	78	59.99 N	2093	47	2018	9	8	8	16	2020	7	3	3	0	MSM76/213-1	MSM93/005-1
F4-OZA	6	19.96 E	79	9.99 N	1418	95	2018	9	8	14	50	2020	7	3	9	12	MSM76/214-2	MSM93/006-1
SCO1-1	25	16.98 W	71	16.98 N	638	405	2018	8	22	16	13						MSM76/127-1	
SCO2-1	25	17.94 W	71	13.86 N	806	590	2018	8	22	17	45						MSM76/128-1	
SCO3-1	21	59.78 W	70	21.25 N	416	242	2018	8	23	12	25						MSM76/132-1	
MSCO_3	20	49.34 W	70	10.52 N	375	115	2018	9	6	6	51						GINR	
Deployments																		
F2-20	8	19.77 E	78	59.97 N	787	24	2020	7	4	15	2						MSM93/013-5	
F3-19	7	59.79 E	79	0.01 N	1078	37	2020	7	6	16	2						MSM93/025-1	
F5-19	5	40.10 E	79	0.02 N	2084	49	2020	7	6	9	36						MSM93/023-1	
F4-OZA	6	19.96 E	79	10.02 N	1422	108	2020	7	6	13	12						MSM93/024-2	

Front study design

Upon completion of the mooring work, a front in the open ocean region in the vicinity of the ice edge was searched for with a ~100km long constant depth Triaxus transect on July 8th and July 9th. When a front had been found, it was surveyed in 3D by parallel UCTD sections and drifters were deployed. The front was followed until July 16th with the repeat of parallel UCTD and Triaxus sections and the occupation of all equipment available (and described in this cruise report) at stations chosen to be representative of the different sides of the front as the front moved in space and evolved in time.

CTD-rosette

The CTD-rosette was used to obtain deep profiles of oceanographic parameters and to collect water for laboratory analyses. A section across the West Spitsbergen Current was occupied during night time in the first part of the cruise when the mooring work took place. During the front study on three days, five stations each were occupied that spanned similar relative positions to the front. Finally, the cruise commenced with a deep station in the Norwegian Sea. In total 51 CTD casts were done during MSM93.

The rosette and sensors belonging to the ship were used and the sensor configuration was as shown in Tab. 5.1.2. The data was not processed at sea and no salinity samples were collected as the expected gradients due to the Atlantic Water – Polar Water transition were expected to be large compared to typical sensor issues. To the extent analyzed at sea, the CTD data appeared to be of good quality.

Tab. 5.1.2: Configuration of CTD-rosette used during MSM93.

Channel	Sensor	Serial number	Calibration date
Frequency 0	Temperature	4459	8-May-20
Frequency 1	Conductivity	2941	7-May-20
Frequency 2	Pressure, Digiquartz with TC	806	21-Jun-18
Frequency 3	Temperature, 2	4456	8-May-20
Frequency 4	Conductivity, 2	2939	7-May-20
A/D voltage 0	Oxygen, SBE 43	2417	26-Feb-20
A/D voltage 1	Oxygen, SBE 43, 2	2418	26-Feb-20
A/D voltage 2	Altimeter	50413	12-Apr-17
A/D voltage 3	PAR/Irradiance, Biospherical/Licor	70278	13-Dec-17
A/D voltage 4	Fluorometer, WET Labs ECO-AFL/FL	1754	15 Mai 2020
A/D voltage 5	Turbidity Meter, WET Labs, ECO-NTU	1754	15 Mai 2020

Vessel Mounted ADCP

The 75kHz and the 38kHz Teledyne Ocean Surveyor ADCPs built into the hull of RV MERIAN were operated continuously during MSM93 when in waters where diplomatic clearances existed.

The data recording was restarted more than once a day to ease subsequent data processing. In the beginning of the cruise various different settings were tried out. In particular, the 75kHz ADCP was programmed to record vertical bins of 4m size. The goal was to get an increased vertical resolution. However, this was switched back to 8m bins on July 5th in order to achieve a better signal to noise ratio. The configuration used for the majority of the cruise is shown in Tab. 5.1.3. The 38kHz ADCP was used in standard configuration. The focus during the cruise was on the 75kHz ADCP in order to obtain higher resolution ocean velocity data in the upper water column where the Triaxus data was collected.

Tab. 5.1.3: Configuration of the 75kHz ADCP from July 5th onwards.

```
; Set for broadband profile mode: narrowband mode disabled (NP000),
; single-ping broadband ensembles (WP), fifty bins (WN),
; 8 meter bin length (WS), 4 meter blanking distance (WF)
NP000
```

```
WP001
WN050
WS0800
WF0400

; Disable single-ping bottom track
BP000

; Output velocity, correlation, echo intensity, percent good
WD111100000

; Time between pings TPmmssff (m-minutes,s-seconds,f-hundredths of seconds)
; set to one second (this is faster than OS can actually ping, so it pings as
fast as possible)
; Ping as fast as possible
TP000000

; Set to calculate speed-of-sound, no depth sensor,
; external synchro heading sensor, use internal
; transducer temperature sensor
EZ1020001

; Output beam data (rotations are done in software)
EX00000

; Set transducer misalignment (hundredths of degrees)
; EA04500

; Set transducer depth to 65 decimeters (6.5m)
ED00065

; Set Salinity (ppt)
ES35

; Save this setup to non-volatile memory in the ADCP
CK
```

Triaxus

The MacArtney Triaxus extended version is a remotely operated towed vehicle (ROTV). It is towed behind the ship between 2 and 10 knots and can undulate in a saw tooth pattern between a few meters below the surface and 350m depth. The umbilical provides power and a fiber optic link to sensors that are mounted on the Triaxus, see Tab. 5.1.4 and Tab. 5.1.5.

Tab. 5.1.4: List of sensors attached to the Triaxus during MSM93.

```
AC-S - In-situ spectrophotometer (ACS)
ADCP #1 - Acoustic Doppler Current Profiler (ADCP_up)
ADCP #2 - Acoustic Doppler Current Profiler (ADCP_down)
CTD - Conductivity Temperatur Depth Sensor (CTD)
Deep SUNA - Ocean Nitrate Sensor (Nitrate)
EK80 - Scientific wide band echo sounder (EK80)
RAMSES - Hyperspectral radiometer (Ramses)
Triaxus - towed sensor carrier system (SN S1512007) (Triaxus)
```

Tab. 5.1.5: List of sensors attached to the SBE911+ CTD during MSM93 that itself was attached to the Triaxus.

Channel	Sensor type	Serial number	Calibration date
Frequency 0	Temperature	5903	27-Feb-20

Frequency 1	Conductivity	4458	27-Feb-20
Frequency 2	Pressure	1251	05-Oct-15
Frequency 3	Conductivity	4457	27-Feb-20
Frequency 4	Temperature	6059	27-Feb-20
A/D voltage 0	PAR_Biospherical	1033	21-SEP-15
A/D voltage 1	WET_LabsCStar	1736	16-JUL-15
A/D voltage 2	Oxygen	3654	13-Feb-20
A/D voltage 3	NotInUse		
A/D voltage 4	pH_Sensor	1373	01-Dec-2017
A/D voltage 5	NotInUse		
A/D voltage 6	FluoroWetlabECO_AFL_FL_	4051	21-JUL-15
A/D voltage 7	NotInUse		

The data collected by the sensors listed in Tab. 5.1.4 were recorded on separate computers, one computer per sensor. Thus, there are 8 separate data streams saved in separate folders. During long Triaxus operations, new data files would be started approximately every 4 hours, because some of the employed software programs do not allow for backing up of the files while they are still being written to.

A number of technical problems happened during MSM93 that sometimes precluded the system from being used at the desired times with the desired operational mode. These were related to an upgraded chip set in the Triaxus, a firmware upgrade, the fact that the altimeters had been removed, and two ground faults at separate locations of the system. As a result of this, the normal mode of automatic vertical undulation at 1m/s vertical speed was possible only for a short period of time (stations MSM93-097, MSM93-103, MSM93-105, MSM93-106). Constant depth transects were carried out by manually adjusting the pitch flaps to approximately maintain the target depth (stations MSM93-021, MSM93-049, MSM93-071) or by using the auto depth function when it was available (MSM93-105, MSM93-106). Manual undulations were carried out by manually adjusting the pitch flaps to climb at approximately 1m/s from depth to the target distance below the surface where the climb was aborted such the vehicle would sink rapidly before its descent speed could again be adjusted to approximately 1m/s (station MSM93-097). Finally, the UCTD was used for a number of sections that should have been occupied by the Triaxus if it had been available with its normal operational mode at the time. The Triaxus was used to find the front, during the front study, and while crossing the East Greenland Current while waiting for improving ice conditions in front of Scoresby Sund. Tab. 5.1.6 provides an overview of the transects occupied with the Triaxus during MSM93.

Tab. 5.1.6: Overview of the transects occupied with the Triaxus during MSM93. If the minimum depth (zmin) and the maximum depth (zmax) are identical, then the transect was a constant depth transect. In some cases, the numbering of the CTD data files did not agree with the action log numbering.

sect_no	name_numeric	name_planning	start_time	end_time	zmin	zmax	cable_length	action_log	CTD_file_name	comment
1	yr=-23km	30km	7/5/20 9:56	7/5/20 14:26	35	35	200	21_1	21_1	
2	yr=0km_1	100km	7/8/20 11:22	7/8/20 19:07	10	10	200	49_1	49_1	
3	yr=0km_2	100km	7/8/20 19:50	7/9/20 2:36	35	35	400	49_1	49_2	
4	yr=0km_3	100km	7/9/20 3:35	7/9/20 10:52	100	100	1000	49_1	49_3	
5	yr=2km_3	Transect West	7/11/20 19:18	7/11/20 22:56	6	6	400	71_1	71_1	
6	yr=2km_4	Transect West	7/11/20 23:18	7/12/20 1:41	20	20	400	71_1	71_2	
7	yr=2km_5	Transect West	7/12/20 1:59	7/12/20 4:16	35	35	400	71_1	71_3	
8	yr=2km_6	Transect West	7/12/20 4:37	7/12/20 7:02	50	50	450	71_1	71_4	
9	yr=2km_7	Transect West	7/12/20 7:22	7/12/20 9:56	75	75	790	71_1	71_5	
10	yr=2km_8	Transect West	7/12/20 10:24	7/12/20 13:21	100	100	1000	71_1	71_6	
11	xr=-7km_3	Transect 4	7/14/20 7:43	7/14/20 11:16	10	100	1000	97_1	97_2	hand undulation
12	xr=-7km_4	Transect 4	7/14/20 11:16	7/14/20 13:56	10	100	1000	97_1	97_3	hand undulation
13	xr=-7km_5	Transect 4	7/14/20 14:54	7/14/20 17:59	5	100	1000	97_2	97_4	700m cable length after 16:09
14	xr=-11km_3	Transect 3	7/14/20 17:59	7/14/20 20:13	5	100	700	97_2	97_5	
15	xr=-15km_3	Transect 2	7/14/20 20:13	7/14/20 22:30	5	100	700	97_2	97_6	
16	xr=-19km_4	Transect 1	7/14/20 22:30	7/15/20 0:36	5	100	700	97_2	97_7	
17	y=0km_2	79 30	7/15/20 0:36	7/15/20 3:59	5	100	700	97_2	97_8	
18	y=0km_3	79 30	7/15/20 3:59	7/15/20 6:17	5	100	700	97_2	97_9	
19	xr=-7km_6	Transect 4	7/15/20 19:11	7/15/20 23:26	10	300	1500	103_1	103_1	
20	xr=-11km_4	Transect 3	7/15/20 23:26	7/16/20 2:10	10	300	1500	103_1	103_2	
21	xr=-7km_7	Transect 4	7/16/20 2:10	7/16/20 9:51	75	200	1200	103_1/2	103_3/4	
22	EGC1_1	EGC1_1	7/21/20 18:39	7/22/20 5:59	10	300	1550	105_1	105_1	1800m cable length until 20:09
23	EGC1_2	EGC1_2	7/22/20 6:47	7/22/20 16:39	10	10	500	105_1	105_2	
24	EGC1_3	EGC1_3	7/22/20 16:53	7/24/20 0:45	5	50	500	105_1/2	105_3	
25	EGC2_1	EGC2_1	7/24/20 8:29	7/24/20 16:03	10	10	500	106_1	106_1	
26	EGC2_2	EGC2_2	7/24/20 16:32	7/25/20 0:08	5	50	500	106_1	106_2	
27	EGC2_3	EGC2_3	7/25/20 0:31	7/25/20 8:07	30	30	500	106_1	106_3	

Underway CTD

The Teledyne Underway CTD was operated at times when the Triaxus ought to have been used scientifically, but was not operational for various reasons (see Triaxus subsection). The UCTD was operated in tow-yo mode: the winch brake is disengaged and the probe is in approximate free-fall at 4m/s to 1m/s vertical speed collecting data for a cast. Then the brake is engaged and the probe is hauled in until it is within 10m horizontal behind the vessel at the sea surface. The winch is then disengaged and the next cast starts. A straight section is collected with the same probe in the water. At the end of the section, the probe is recovered and another probe is used for the next section. The data is recorded internally on the probe and only read out once the probe is back on deck. The time of data recovery on deck is also used for charging of the battery in the probe. During one section, an operator error resulted in the fact that the probe appeared to have been started while in fact it had not been started before deployment. This was only realized upon recovery of the probe, meaning that no data was collected during that section. This occurred on July 10th between 21:29 and 23:17 UTC (station MSM93-062). At all times when the UCTD was operated, two scientists were on deck: An operator of the winch and a person taking notes and counting the free-fall and haul-in times. Three different probes were used during MSM93: serial numbers 186, 133, 240. Probe SN240 was only used for one section and probes SN186 and SN133 were subsequently used on alternating sections.

The operation in tow-yo mode entails a trade-off between horizontal resolution, vertical profile depth, and time taken for a section. This was achieved by selecting the ship speed and the target time between the start of consecutive profiles. During the cruise three different sets of the combination between the duration of the repeat cycles and the ship speed were used: 5minutes/6knots (July 9th to July 11th) with a maximum depth of ~200m, 3minutes/6knots (night time on July 13th and July 14th) with a maximum depth of ~130m, and 2minutes/4knots (day time on July 13th) with a maximum depth of ~110m. In total 21 sections were occupied excluding the section where no data was recorded (station MSM93-062). Tab. 5.1.7 provides an overview of the transects occupied with the UCTD during MSM93.

Tab. 5.1.7: Overview of the transects occupied with the UCTD during MSM93 excluding the transect when no data was recorded.

sect_no	name_numeric	name_planning	start_time	end_time	zmax	action_log	serial_number
1	yr=-2km_1	Transect east	7/10/20 0:29	7/10/20 2:18	200	MSM93_53-1	186
2	yr=0km_5	Transect middle	7/10/20 2:30	7/10/20 4:18	200	MSM93_54-1	186
3	yr=2km_1	Transect west	7/10/20 4:32	7/10/20 6:24	200	MSM93_55-1	240
4	yr=-2km_2	Transect east_2	7/10/20 19:18	7/10/20 21:10	200	MSM93_60-1	133
5	yr=2km_2	Transect west_2	7/10/20 23:35	7/11/20 1:23	200	MSM93_63-1	186
6	yr=6km_1	Transect far west	7/11/20 1:49	7/11/20 3:34	200	MSM93_64-1	133
7	yr=-6km_1	Transect far east	7/11/20 4:33	7/11/20 6:20	200	MSM93_65-1	186
8	xr=-19km_1	Transect 1	7/13/20 1:44	7/13/20 2:40	130	MSM93_79-1	133
9	xr=-15km_1	Transect 2	7/13/20 3:05	7/13/20 4:02	130	MSM93_80-1	186
10	xr=-11km_1	Transect 3	7/13/20 4:27	7/13/20 5:24	130	MSM93_82-1	186
11	xr=-7km_1	Transect 4	7/13/20 5:44	7/13/20 7:26	130	MSM93_83-1	133
12	x=-12km_1	Looping pattern	7/13/20 9:10	7/13/20 9:35	110	MSM93_85-1	186
13	x=-10km_1	Looping pattern	7/13/20 9:51	7/13/20 12:55	110	MSM93_87-1	133
14	x=-8km_1	Looping pattern	7/13/20 13:13	7/13/20 18:37	110	MSM93_87-2	186
15	x=-6km_1	Looping pattern	7/13/20 18:55	7/13/20 20:41	110	MSM93_89-1	133
16	x=-4km_1	Looping pattern	7/13/20 20:59	7/13/20 22:52	110	MSM93_91-1	186
17	x=-2km_1	Looping pattern	7/13/20 23:07	7/14/20 0:34	110	MSM93_93-1	133
18	y=3km_1	Looping pattern	7/13/20 9:10	7/14/20 0:36	110	MSM93_85-1	186
19	y=-3km_1	Looping pattern	7/13/20 9:10	7/14/20 0:36	110	MSM93_87-1	133
20	xr=-7km_2	Transect 4_2	7/14/20 0:59	7/14/20 2:19	130	MSM93_94-1	186
21	xr=-11km_2	Transect 3_2	7/14/20 2:42	7/14/20 4:02	130	MSM93_95-1	133

Surface Drifters

Southtek Iridium GPS drifters of type Offshore NOMAD were deployed on MSM93 to elucidate the surface flows. The drifters had a 50cm long PVC drogue of type Satis. They were programmed to determine their position with GPS once every 10 minutes and to transmit those positions via Iridium once every 30 minutes. Towards the end of the cruise on July 28th those intervals were lengthened to hourly position acquisition and transmission in order to increase their life-time. The last transmission from a drifter occurred on November 18th. Fig. 5.1.1 provides an overview of how the drifters moved during the front study.

It was planned to deploy drifters on three occasions during the cruise. The third occasion did not materialize such that drifters were only deployed on two occasions and 13 drifters (including one faulty drifter) were returned home after the cruise.

Drifters were deployed during UCTD sections. The UCTD was operated from the stern at the port side. When the UCTD probe would be a few meters behind the ship just prior to the start of the downcast, the drifter would be thrown from the stern at the starboard side by a third person. The time of deployment and the number of the UCTD cast within its section starting immediately after the drifter deployment is shown in Tab. 5.1.8.

Drifter LCE00507 was faulty in that it did not obtain reliable position fixes when it was tested prior to the first set of deployments. The mistake was found and it would have been ready for a third set of deployments. Drifter LCE00527 appears to have had an electronic problem in that the battery was either faulty or internally disconnected. It could not be charged or connected to.

Tab. 5.1.8: Serial numbers and modem numbers of surface drifters, their deployment time, the name of the UCTD section during which they were deployed, and the number of the UCTD cast during the section when they were deployed

Intern ID	Modem NR.	Date Time UTC	UCTD Section name	UCTD cast
LCE00506	300 534 060 655 380	10-Jul-2020 19:25	MSM93-060-1	2
LCE00507	300 534 060 551 660	Faulty during tests		
LCE00508	300 534 060 558 700	10-Jul-2020 19:40	MSM93-060-1	5

LCE00509	300 534 060 357 380	10-Jul-2020 19:55	MSM93-060-1	8
LCE00510	300 534 060 557 700	10-Jul-2020 20:09	MSM93-060-1	11
LCE00511	300 534 060 356 390	10-Jul-2020 20:25	MSM93-060-1	14
LCE00512	300 534 060 557 890	10-Jul-2020 20:39	MSM93-060-1	17
LCE00513	300 534 060 650 370	10-Jul-2020 20:54	MSM93-060-1	20
LCE00514	300 534 060 659 360	10-Jul-2020 21:34	MSM93-062-1	2
LCE00515	300 534 060 453 070	10-Jul-2020 21:49	MSM93-062-1	5
LCE00516	300 534 060 658 400	10-Jul-2020 22:04	MSM93-062-1	8
LCE00517	300 534 060 558 830	10-Jul-2020 22:20	MSM93-062-1	11
LCE00518	300 534 060 557 640	10-Jul-2020 22:36	MSM93-062-1	14
LCE00519	300 534 060 553 650	10-Jul-2020 22:51	MSM93-062-1	17
LCE00521	300 534 060 352 370	10-Jul-2020 23:06	MSM93-062-1	20
LCE00522	300 534 060 655 300	10-Jul-2020 23:41	MSM93-063-1	2
LCE00523	300 534 060 654 180	10-Jul-2020 23:56	MSM93-063-1	5
LCE00524	300 534 060 650 650	11-Jul-2020 00:11	MSM93-063-1	8
LCE00525	300 534 060 657 620	11-Jul-2020 00:26	MSM93-063-1	11
LCE00526	300 534 060 558 640	11-Jul-2020 00:42	MSM93-063-1	14
LCE00527	300 534 060 355 570	Faulty no battery		
LCE00528	300 534 060 553 700	11-Jul-2020 00:57	MSM93-063-1	17
LCE00529	300 534 060 553 730	11-Jul-2020 01:12	MSM93-063-1	20
LCE00530	300 534 060 556 930	13-Jul-2020 03:11	MSM93-081-1	3
LCE00531	300 534 060 458 030	13-Jul-2020 03:23	MSM93-081-1	7
LCE00532	300 534 060 651 190	13-Jul-2020 03:35	MSM93-081-1	11
LCE00534	300 534 060 353 160	13-Jul-2020 05:17	MSM93-082-1	18
LCE00535	300 534 060 356 590	13-Jul-2020 03:46	MSM93-081-1	15
LCE00536	300 534 060 657 600	13-Jul-2020 03:58	MSM93-081-1	19
LCE00537	300 534 060 650 290	13-Jul-2020 04:29	MSM93-082-1	3
LCE00538	300 534 060 653 590	13-Jul-2020 04:42	MSM93-082-1	6
LCE00539	300 534 060 657 220	13-Jul-2020 04:54	MSM93-082-1	10
LCE00540	300 534 060 554 730	13-Jul-2020 05:05	MSM93-082-1	14
LCE00541	300 534 060 650 160	Not deployed		
LCE00542	300 534 060 555 700	Not deployed		
LCE00544	300 534 060 653 660	Not deployed		
LCE00546	300 534 060 650 400	Not deployed		
LCE00547	300 534 060 651 400	Not deployed		
LCE00549	300 534 060 651 200	Not deployed		
LCE00550	300 534 060 653 390	Not deployed		
LCE00551	300 534 060 558 620	Not deployed		
LCE00552	300 534 060 555 870	Not deployed		
LCE00561	300 534 060 451 020	Not deployed		
LCE00562	300 534 060 652 200	Not deployed		

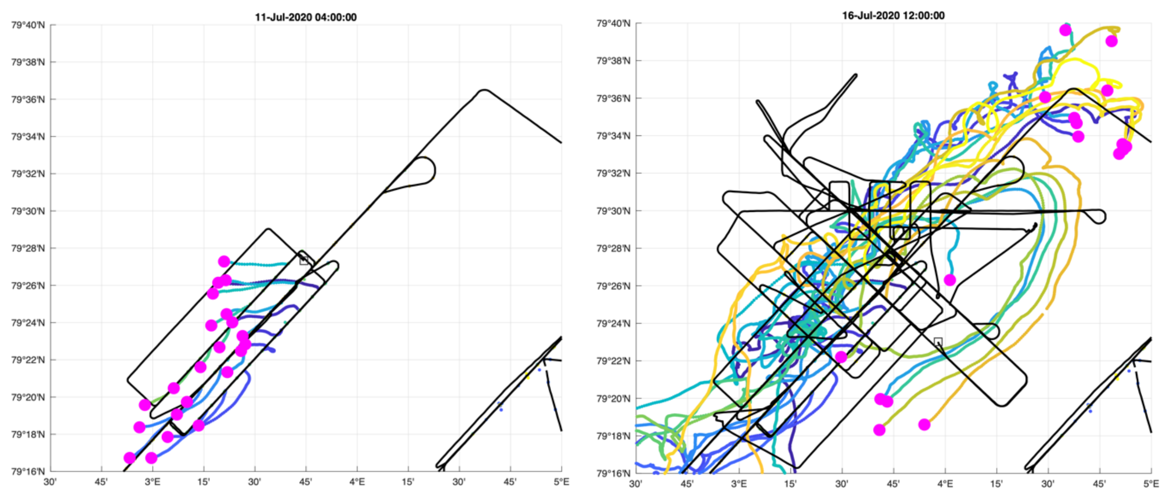

Fig. 5.1.1: Tracks of the surface drifters overlaid on the cruise track until July 11th 4:00UTC (left) and July 16th 12:00UTC (right). The cruise track is in black, the most recent drifter positions are in magenta, and the tracks of each drifter are marked by different colors. The drifters deployed on either side of the front behaved different, either leaving the domain to the southwest or clustering and moving to the northeast.

Visual and radar observations

The front was also visible as streaks of smoother sea surface. This is likely due to the accumulation of positively buoyant surfactants that remain behind at the sea surface when water subducts from the surface. For example, on July 11th, the front was crossed around 21:20UTC. Fig. 5.1.2 highlights the front in the ice radar just prior to crossing it and Fig. 5.1.3 is a visual image of it about 10 minutes later (distance of 1 nautical mile). Another example is Fig. 5.1.4 from July 13th. Some of the deployed surface drifters were seen in close proximity to the steaks. The accumulation of garbage (e.g. toilet paper) was also seen. Those observations were documented as part of the deployment protocols.

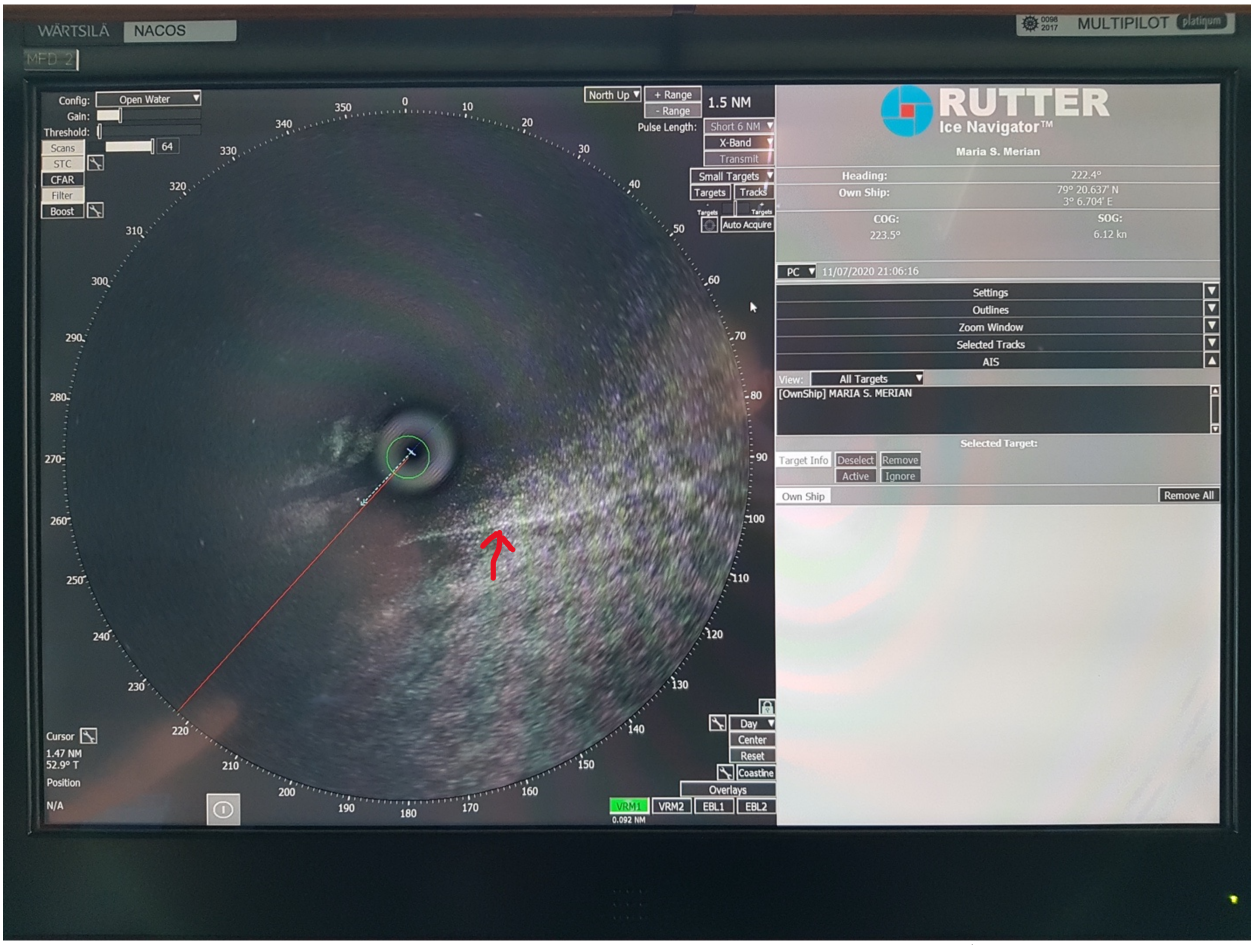

Fig. 5.1.2: Photo of the Rutter Ice Navigator system taken on July 11th at 21:16:35UTC at 79°20.637'N 3°6.704'E. Note the streak marked by the arrow. (Photo by W.-J. von Appen)

Fig. 5.1.3: Photo taken from the bridge facing starboard and slightly forward on July 11th at 21:25:09UTC at 79° 20' 1.998'' N 3° 3' 39'' E. Note the streak marked by the arrow. (Photo by W.-J. von Appen)

Fig. 5.1.4: Photo taken off the stern of the ship on July 13rd at 23:24:15UTC at 79° 30' 28.998" N 3° 55' 46.002" E. The UCTD winch is on the left. Note the streaks crossing at an oblique angle as marked by the arrow. (Photo by W.-J. von Appen)

5.2 Biological Oceanography (Seapump)

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Vertical profiles with the Particle-Camera Package

System description

General description

The Particle-Camera Package consisted of different camera systems to measure vertical profiles of particle size and abundance distributions in the water column. On the frame (Fig. 5.2.1) the In-Situ camera (ISC), the ROSINA (remotely observing in-situ camera for aggregates) system, the UVP (Underwater vision profiler) and a CTD (OceanSeven 310, Idronaut S.r.l) were mounted together. Via a telemetry unit (Fig. 1.2), data and settings of some instruments (ROSINA, CTD) could be observed online during the deployment.

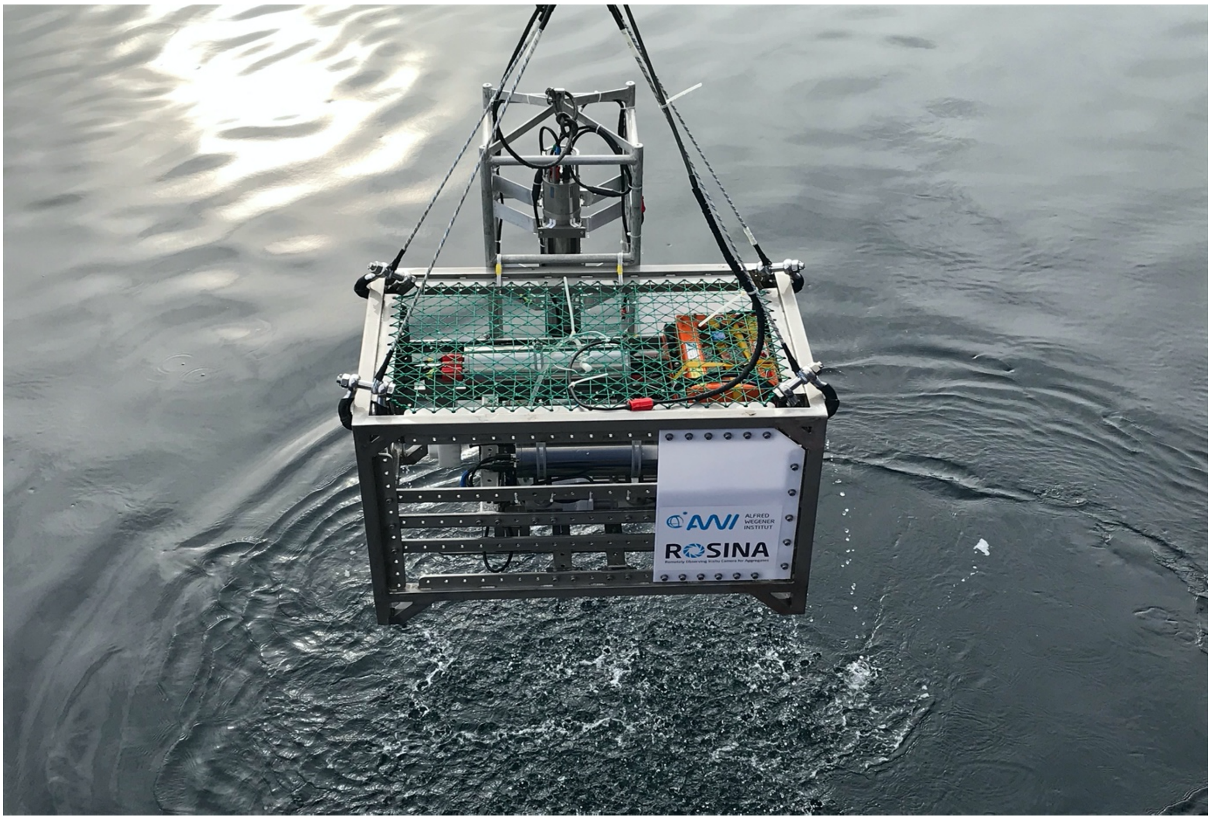

Fig. 5.2.1: ROSINA frame with ROSINA camera system, In-Situ camera and the CTD mounted inside and the UVP mounted outside of the frame in the back (photo by: Christian Konrad)

Fig 5.2.2: Deck unit if the ROSINA system with online monitoring of ROSINA camera and the CTD system (photo by: Christian Konrad)

In-situ Camera

The In-Situ Camera (ISC) consisted of an industrial camera with removed infrared filter (from Basler) with backend electronics for timing, image acquisition and storage of data and a fixed focal length lens (16mm Edmund Optics). Furthermore, a DSPL battery (24V, 38Ah) was used to power the system.

A single board computer was both used as the operating system for the infrared camera and to acquire the images from the camera and send them to an SSD hard drive where they were stored. The illumination was provided by a custom-made light source that consisted of infrared LEDs which were placed in an array in front of the camera. The choice of the infrared illumination was done to avoid disturbing the zooplankton that potentially would feed on the settling particles. With this geometrical arrangement of the camera and the light source we obtained shadow images of particles through the water column. We captured 2 images per second and lowered the particle camera frame with ~0.3 meters per second.

ROSINA (Remotely ObServing IN-situ camera for Aggregates)

The profiling particle camera ROSINA is a highly flexible and modular system and, thus, able to address a range of different research questions related to the biological carbon pump and organic matter transport and transformation. The system consists of a measurement unit and a control unit. The measurement unit (Fig. 1.1) is a stainless-steel frame with all components for the in-situ measurement. It consists of the optical system (camera, lenses and light sources), computing unit, standalone CTD, battery and telemetry. All components of the measurement unit are rated to a depth of at least 4000 m. Since the system is equipped with telemetry, the operator is able to observe the measurement and make changes via the control unit during deployment. The control unit consists of the telemetry, which provides the communication interface and power for the measurement unit, and an operator workstation consisting of a KVM console, PCs, NAS and Ethernet switch (Fig. 5.2.2).

The optical system consists of a 29MPixel camera with global shutter, M58 mount and Dual GigE Vision interface (SVS-Vistec, Germany) and a modular optical front end. Different lenses and adapters are available to cover a wide range of measurement volumes and pixel sizes. For this cruise the optics was usually set to a pixel size of 9.75 µm with a corresponding measurement volume of app. 90 mL per image and app. one image per second. The standard measurements were done with a custom-made backlight source to obtain shadow images.

Via the deck unit of the system, settings and parameters can be changed during the cast and with the online processing feature of the software particle abundance, total area and average equivalent particle diameter can be observed as well as big particles (see Fig. 5.2.3)

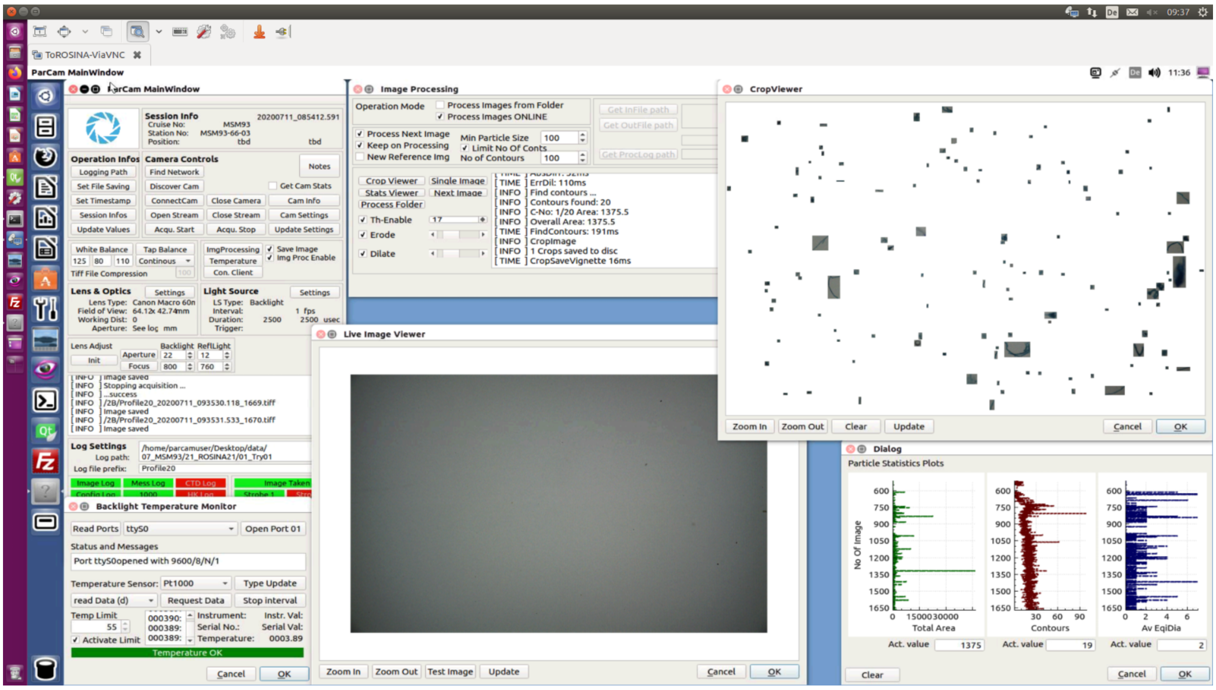

Fig. 5.2.3: Overview of the ROSINA software interface during the cast on the deck unit.

UVP (Underwater Vision Profiler)

The Underwater Vision Profiler fifth generation (UVP5) is a complimentary tool to the *in-situ* camera systems (ROSINA, ISC) and marine snow collecting systems used during the cruise MSM93. The UVP5 is an autonomous instrument with an internal battery and storage. It records particles and images with a maximal frequency of 20Hz. This camera automatically recognises, measures and stores every particle larger than 2 pixels within a defined sample volume (~1L). We worked in the MixtFD mode, which involve cropping out the objects larger than 80 pixels from each image and storing them as vignettes, in order to reduce the amount of data. Given that the UVP5 was mounted on with its aluminium frame (45x45x130 cm) onto the ROSINA frame, all profiles were done at a lowering speed of ~0.3 m/s instead, somewhat slower than the typical deployment speed of 1 m/s for the UVP5 camera. Thus, we adapted the acquisition frequency to 10Hz (mixt10 mode).

The UVP5 can start and stop acquisition following four different modes (manual, pressure, time and I/O). Due to the several inconclusive tests to use the manual acquisition via ROSINA telemetry, the pressure acquisition was used during all deployments except for MSM_22_01 where the I/O sequence was used (YOYO casts). The pressure mode uses the embedded pressure sensor, whereas the I/O mode uses a switch (I/O shunt) to start and stop sequence.

ImageJ (java-based image processing program) and Zooprocess (suite of routine in ImageJ macro language) was used for basic processing after downloading the data. The metadata were stored (*e.g.* cruise, profile ID, station ID) prior to processing of the BRU, DAT, PID files and vignettes.

OceanSeven 310 CTD (Idronaut S.r.l.)
The OceanSeven 310 CTD multi-parameter probe can interface up to 14 analogue sensors and three digital sensors at sampling rates up to 28Hz. During this cruise the CTD was equipped with a sensor for pressure, temperature, conductivity, oxygen, turbidity and chlorophyll *a* (Chla). The system was partly used in unattended mode and partly in attended mode via the ROSINA telemetry to get online profiles of the above mentioned parameters. A sampling rate of 2Hz was chosen for the vertical profiles.

Work at Sea
We made 35 vertical profiles (most of them to from the surface to 500 m) with the Particle-Camera system. An overview of the casts is given in Table 1.1. The 35 stations included three transects. The distance of the transect 1, 2 and 3 were respectively of 35 km (10 stations), 16 km (4 stations) and 3 km (7 stations). In addition, we made a profile before and after the deployments and recoveries of the free-drifting sediment traps. Some of the remaining casts were isolate stations to characterise polar / Atlantic water masses and some of them were test deployments for testing the functionality of the individual systems. The station 04_02 was aborted directly after deployment. Station 13_02 was a successful test deployment with the configuration of ROSINA used for the subsequent casts (Station 22_01 to 99_03). Station 99_03 was run without ROSINA due to a communication error between the camera system and the deck-unit. ROSITEST01 was a test deployment with different optical settings, which were then used also for the station 107_03 cast to 2700m.
For the stations 13_02, 73_01 and 75_01, the UVP5 turned on and recorded data, but only down to 40 m depth. This issue seems to come from of a handling mistake during the pressure start protocol (*e.g.* wrong flushing depth and/or flushing time). Except this problem, the UVP5 and the In-Situ camera were running successfully during all the casts.

Due to a several issues with the CTD system (i*.e.* from ROSINA12), some of the CTD profiles are not available. During the third transect, CTD data were only recorded for the upper 40 m and not down to 500 m, as intended. A wrong factory calibration of the CTD pressure sensor was observed and corrected temporally with the UVP5 pressure sensor. The CTD system will be sent back to the manufacturer to obtain a pressure correction function for the performed casts.

Tab. 5.2.1: Overview of particle camera package casts

Station No	Name	Gears	Profile No.	Date	Start Time	Wdepth	Pdepth
a.u.	a.u.	a.u.	a.u.	DD/MM/YYYY	HH:MM	m	m
MSM93-04-02	ROSINA01	ROSINA, CTD, UVP, ISC	---	02.07.2020	19:44:50	2042	---
MSM93-04-02	ROSINA02	ROSINA, CTD, UVP, ISC	1	04.07.2020	10:49:50	782	500
MSM93-22-01	ROSINA03	ROSINA, CTD, UVP, ISC	2	05.07.2020	18:47:02	2493	500
MSM93-30-01	ROSINA04	ROSINA, CTD, UVP, ISC	3	07.07.2020	06:03:42	2367	500
MSM93-31-01	ROSINA05	ROSINA, CTD, UVP, ISC	4	07.07.2020	07:24:55	2352	500
MSM93-32-01	ROSINA06	ROSINA, CTD, UVP, ISC	5	07.07.2020	08:44:16	2332	500
MSM93-33-01	ROSINA07	ROSINA, CTD, UVP, ISC	6	07.07.2020	10:02:40	2331	500
MSM93-34-01	ROSINA08	ROSINA, CTD, UVP, ISC	7	07.07.2020	11:28:59	2357	500
MSM93-35-01	ROSINA09	ROSINA, CTD, UVP, ISC	8	07.07.2020	12:47:05	2387	500
MSM93-36-01	ROSINA10	ROSINA, CTD, UVP, ISC	9	07.07.2020	16:26:41	2434	500
MSM93-37-01	ROSINA11	ROSINA, CTD, UVP, ISC	10	07.07.2020	17:43:00	2422	500
MSM93-38-01	ROSINA12	ROSINA, CTD, UVP, ISC	11	07.07.2020	19:04:20	2394	500
MSM93-39-01	ROSINA13	ROSINA, CTD, UVP, ISC	12	07.07.2020	20:27:06	2270	500
MSM93-50-02	ROSINA14	ROSINA, CTD, UVP, ISC	13	09.07.2020	12:18:35	2365	500

MSM93-51-01	ROSINA15	ROSINA, CTD, UVP, ISC	14	09.07.2020	19:24:44	1706	500
MSM93-52-02	ROSINA16	ROSINA, CTD, UVP, ISC	15	09.07.2020	22:20:21	3169	500
MSM93-56-02	ROSINA17	ROSINA, CTD, UVP, ISC	16	10.07.2020	07:47:15	1703	500
MSM93-57-01	ROSINA18	ROSINA, CTD, UVP, ISC	17	10.07.2020	11:37:40	2159	500
MSM93-58-03	ROSINA19	ROSINA, CTD, UVP, ISC	18	10.07.2020	15:42:17	3167	500
MSM93-59-01	ROSINA20	ROSINA, CTD, UVP, ISC	19	10.07.2020	17:00:22	3206	500
MSM93-66-02	ROSINA21	ROSINA, CTD, UVP, ISC	20	11.07.2020	09:01:15	2355	500
MSM93-70-01	ROSINA22	ROSINA, CTD, UVP, ISC	21	11.07.2020	16:54:12	3207	500
MSM93-72-01	---	ROSINA, CTD, UVP, ISC	---	12.07.2020	16:20:44	2587	500
MSM93-72-02	ROSINA23	ROSINA, CTD, UVP, ISC	22	12.07.2020	16:47:50	2587	500
MSM93-73-01	ROSINA24	ROSINA, CTD, UVP, ISC	23	12.07.2020	17:58:33	2621	500
MSM93-74-01	ROSINA25	ROSINA, CTD, UVP, ISC	24	12.07.2020	19:11:18	2676	500
MSM93-75-01	ROSINA26	ROSINA, CTD, UVP, ISC	25	12.07.2020	20:24:47	2755	500
MSM93-76-01	ROSINA27	ROSINA, CTD, UVP, ISC	26	12.07.2020	21:42:53	2780	500
MSM93-77-01	ROSINA28	ROSINA, CTD, UVP, ISC	27	12.07.2020	22:57:13	2831	500
MSM93-78-01	ROSINA29	ROSINA, CTD, UVP, ISC	28	13/07/2020	00:15:50	2849	500
MSM93-88-03	ROSINA30	ROSINA, CTD, UVP, ISC	29	13/07/2020	15:40:04	3076	500
MSM93-96-01	ROSINA31	ROSINA, CTD, UVP, ISC	30	14/07/2020	06:36:25	3104	500
MSM93-99-03	ROSINA32	ROSINA, CTD, UVP, ISC	31	15/07/2020	10:20:49	3842	500
MSM93-104-01	ROSINA33	CTD, UVP, ISC	32	16/07/2020	05:18:02	2722	500
---	ROSITEST01	ROSINA, CTD, UVP, ISC	---	21/07/2020	06:45:24		500
MSM93-107-03	ROSINA34	ROSINA, CTD, UVP, ISC	33	26/07/2020	18:07:35	2786	2700

Preliminary results

The preliminary results obtained by CTD measurements seem to highlight a frontal structure in the first hundred meters depth during the transect 1 (Fig. 1.4). This hydrological feature has been characterised by a strong salinity and temperature gradient from southwest to northeast (Fig. 1.4). Sharp differences in the frontal zone were also observed for other environmental variables such as chlorophyll *a* (Chla), turbidity and dissolved oxygen. Along this transect, we observed two water masses of different origin; the (*i*) polar ice melt water mass identified by low salinity and temperature and the (*ii*) Atlantic water mass warmer and saltier. Like for the turbidity measurements, the Chl *a* gradient was less clear, but low concentrations seemed to be recorded in the frontal area (~15 km). No oxygen gradient was observed at the surface but, surprisingly, a small area with a low oxygen concentration was identified at 50 m depth in the frontal zone. This anomaly indicates a high oxygen consumption, potentially due to a high microbial activity or zooplankton grazing.

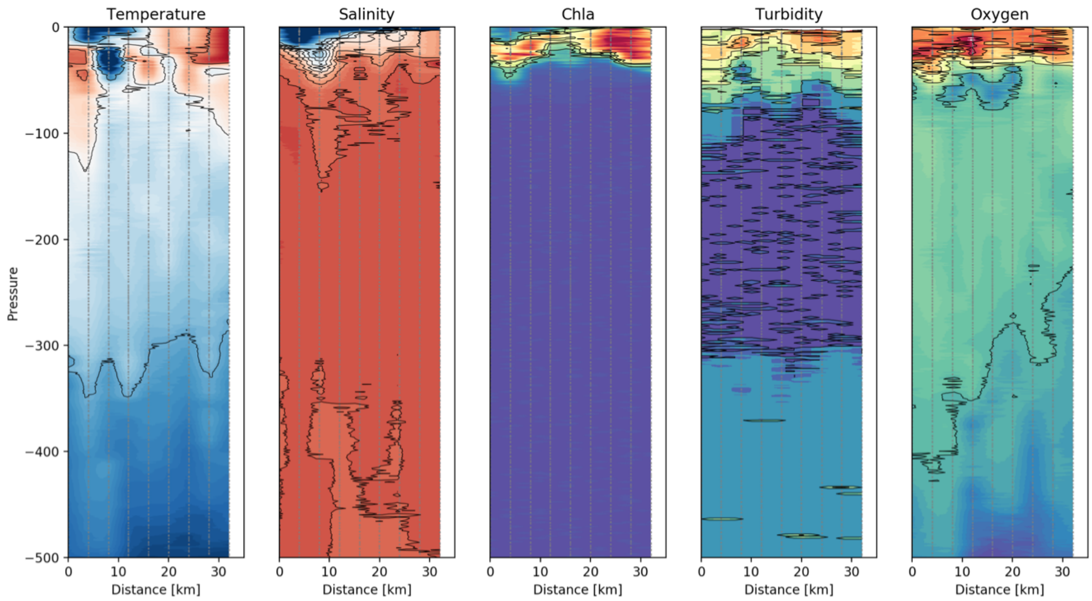

Fig. 5.2.4: Temperature, salinity, chlorophyll a (Chla), turbidity and oxygen representation along the first camera transect during the cruise MSM93.

The simultaneous deployment of the three *in situ* camera systems during the cruise MSM93 represents a great opportunity to describe the sizes and spatial distribution of the particles along the water column. The preliminary results of the inter-comparison between the UVP5 and ROSINA for the total number of observations were promising and showed similar trends for all transects (result not shown). Unsurprisingly, both instruments detected a higher aggregate abundance in the first tens meters depths during the first camera transect (Fig. 5.2.5). ROSINA, and to a lesser extent the UVP5, also recorded a high particle concentration from 50 to 500m depth in the central zone of the front (~15 km). These results suggested that the mesoscale structure promotes particle concentration and export them from the surface to the deep ocean. On the basis of the particle abundance for different size classes from ROSINA, the slope of the size spectra was computed (high and low values represent a dominance of small and large particles, respectively) and showed a dominance of small particles in the core compare to the edge of the hydrological feature (Fig. 5.2.5).

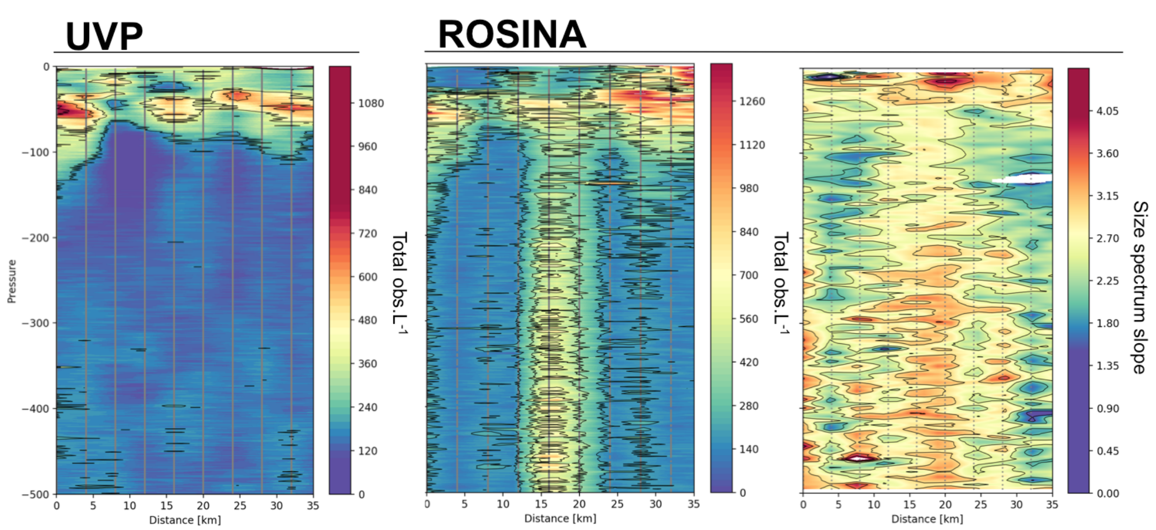

Fig. 5.2.5: Total number of observations recorded by UVP5/ROSINA and the slope size spectra computed from ROSINA particle size-classes along the first camera transect during the cruise MSM93.

The following taxa or groups could be identified from the UVP5 raw images with relative ease (the list is not complete): marine snow (*e.g.* irregular aggregates and faecal pellets), cnidarian, krill, radiolarian, chaetognath, copepod, appendicularian, pteropod and amphipod (Fig. 1.6). As mentioned above, all vignettes and tab separated value tables are being prepared to be imported into the Ecotaxa sorting application. A relationship between planktonic abundances and environmental variables is suspected, however, without a final vignette classification, it is too premature to establish any conclusions about mesozooplankton and/or faecal pellets spatial distribution within the frontal structures.

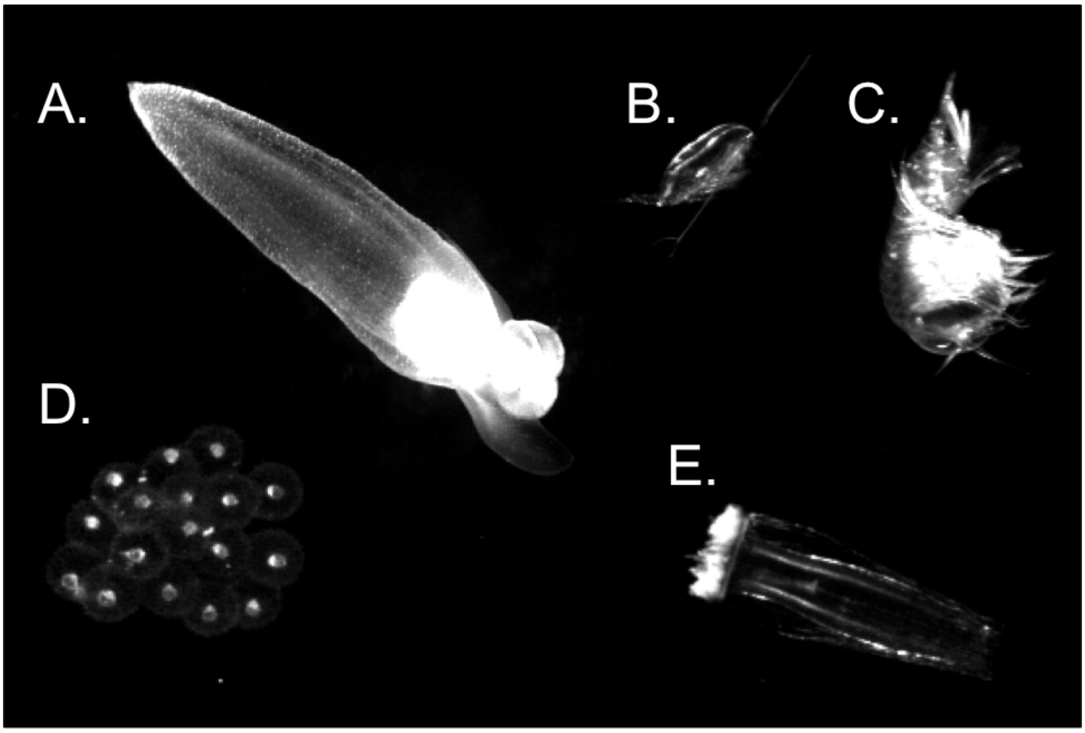

Fig. 5.2.6: Examples of organisms recorded by the UVP5 during the cruise MSM93. The image illustrates the group of (A) pteropod, (B) copepod, (C) amphipod, (D) radiolarian, and (E) cnidarian.

Export flux measured with free-drifting sediment traps

Objectives and work on board

We used an array of free-drifting surface-tethered sediment traps to measure the biogeochemical export fluxes at 100 m, 200 m, and 400 m depth in a polar front system near the ice-edge (Table 5.2.2, Fig. 5.2.7). We deployed the drifting trap three times during the MSM93 cruise and aimed to have a deployment at the frontal zone where Atlantic and Polar waters meet, one deployment in the Polar influenced water, and one deployment in the Atlantic influenced water. The drifting trap array consisted of a surface buoy equipped with an Iridium satellite sender that provided trap positions every 10 minutes with a resolution of two minutes, and two benthos floats for buoyancy. 18 small buoyancy balls were placed between the surface buoy and the two benthos floats to act as wave breakers and thereby reducing the hydrodynamic effects on the sediment traps. Each collection depth had a trap station that consisted of four cylindrical collection tubes, which were mounted to the trap station with gimbal mounts ensuring that they were maintaining a vertical position in the water column (Fig. 5.2.7).

Tab. 5.2.2: Deployments (Depl.) and recovery (Recov.) of free-drifting sediment traps with information about the station numbers (Station No) with dates, times and geographical positions of deployments and recoveries.

Station No a.u.	Profile No. a.u.	Date DD/MM/YY	Time HH:MM	Pos. Lat. dd°mm,mmm'	Pos. Lon. ddd°mm,mmm'
MSM93-56-05	FDF18 Depl.	10/07/20	11:04	79°19,725'N	003°10,065'E
MSM93-56-05	FDF18 Recov.	11/07/20	08:05	79°19,006'N	002°53,538'E
MSM93-88-06	FDF19 Depl.	13/07/20	17:25	79°29,989'N	003°37,993'E
MSM93-88-06	FDF19 Recov.	14/07/20	06:00	79°31,552'N	003°47,300'E
MSM93-99-06	FDF20 Depl.	15/07/20	11:53	79°29,995'N	004°06,050'E
MSM93-99-06	FDF20 Recov.	16/07/20	08:21	79°28,953'N	004°24,183'E

Three of the four collection tubes at each depth collected biogeochemical fluxes for total dry weight, particulate organic carbon, particulate organic nitrogen, particulate inorganic carbon, biogenic silica, lithogenic material, lipids, polysaccharides, etc.. The fourth trap cylinder at each depth was equipped with a viscous gel that preserved the structure, shape and size of the fragile settling particles. After recovery of the drifting traps, the material of one collection cylinder per depth was fixed with $HgCl_2$, stored at 4°C and will be used for bulk biogeochemical analyses in the home laboratory. The material of the remaining two collection cylinders was frozen at -20°C. The particles collected in the gel traps were photographed with a digital camera and with a microscope at four different magnifications on board and frozen at -20°C for further detailed investigations in the home laboratory. The image analyses of the gel traps will be used to determine the type, composition, abundance and size distribution of the sinking particles.

The primary production during the deployment was investigated using the 13C method. Prior each deployment, water from 10 m, 25 m, 50 m and 75 m was collected and filled in 1 L PE bottle. For each depth one light and one dark bottle was labeled with $NaH^{13}CO_3$. The bottles were attached on the drifting trap array and incubated in the corresponding depths during the deployment. After recovery, the labeled water was filtered onto GF/F filters and will be analyzed in the home laboratory.

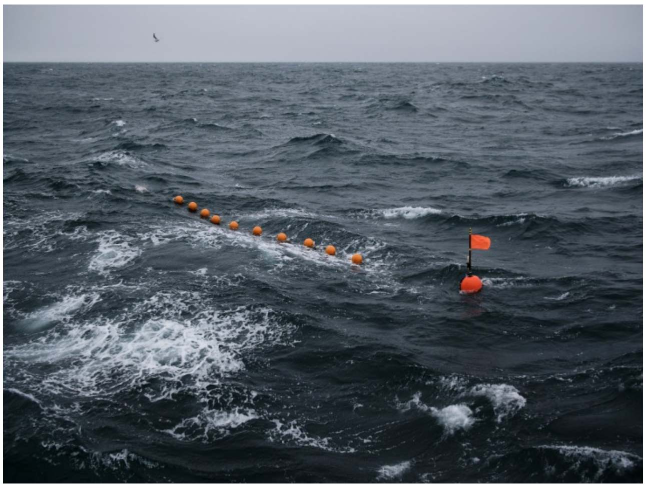

Fig. 5.2.8: Free-drifting sediment trap (left). One of the trap stations with the four sediment trap collection tubes (right). (photos by Tim Kalvelage)

First results

All drifting trap collection tubes contained high densities of slow-sinking *Phaeocystis* colonies. We therefore gently siphoned out the overlaying water from the collection tubes and sieved it through a 5 µm sieve to concentrate and collect the colonies before we collected the faster settling material from the bottom of the collection tubes. The fast-sinking aggregates in the collection cylinders primarily consisted of a mixture of copepod and krill fecal pellets and marine snow aggregates (Fig. 5.2.9). The gel traps deployed in the Polar influenced waters showed a high concentration of small crystalline particles.

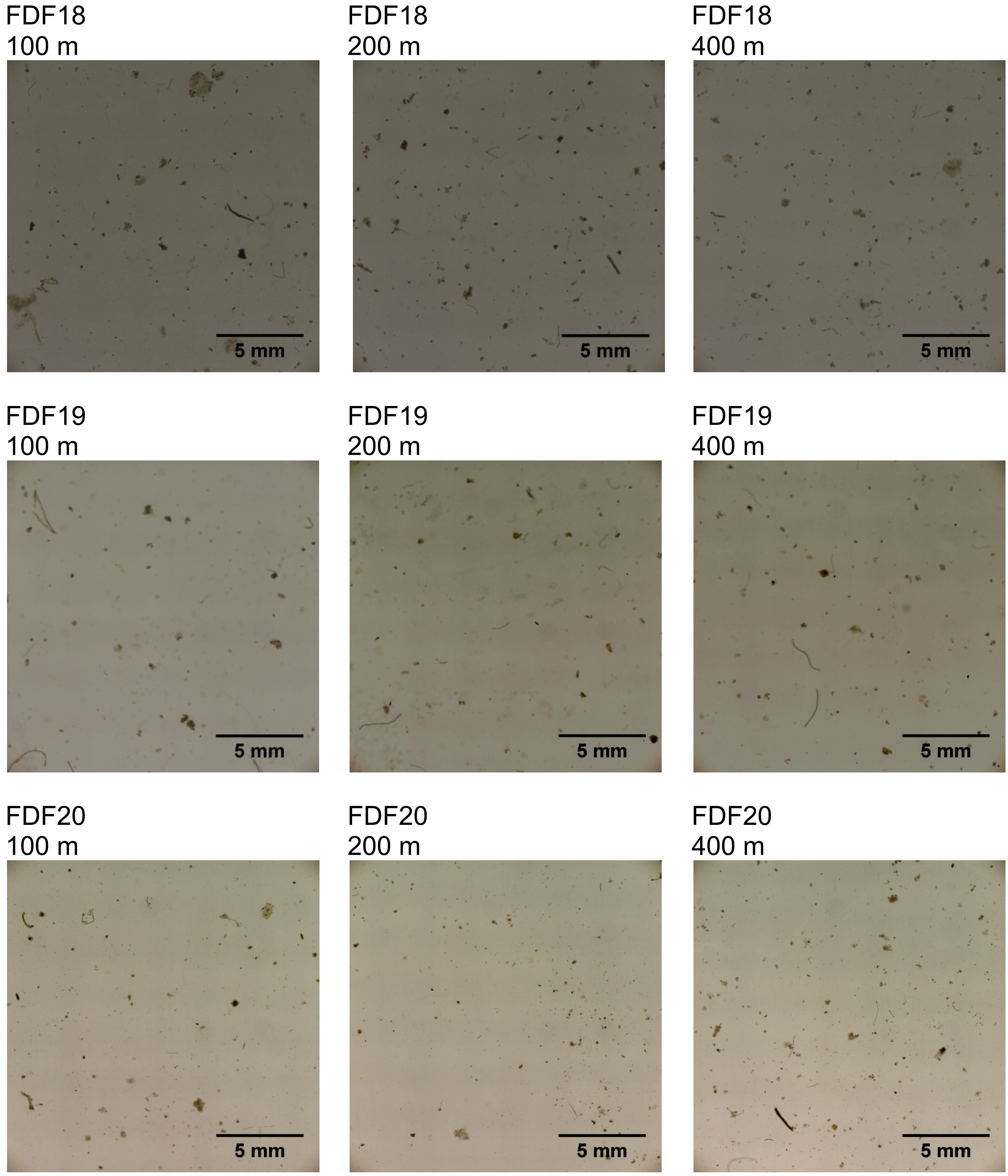

Fig. 5.2.9: Examples of aggregates collected in the gel traps at 100 m, 200 m, and 400 m during 3 drifting trap deployments FDF18, FDF19 and FDF20.

Dissolved nutrients and plankton community composition

Objectives and work on board

The objective of this work was to relate the nutrient concentrations to the water masses influenced by Atlantic versus Polar waters, as well as linking the abundance and composition of phytoplankton and heterotrophic organism to water masses and nutrient concentrations and see their impact on primary production, aggregate formation and export flux.

Nutrients were sampled from Niskin bottles using the CTD-Rosette cast. We generally sampled six to eight water depths through the upper 400 m of the water column (Table 5.2.3). 50 mL water

samples were taken for nutrients analysis which were immediately frozen and stored at -20°C for analysis in the home laboratory. The ammonium concentration of the samples was measured fluorometric on board using a spectrometer.
Samples for identification of phytoplankton and microzooplankton were collected from the chlorophyll maximum depth. We collected 50 mL of sea water for microscopic analyses of phytoplankton and fixed them with formaldehyde to a final concentration of 0.5% before the samples were stored at 4°C. For microscopic analyses of microzooplankton two times 14 mL of sea water were fixed with 1 mL Lugol's iodine and stored at 4°C. Samples for cell counts using Flow Cytometry from the chlorophyll maximum were fixed with 1.2% Glutardialdehyde, flash frozen with liquid nitrogen and stored at –80°C.
To determine the aggregate potential of the plankton community, we incubated water from the chlorophyll maximum in roller tanks (five replicates) at three stations i) the frontal zone, ii) a station that was dominated by Atlantic water and iii) a station that dominated by Polar water.

Tab. 5.2.1: Overview of CTD casts for nutrient and plankton sampling, including station number (Station No), CTD cast, sampling date (Date), sampling time (Time), and geographical position (Pos. Lat. And Pos. Lon.).

Station No a.u.	CTD cast a.u.	Date DD/MM/YY	Time HH:MM	Pos. Lat. dd°mm,mmm'	Pos. Lon. ddd°mm,mmm'
MSM93-04-01	CTD04_01	02/07/20	17:47	79°00,463'N	005°40,000'E
MSM93-39-02	CTD39_02	07/07/20	21:33	79°30,569'N	005°37,859'E
MSM93-41-01	CTD41_01	08/07/20	02:53	79°18,032'N	004°33,987'E
MSM93-43-01	CTD43_01	08/07/20	04:41	79°21,151'N	004°49,830'E
MSM93-45-01	CTD45_01	08/07/20	06:22	79°24,293'N	005°05,800'E
MSM93-47-01	CTD47_01	08/07/20	08:24	79°27,436'N	005°21,798'E
MSM93-50-01	CTD50_01	09/07/20	11:29	79°51,363'N	000°49,924'E
MSM93-51-02	CTD51_02	09/07/20	20:18	79°19,721'N	003°10,124'E
MSM93-56-01	CTD56_01	10/07/20	06:53	79°19,723'N	003°10,075'E
MSM93-57-02	CTD57_02	10/07/20	12:38	79°21,556'N	003°19,536'E
MSM93-58-02	CTD58_02	10/07/20	14:58	79°24,577'N	003°34,664'E
MSM93-59-02	CTD59_02	10/07/20	18:05	79°26,005'N	003°42,004'E
MSM93-66-01	CTD66_01	11/07/20	07:07	79°18,776'N	002°54,875'E
MSM93-88-01	CTD88_01	13/07/20	13:41	79°29,988'N	003°37,993'E
MSM93-99-01	CTD99_01	15/07/20	08:25	79°29,995'N	004°06,051'E

First results
The peak in ammonium concentration was typically observed below the depth of chlorophyll maximum (Fig. 5.2.10). At depths below 200 m the ammonium concentration was lower than the detection level at all measured stations.

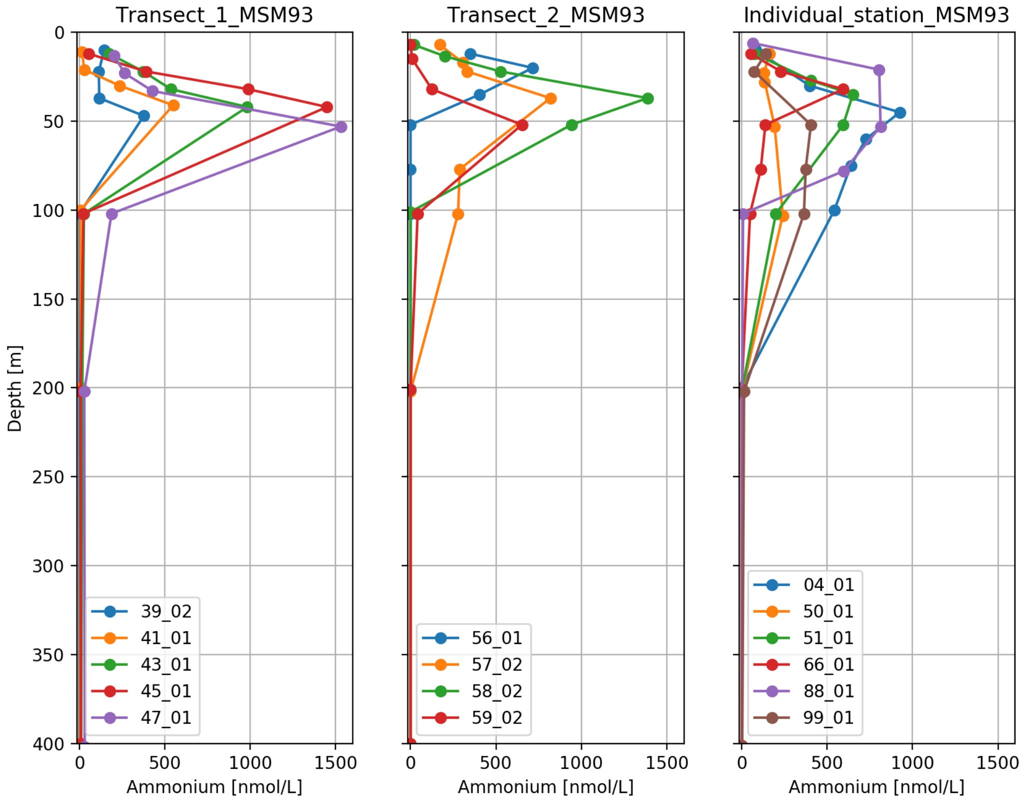

Fig. 5.2.10: Ammonium [nmol/L] depth profiles along two transects (left and middle panel) and at individual stations (right panel) during the cruise (MSM93).

Marine Snow Catcher

Objectives and work on board

Marine Snow Catchers (MSCs, company OSIL) were used to collect *in situ* formed marine snow aggregates in the Arctic front system. The MSCs were deployed ~10 m below the depth of chlorophyll maximum (Table 5.2.4), except when specific water masses were targeted. This depth generally had a high concentration of larger aggregates in the vertical camera profiles measured with the ROSINA (see the cruise report for ROSINA). After recovery, the MSCs were left on deck to allow the collected aggregates to sink to the bottom compartment of the MSCs. Hereafter the overlaying water in the MSCs were gently drained and the bottom compartment with aggregates and water was brought to the laboratory for further measurements.

The aggregate size and settling velocities were measured in a vertical flow chamber. An O_2 microsensor was used to measure the microbial respiration rate. Single aggregates were photographed to determine the aggregate composition. Similar aggregate types and sizes were then pooled and filtered on GF/F for measurements of dry weight and particulate organic carbon and nitrogen content.

Tab. 5.2.4: Overview of Marine Snow Catcher deployments, including station number (Station No), MSC deployment (Name), date, time, deployment depth (Depth), and geographical position (Pos. Lat. and Pos. Lon.).

Station No a.u.	Name a.u.	Date DD/MM/YY	Time HH:MM	Depth m	Pos. Lat. dd°mm,mmm'	Pos. Lon. ddd°mm,mmm'
MSM93-13-03	MSC01	04/07/20	14:13	45	78°59,994'N	008°19,722'E
MSM93-13-03	MSC02	04/07/20	14:25	45	78°59,994'N	008°19,722'E
MSM93-39-03	MSC03	07/07/20	22:33	35	79°30,570'N	005°37,857'E
MSM93-56-03	MSC05	10/07/20	08:55	25	79°19,725'N	003°10,066'E
MSM93-88-04	MSC06	13/07/20	16:45	45	79°29,989'N	003°37,994'E
MSM93-88-05	MSC07	13/07/20	17:00	50	79°29,989'N	003°37,994'E
MSM93-99-04	MSC08	15/07/20	11:26	40	79°29,995'N	004°06,051'E
MSM93-99-05	MSC09	15/07/20	11:38	40	79°29,995'N	004°06,051'E

First results

The marine snow aggregates consisted primarily of diatoms, *Phaeocystis,* mucus, degraded fecal pellet and intact fecal pellet (Fig. 5.2.11). Dinoflagellates and ciliates were associated as grazers to the aggregates. An example of size to settling velocities measured on the cruise can be found in Fig. 5.2.12.

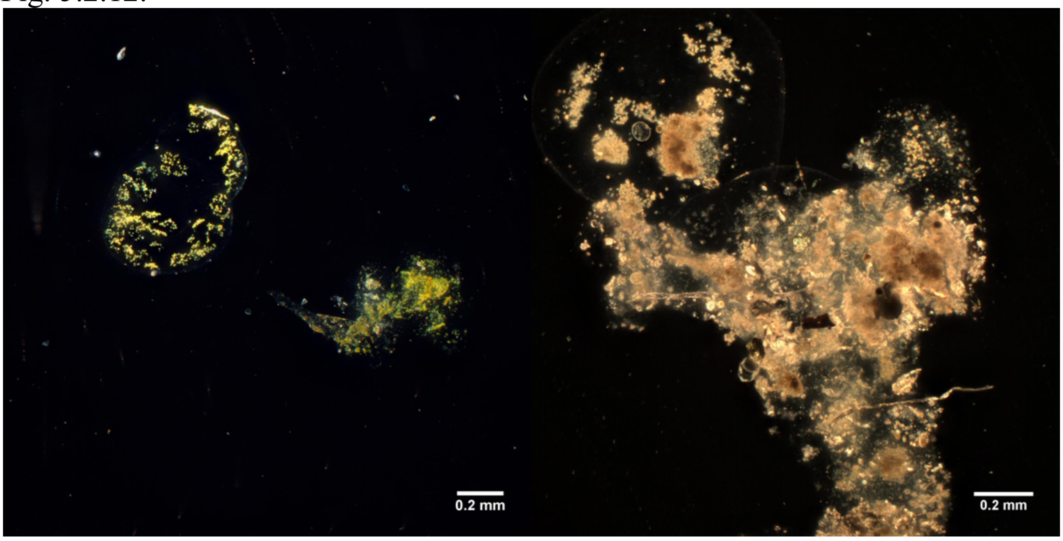

Fig. 5.2.11: Example of marine snow aggregates found in the Arctic front study.

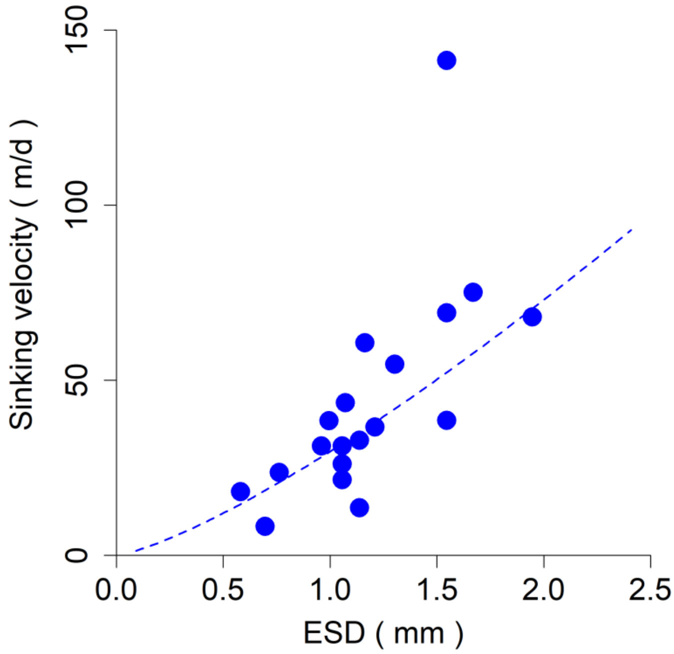

Fig. 5.2.12: Size to settling velocities of MSC3 on cruise MSM93: Sinking velocity in m/d is plotted against Equivalent spherical diameter (ESD) in mm. The sinking velocities of each individual aggregate of MSC3 are plotted as well as the corresponding power function.

5.3 Optical Phytoplankton Observations (Phytooptics)

J. Oelker (UniHB), W. Körtke (UniHB), A. Bracher (AWI/UniHB, not on board)

Active and passive bio-optical measurements for the survey of the underwater light field, and of the particle and phytoplankton composition and distribution.

General description

Marine phytoplankton is the basis of the marine food web and also a main component of biogeochemical fluxes, thus, an important source of dissolved and particulate organic substances. At this cruise we focused to broaden our sampling frequency of information on phytoplankton, particulate and chromophoric dissolved organic matter (CDOM) abundance and composition by taking continuous optical measurements which directly give information on inherent and apparent optical properties (IOPs, and AOPs, respectively), These can later be inverted to extract information on the above listed parameters. Additionally, the measurements of the spectrally resolved underwater light intensity are important input parameter to calculate phytoplankton productivity from proxy data. The specific objectives during MSM939 were to

- collect a high spatial and temporal resolved data set on phytoplankton (total and composition) and its degradation products at the surface (with benchtop-based instrumentation), and for the full euphotic zone at discrete stations (with a light profiler) and continuous transects (with instrumentation mounted to the Triaxus system) using continuous optical observations during the cruise calibrated with discrete water sample measurements,
- support the optical data collection by the TOPAWI-Triaxus via instrument calibration, monitoring and comparisons to our underway and station optical data collection,
- develop and validate (global and regional) algorithms and associated radiative transfer models in accordance to the previous objective by using discrete water samples for pigment analysis and absorption measurements,
- obtain a big data set for ground-truthing ocean color satellite data, specifically from the new Sentinel-3 (A and B) OLCI and the Sentinel-5-Precursor TROPOMI sensors,
- identify bio-physical-chemical coupling with cooperation partners from MSM93 by using this comprehensive data sets to detect shifts in phytoplankton community biomass and composition and the factors driving the variability and changes in phytoplankton community and its degradation products.

Work at Sea

Continuous surface phytoplankton, other particle and dissolved organic matter data

For the continuous underway surface sampling an in-situ–spectrophotometer (AC-S; Wetlabs) was operated continuously from 27 June until 20 July 2020 in flow-through mode to obtain total and particulate matter attenuation and absorption spectra of surface water with high spectral (~3.3 nm) resolution from 400 to 800 nm. The instrument was mounted to a seawater supply taking water from about 11 m depth through the teflon tubing with a membrane pump. A flow-control with a time-programmed filter was connected to the AC-s to allow alternating measurements of the total and the CDOM inherent optical properties of the sea water. Flow-control and debubbler-system ensured water flow through the instrument with no air bubbles. The instrument is operated via the Wetlabs software COMPACTt which stores the data recorded at 4 Hz every 10 min. into a new file. The setup and measured spectra of the flowthrough AC-S on MSM93 can be seen on Figure 5.3.1.

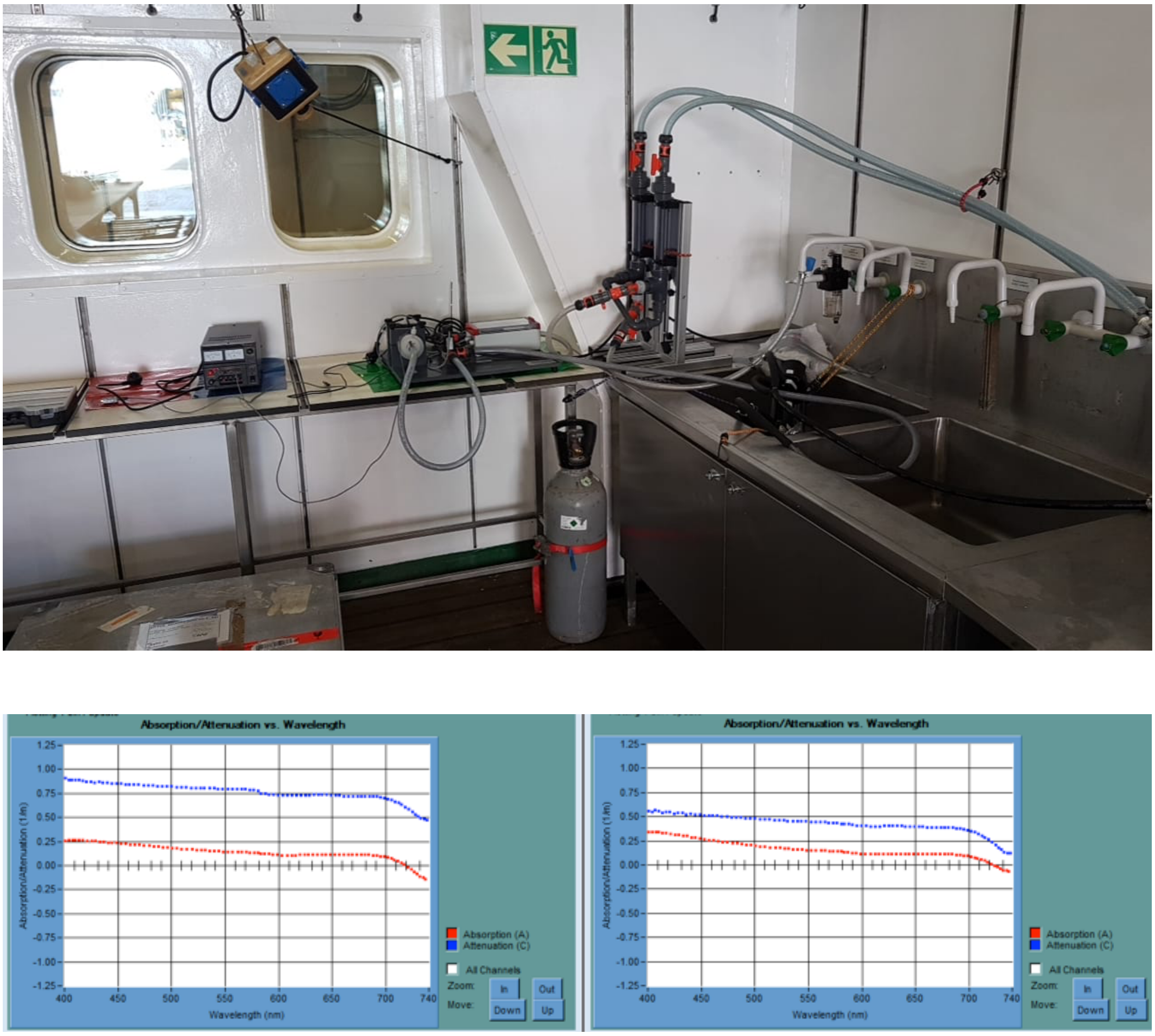

Fig. 5.3.1: Underway surface water measurements of total and particulate absorption and attenuation with the AC-s system. Upper panel: setup of instrumentation on MSM. Lower panel: Examples of absorption (red) and attenuation (blue) spectra acquired with the AC-S instrument.

Transects monitoring within the water column phytoplankton, other particle and dissolved organic matter with active and passive optical instrumentation

A second AC-S instrument was mounted on a steel frame together with a depth sensor together with a set of radiometers (RAMSES sensor, TRIOS) and operated after or before CTD stations (see Figure 5.3.2 left panel) at 15 Stations in total (see Table 5.3.1). The frame was lowered down to maximally 130 m with a continuous speed of 0.1 m/s and with about a 30 second stop at every 5 m until 30m and then every 10m until the maximum depth. The frame was then heaved with a continuous speed of 0.5 m. Data from both instrumentation systems were stored onto a DH-4 data logger and downloaded immediately after each cast.

A third AC-s instrument and another RAMSES irradiance sensor, looking upwards and collecting downwelling iradiance data, were mounted looking upwards at the TOPAWI Triaxus system (Figure 5.3.2 right panel) and operated at all Triaxus deployments. Data were online transferred to the steering computers on the ship using for RAMSES sensor the original Trios software msda_xe and for ACS the Wetlabs COMPACT software-

The second and third AC-s instruments only obtained total absorption and attenuation data, since no filter could be mounted to the instruments during operation in water. All three AC-S instruments were regularly calibrated by taking measurements of MilliQ water. The flowthrough-ACS was calibrated daily, the discrete station profiling AC-s was calibrated after every 2 casts and the TRIAXUS-AC-s was calibrated before each TRIAXUS deployment.

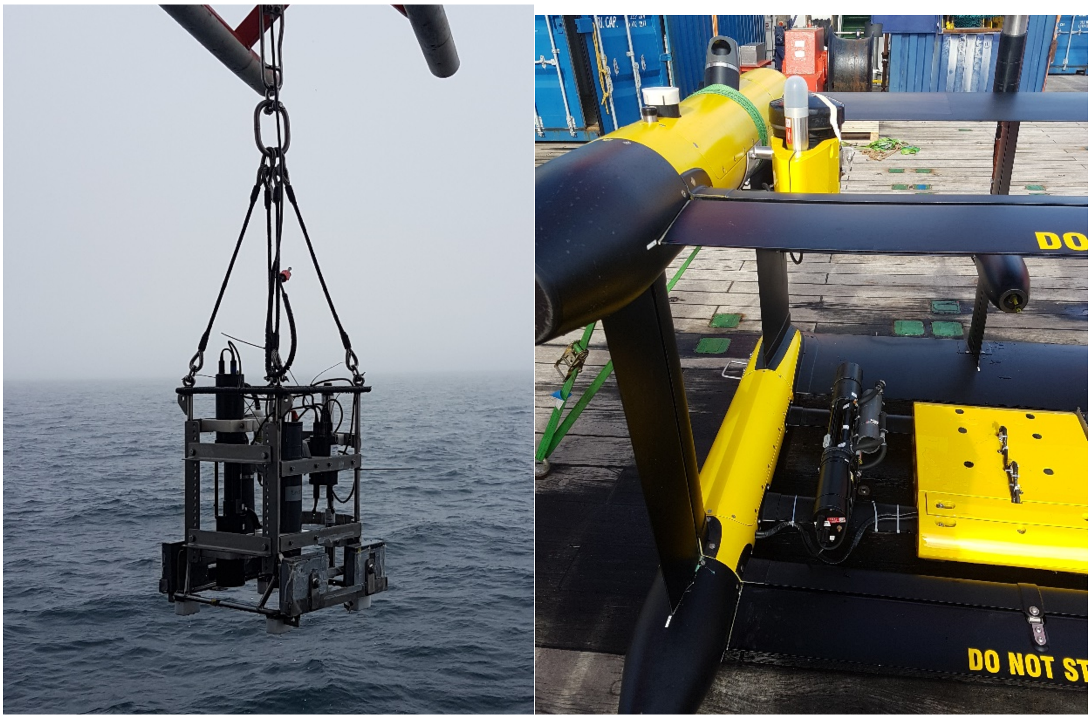

Fig. 5.3.2: Left - light profiler operated at discrete stations down to 130 m with a hyperspectral transmissiometer and absorptionmeter (AC-s, Wetlabs) and hyperspectral upwelling radiance (ACS-RAMSES, Trios) and downwelling irradiance sensors ACC-(RAMSES, Trios); right - topAWI Triaxus system with the two hyperspectral instruments AC-s (Wetlabs; lower part) and downwelling irradiance sensor (RAMSES, Trios; upper part).

The RAMSES underwater radiation data were corrected by changes in solar irradiance, which measured continuously during the light stations and TRIAXUS deployments with another RAMSES ACC irradiance sensor on the same side of the ship cruise. This sensor was operated always without shading by the ship.

Validation of geophysical quantities on phytoplankton, other particle and dissolved organic matter composition and abundance with discrete water sample analysis data

For the validation of the geophysical quantities derived from the ACS and RAMSES instrumentation on the various platforms (benchtop, light profiler, Triaxus) we further took water samples for HPLC pigment analysis and the absorption of particulate matters (PAB) and phytoplankton and CDOM absorption. Samples were collected 1) from the underway surface sampling (as for the AC-s flow-through system at from the ship's sea water pump) at an interval of 3 hours (212 underway stations in total), 2) from the CTD station water sampling collected at 6 depths and collocated to the light profiler stations, and 3) additionally from 27 more CTD stations sampled at 12 m depth when also the optical instruments on the TRIAXUS system were operated.

Samples for determination of phytoplankton pigment concentrations were filtered on board immediately after sampling and the filters are thermally shocked in liquid nitrogen. Samples were stored at -80°C until ship was back in Emden and then directly transported on dry ice to AWI

Bremerhaven and then further stored there until their analysis by High Performance Liquid Chromatography Technique (HPLC) in January 2021 following Taylor et al. (2011). Samples for analysis of CDOM absorption were filtered through 0.2 µm filters and analyzed later at AWI with the Liquid Waveguide Capillary Cell system (LWCC, WPI) following Levering et al. (2017). Particulate and phytoplankton absorption coefficients were determined with the quantitative filter techniques using sample filtered onto glass-fiber filters QFT-ICAM and measuring them in a portable QFT integrating cavity setup according to Röttgers et al. (2016) immediately after filtration of the water sample on board.

Preliminary Results

All samples collected at discrete stations and ACS and RAMSES measurements obtained at discrete stations are listed in Table 5.3.1. Due to limited personnel onboard MSM93 for Phytooptics tasks (related to COVID-19 adaptations of the cruise schedule) no preliminary results were obtained during MSM93. Samples for HPLC, PABS, CDOM were collected and measured for PAB on board, but will be further measured by HPLC and CDOM at AWI. All discrete sample data are analysed back in the home laboratories at AWI.

The Light profiler data logger output data will be converted for the AC-S data into ascii files using Wetlabs software Wetview and RAMSES data using own written software for conversion into msda_xe formatted ascii output. Further, all ACS- and RAMSES which were collected require further processing to derive IOPs and AOPs. Thee RAMSES station and Triaxus data are going to be processed as in Taylor et al. (2011) and further detailed in Tilstone et al. (2020) following IOCCG protocol from 2019. The AOP data will be further analysed to obtain phytoplankton composition and abundance in the profile using the method developed in Bracher et al. (2020). From the AC-s measurements the inherent optical properties (IOPs: total attenuation, scattering and absorption) in the water profile will be derived. The AOP and IOP data will be further analysed by applying inverse radiative transfer modelling and optimal estimation approaches using spectral decomposition to derive the composition and amount of phytoplankton, other particles and CDOM (e.g., following Liu et al. 2018, Liu et al. 2019, Bracher et al. 2020).

Tab. 5.3.1: Bio-optical parameters sampled at MSM93. HPLC: Phytoplankton pigments by High Pressure Liquid Chromatography; CDOM: Coloured Dissolved Organic Matter absorption; PAB: Particulate and phytoplankton absorption; RAMSES: hyperspectral upwelling and downwelling radiation in the water; ACS: hyperspectral total absorption and attenuation. The samples for HPLC, PAB and CDOM were collected at discrete depths indicated under "depth", the ACS- and RAMSES profile were obtained until 130m depth.

Station	Date time (Action)	Latitude	Longitude	Depth	HPLC	PAB	CDOM	Light profile
MSM93_4-1	7/2/2020 17:45	79.01	5.66	13, 23, 47, 62, 77, 102	X	X	X	4-3 & 4-4
MSM93_9-1	7/3/2020 18:27	79.00	9.32	12, 22, 37, 71, 101, 151	X	X	X	9-2
MSM93_10-1	7/3/2020 20:40	79.00	9.00	12	X	X	X	
MSM93_12-1	7/3/2020 22:30	79.01	8.33	12	X	X	X	
MSM93_13-6	7/4/2020 15:23	79.00	8.30	12, 27, 62, 82, 102, 152	X	X	X	13-7
MSM93_15-1	7/4/2020 19:16	79.00	7.66	13	X	X	X	
MSM93_16-1	7/4/2020 20:39	79.00	7.33	12	X	X	X	
MSM93_17-1	7/4/2020 22:08	78.99	6.98	12	X	X	X	
MSM93_18-1	7/4/2020 23:27	79.00	6.66	12	X	X	X	
MSM93_19-1	7/5/2020 0:58	79.00	6.33	12	X	X	X	
MSM93_20-1	7/5/2020 2:30	79.00	6.00	12	X	X	X	but 24-1
MSM93_26-2	7/6/2020 19:45	79.00	5.61	12, 17, ,27, ,37, 62, 102	X	X	X	26-1
MSM93_27-1	7/6/2020 22:05	79.00	5.33	12	X	X	X	
MSM93_28-1	7/7/2020 0:11	79.00	5.00	12	X	X	X	
MSM93_29-1	7/7/2020 2:22	79.00	4.67	12	X	X	X	
MSM93_39-2	7/7/2020 21:32	79.51	5.63	12, 22, 37, 47, 62, 102	X	X	X	39-4
MSM93_41-1	7/8/2020 2:52	79.30	4.57	11	X	X	X	
MSM93_43-1	7/8/2020 4:39	79.35	4.83	12	X	X	X	
MSM93_45-1	7/8/2020 6:31	79.40	5.10	12	X	X	X	
MSM93_47-1	7/8/2020 8:24	79.46	5.36	13	X	X	X	
MSM93_50-1	7/9/2020 11:28	78.86	0.83	12	X	X	X	
MSM93_51-2	7/9/2020 20:23	79.33	3.17	12	X	X	X	
MSM93_52-1	7/9/2020 21:42	79.40	3.51	12	X	X	X	
MSM93_56-1	7/10/2020 6:53	79.33	3.17	12, 20, 35, 52, 77, 102	X	X	X	56-4
MSM93_57-2	7/10/2020 12:37	79.36	3.33	12	X	X	X	
MSM93_58-2	7/10/2020 14:56	79.41	3.58	13.5,22,37,52,101,151	X	X	X	58-1
MSM93_59-2	7/10/2020 18:03	79.43	3.70	12	X	X	X	
MSM93_67-1	7/11/2020 10:32	79.33	3.17	17, 27, 37, 72, 102, 152	X	X	X	67-2
MSM93_68-1	7/11/2020 13:02	79.36	3.32	12	X	X	X	
MSM93_69-2	7/11/2020 15:38	79.41	3.58	17, 27, 42, 72, 101, 151	X	X	X	69-1
MSM93_84-1	7/13/2020 8:16	79.50	3.44	12	X	X	X	
MSM93_86-1	7/13/2020 10:32	79.50	3.53	12,17,32,52,72,102	X	X	X	86-2
MSM93_88-1	7/13/2020 13:41	79.50	3.63	6, 21, 33, 53, 78, 102	X	X	X	88-2
MSM93_90-1	7/13/2020 19:24	79.50	3.73	10	X	X	X	
MSM93_92-1	7/13/2020 21:25	79.50	3.83	12	X	X	X	
MSM93_98-1	7/15/2020 7:00	79.50	3.98	10	X	X	X	
MSM93_99-1	7/15/2020 8:22	79.50	4.10	12,22,52,77,102	X(not77)	X	X	99-2
MSM93_100-1	7/15/2020 13:00	79.50	3.85	12	X	X	X	
MSM93_101-1	7/15/2020 14:26	79.50	3.73	7, 12, 22, 52, 67, 102	X	X	X	101-2
MSM93_102-1	7/15/2020 16:46	79.50	3.60	12	X	X	X	
MSM93_107-2	7/26/2020 16:46	65.73	-5.37	12, 27, 42, 62, 102, 152	X	X	X	107-2

5.4 Trace Gas Sampling

W. Körtke (Uni Bremen), L. Mathieu (AWI), Z. Hofmann (AWI), M. Walter (UniHB, not on board)

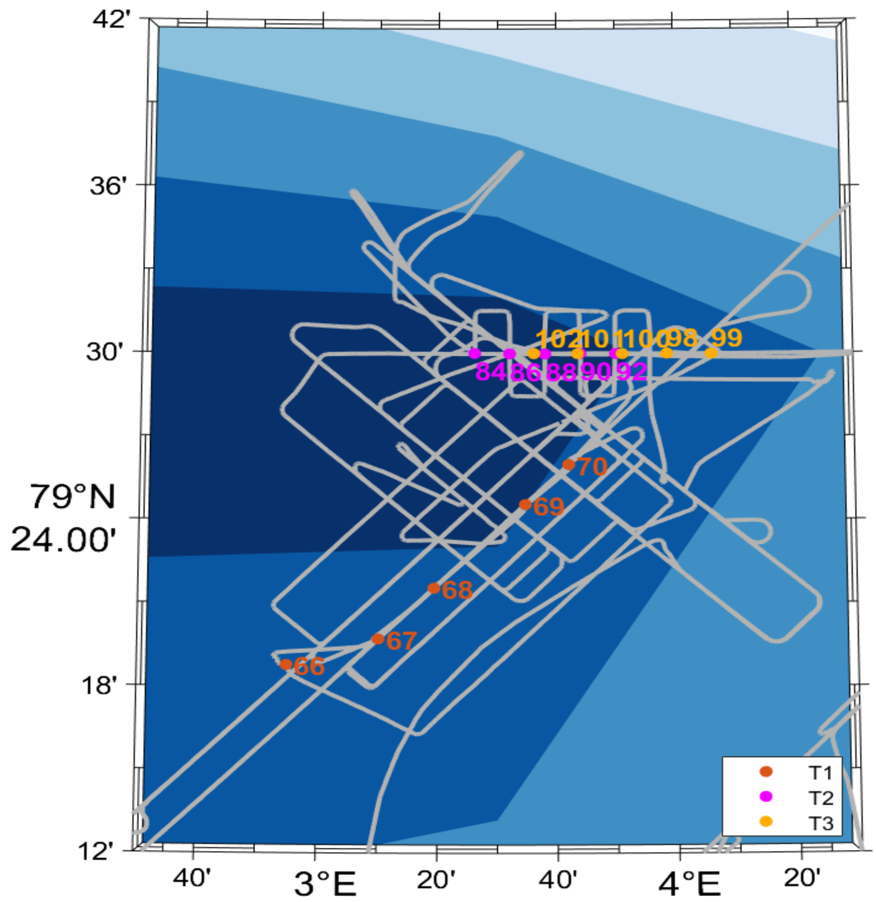

Fig. 5.4.1: Map showing the location of station tracer sampling on three Transects (T1 - T3) within the front study area.

The gas sampling is split into three different parts: transient tracers (CFC-11, CFC-12, SF_6), noble gases (He, Ne), and Tritium. Within the area of the front study, all three components were sampled at all station in the same depths. At each station, nine different depths between the surface and 500 m depth were covered, with a higher resolution in the upper 200 m. For the transient tracers and the noble gases one replicate sample was taken at each station for quality control.

In most cases, it was possible to sample the transient tracers and the noble gases from different Niskin bottles. Thus, the samples were taken from freshly opened bottles, to minimize contamination with air from the surrounding atmosphere. Tritium was mostly taken from the same CTD-bottle as the transient tracers before.

Fig. 5.4.1 is showing the front study area. The stations of tracer gas sampling are indicated by the coloured dots, color-coded for the different transects, respectively. In Fig. 5.4.3 the temperature profiles along Transect 1 are shown. The red dots show the depth distribution of the taken samples. A sampling took place at every station in eight pre-defined depths. An additionally depth was chosen in the depth range of 5 – 20 m, depending on the observed water masses at each station. Consequently, nine depths were covered at each station. For each profile, double samples were taken in different depths, covering different concentrations of the gases. Details on the sampling depths can be found in Tab. 5.4.1.

Sampling of Transient Tracers

During the cruise MSM93 samples for the anthropogenic trace gases sulphurhexafluoride (SF_6) and chlorofluorocarbons (CFC-11, CFC-12), were taken. The sampling at sea was a so-called offline tracer sampling, as the samples will be analysed post-cruise in the IUP-laboratory at the University of Bremen.

The water samples were taken from the Niskin and collected in 200 ml glass ampoules. No contact to the atmosphere during tapping took place. After sampling, the glass ampoules were flame sealed. A CFC-free headspace of pure nitrogen was applied before sealing (see Fig. 5.4.2).

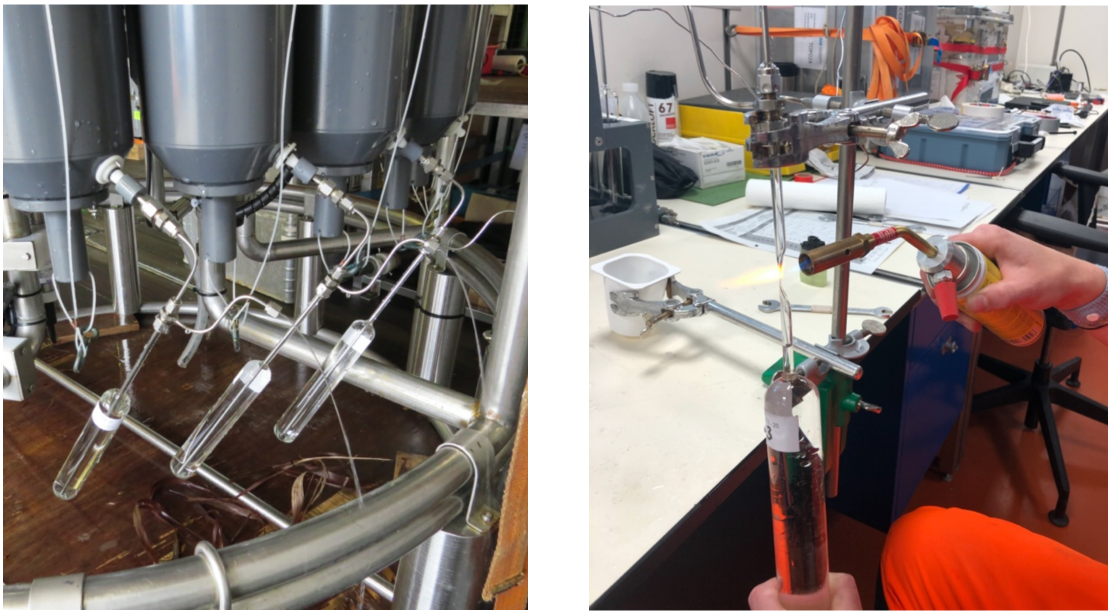

Fig. 5.4.2: Transient Tracer sampling into 200 ml glass ampoules from the CTD (left) and flame sealing of a glass ampoule (right). (Photo: W. Körtke and C. Engicht)

In total 163 ampoules with water samples for the tracer concentration were sampled at 17 stations. Station 04 was a test-station to check workflow and equipment. Three double samples were taken in different depths. The last station, station 107, was done in international waters outside the front study area. Samples were taken to compare the age analysis by trace gases with the age analysis based on biological parameters.

Within the working area of the front study, five stations per transect and day were performed. At each station ten samples for the transient tracers were collected from the CTD-system. Only once (Station 84), the 100 m depth sample could not be sampled due to a leaky Niskin. Samples were taken on both sides of the front to cover the different oceanographic conditions, namely Polar and Atlantic Water. The analysis of the samples will commence in January 2021 and is planned to be finished mid-2021.

Sampling of Noble Gases

In total, 155 water samples for Helium (He) and Neon (Ne) in copper tubes were taken at 16 stations. One station (Station 04) was performed as a station for testing equipment and methods. The following 15 stations were part of the front study. Ten samples (including replicate sample) were taken at each station. Five stations per transect were executed. One measurement in 100 m depth at station 84 is missing due to a leaky Niskin bottle. All other samples could be taken.

The water samples for He and Ne were tapped from the CTD-bottle-system into gas tight copper tubes. All air bubbles were removed before both ends of the tube were shut to prevent further gas exchange with the environment (see Fig. 5.4.2). The analysis of the noble gases will be done later in the IUP Bremen noble gas mass spectrometry lab. The analysis is planned to be finished mid-2021.

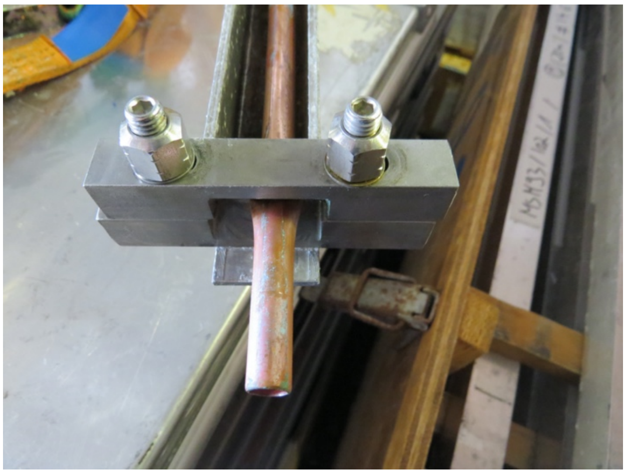

Fig. 5.4.3: Shut copper tube for Noble Gas sampling. (Photo: W. Körtke)

Sampling of Tritium

For the analysis of the tritium concentration, a total amount of 139 water samples were taken from the CTD-bottle-system. For the sampling 1.5 L rinsed water bottles were used. After tapping the water from the Niskin bottles, the water bottles were tightly closed.

The analysis of the tritium samples will take place post-cruise in the laboratory at the University in Bremen. At station 84 the 100 m sample is missing due to a leaking Niskin.

Since the background signal for ^{3}He may be altered by tritiugenic helium, the tritium samples were taken. In the area of Fram Strait these processes are not well known, thus it was decided to sample tritium at every station Helium was sampled. The aim is to understand the processes changing the helium concentrations in the Arctic Ocean.

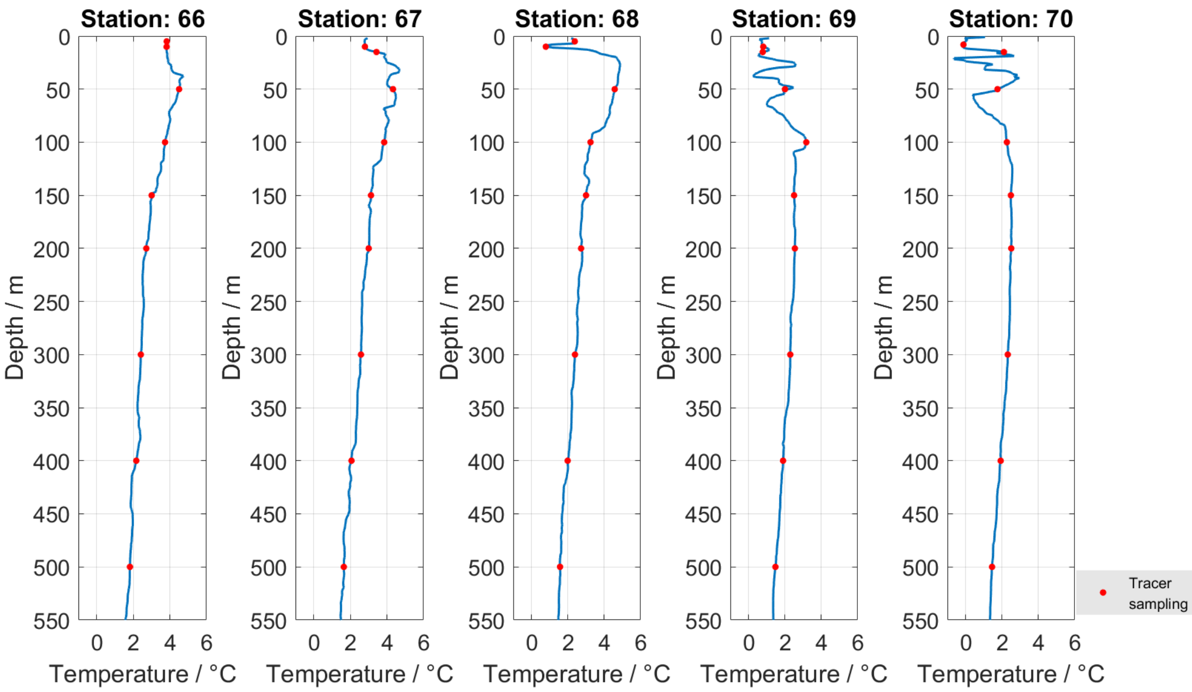

Fig. 5.4.4: Temperature profiles along Transect 1 with depth of the tracer sampling

Tab. 5.4.1: Sampling protocol trace gases. All sampled depths are indicated with x, all duplicate samples with x*.

station	cast	depth (target)	# CFC-No	# He-No.	# Tr-No
4	1	2000	x	x	x
4	1	1000	x*	x	x
4	1	500	x	x	
4	1	200	x	x	x
4	1	100	x*	x	x
4	1	50	x	x	
4	1	10	x*	x	x
66	1	500	x	x	x
66	1	400	x	x	x
66	1	300	x	x	x
66	1	200	x	x	x
66	1	150	x	x*	x
66	1	100	x	x	x
66	1	50	x	x	x
66	1	10	x	x	x
66	1	5	x	x	x
67	1	500	x	x	x
67	1	400	x*	x*	x
67	1	300	x	x	x
67	1	200	x	x	x
67	1	150	x	x	x
67	1	100	x	x	x
67	1	50	x	x	x
67	1	15	x	x	x
67	1	10	x	x	x
68	1	500	x	x	x
68	1	400	x	x	x
68	1	300	x	x	x
68	1	200	x	x	x
68	1	150	x	x	x
68	1	100	x	x	x
68	1	50	x	x	x
68	1	10	x*	x*	x
68	1	5	x	x	x
69	1	500	x	x	x
69	1	400	x	x	x

69	1	300	x	x	x
69	1	200	x	x	x
69	1	150	x	x	x
69	1	100	x*	x*	x
69	1	50	x	x	x
69	1	15	x	x	x
69	1	10	x	x	x
70	2	500	x	x	x
70	2	400	x	x	x
70	2	300	x	x	x
70	2	200	x	x	x
70	2	150	x	x	x
70	2	100	x	x	x
70	2	50	x*	x*	x
70	2	15	x	x	x
70	2	8	x	x	x
84	1	500	x	x	x
84	1	400	x	x	x
84	1	300	x*	x*	x
84	1	200	x	x	x
84	1	150	x	x	x
84	1	100	x	x	x
84	1	50	x	x	x
84	1	20	x	x	x
84	1	5	x	x	x
86	1	500	x	x	x
86	1	400	x	x	x
86	1	300	x	x	x
86	1	200	x*	x*	x
86	1	150	x	x	x
86	1	100	x	x	x
86	1	50	x	x	x
86	1	20	x	x	x
86	1	5	x	x	x
88	1	500	x	x	x
88	1	400	x*	x*	x
88	1	300	x	x	x
88	1	200	x	x	x
88	1	150	x	x	x
88	1	100	x	x	x

88	1	50	x	x	x
88	1	20	x	x	x
88	1	5	x	x	x
90	1	500	x*	x*	x
90	1	400	x	x	x
90	1	300	x	x	x
90	1	200	x	x	x
90	1	150	x	x	x
90	1	100	x	x	x
90	1	50	x	x	x
90	1	20	x	x	x
90	1	5	x	x	x
92	1	500	x	x	x
92	1	400	x	x	x
92	1	300	x	x	x
92	1	200	x	x	x
92	1	150	x	x	x
92	1	100	x	x	x
92	1	50	x	x	x
92	1	20	x	x	x
92	1	5	x*	x*	x
98	1	500	x	x	x
98	1	400	x	x	x
98	1	300	x	x	x
98	1	200	x	x	x
98	1	150	x	x	x
98	1	100	x	x	x
98	1	50	x	x	x
98	1	20	x	x*	x
98	1	5	x	x	x
99	1	500	x	x	x
99	1	400	x	x	x
99	1	300	x*	x*	x
99	1	200	x	x	x
99	1	150	x	x	x
99	1	100	x	x	x
99	1	50	x	x	x
99	1	20	x	x	x
99	1	5	x	x	x

100	1	500	x	x	x
100	1	400	x	x	x
100	1	300	x	x	x
100	1	200	x	x	x
100	1	150	x*	x*	x
100	1	100	x	x	x
100	1	50	x	x	x
100	1	20	x	x	x
100	1	5	x	x	x
101	1	500	x	x	x
101	1	400	x	x	x
101	1	300	x	x	x
101	1	200	x	x	x
101	1	150	x	x	x
101	1	100	x	x	x
101	1	50	x	x	x
101	1	20	x*	x*	x
101	1	5	x	x	x
102	1	500	x	x	x
102	1	400	x	x	x
102	1	300	x	x	x
102	1	200	x	x	x
102	1	150	x	x	x
102	1	100	x	x	x
102	1	50	x*	x*	x
102	1	20	x	x	x
102	1	5	x	x	x
107	2	500	x		
107	2	200	x		
107	2	25	x		
107	4	2794	x		
107	4	2500	x		
107	4	2000	x*		
107	4	1500	x		
107	4	1000	x		
107	4	750	x		
			CFC	He	Tr
		total	163	155	139

6 Station List MSM93

6.1 Overall Station List

Station	Gear	Date / Time	Position	Position	Depth	Comment
No.		[UTC]	Lat	Lon	[m]	
MSM93_1-1	topAWI	7/2/20 07:50	79° 22,024' N	004° 54,853' E	2355.4	Trim Test
MSM93_1-2	topAWI	7/2/20 07:57	79° 22,024' N	004° 54,854' E	2355.3	Trim Test
MSM93_1-3	topAWI	7/2/20 08:40	79° 22,024' N	004° 54,852' E	2355.5	Trim Test
MSM93_2-1	topAWI	7/2/20 10:36	79° 21,096' N	005° 12,501' E	2153.9	
MSM93_3-1	topAWI	7/2/20 13:39	79° 27,008' N	005° 37,361' E	2184	
MSM93_4-1	CTD	7/2/20 17:45	79° 00,463' N	005° 39,344' E	2054.6	
MSM93_4-2	ISC	7/2/20 19:44	79° 00,463' N	005° 39,350' E	2042.8	
MSM93_4-3	LIOP	7/2/20 21:54	79° 00,462' N	005° 39,351' E	2042.9	
MSM93_4-4	LIOP	7/2/20 23:25	79° 00,462' N	005° 39,354' E	2043	
MSM93_5-1	MOOR	7/3/20 04:57	78° 59,967' N	005° 40,049' E	2082.8	
MSM93_5-1	MOOR	7/3/20 06:00	78° 59,672' N	005° 38,646' E	2126	
MSM93_5-1	MOOR	7/3/20 07:50	79° 01,265' N	005° 43,797' E	1863.4	F5-18
MSM93_6-1	MOOR	7/3/20 10:35	79° 09,526' N	006° 15,451' E	1360.8	F4-OZA
MSM93_7-1	MOOR	7/3/20 14:22	79° 00,924' N	007° 56,601' E	1106.7	F3-18
MSM93_9-1	CTD	7/3/20 18:27	79° 00,022' N	009° 19,347' E	200.5	
MSM93_9-2	LIOP	7/3/20 19:07	79° 00,008' N	009° 19,978' E	199.6	
MSM93_10-1	CTD	7/3/20 20:40	79° 00,033' N	009° 00,065' E	199.3	
MSM93_11-1	CTD	7/3/20 21:30	79° 00,023' N	008° 40,055' E	245.4	
MSM93_12-1	CTD	7/3/20 22:30	79° 00,567' N	008° 19,803' E	789.8	
MSM93_8-1	MOOR	7/4/20 07:10	79° 00,086' N	008° 32,335' E	347	F1-17
MSM93_13-1	MOOR	7/4/20 09:55	78° 59,773' N	008° 20,202' E	768.8	F2-19
MSM93_13-2	ISC	7/4/20 10:52	78° 59,994' N	008° 19,721' E	782.1	
MSM93_13-3	MSC	7/4/20 12:14	78° 59,994' N	008° 19,721' E	782.2	
MSM93_13-4	MSC	7/4/20 12:33	78° 59,994' N	008° 19,721' E	782.1	
MSM93_13-5	MOOR	7/4/20 15:03	78° 59,973' N	008° 19,767' E	780.5	F2-20
MSM93_13-6	CTD	7/4/20 15:23	78° 59,994' N	008° 17,891' E	819.8	
MSM93_13-7	LIOP	7/4/20 16:19	78° 59,994' N	008° 17,893' E	819.6	
MSM93_14-1	CTD	7/4/20 17:56	78° 59,993' N	007° 58,122' E	1080.5	
MSM93_15-1	CTD	7/4/20 19:16	78° 59,977' N	007° 39,842' E	1176.7	
MSM93_16-1	CTD	7/4/20 20:39	79° 00,001' N	007° 19,865' E	1246.1	
MSM93_17-1	CTD	7/4/20 22:08	78° 59,693' N	006° 58,957' E	1190.2	
MSM93_18-1	CTD	7/4/20 23:27	79° 00,011' N	006° 39,690' E	1293.5	
MSM93_19-1	CTD	7/5/20 00:58	78° 59,986' N	006° 19,828' E	1515.8	
MSM93_20-1	CTD	7/5/20 02:30	79° 00,026' N	006° 00,224' E	1817.6	
MSM93_21-1	topAWI	7/5/20 08:30	79° 36,750' N	006° 07,030' E	1452.8	
MSM93_22-1	ISC	7/5/20 18:47	78° 47,964' N	002° 05,658' E	2492.7	

MSM93_23-1	MOOR	7/6/20 09:37	79° 00,015' N	005° 40,008' E	2071.3	F5-19
MSM93_24-1	LIOP	7/6/20 11:08	79° 09,981' N	006° 19,929' E	1411	
MSM93_24-2	MOOR	7/6/20 13:12	79° 10,015' N	006° 19,962' E	1412.5	F4-OZA-2
MSM93_25-1	MOOR	7/6/20 16:01	79° 00,014' N	007° 59,793' E	1071.4	F3-19
MSM93_26-1	LIOP	7/6/20 18:31	79° 00,240' N	005° 38,290' E	2087	
MSM93_26-2	CTD	7/6/20 19:45	79° 00,057' N	005° 36,553' E	2121.9	
MSM93_27-1	CTD	7/6/20 22:05	78° 59,979' N	005° 19,860' E	2283.6	
MSM93_28-1	CTD	7/7/20 00:11	78° 59,970' N	005° 00,006' E	2386.4	
MSM93_29-1	CTD	7/7/20 02:22	79° 00,001' N	004° 39,906' E	2434	
MSM93_30-1	ISC	7/7/20 06:03	79° 16,462' N	004° 26,050' E	2367.2	
MSM93_31-1	ISC	7/7/20 07:25	79° 18,021' N	004° 33,939' E	2325.5	
MSM93_32-1	ISC	7/7/20 08:44	79° 19,591' N	004° 41,895' E	2332.1	
MSM93_33-1	ISC	7/7/20 10:02	79° 21,154' N	004° 49,844' E	2331.5	
MSM93_33-1	ISC	7/7/20 10:39	79° 21,156' N	004° 49,865' E	2331.2	
MSM93_34-1	ISC	7/7/20 11:29	79° 22,717' N	004° 57,768' E	2357.3	
MSM93_35-1	ISC	7/7/20 12:47	79° 24,282' N	005° 05,681' E	2386.2	
MSM93_36-1	ISC	7/7/20 16:26	79° 25,861' N	005° 13,775' E	2434.6	
MSM93_37-1	ISC	7/7/20 17:42	79° 27,430' N	005° 21,776' E	2422	
MSM93_38-1	ISC	7/7/20 19:04	79° 29,016' N	005° 29,672' E	2395.2	
MSM93_39-1	ISC	7/7/20 20:27	79° 30,568' N	005° 37,855' E	2270.6	
MSM93_39-2	CTD	7/7/20 21:32	79° 30,569' N	005° 37,861' E	2270.2	
MSM93_39-3	MSC	7/7/20 22:29	79° 30,569' N	005° 37,858' E	2270.4	
MSM93_39-4	LIOP	7/7/20 22:52	79° 30,567' N	005° 37,850' E	2271	
MSM93_40-1	CTD	7/8/20 02:00	79° 16,447' N	004° 26,026' E	2370	
MSM93_41-1	CTD	7/8/20 02:52	79° 18,033' N	004° 33,983' E	2326.8	
MSM93_42-1	CTD	7/8/20 03:51	79° 19,589' N	004° 41,881' E	2332.6	
MSM93_43-1	CTD	7/8/20 04:39	79° 21,151' N	004° 49,833' E	2332.2	
MSM93_44-1	CTD	7/8/20 05:37	79° 22,726' N	004° 57,800' E	2357.2	
MSM93_45-1	CTD	7/8/20 06:31	79° 24,293' N	005° 05,800' E	2385.8	
MSM93_46-1	CTD	7/8/20 07:32	79° 25,862' N	005° 13,769' E	2433.9	
MSM93_47-1	CTD	7/8/20 08:24	79° 27,437' N	005° 21,800' E	2421.1	
MSM93_48-1	CTD	7/8/20 09:24	79° 29,009' N	005° 29,795' E	2390.8	
MSM93_49-1	topAWI	7/8/20 11:22	79° 35,707' N	004° 31,981' E	3041.7	
MSM93_50-1	CTD	7/9/20 11:28	78° 51,363' N	000° 49,924' E	2365.3	
MSM93_50-2	ISC	7/9/20 12:20	78° 51,363' N	000° 49,928' E	2365.5	
MSM93_50-3	MSC	7/9/20 14:06	78° 51,361' N	000° 49,923' E	2365.7	
MSM93_49-2	topAWI	7/9/20 14:34	78° 51,219' N	000° 49,261' E	2372.1	
MSM93_51-1	ISC	7/9/20 19:24	79° 19,721' N	003° 10,127' E	1705.9	
MSM93_51-2	CTD	7/9/20 20:23	79° 19,721' N	003° 10,123' E	1706.5	
MSM93_52-1	CTD	7/9/20 21:42	79° 23,703' N	003° 30,343' E	3169.4	
MSM93_52-2	ISC	7/9/20 22:21	79° 23,702' N	003° 30,341' E	3170.9	
MSM93_53-1	UCTD	7/10/20 00:29	79° 25,951' N	003° 49,559' E	3693.1	
MSM93_54-1	UCTD	7/10/20 02:30	79° 19,042' N	003° 06,752' E	2030.8	

MSM93_55-1	UCTD	7/10/20 04:32	79° 27,436' N	003° 41,231' E	3033.6	
MSM93_56-1	CTD	7/10/20 06:53	79° 19,723' N	003° 10,075' E	1704.8	
MSM93_56-2	ISC	7/10/20 07:44	79° 19,723' N	003° 10,075' E	1704	
MSM93_56-3	MSC	7/10/20 08:50	79° 19,724' N	003° 10,074' E	1703.9	
MSM93_56-4	LIOP	7/10/20 09:04	79° 19,725' N	003° 10,066' E	1702.9	
MSM93_56-5	DF	7/10/20 11:03	79° 19,728' N	003° 10,000' E	1701.4	
MSM93_57-1	ISC	7/10/20 11:37	79° 21,555' N	003° 19,525' E	2159.4	
MSM93_57-2	CTD	7/10/20 12:37	79° 21,556' N	003° 19,535' E	2157.6	
MSM93_58-1	LIOP	7/10/20 13:57	79° 24,577' N	003° 34,660' E	3165.4	
MSM93_58-2	CTD	7/10/20 14:56	79° 24,577' N	003° 34,664' E	3181	
MSM93_58-3	ISC	7/10/20 15:42	79° 24,577' N	003° 34,665' E	3175.6	
MSM93_59-1	ISC	7/10/20 17:00	79° 26,005' N	003° 42,009' E	3205.8	
MSM93_59-2	CTD	7/10/20 18:03	79° 26,006' N	003° 42,008' E	3206.5	
MSM93_60-1	UCTD	7/10/20 19:18	79° 26,174' N	003° 50,866' E	3722.8	
MSM93_61-1	DRIFT	7/10/20 19:24	79° 25,746' N	003° 48,655' E	3674.1	LCE00506
MSM93_61-2	DRIFT	7/10/20 19:40	79° 24,632' N	003° 43,038' E	3754.9	LCE00508
MSM93_61-3	DRIFT	7/10/20 19:55	79° 23,564' N	003° 37,553' E	3752	LCE00509
MSM93_61-4	DRIFT	7/10/20 20:09	79° 22,501' N	003° 32,227' E	3593.8	LCE00510
MSM93_61-5	DRIFT	7/10/20 20:24	79° 21,413' N	003° 26,660' E	3182.1	LCE00511
MSM93_61-6	DRIFT	7/10/20 20:39	79° 20,333' N	003° 21,244' E	2311.2	LCE00512
MSM93_61-7	DRIFT	7/10/20 20:54	79° 19,267' N	003° 15,843' E	2113.4	LCE00513
MSM93_62-1	UCTD	7/10/20 21:28	79° 19,041' N	003° 06,745' E	2066.8	
MSM93_61-8	DRIFT	7/10/20 21:34	79° 19,476' N	003° 08,900' E	1752.6	LCE00514
MSM93_61-9	DRIFT	7/10/20 21:49	79° 20,532' N	003° 14,258' E	1711.7	LCE00515
MSM93_61-10	DRIFT	7/10/20 22:04	79° 21,662' N	003° 19,962' E	2299.9	LCE00516
MSM93_61-11	DRIFT	7/10/20 22:20	79° 22,820' N	003° 25,840' E	2859.6	LCE00517
MSM93_61-12	DRIFT	7/10/20 22:35	79° 23,936' N	003° 31,473' E	3218.5	LCE00518
MSM93_61-13	DRIFT	7/10/20 22:51	79° 25,038' N	003° 37,071' E	3080	LCE00519
MSM93_61-14	DRIFT	7/10/20 23:06	79° 26,147' N	003° 42,727' E	3227.4	LCE00521
MSM93_63-1	UCTD	7/10/20 23:35	79° 27,479' N	003° 41,456' E	3044.6	
MSM93_61-15	DRIFT	7/10/20 23:40	79° 27,099' N	003° 39,469' E	2972.3	LCE00522
MSM93_61-16	DRIFT	7/10/20 23:55	79° 26,005' N	003° 33,876' E	2730.9	LCE00523
MSM93_61-17	DRIFT	7/11/20 00:11	79° 24,891' N	003° 28,197' E	2908.2	LCE00524
MSM93_61-18	DRIFT	7/11/20 00:26	79° 23,809' N	003° 22,700' E	2800.8	LCE00525
MSM93_61-19	DRIFT	7/11/20 00:42	79° 22,640' N	003° 16,758' E	2388.6	LCE00526
MSM93_61-20	DRIFT	7/11/20 00:57	79° 21,534' N	003° 11,199' E	1693.7	LCE00528
MSM93_61-21	DRIFT	7/11/20 01:11	79° 20,477' N	003° 05,838' E	1483.3	LCE00529
MSM93_64-1	UCTD	7/11/20 01:49	79° 21,128' N	002° 53,305' E	1554.5	
MSM93_65-1	UCTD	7/11/20 04:33	79° 24,414' N	003° 57,988' E	3232.3	
MSM93_66-1	CTD	7/11/20 07:06	79° 18,776' N	002° 54,881' E	2430.1	
MSM93_56-5	DF	7/11/20 08:14	79° 19,024' N	002° 53,510' E	2452.3	recovered

MSM93_66-2	ISC	7/11/20 09:00	79° 19,076' N	002° 52,629' E	2356.1	
MSM93_67-1	CTD	7/11/20 10:32	79° 19,716' N	003° 10,110' E	1704.2	
MSM93_67-2	LIOP	7/11/20 11:39	79° 19,716' N	003° 10,116' E	1707.2	
MSM93_68-1	CTD	7/11/20 13:02	79° 21,553' N	003° 19,399' E	2126	
MSM93_69-1	LIOP	7/11/20 14:33	79° 24,568' N	003° 34,652' E	3157.3	
MSM93_69-2	CTD	7/11/20 15:38	79° 24,568' N	003° 34,659' E	3174.1	
MSM93_70-1	ISC	7/11/20 16:55	79° 26,005' N	003° 41,949' E	3208.3	
MSM93_70-2	CTD	7/11/20 17:55	79° 26,004' N	003° 41,952' E	3208.1	
MSM93_71-1	topAWI	7/11/20 19:18	79° 29,111' N	003° 49,655' E	3572	
MSM93_72-1	ISC	7/12/20 16:20	79° 25,840' N	003° 17,680' E	2587.7	
MSM93_72-2	ISC	7/12/20 16:47	79° 25,840' N	003° 17,687' E	2586.8	
MSM93_73-1	ISC	7/12/20 17:58	79° 25,646' N	003° 18,830' E	2615.6	
MSM93_74-1	ISC	7/12/20 19:11	79° 25,464' N	003° 19,900' E	2674	
MSM93_75-1	ISC	7/12/20 20:26	79° 25,280' N	003° 20,972' E	2760.1	
MSM93_76-1	ISC	7/12/20 21:42	79° 25,101' N	003° 21,997' E	2780.8	
MSM93_76-1	ISC	7/12/20 22:33	79° 25,097' N	003° 22,017' E	2783.4	
MSM93_77-1	ISC	7/12/20 22:57	79° 24,914' N	003° 23,086' E	2831.5	
MSM93_78-1	ISC	7/13/20 00:15	79° 24,730' N	003° 24,152' E	2857.8	
MSM93_79-1	UCTD	7/13/20 01:44	79° 25,446' N	003° 07,661' E	2631.1	
MSM93_80-1	UCTD	7/13/20 03:05	79° 23,290' N	003° 37,266' E	3728.6	
MSM93_81-1	DRIFT	7/13/20 03:11	79° 23,709' N	003° 34,852' E	3475.2	LCE00530
MSM93_81-2	DRIFT	7/13/20 03:23	79° 24,506' N	003° 30,226' E	3058.3	LCE00531
MSM93_81-3	DRIFT	7/13/20 03:34	79° 25,299' N	003° 25,570' E	2663.2	LCE00532
MSM93_81-4	DRIFT	7/13/20 03:46	79° 26,105' N	003° 20,837' E	2501.5	LCE00535
MSM93_81-5	DRIFT	7/13/20 03:58	79° 26,925' N	003° 16,051' E	2546.1	LCE00536
MSM93_82-1	UCTD	7/13/20 04:27	79° 28,696' N	003° 22,743' E	2679.4	
MSM93_81-6	DRIFT	7/13/20 04:31	79° 28,384' N	003° 24,645' E	2573.9	LCE00537
MSM93_81-7	DRIFT	7/13/20 04:42	79° 27,686' N	003° 28,820' E	2592.8	LCE00538
MSM93_81-8	DRIFT	7/13/20 04:53	79° 26,877' N	003° 33,473' E	2767.7	LCE00539
MSM93_81-9	DRIFT	7/13/20 05:05	79° 26,068' N	003° 38,211' E	2922.9	LCE00540
MSM93_81-10	DRIFT	7/13/20 05:17	79° 25,255' N	003° 42,981' E	3442.6	LCE00534
MSM93_83-1	UCTD	7/13/20 05:44	79° 26,415' N	003° 53,275' E	3694.9	
MSM93_84-1	CTD	7/13/20 08:16	79° 30,011' N	003° 26,137' E	2585.9	
MSM93_85-1	UCTD	7/13/20 09:12	79° 30,032' N	003° 26,184' E	2598.8	
MSM93_86-1	CTD	7/13/20 10:32	79° 29,994' N	003° 32,038' E	2918.7	
MSM93_86-2	LIOP	7/13/20 11:36	79° 29,993' N	003° 32,039' E	2934.4	
MSM93_87-1	UCTD	7/13/20 12:33	79° 29,967' N	003° 32,028' E	2950.4	
MSM93_87-2	UCTD	7/13/20 12:45	79° 29,212' N	003° 32,081' E	2673.4	
MSM93_88-1	CTD	7/13/20 13:41	79° 29,988' N	003° 37,993' E	3076.2	
MSM93_88-2	LIOP	7/13/20 14:41	79° 29,988' N	003° 37,994' E	3076.2	
MSM93_88-3	ISC	7/13/20 15:41	79° 29,989' N	003° 37,990' E	3076.4	
MSM93_88-4	MSC	7/13/20 16:45	79° 29,989' N	003° 37,993' E	3076.4	

MSM93_88-5	MSC	7/13/20 17:01	79° 29,989' N	003° 37,993' E	3076.4	
MSM93_88-6	DF	7/13/20 18:09	79° 29,955' N	003° 37,848' E	3092.9	
MSM93_89-1	UCTD	7/13/20 18:16	79° 29,990' N	003° 37,697' E	3080.4	
MSM93_90-1	CTD	7/13/20 19:24	79° 30,007' N	003° 43,924' E	3207.2	
MSM93_91-1	UCTD	7/13/20 20:20	79° 29,951' N	003° 44,024' E	3192.2	
MSM93_92-1	CTD	7/13/20 21:25	79° 30,000' N	003° 49,910' E	3324.8	
MSM93_93-1	UCTD	7/13/20 22:30	79° 30,017' N	003° 49,824' E	3322.3	
MSM93_94-1	UCTD	7/14/20 00:59	79° 25,652' N	003° 57,801' E	3388.1	
MSM93_95-1	UCTD	7/14/20 02:42	79° 29,502' N	003° 18,129' E	2983.1	
MSM93_88-6	DF	7/14/20 06:27	79° 31,520' N	003° 47,296' E	3103.4	recovered
MSM93_96-1	ISC	7/14/20 06:36	79° 31,520' N	003° 47,296' E	3103.4	
MSM93_97-1	topAWI	7/14/20 07:43	79° 31,527' N	003° 46,195' E	3050.9	
MSM93_97-2	topAWI	7/14/20 14:54	79° 35,726' N	003° 06,202' E	3115.6	
MSM93_98-1	CTD	7/15/20 07:00	79° 30,005' N	003° 58,573' E	3818.1	
MSM93_99-1	CTD	7/15/20 08:22	79° 29,994' N	004° 06,051' E	3843	
MSM93_99-2	LIOP	7/15/20 09:25	79° 29,995' N	004° 06,052' E	3843	
MSM93_99-3	ISC	7/15/20 10:20	79° 29,996' N	004° 06,053' E	3842.9	
MSM93_99-4	MSC	7/15/20 11:23	79° 29,995' N	004° 06,052' E	3842.7	
MSM93_99-5	MSC	7/15/20 11:36	79° 29,996' N	004° 06,050' E	3842.7	
MSM93_99-6	DF	7/15/20 12:27	79° 29,957' N	004° 06,104' E	3837.4	
MSM93_100-1	CTD	7/15/20 13:00	79° 29,996' N	003° 51,037' E	3383.8	
MSM93_101-1	CTD	7/15/20 14:26	79° 30,000' N	003° 43,529' E	3180.1	
MSM93_101-2	LIOP	7/15/20 15:29	79° 30,004' N	003° 43,516' E	3178.8	
MSM93_102-1	CTD	7/15/20 16:46	79° 30,003' N	003° 36,114' E	3101	
MSM93_103-1	topAWI	7/15/20 19:11	79° 36,883' N	003° 32,896' E	3646.8	
MSM93_104-1	ISC	7/16/20 05:18	79° 29,041' N	004° 25,962' E	2722.2	
MSM93_99-6	DF	7/16/20 06:48	79° 28,863' N	004° 23,579' E	2694.9	recovered
MSM93_103-2	topAWI	7/16/20 08:18	79° 27,396' N	003° 47,590' E	3517.1	
MSM93_105-1	topAWI	7/21/20 17:40	70° 23,235' N	019° 00,032' W	553.6	
MSM93_105-2	topAWI	7/23/20 16:36	70° 22,009' N	018° 01,344' W	1640.4	
MSM93_106-1	topAWI	7/24/20 08:00	71° 10,649' N	018° 15,365' W	1652.4	
MSM93_107-1	LIOP	7/26/20 16:13	65° 44,015' N	005° 22,010' W	2786.7	
MSM93_107-2	CTD	7/26/20 17:24	65° 43,987' N	005° 21,996' W	2786.5	
MSM93_107-3	ISC	7/26/20 18:09	65° 43,986' N	005° 21,997' W	2786.6	
MSM93_107-4	CTD	7/26/20 21:36	65° 43,986' N	005° 21,998' W	2786.2	
MSM93_107-5	MSC	7/26/20 23:45	65° 43,986' N	005° 21,997' W	2786	
MSM93_107-6	MSC	7/26/20 23:58	65° 43,986' N	005° 21,997' W	2786.1	

7 Data and Sample Storage and Availability

The raw data collected during the cruise is stored on work group servers at AWI and will be submitted to the PANGAEA Data Publisher for Earth & Environmental Science. The samples collected during the cruise are stored in laboratories at AWI and University of Bremen. Once the data and sample processing has been completed, the processed data sets will also be submitted to PANGAEA. Two years after the cruise the processed data will be made freely available.

Table 7.1 Overview of data availability

Type	Database	Available	Free Access	Contact
Mooring	PANGAEA	Jul. 2021	Jul. 2022	wjvappen@awi.de
CTD	PANGAEA	Jul. 2021	Jul. 2022	wjvappen@awi.de
UCTD	PANGAEA	Jul. 2021	Jul. 2022	wjvappen@awi.de
Triaxus	PANGAEA	Jul. 2021	Jul. 2022	wjvappen@awi.de
Vessel Mounted ADCP	PANGAEA	Jul. 2021	Jul. 2022	wjvappen@awi.de
Surface Drifter	PANGAEA	Jul. 2021	Jul. 2022	wjvappen@awi.de
Particle camera	PANGAEA	Jul. 2022	Jul. 2023	Christian.Konrad@awi.de
Sediment trap flux	PANGAEA	Jul. 2022	Jul. 2023	miversen@awi.de
Nutrient samples	PANGAEA	Jul. 2022	Jul. 2023	miversen@awi.de
Phytoplankton and microzooplankton identification	PANGAEA	Jul. 2022	Jul. 2023	miversen@awi.de
Marine snow catcher	PANGAEA	Jul. 2022	Jul. 2023	miversen@awi.de
AC-s, RAMSES, QFT-ICAM	PANGAEA	Jul. 2022	Jul. 2022	Astrid.Bracher@awi.de
HPLC and CDOM samples	PANGAEA	Jul. 2022	Jul. 2022	Astrid.Bracher@awi.de
Noble gases	PANGAEA	Jul. 2022	Jul. 2022	maren.walter@uni-bremen.de
Tritium	PANGAEA	Jul. 2022	Jul. 2022	maren.walter@uni-bremen.de
CFCs	PANGAEA	Jul. 2022	Jul. 2022	maren.walter@uni-bremen.de

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9 References

B. B. Taylor, E. Torrecilla, A. Bernhardt, M. H. Taylor, I. Peeken, R. Röttgers, J. Piera, and A. Bracher, Bio-optical provinces in the eastern Atlantic Ocean and their biogeographical relevance, Biogeosciences, 8, 3609-3629, 2011, doi:10.5194/bg-8-3609-2011

Röttgers, R., D. Doxaran, and C. Dupouy (2016), Quantitative filter technique measurements of spectral light absorption by aquatic particles using a portable integrating cavity absorption meter (QFT-ICAM), Opt. Express 24(2): A1-A20.

Ina Lefering, Rüdiger Röttgers, Christian Utschig, and David McKee (2017) Uncertainty budgets for liquid waveguide CDOM absorption measurements, Applied Optics 56 (22): 6357-6366

Yangyang Liu, Rüdiger Röttgers, Marta Ramirez-Perez, Tilman Dinter, Francois Steinmetz, Eva-Maria Nöthig, Sebastian Hellmann, Sonja Wiegmann, Astrid Bracher, (2018). Underway spectrophotometry in the Fram Strait (European Arctic Ocean): a highly resolved chlorophyll a data source for complementing satellite ocean color. Opt. Express 26(14), A678–A696

Y. Liu, E. Boss, A. Chase, H. Xi, X. Zhang, R. Röttgers, Y. Pan, and A. Bracher (2019): Retrieval of phytoplankton pigments and functional types from underway spectrophotometry in the Fram Strait Data Collection. Remote Sens. 11(3), 318; doi: 10.3390/rs11030318

Bracher A., Xi H., Dinter T., Mangin A., Strass V. H., von Appen W.-J., Wiegmann S. (2020) High resolution water column phytoplankton composition across the Atlantic Ocean from ship-towed vertical undulating radiometry. Frontiers in Marine Science 7: 235, doi:10.3389/fmars.2020.00235

Tilstone, G., Dall'Olmo, G., Hieronymi, M., Ruddick, K., Beck, M., Ligi, M., Costa, M., D'Alimonte, D., Vellucci, V., Vansteenwegen, D., Bracher, A., Wiegmann, S., Kuusk, J., Vabson, V., Ansko, I., Vendt, R., Donlon, C., & Casal, T. (2020): Field Intercomparison of Radiometer Measurements for Ocean Colour Validation. Remote Sens. 2020, 12, 1587, doi:10.3390/rs12101587