MARIA S. MERIAN-Berichte

The Role of the Deep Western Boundary Current in the Subpolar North Atlantic for the Discontinuity of Atlantic Meridional Overturning variability, the Transition Zone at 47°N

Cruise No. MSM121

22.09.2023 – 16.10.2023,

Nuuk (Greenland) – Ponta Delgada (Portugal)

Christian Mertens, Andreas Welsch, Jürgen Stake, Ilmar Leimann, Eleanor Frajka-Williams, Dagmar Hainbucher, Viktoria Nikolaus, Lukas Dirksen, Reiner Steinfeldt, María-Jesús Rapanague Sepúlveda, Dinora Garcia Santacruz, Stefan Pauls, Lara Jane Aschenbeck, Duncan Dale, Damien Desbruyères, Sébastien Prigent, Stéphane Leizour, Hugo Sellet

Christian Mertens

Universität Bremen

2024

Table of Contents

1 Cruise Summary

1.1 Summary in English

MARIA S. MERIAN cruise MSM121 was a contribution to the field experiments of the coordinated Horizon Europe project EPOC (Explaining and Predicting the Ocean Conveyor), in particular to work package WP2 “Key processes of meridional connectivity” with the aim to determine the processes that maintain or disrupt the meridional connectivity of ocean transports and to assess their representation in high-resolution coupled models. In the Transition Zone at Flemish Cap and the Grand Banks, between subpolar and subtropical North Atlantic, models consistently show a breakdown of the meridional coherence of the Atlantic Meridional Overturning Circulation (AMOC). MSM121 marks the beginning of a targeted 2-year field experiment that will improve the understanding of the processes responsible for breaking the coherence. These processes include the upstream variability of deep water masses and boundary currents, local instabilities, eddies or flow-topography interactions of the Deep Western Boundary Current (DWBC). The main objective of the cruise MSM121 was to deploy 17 bottom-mounted inverted echo sounders, which measure time series of round-trip acoustic travel time and bottom pressure (PIES and C-PIES), and nine tall moorings with acoustic current meters and temperature-conductivity recorders. Four moorings were deployed north of Flemish Cap, one mooring in Flemish Pass and 4 moorings south of the Grand Banks. In addition, two drift-free bottom pressure recorders were deployed south of the Grand Banks. A total of 60 top-to-bottom CTD/LADCP casts were conducted along the moored arrays. Recovery of the moored instruments is scheduled for the summer 2025.

1.2 Zusammenfassung

MARIA S. MERIAN Fahrt MSM121 war ein Beitrag zu den Feldexperimenten des koordinierten Horizon Europe-Projekts EPOC (Explaining and Predicting the Ocean Conveyor), insbesondere zum Teilprojekt WP2 "Key processes of meridional connectivity" (Schlüsselprozesse der meridionalen Konnektivität) mit dem Ziel, die Prozesse zu bestimmen, die die meridionale Konnektivität des Ozeantransports aufrechterhalten oder stören, und deren Darstellung in hochauflösenden gekoppelten Modellen zu bewerten. In der Übergangszone rund um Flemish Cap, zwischen dem subpolaren und dem subtropischen Nordatlantik, zeigen Modelle einen Zusammenbruch der meridionalen Kohärenz der atlantischen meridionalen Umwälzbewegung (AMOC). Die Fahrt MSM121 steht am Beginn eines gezielten zweijährigen Feldexperiments das zu einem besseren Verständnis der Prozesse beitragen soll, die für das Aufbrechen der Kohärenz verantwortlich sind. Zu den Prozessen gehören die Variabilität der Bildung von Tiefenwasser und des Randstromtransports, lokale Instabilitäten, Wirbel oder Interaktionen des tiefen westlichen Randstroms (DWBC) mit der Bathymetrie. Das Hauptziel der Fahrt MSM121 war die Auslegung von 17 Inverted Echo Soundern (PIES und C-PIES), die Zeitreihen der akustischen Laufzeit und des Bodendrucks messen, sowie von neun Verankerungen mit akustischen Strömungsmessern und Temperatur-Leitfähigkeitsrekordern. Vier Verankerungen wurden nördlich von Flemish Cap, eine Verankerung in Flemish Pass und vier Verankerungen südlich der Grand Banks ausgelegt. Zusätzlich wurden zwei driftfreie Bodendrucksensoren südlich der Grand Banks ausgelegt. Insgesamt wurden 60 top-to-bottom CTD/LADCP-Profile entlang der verankerten Arrays durchgeführt. Die Bergung der verankerten Instrumente ist für den Sommer 2025 vorgesehen.

2 Participants

2.1 Principal Investigators

Name	Institution
MERTENS, Christian, Dr.	IUP
FRAJKA-WILLIAMS, Eleanor, Prof. Dr.	IFM
DESBRUYÈRES, Damien, Dr.	Ifremer

2.2 Scientific Party

Name	Discipline	Institution
MERTENS, Christian, Dr.	Chief Scientist	IUP
STAKE, Jürgen	Inverted echo sounders	IUP
FRAJKA-WILLIAMS, Eleanor, Prof. Dr.	Bottom pressure recorders	IFM
WELSCH, Andreas	Bottom pressure recorders	IFM
DESBRUYÈRES, Damien, Dr.	Moorings	Ifremer
LEIZOUR, Stéphane	Moorings	Ifremer
PRIGENT, Sébastien	Moorings	Ifremer
SELLET, Hugo	Moorings	Ifremer
DALE, Duncan	Tracer	ETH
STEINFELDT, Reiner, Dr.	Tracer, salinometer	IUP
DIRKSEN, Lukas	Oxygen	IUP
LEIMANN, Ilmar	ADCP	IUP/MARUM
GARCIA SANTACRUZ, Dinora	CTD	IUP/MARUM
HAINBUCHER, Dagmar	CTD	IFM
NIKOLAUS, Viktoria	CTD	IFM
PAULS, Stefan	CTD	IUP
ASCHENBECK, Lara	CTD	IUP
RAPANAGUE SEPÚLVEDA, María-Jesús	CTD	MPIM

2.3 Participating Institutions

IUP	Institut für Umweltphysik, Universität Bremen
MARUM	Zentrum für Marine Umweltwissenschaften, Universität Bremen
IFM	Institut für Meereskunde, Universität Hamburg
Ifremer	Institut Français de Recherche pour l'Exploitation de la Mer, Plouzané
MPIM	Max-Planck-Institut für Meteorologie, Hamburg
ETH	Eidgenössische Technische Hochschule, Zürich

3 Research Program

3.1 Description of the Work Area

MARIA S. MERIAN cruise MSM121 was a contribution to the field experiments of the coordinated Horizon Europe project EPOC (Explaining and Predicting the Ocean Conveyor), in particular to work package WP2 "Key processes of meridional connectivity" with the aim to determine the processes that maintain or disrupt the meridional connectivity of ocean transports and to assess their representation in high-resolution coupled models. The work area is located in the Transition Zone at Flemish Cap and the Grand Banks of Newfoundland, between the subpolar and subtropical North Atlantic, where ocean models consistently show a breakdown of the meridional coherence of the Atlantic Meridional Overturning Circulation (AMOC).

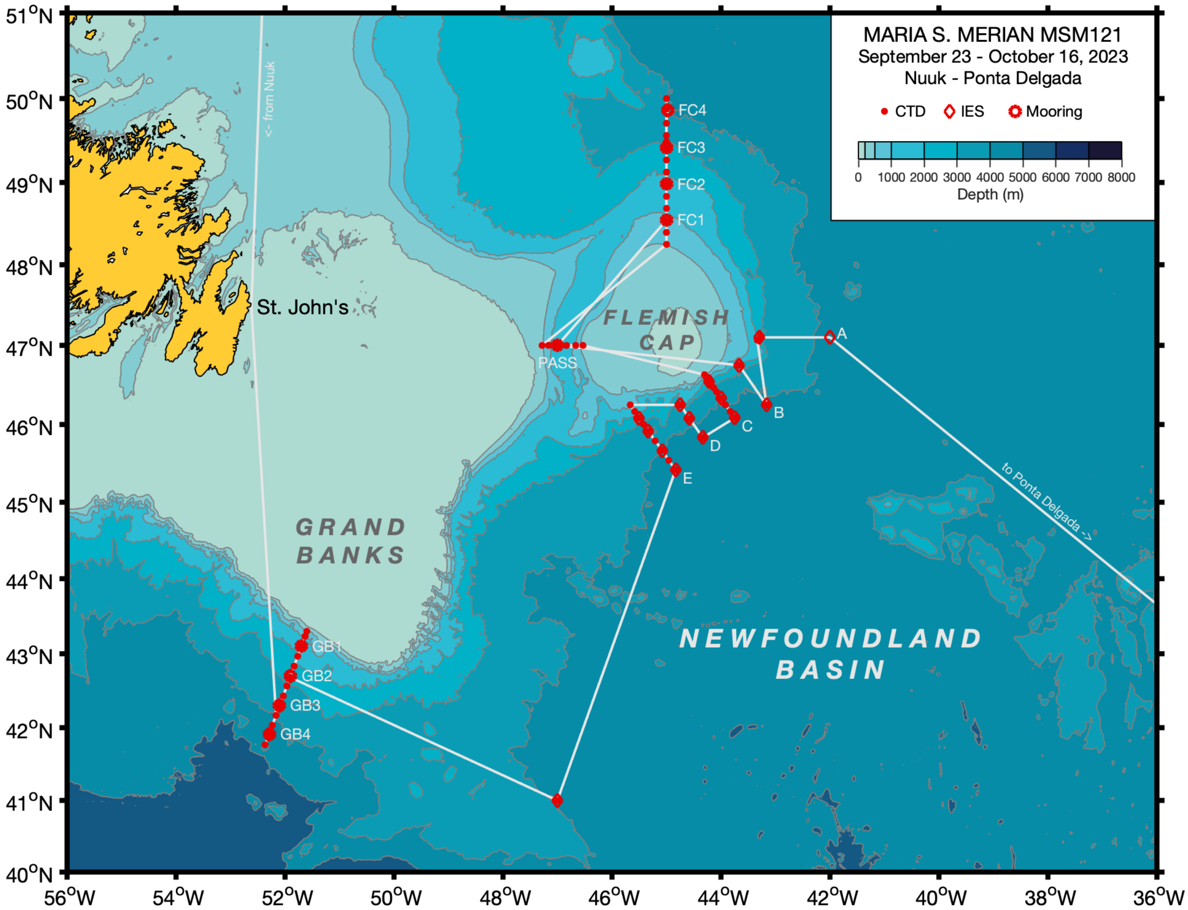


Fig. 3.1 Cruise track and hydrographic stations of RV MARIA S. MERIAN cruise MSM121 from Nuuk (Greenland) to Ponta Delgado (Azores). Moorings were deployed south of the Grand Banks (GB1-4), north of Flemish Cap (FC1-4) and in the Flemish Pass (PASS). Inverted echo sounders were deployed southeast of Flemish Cap (Lines A-E). Bathymetry from GEBCO Compilation Group (2023).

3.2 Aims of the Cruise

The Atlantic Meridional Overturning Circulation (AMOC) is a key component of the climate system, responsible for ocean heat and freshwater transport. However, the link between ocean transport and deep water formation relies on the common conceptual view of the AMOC as a 'great ocean conveyor' which was developed to explain millennial fluctuations in climate. The collaborative Horizon Europe project EPOC (Explaining and Predicting the Ocean Conveyor) aims to generate a new conceptual framework for the AMOC, to understand how it functions in the Earth system and impacts on weather and climate.

The objective of the EPOC field program is to determine physical processes that maintain or disrupt the meridional connectivity of ocean transports around Flemish Cap and the Grand Banks of Newfoundland, the so-called Transition Zone (TZ) between the subpolar and subtropical Atlantic. The cruise marks the beginning of the 2-year EPOC field experiment that, together with high-resolution coupled model simulations, will improve the understanding of the physical processes that determine transport variability. These processes include upstream variability of deep water masses and boundary currents, local instabilities, eddies or flow-topography interactions of the Deep Western Boundary Current (DWBC). The field program consists of three phases: (1) deployment of moorings and inverted echo sounders in 2023, (2) a hydrography survey on a French research vessel conducted by project partners from Ifremer (Brest) in 2024, and (3) recovery of the moored instruments in 2025.

3.3 Agenda of the Cruise

The main objective of cruise MSM121 was to deploy nine tall moorings and 17 bottom-mounted inverted echo sounders. The moorings consist of acoustic current meters and temperature-conductivity recorders. Each mooring has an upward looking ADCP at the top. Four moorings were deployed north of Flemish Cap (FC array) to measure the upstream conditions and four moorings were deployed south of the Grand Banks (GB array) where the DWBC leaves the transition zone. A single mooring was deployed in Flemish Pass to capture the flow between the Grand Banks and Flemish Cap. The second component of the observational program is a densely spaced array of 14 bottom-mounted inverted echo sounders south of Flemish Cap, that measure acoustic travel times between the instrument and the sea surface. The traveltime variability is used to determine the baroclinic transport variability. All of the inverted echo sounders are equipped with pressure sensors (PIES), which will allow the determination of the barotropic transport variability. Five of the inverted echo sounders are additionally equipped with current meters that measure flow speed 50 m above the seafloor. Inverted echo sounders were also deployed near the deepest moorings of the FC and GB arrays. Together with a PIES deployed near 41°N, 47°W, these instruments will allow to estimate the large scale cross-bathymetric flow around Flemish Cap and the Grand Banks. The group from the University of Hamburg deployed two drift-free bottom pressure sensors nearby the moorings GB2 and GB3. Using internal reference measurements these instruments correct for the slow drift of the pressure sensors, which otherwise needs to be removed, causing the slowly varying part of the barotropic flow to be lost.

The cruise was carried out in accordance with the declarations on responsible marine research (Appendices 1 to 3 of the GPF Cruise Proposal Preparation Instructions). In particular, use of hydroacoustic sources with pulsed sound emissions was limited to those that were strictly necessary for scientific purposes.

4 Narrative of the Cruise

The RV MARIA S. MERIAN left the port of Nuuk, Greenland, on Friday, September 22 2023, at 17:30 LT heading to St. John's, Newfoundland. Underway measurements started at 21:00 LT.

The scientific party comprised 18 scientists from the Universities of Bremen and Hamburg, the Institut Français de Recherche pour l’Exploitation de la Mer (Ifremer) in Brest, and the ETH Zurich. The detour to St. John’s became necessary, because one of the containers with mooring material had not arrived on the ship for reasons not yet fully clarified. The equipment that was missing were mainly the anchor weights without the moorings cannot be deployed. Replacements were unavailable in Nuuk and waiting for delivery of the container would have meant a delay of at least six days. Through the support from the ship and the Control Center for German Research Vessels it was possible to get the anchor weights in St. John’s. The ship arrived there on September 26 at 15:00 and after about two hours everything was loaded and we left the harbour in the direction of the first work area.

The first mooring array was deployed south of the Grand Banks, at approximately 52°W. Work on this began on the afternoon of September 27 with mooring GB4 and an inverted echo sounder with pressure (PIES). Mooring GB3 was deployed on the next day together with a drift-free bottom pressure recorder close to it. Moorings GB1 and GB2 were deployed on September 29, with an additional drift-free bottom pressure recorder close to GB2. CTD/LADCP casts were made along a transect parallel to the mooring array, mostly during the nights. Work along the GB array was completed at 20:00 LT on September 30. After a transit of 21 hours we deployed a PIES at 41°N, 47°W.

Deployment of PIES south of Flemish Cap begann at 20:00 LT on October 2 along line E at the southwest end of the array. A total of four PIES were deployed along this line, two of which were C-PIES with an additional current meter 50 m above the seafloor. A total of 9 CTD casts were made along line E, at and between the PIES sites. Line E was completed on October 3 at 21:00 LT and we moved on to line D. Two PIES and one C-PIES were deployed along line D, CTD casts were made at the deployment positions. Line D was completed at 10:00 LT on October 4. Line C was started at about 12:30 LT on the same day. Two C-PIES and one PIES were deployed along this line and 11 CTD casts made. In the morning of October 4, the weather worsened and winds reached gale force with speeds of up to 23 m/s at the last CTD station of line C. We proceeded to Flemish Pass, where we arrived on October 5 at about 10:30 LT. Wind and swell had somewhat decreased overnight, but remained too strong for mooring work. Instead we proceeded with the CTD program at Flemish Pass.

On October 7, at about 10:00 LT we started a CTD section along the planned Flemish Cap (FC) mooring array. Since the weather continued to be too unfavorable for mooring deployments, we continued the CTD work until the afternoon of October 8. By this time, the weather had calmed down sufficiently to deploy the first mooring of the array, FC4. The other three moorings of the array, FC1, FC2 and FC3, could then be deployed in much calmer conditions on October 9. After a transit during the night, we were then able to deploy the mooring in Flemish Pass on October 10 and then return to the PIES array south of Flemish Cap. Two PIES (line B) where deployed on October 11, followed by an 11-hour CTD tow-yo over the Flemish Cap continental slope to obtain a high-resolution section of current velocity and stratification. The scientific program ended with the deployment of two more PIES (line A) in the night. The transit to Ponta Delgada started on 12 October at 03:30 LT. On the way we had the opportunity to recover the torn-off telemetry buoy of a GEOMAR mooring. The underway measurements were stopped on October 15, 22:00 LT. The ship docked at Ponta Delgada pier on October 16, 08:30 LT.

5 Preliminary Results

5.1 CTD/O Measurements and Sensor Calibration

(R. Steinfeldt, L. Dierksen)

5.1.1 CTD/O System and Performance

The CTD measurements on MSM121 were performed with a SBE-911 plus instrument. All profiles were operated with two sensor packages (temperature, conductivity and SBE-43 oxygen sensors). The instrument was mounted to a frame with 22 Niskin bottles of 10 l volume and 2 lowered ADCPs. Water samples from the Niskin bottles were drawn at selected stations and will be analysed with respect to the anthropogenic tracers ^{129}I, ^{236}U, CFC-12, SF_6 and tritium. In addition, oxygen and salinity samples were collected to calibrate the conductivity and oxygen sensors. Depending on the water depth, 2-5 salinity and 2-7 oxygen samples (including one double sample) were taken at most stations.

Table 5.1 List of CTD-sensors and serial numbers.

Device	Serial number
SBE 09plus with digiquartz pressure sensor	09p26816-0657
SBE 05T, submersible pump (CTD1)	05-3138/05-11746
SBE 05T, submersible pump (CTD2)	05-11202
SBE 03plus, temperature sensor (CTD1)	03P4456
SBE 03plus, temperature sensor (CTD2)	03P4156
SBE 04C, conductivity sensor (CTD1)	04-2646
SBE 04C, conductivity sensor (CTD2)	04-2643
SBE-43, oxygen sensor (CTD1)	43-0547
SBE-43, oxygen sensor (CTD2)	43-0267

Table 5.2 CTD conductivity sensor calibration determined by salinometer measurements of bottle samples.

CTD-system	Conductivity Calibration
CTD 1 (sensor #04-2646)	$C_{corr} = C + 3.4925 \times 10^{-3}$
CTD 2 (sensor #04-2643)	$C_{corr} = C + 3.8071 \times 10^{-3}$

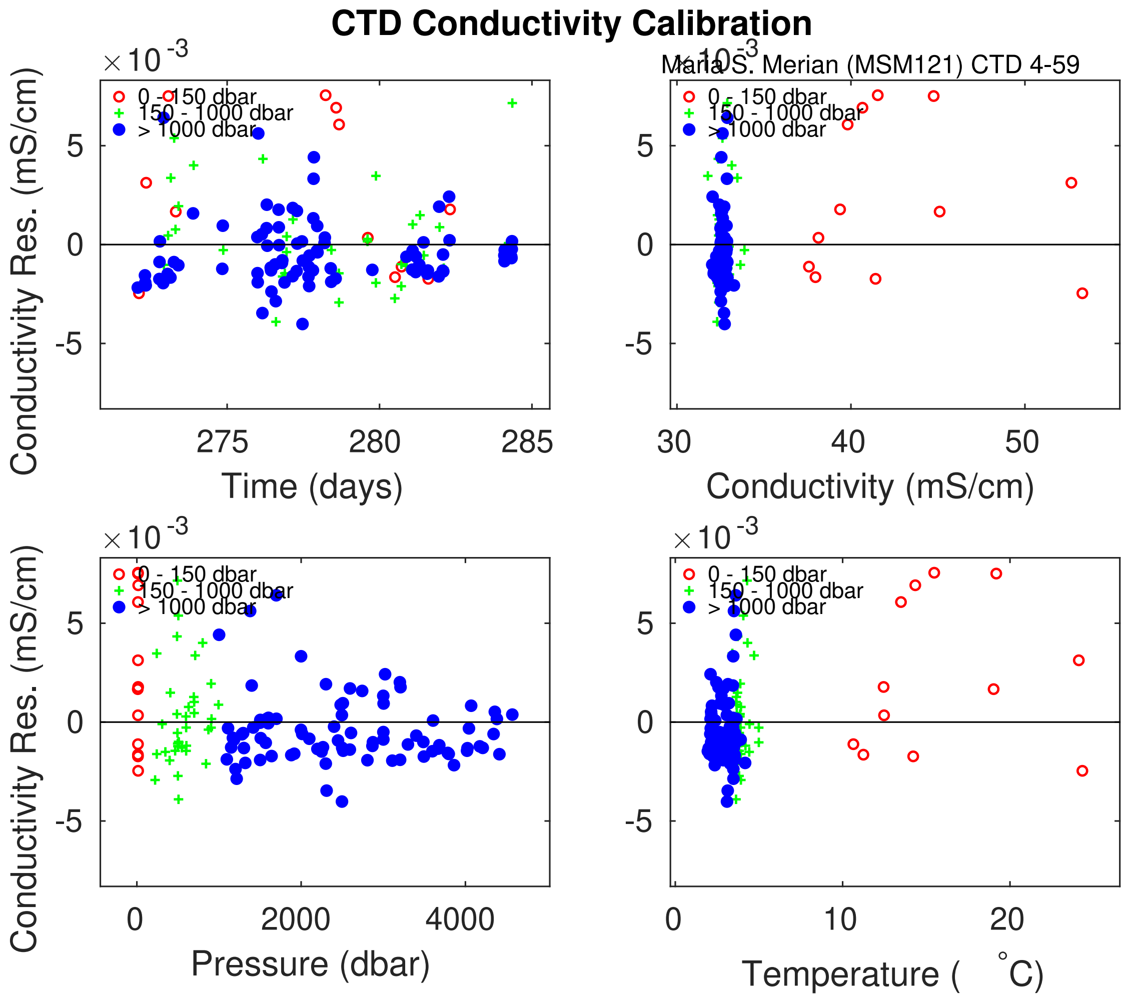


Fig. 5.1 Conductivity residuals between calibrated conductivity for CTD system 1 and measured bottle salinity samples.

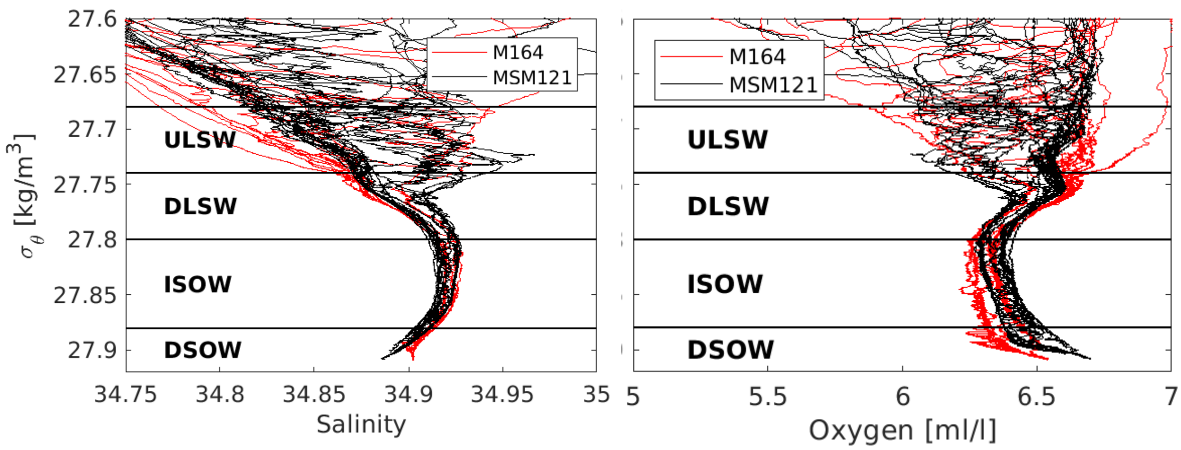


Fig. 5.2 Salinity (left) and oxygen (right) profiles for the two northern sections around Flemish Cap from MSM121 compared to profiles from 47°N directly east of Flemish Cap from cruise M164 in 2020. Isopycnals denote boundaries of water masses. U(D)LSW: Upper(Deep) Labrador Sea Water; ISOW: Iceland Scotland Overflow Water; DSOW: Denmark Strait Overflow Water.

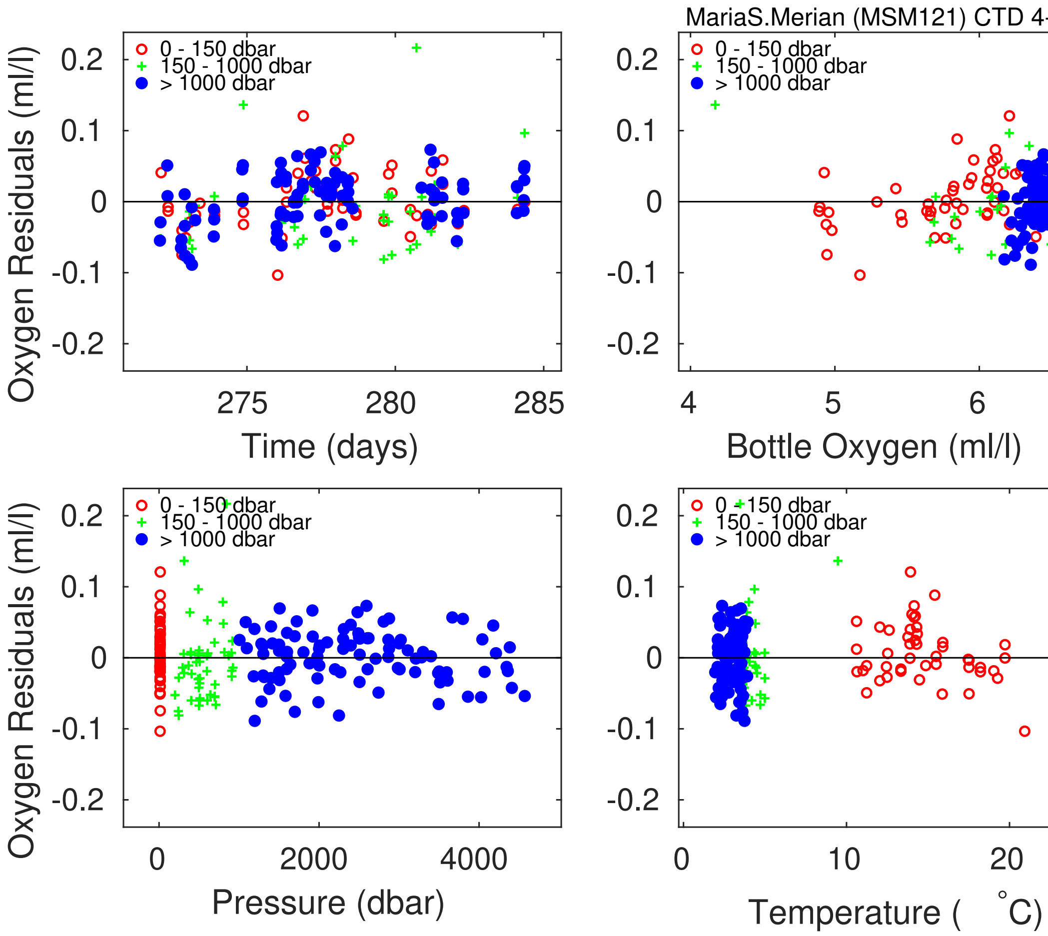


Fig. 5.3 Oxygen residuals between calibrated CTD oxygen for system 1 and measured bottle oxygen samples.

On the first three stations, the salinity and oxygen of CTD system 1 was very noisy, probably due to a malfunction of the pump. After exchanging the pump, the data quality became good. On station/profile #4, the salinity from CTD system 2 was noisy for unknown reasons. From station/profile #5 on, the data were good again without any change of the hardware. Probably due to particles in the sensor cells, on two more stations the salinity and oxygen values were of poor quality: At station/profile #56 for CTD system 2 below 1160 dbar, and at station/profile #57 for CTD system 1 roughly between 700 and 1000 dbar.

Station/profile #60/64 was a CTD tow-yo consisting of 13 up- and downcasts. From the fourth cast on, the oxygen began to show larger differences between up- and downcast, and the values were too low, especially during the downcasts. These data were discarded. For casts #4 to #12, the salinity of CTD system 1 was sometimes noisy, these data were also flagged bad.

Table 5.3 CTD oxygen sensor calibration determined by Winkler titration of bottle samples.

CTD-system	**Oxygen Calibration**
CTD 1 (sensor #43-0547)	$O_{corr} = O + 0.1764 + 4.1099 \times 10^{-3}\,T + 4.8920 \times 10^{-5}\,P$
CTD 2 (sensor #43-0267)	$O_{corr} = O + 0.3227 + 1.8298 \times 10^{-3}\,T + 5.5267 \times 10^{-5}\,P$

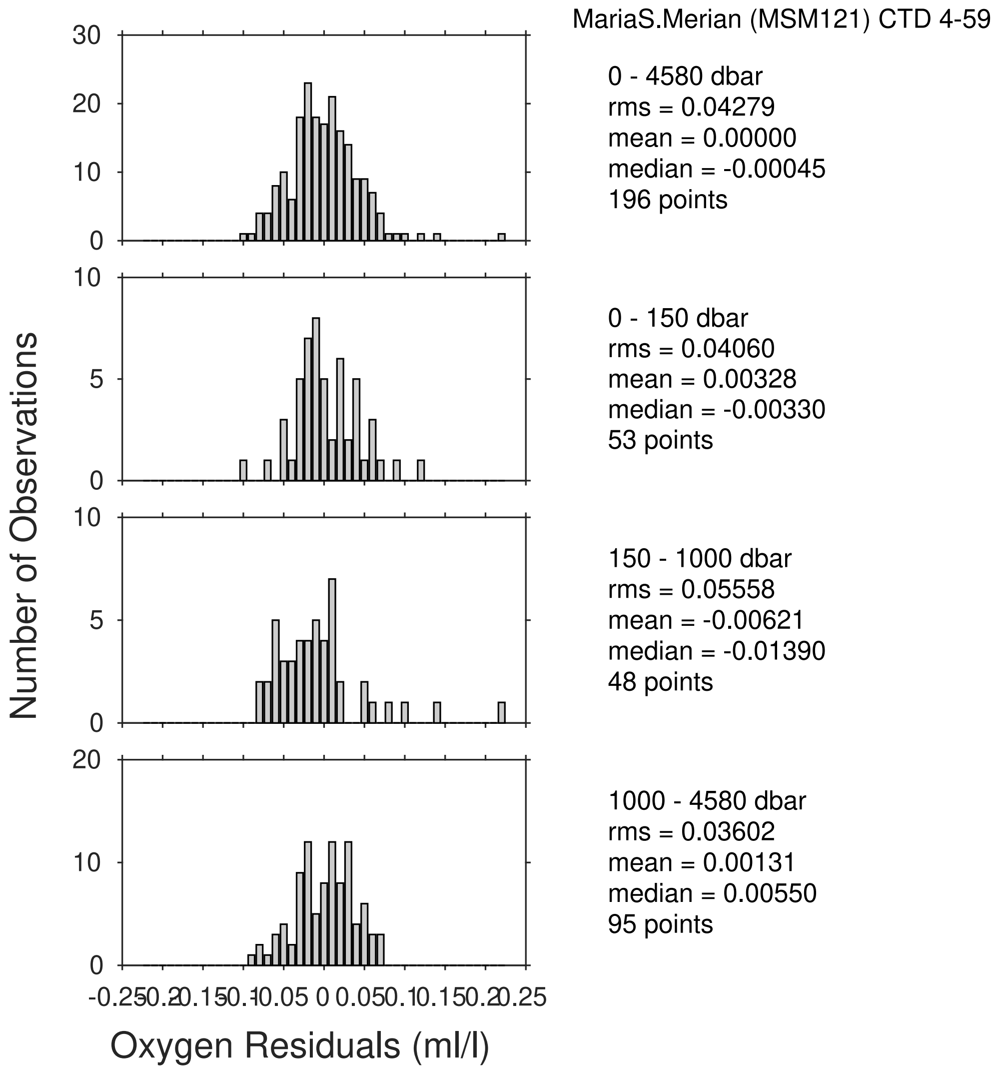


Fig. 5.4 Histogram of oxygen residuals between calibrated CTD system 1 and bottle oxygen.

5.1.2 CTD/O Sensor Calibration

The salinity samples from the Niskin bottles were measured by means of a salinometer, type Guildline Autosal 8400A. At the beginning of each measurement session, the salinometer was standardized with an IAPSO seawater batch P167. The salinometer showed almost no drift between the sessions. During every session, the salinometer was controlled with measuremenst of older standard seawater. No drift of the instrument could be detected.

The calibration of the conductivity sensor resulted in a correction of the order of $3.5x10^{-3}$ mS/cm for both CTD systems independent from time. The standard deviation between calibrated CTD salinitiy and the measured bottle salinity is about 0.0025 psu for both CTD systems. If an error of the Autosal of 0.001 psu is assumed, the accuracy of the CTD salinity data is better than 0.003 psu.

The calibration of the CTD oxygen sensors was performed on the basis of the bottle oxygen analysed from the Niskin bottles (see below). Using the original bottle oxygen results based on the daily variations of the titer factor leads to temporal oscillations in the offset between the CTD and bottle oxygen data. Applying a constant titer factor for the bottle oxygen reduces these fluctuations. Hence, the mean of all titer factors determined during the cruise was used to recalculate the bottle oxygen. However, using this mean titer factor would lead to oxygen concentrations that are too high compared to a previous cruise around Flemish Cap from 2020 (M164). In the Labrador Sea Water, one would expect an oxygen decline compared to 2020 due to reduced convective activity in the Labrador and Irminger Sea. Calibrating the CTD oxygen with the mean titer factor leads to oxygen concentrations in the density range of Labrador Sea Water for this cruise that are comparable to those from 2020. Decreasing the oxygen of this cruise by 1% results in a more reasonable relation towards the oxygen measured in 2020: A decrease of oxygen in the Labrador Sea Water and a slight increase in the Overflow Waters. The salinity changed in the opposite direction since 2020: The LSW became slightly saltier due to a reduction in the LSW renewal, the Overflow Waters show a freshening tendency (Fig. 5.2).

The residual between bottle oxygen (calculated with the mean titer factor and reduced by 1%) and the CTD oxygen is about 0.04 ml/l or 0.7% for both sensors. The calibration contains a constant offset and terms proportional to temperature and pressure. Taking into account the error of the bottle oxygen determination, the accuracy of the CTD oxygen is 1.4%. The rms/mean differences between the two calibrated CTD sensor systems below 100 dbar are 2.4/0.7 mK for temperature, 0.0011/0.0001 psu for salinity and 0.01/0.002 ml/l for oxygen.

5.1.3 Analyses of Bottle Oxygen

In order to calibrate the CTD oxygen sensors, 2 – 7 samples taken from the Niskin bottles were analysed. In case of very dense station spacing, every second station was skipped. In total 239 samples were measured, including 23 double samples.

The method used for the oxygen analyses is based on the Winkler procedure for the determination of dissolved oxygen in sea water. After drawing the sample, the oxygen is fixated by adding 1 ml manganese(II)-chloride ($MnCl_2$) with the concentration of 200 g in 500 ml of pure water and 1 ml of alkaline solution (NaOH-KI) with a concentration of 180 g of sodium hydroxide (NaOH) and 75 g of potassium iodide (KI) in 500 ml of distilled water. Before measuring, 2 ml of 50% sulfuric acid (H_2SO_4) were added. The titration itself was performed by a Schott TitroLine alpha, where the endpoint of the titration is determined by measuring the voltage at the instrument's electrode. As titer solution, sodium thiosulfate ($Na_2S_2O_3$) with a normality of 0.02 N was used.

The standardization of the sodium thiosulfate was performed by a 0.1 N KIO_3 solution. This standard was titrated every day 3 – 4 times before the measurements of the oxygen samples started. Theoretically, for 1 ml of 0.1 N KIO_3 5 ml of 0.02 N $Na_2S_2O_3$ are needed. With the Schott TitroLine device used on this cruise, the amount of $Na_2S_2O_3$ was about 3 – 4% higher. The error of the daily standard measurements was 0. 7%. The rms difference between the daily mean values over the time of the cruise gives a deviation of 0.6%. The difference between the measurements of dublicate samples was smaller, 0.3%. Altogether, the measurement error for oxygen is about 1% for this cruise.

5.2 Transient Tracer Sampling

(D. Dale, R. Steinfeldt, L. Dierksen, S. Pauls)

Transient tracers are generally artificial substances that human activities have generated and ultimately released to the marine environment. Depending on their biological, chemical and physical characteristics, they are capable of labeling different ocean processes. In particular, those behaving conservatively in seawater have been used as powerful tools that provide a unique opportunity to study the effects of the changing climate on the ocean. They are being used here as part of EPOC with the goal of obtaining a "tracer-eye view" of the architecture and dynamics of the lower limb of the AMOC.

5.2.1 Point Source Tracers – ^{129}I & ^{236}U

The long-lived (i.e. $t_{½}$ of millions of years) artificial radionuclides ^{129}I and ^{236}U are two novel oceanographic transient tracers that have emerged in the last 20 years thanks to advancements in Accelerator Mass Spectrometry (AMS) techniques. Both radionuclides have been introduced to the marine environment by point source-like releases from Nuclear Reprocessing Plants (NRP) in the UK and France with some global surface addition of ^{236}U from atmospheric weapon tests. Given their input to the oceans since the 1950s and their different release histories, they are used today as excellent markers to understand the origin of water masses, their circulation timescales and the mixing regimes of waters. They are being measured here particularly to connect with recent measurements made in the vicinity of Iceland, the Labrador Sea and Bermuda in an effort to fill a critical gap in our tracer-view mapping of the ocean circulation architecture around Grand Banks.

During this cruise, 96 samples of 3.25 L of seawater were collected to be analysed for both tracers from a range of depths from 10 stations: three from three of the hydrographic sections plus one from Flemish Pass. They will be analysed for tracer concentrations at the Laboratory of Ion-Beam Physics at ETH Zürich. Initial analysis of CTD data collected at the sampled stations indicates a good selection of key water masses have been sampled, particularly Denmark Strait Overflow Water (DSOW) and Labrador Sea Water (LSW), which can be tied to similar measurements of these water masses at different points in the ocean conveyor.

5.2.2 Ventilation Tracers – CFC, SF_6, ^3H

Chlorofluorocarbons (CFC) and sulfur hexafluoride (SF_6) are anthropogenic gases that enter the ocean surface by air-sea exchange. They are therefore particularly useful as tracers of circulation and mixing involving movement of seawater away from the ocean surface, as with the deep convection events in the Labrador and Irminger Seas that are so critical to the ocean conveyor architecture. Tritium (^3H) is another surface ventilation tracer but with a different input function tied to the atmospheric weapons tests of the 1950-60s. There may also be a point source-like component from the NRP in the NE Atlantic. It is hoped that by combining measurements of these "ventilation" tracers with those of point source tracers (which trace lateral advection and mixing), we will be provided with a higher-dimensional tracer-eye view of the structure and dynamics of the ocean conveyor in this region. 91 samples of ^3H (in 0.5 and 1.5 l bottles) were collected at the same locations simultaneous to the heavy radionuclides. 88 samples for CFC and SF_6 analyses were drawn mainly at the same locations. They were immediately flame sealed into gas-tight glass ampules to prevent contact with atmospheric gases. In addition, 7 samples were filled in steel cylinders at the same positions as glass ampoules. They will be used to test the suitability of these steel containers for CFC/SF_6 sampling. All ventilation tracers will be measured at the University of Bremen. Six duplicate ^3H samples were collected for analysis at ETH Zürich for an inter-lab comparison of results and improved estimate of reproducibility.

5.4 Lowered Acoustic Doppler Current Profiler

(I. Leimann)

The lowered Acoustic Doppler Current Profiler (LADCP) setup used during cruise MSM121 consisted of two Teledyne RD Instruments (TRDI) Workhorse Monitor ADCPs operating at 300 kHz. These ADCPs were attached to an SBE32 carousel water sampler. To stabilize the water sampler, considering the additional weights of the ADCPs and their power supply, a total weight of approximately 250 kg was mounted on the water sampler. Typically, the water sampler was lowered and raised at a speed of 1.0 m/s, reducing the velocity within the upper and lower 100 meters of the water column. The ADCP instruments were configured to operate synchronously, with the downward-looking device mounted at the bottom of the water sampler triggering the

Table 5.4 Sequence of Teledyne-RDI commands used during cruise MSM121 in order to program the LADCP instruments in a synchronized mode with required settings.

Downward-looking device	**Upward-looking device**
WM15	WM15
WV250	WV250
WN20	WN20
WS1000	WS1000
WF0	WF0
WB1	WB1
EZ0011101	EZ0011101
EX11111	EX11111
CF11101	CF11101
WP1	WP1
TP 00:01.00	TP 00:01.00
TE 00:00:01.00	TE 00:00:01.00
SM1	SM2
SA001	SA001
SW75	ST3600
CQ255	CQ255
CK	CK
CS	CS

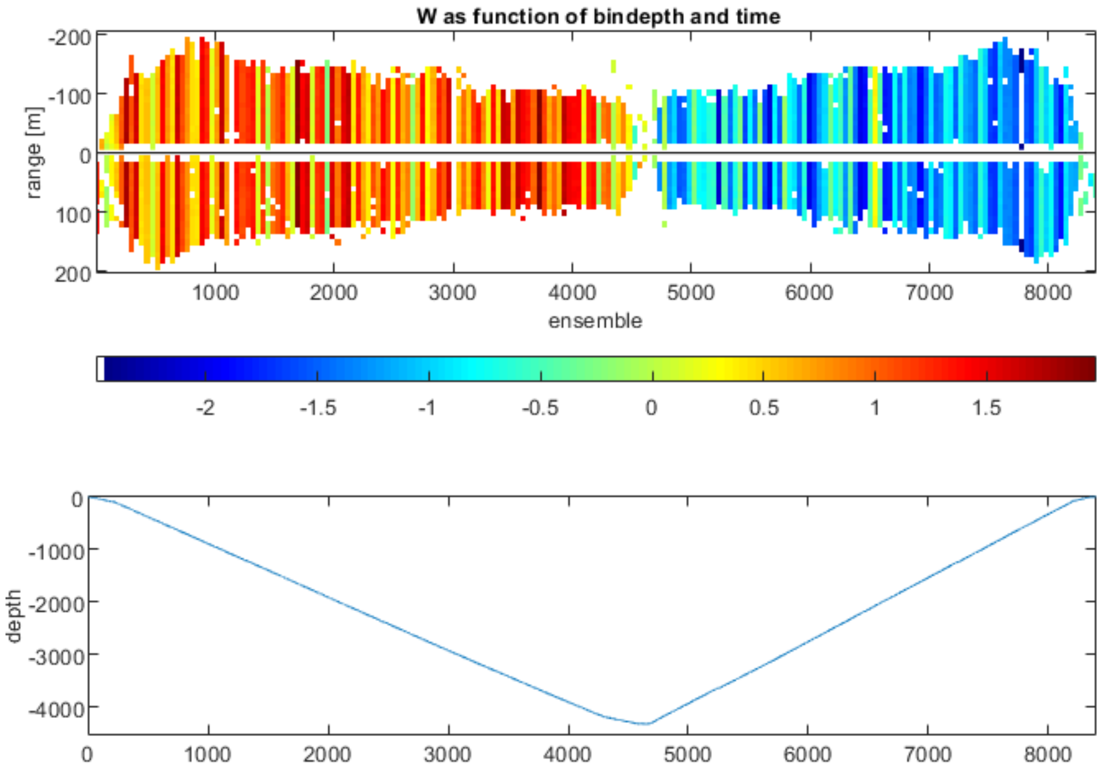


Fig. 5.5 Upper panel: Vertical range of good LADCP data from vertical velocity profile time series. Lower panel: Depth vs. time of LADCP. Both examples are shown for cast 27.MSM121.

upward-looking device at its top. LADCP data were recorded during all CTD casts, totaling 60 CTD/LADCP casts performed.

Prior to the cruise, the four ADCP devices were checked and calibrated at the University of Bremen, particularly with regard to the internal compass. Two of the instruments (serial numbers 24710 and 24522) were calibrated for downward-looking measurements, while the other two (serial numbers 24708 and 2161) were calibrated for upward-looking measurements. Throughout the cruise, the instruments were powered by an external battery pack consisting of 35 high-quality 1.5 V batteries, providing power for approximately 40 to 45 hours. These batteries were assembled within a modified Aanderaa pressure housing. The ADCP system was configured with a ping rate of 1 Hz and a 10 m depth cell size (bin length). Detailed settings for each individual instrument can be found in Table 5.4. ´

The raw data were processed using the LDEO LADCP processing software, version IX.14 (Thurnherr, 2021), which generated the final LADCP dataset for cruise MSM121. Vessel-mounted ADCP (75 kHz Ocean Surveyor) data for the upper part of the water column were integrated to constrain the inverse solution for the resulting absolute velocity profiles. Additionally, the GPS-derived latitude, longitude, and time, as well as CTD pressure data obtained from the corresponding casts, with a resolution of 1 Hz for time, to estimate the location of the ADCP devices within the water column. Furthermore, CTD conductivity is used to correct for sound speed variations within the water column. Instrument clocks were automatically synchronized with the vessel's UTC time server to compensate for any clock drifts. The final processed LADCP dataset includes absolute ocean velocity (u, v) on a depth grid with a resolution of 10 m. The International Geomagnetic Reference Field 13 (IGRF13), valid in spring 2023, was used to determine the correct magnetic declination, i.e., the difference between magnetic and true bearings, at each station location and time.

Power consumption of the ADCP system was monitored and runtime of the devices tracked for each cast. As a result, we used a total of four sets of batteries equipped with fresh cells. The individual battery cycle times ranged from 40 to 45 hours. Fortunately, the power supply did not experience any failures. An exception was during cast #14, where we attached a new battery case with fresh batteries for testing purposes. Consequently, only the downward-looking instrument operated correctly throughout the entire cast. We switched back to the modified Aanderaa pressure housing and continued to use that battery case for the remainder of MSM121.

Additionally, on this cruise, a tow-yo was performed, designated as cast 060. In this procedure, the CTD is left in the water for extended periods, being repeatedly lowered and raised (yo-yo) while being towed by the ship at a slow speed, typically around 0.5 knots. The CTD is generally raised to a depth of 700 meters and then lowered again. This method offers several benefits: it allows the CTD to profile a larger area, especially when using the LADCP. It also saves time by focusing solely on the depth ranges of interest, eliminating the wasted time during recovery and deployment. Additionally, the CTD spends less time transitioning through the surface, reducing the risk of damage to the instruments, which typically occurs there. One of the additional outputs of the LDEO software is an initial battery voltage estimate. However, the software is not calibrated to the specific devices we used. Therefore, from time to time, we measured the battery voltage after each profile using a multimeter to compare it with the software's provided value.

One potential source of error is the influence of strong currents. The higher the current velocity, the greater the forces acting on the water sampler. During the cruise, we observed that high current velocities often caused the water sampler to rotate, as it is not perfectly streamlined. The signal range of each instrument was typically at least 180 meters in the upper portions of the water column and approximately 100 meters at depths exceeding 3000 meters, as exemplified in Figure 5.5 for cast 27. Consequently, the total range of the configuration comprising both instruments varied between 150 meters and 300 meters. With lowering and heaving velocities of 1 m/s and up to 1.2 m/s, respectively, this range corresponds to approximately 150 estimates of current shear in each depth cell in deep water, and even more toward the sea surface, depending on the abundance of scatterers.

5.5 Moorings

(D. Desbruyères)

An array of 9 tall moorings has been deployed at three choke points of the continental slope: Flemish Cap, Flemish Pass, and the tail of the Grand banks (Fig. 5.6). This array will monitor for 2 years the deep western boundary current (velocity, temperature, salinity) upstream (FC lines), within (PASS line) and downstream (GB lines) of the North Atlantic "Transition Zone" that separates subarctic and subtropical basins. Each mooring line was built in either Dynema, steel, Kevlar, or a combination of those. All lines consist of the following elements:

- top float equipped with an upward-looking ADCP 75 kHz (or 150 kHz for the PASS mooring) with sampling rate of 300 s
- Aquadopp 6000 current meters with sampling rate of 600 s
- MicroCAT (SBE37-SM, SBE37-SMP, SBE37-IMP) with sampling rate of 120 or 360 s

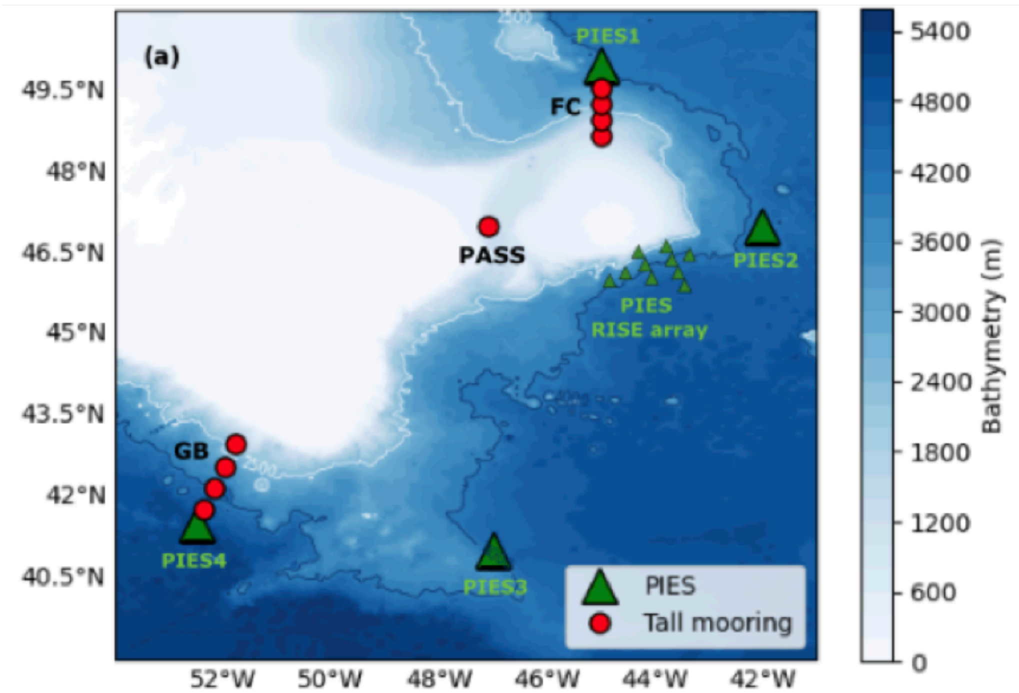


Fig. 5.6 Mooring arrays deployed north of Flemish Cap (FC), in Flemish Pass (PASS) and south of the Grand Banks. Also shown are the deployment positions of inverted echo sounder with pressure sensors (PIES).

Table 5.5 List of mooring deployments and triangulated positions on cruise MSM121.

Station		Date and duration of deployment	Triangulated position	Depth	# MicroCATs	# current meters
MSM121_3-2	**GB4**	28.09.2023 4 h 13 min	41°54.579'N, 052°17.780'W	4412 m	10	5
MSM121_5-3	**GB3**	29.09.2023 3 h 10 min	42°18.045'N, 052°06.0515'W	3675 m	9	5
MSM121_13-1	**GB2**	30.09.2023 2 h 19 min	42°42.087'N, 051°54.019'W	2645 m	7	4
MSM121_12-2	**GB1**	30.09.2023 1 h 34 min	43°06.000'N, 051°42.022'W	1556 m	4	2
MSM121_55-1	**FC4**	08.10.2023 2 h 09 min	49°51.861'N, 044°59.100'W	3912 m	11	5
MSM121_58-1	**FC3**	09.10.2023 2 h 28 min	49°25.116'N, 044°59.880'W	2851 m	10	5
MSM121_59-1	**FC2**	09.10.2023 1 h 15 min	48°58.750' N*, 045°00.000'W*	1570 m*	5	2
MSM121_60-1	**FC1**	09.10.2023 0 h 35 min	48°32.681'N, 044°59.988'W	868 m	3	1
MSM121_61-1	**PASS**	10.10.2023 1 h 29 min	46°59.957'N, 047°00.002'W	1153 m	3	2

*No triangulation. This is the a priori position.

- two acoustic releases
- an anchor weight (chain)
- an iridium beacon
- Benthos floats

The mooring positions were determined by triangulation after deployment. A CTD cast was carried out at each position prior or after deployment. The number of instruments for each mooring is provided in Table 5.5, along with the date and duration of deployments and the triangulated positions. Schematic diagrams of all moorings can be found in the appendix.

5.6 Inverted Echo Sounders and Bottom Pressure Sensors

(C. Mertens, L. Aschenbeck, D. Desbruyères, E. Frajka-Williams)

An array of 14 inverted echo sounders was deployed along five lines around the southeastern part of Flemish Cap (Fig. 5.7). Each line consists of two to four instruments, crossing the DWBC. Inverted echo sounders make hourly measurements of the travel time of an acoustic signal through the overlying water column. The travel time variability can be linked to the variability of baroclinic transports using historical hydrographic data. All instruments are additionally equipped with high-precision pressure sensors (PIES). The bottom pressure measurements will be used to derive time series of barotropic transport variability. Five of the instruments were equipped with a Doppler current sensor (C-PIES). The current sensor is attached to the inverted echo sounder by a 50-m cable for power supply and data transfer. The current sensor is hold upright above the inverted echo sounder by a single buoyancy float. The PIES are mounted on a steel tripod with a weight of approximately 40 kg that is used as ground weight. The C-PIES a deployed using custom-build stands. These are designed so that the device can return to an upright position after being knocked over by a particularly strong current. The PIES were deployed

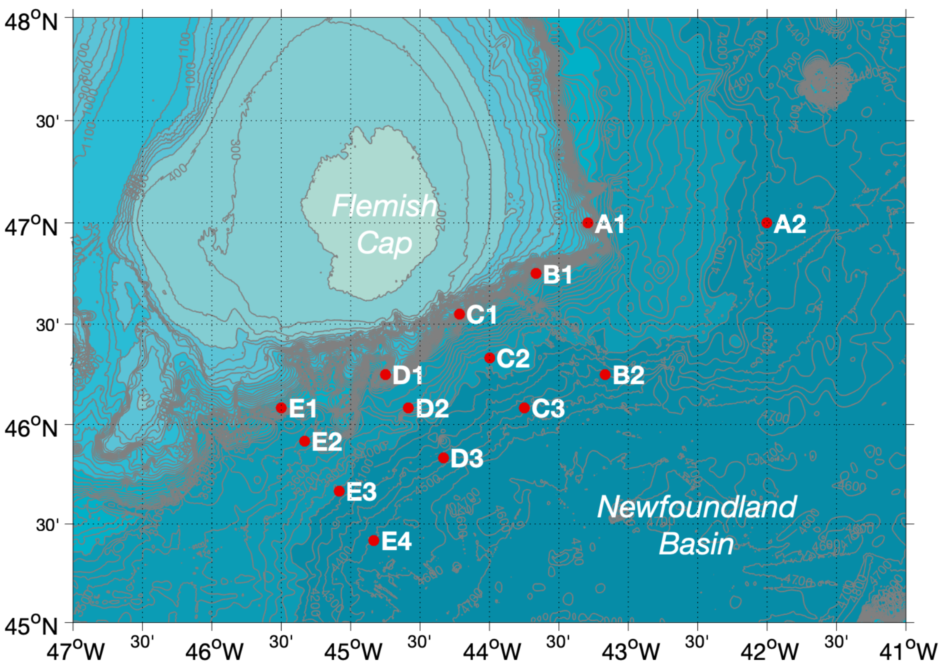


Fig. 5.7 Inverted echo sounders deployed southeast of Flemish Cap on MSM121.

Table 5.6 List of inverted echo sounders deployed during cruise MSM121.

Station	Site ID	Date	Time	Latitude	Longitude	Depth
		(y/m/d)	(UTC)			(m)
MSM121_3-3	GB4P/PIES4	2023/09/28	21:50	41° 54.394' N	52° 17.725' W	
MSM121_5-2	GB3LZ	2023/09/29	09:21	42° 18.000' N	52° 05.998' W	3751
MSM121_13-2	GB2LZ	2023/09/30	18:58	42° 41.967' N	51° 54.111' W	2675
MSM121_14-1	PIES3	2023/10/01	18:49	42° 00.033' N	47° 00.167' W	4110
MSM121_19-1	E4	2023/10/02	22:07	45° 25.000' N	44° 50.006' W	4528
MSM121_17-1	E3	2023/10/03	05:32	45° 40.027' N	45° 04.906' W	4034
MSM121_19-1	E2	2023/10/03	12:28	45° 55.015' N	45° 20.015' W	3445
MSM121_21-1	E1	2023/10/03	18:12	46° 04.986' N	45° 30.044' W	2421
MSM121_24-1	D1	2023/10/04	02:47	46° 15.026' N	44° 45.025' W	1901
MSM121_25-1	D2	2023/10/04	05:29	46° 04.799' N	44° 34.843' W	3610
MSM121_26-1	D3	2023/10/04	09:30	45° 50.023' N	44° 19.960' W	4327
MSM121_27-1	C3	2023/10/04	14:25	46° 05.094' N	43° 44.842' W	4367
MSM121_30-1	C2	2023/10/05	00:30	46° 20.027' N	44° 00.015' W	3894
MSM121_34-1	C1	2023/10/05	10:48	46° 33.002' N	44° 12.992' W	2279
MSM121_55-2	FC4P/PIES1	2023/10/08	20:58	49° 51.950' N	44° 59.220' W	3938
MSM121_62-1	B1	2023/10/11	01:23	46° 44.996' N	43° 40.000' W	2591
MSM121_63-1	B2	2023/10/11	06:17	46° 15.008' N	43° 09.956' W	4281
MSM121_65-1	A1	2023/10/12	00:47	47° 05.999' N	43° 18.006' W	2525
MSM121_66-1	A2/PIES2	2023/10/12	05:16	47° 05.987' N	41° 59.999' W	4224

over the side of the ship and the C-PIES from the stern. First the buoyancy float, than the current meter and in the end the PIES with the anchor to avoid entanglement.

The descent of the PIES was tracked acoustically using the ships hydrophone. For most of the deployments (except at the sites A1 and A2) a CTD cast was made in parallel. Noise generated by the maneuvering ship several times hampered the tracking. The descent times varied between 43 and 82 minutes, corresponding to a descent speed of about 55 meters per minute for PIES and 63 meters per minute for C-PIES.

Inverted echo sounders were also deployed near the deepest moorings of the FC and GB arrays. Together with a PIES deployed near 41°N, 47°W and PIES A2, these instruments complete the tall mooring array and will allow to estimate the large scale cross-bathymetric flow around Flemish Cap and the Grand Banks (Fig. 5.6).

5.7 Landers with Drift-free Pressure Sensors

(E. Frajka-Williams, A. Welsch, V. Nikolaus)

Drift-free (or drift-measuring) bottom pressure recorders were deployed for the EPOC project, work package 5 on future AMOC observing. The principle behind these sensors is that:

Table 5.7 List of landers with bottom pressure sensors deployed by IfM at University of Hamburg during cruise MSM121.Positions given are the triangulated positions.

Station	Site ID	Date	Time	Latitude	Longitude	Depth
		(y/m/d)	(UTC)			(m)
MSM121_5-2	GB3LZ	2023/09/29	09:21	42° 18.000' N	52° 05.998' W	3751
MSM121_13-2	GB2LZ	2023/09/30	18:58	42° 41.967' N	51° 54.111' W	2675

- Pressure sensors drift
- Error or inaccuracy is a percentage of the depth-rating of the sensor
- Absolute error on pressure should be better than about 1 cm liquid water equivalent (LWE) in order to be used for geostrophic reference velocity estimation.

Multiple mooring arrays have been deployed across the Atlantic to estimate the strength of the meridional overturning circulation (MOC). These arrays include the OSNAP array in the subpolar North Atlantic, the RAPID array at 26°N, the MOVE array at 16°N, and the SAMOC array at 34.5°S. All arrays use the thermal wind equation to estimate the vertical shear (d/dz) of meridional velocity (v) from zonal gradients (d/dx) in seawater density. To derive velocity (v), rather than velocity shear (dv/dz), a reference level velocity is required for the integration. This could be derived from zonal gradients in ocean pressure, except that pressure sensors are subject to drift. This drift typically has an exponential-linear character, where the exponential drift is most apparent in the first ~50 days.

A method has been developed to characterise the in situ drift on pressure sensors, referred to as the 'A-zero-A' method. By this method, a pressure sensor measures the ambient pressure, then the 'zero' or controlled pressure, and again the ambient. In the case of these bottom pressure sensors, the zero is constructed by including an internal pressure hull inside the instrument pressure casing, within which the pressure is maintained at near atmospheric pressure (about 10 dbar). Within this secondary internal pressure hull, a 'barometric' pressure sensor rated to near

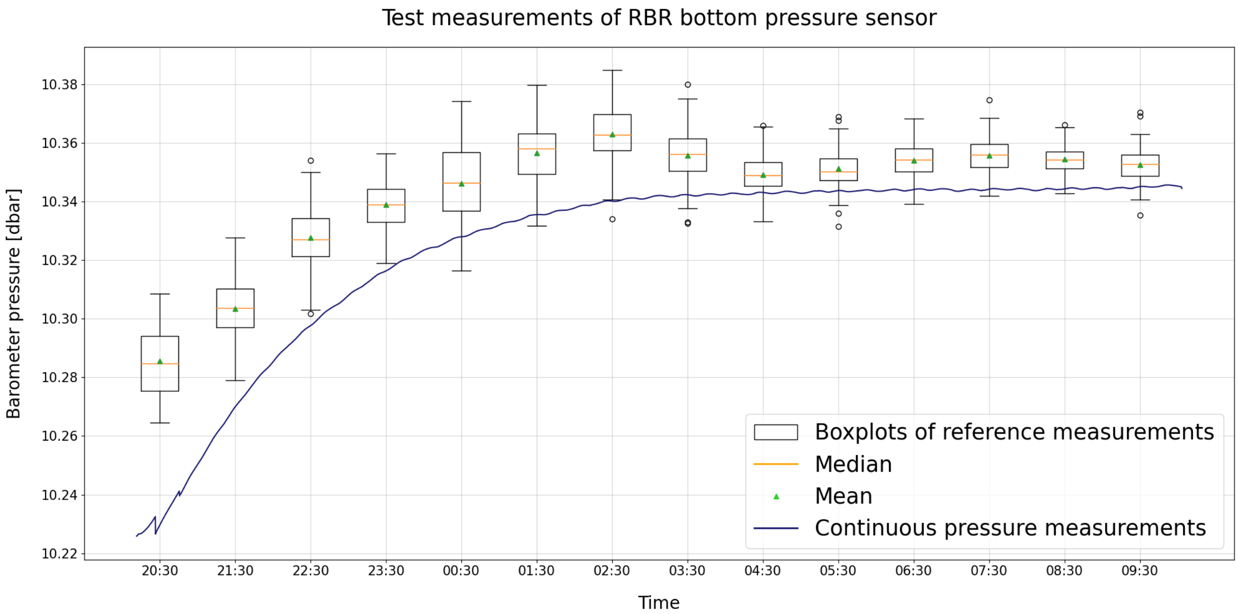


Fig. 5.8 Test measurements for the RBR over 10 hours.

Table 5.8 Setup of the 75 kHz Ocean Surveyor, operated during cruise MSM121.

	Narrow-band mode
Bin size [m]	8
Number of Bins	100
Blanking Distance [m]	8
Maximum Range [m]	600-700
Transducer Angle [°]	45
Transducer Depth [m]	6.5

atmospheric pressures is installed. This barometric sensor measures the pressure inside the hull at high absolute accuracy, while the ambient pressure is measured using a sensor rated up to 6000 dbar pressure. At a scheduled time, an internal valve switches so that the ambient pressure sensor is instead measuring the pressure from inside the secondary hull (near 10 dbar). The difference between ambient sensor and barometric sensor measurements of the pressure inside the secondary hull can be used to quantify the drift experienced by the ambient sensor, and thus to remove this drift from the ambient pressure measurements.

Bottom pressure recorders from two manufacturers (RBR and Sonardyne) were deployed on MSM121. The Sonardyne instrument "Fetch AZA" was deployed near the GB3 tall mooring, and named GB3LZ. The RBR instrument "BPRzero" was deployed near the GB2 tall mooring and named GB2LZ. The RBR BPRzero is a self-contained, self-logging instrument supplied with a secondary battery canister (the RBR fermata). The fermata is powered by 56 D-cell alkaline batteries in a carousel and connected to the main instrument using a cable supplied by the manufacturer. It was very straightforward to setup using the manufacturer provided Ruskin software and connecting to the instrument with a USB-C cable. The software also provides an indication of the battery life anticipated at the user-selected sampling rates. With the external pack, the instrument is capable of sampling pressure every 10 seconds for 6.3 years. We tested the RBR BPR zero over a duration of 10 hours with reference measurements every hour for 10 minutes. To get an initial understanding of the data, and to see if the data showed what we expected, we used RBS's Python toolbox: pyRSKtools.

5.8 Vessel-Mounted Acoustic Doppler Current Profiler

(I. Leimann, L. Aschenbeck)

A 75 kHz Ocean Surveyor (OS75) with flat phased-array transducers manufactured by Teledyne RD Instruments (TRDI) was used for continuous recording of single ping velocity data in the upper water column. The instrument was mounted into the hull of the ship. Since the VMADCPs do not have any further built-in sensors, additional data on heading and tilt were obtained from the ship's Seapath system. Data recording was carried out with the TRDI VmDas software, version 1.49. For the whole cruise, the ADCP worked in narrow-band mode to provide maximum vertical coverage and sustain consistency with the existing data series obtained from previous cruises. Setup parameters for the device are listed in Table 5.7.

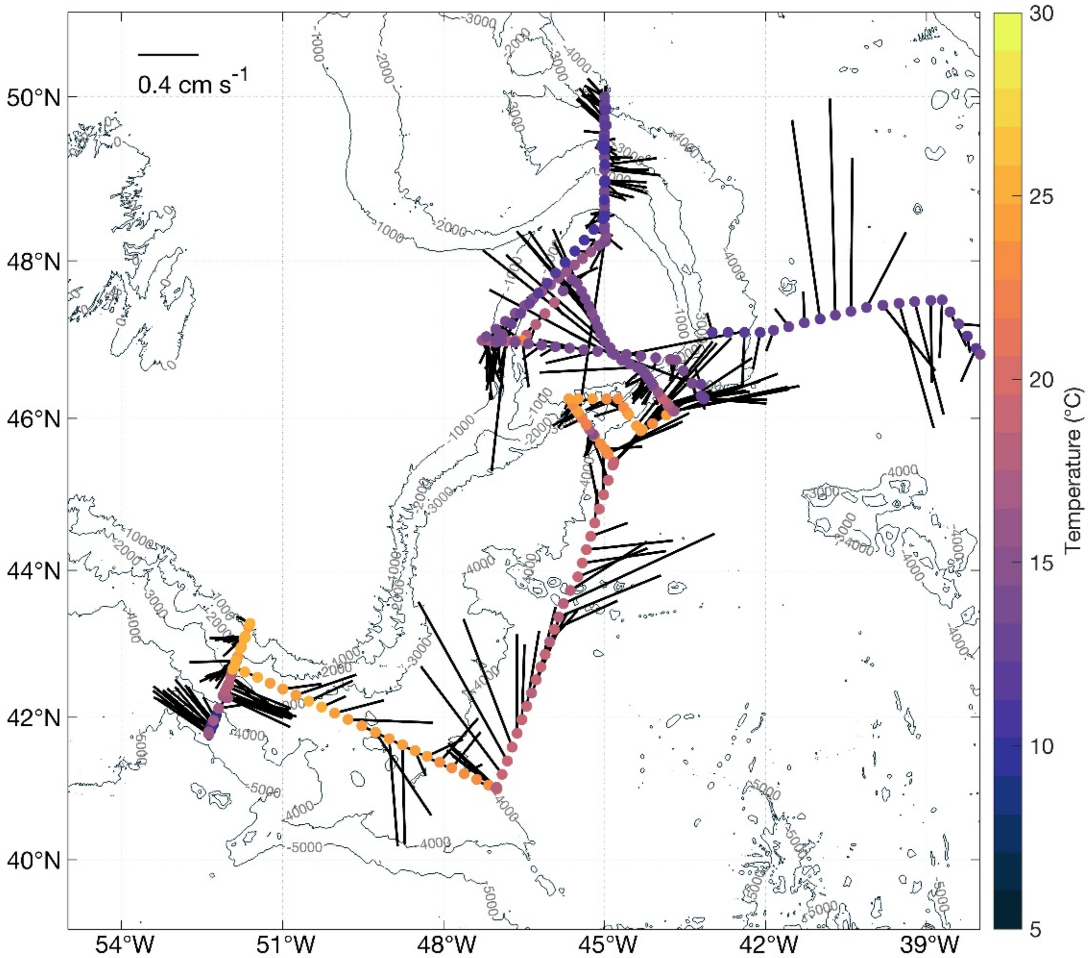


Fig. 5.9 Current velocities recorded by the OS75 VMADCP, averaged over the upper 400m, cruise MSM121.

The obtained raw data will be submitted to the Deutsche Allianz Meeresforschung (DAM), for processing and data publication. To obtain the preliminary results, the raw data were processed using a Matlab toolbox from GEOMAR that resulted in datasets of zonal and meridional current velocities, distributed over latitude, longitude, time, depth along the ship track.

The data recording started on September 23, 2023 at 04:19 UTC in the national waters of Greenland, as the ship left Nook. Recording stopped on the October 15, 2023, 23:33 UTC in the national waters of Portugal, Azores. Data collection was interrupted on September 26 for the port call in St. John's, Canada. Whenever a system was restarted, individual files were created and the file counter was automatically increased. During the data recording period, the VMADCP was switched off and on several times due to various reasons, i.e. in the port of St. John's or when low-noise acoustic environments were required.

The instrument has worked properly during the whole cruise, and the preliminary data are of good quality. However, the data need further additional post-cruise quality control and post-processing steps to obtain a final dataset, e.g. detailed inspection and manual editing of suspicious measurements, which will be done by DAM.

Figure 5.8 shows the working area and the track of the cruise. As black lines there is the mean velocity and direction of the upper 400 m measured by the ADCP. The strength depends on the length of the lines. Furthermore, the sea surface temperature was measured using the ship's thermosalinograph and is shown as dots at the measured position.

5.9 Thermosalinograph

(R. Steinfeldt)

During cruise MSM121 15 water samples from the thermosalinigraph system of the ship have been taken, seven from container 1 and 8 from container 2. These were analysed with the Guildline Autosal 8400A salinometer towards the end of the cruise. The results have been sent to the DAM, where they are used for calibration of the thermosalinograph salinity.

6 Ship's Meteorological Station

Meteorological data were collected automatically by the meteorological station, that is operated by the DWD (Deutscher Wetterdienst).

7 Overall Station List MSM121

Station	Date / Time UTC	Device	Latitude	Longitude	Depth (m)	Comment
MSM121_1-1	2023/09/28 02:29	CTD	42° 10.049' N	052° 09.975' W	4025	
MSM121_2-1	2023/09/28 06:51	CTD	42° 02.002' N	052° 13.998' W	4168	
MSM121_3-1	2023/09/28 11:54	CTD	41° 54.484' N	052° 17.629' W	4437	
MSM121_3-2	2023/09/28 19:25	Mooring	41° 54.661' N	052° 17.158' W	4430	GB4
MSM121_3-3	2023/09/28 21:50	PIES	41° 54.394' N	052° 17.725' W		GB4P/PIES4 (Sonardyne)
MSM121_4-1	2023/09/29 00:27	CTD	41° 45.986' N	052° 22.060' W	3730	
MSM121_5-1	2023/09/29 06:10	CTD	42° 17.927' N	052° 05.939' W	3753	
MSM121_5-2	2023/09/29 09:21	Lander	42° 18.000' N	052° 05.998' W	3751	GB3LZ Bottem Pressure
MSM121_5-3	2023/09/29 13:56	Mooring	42° 18.132' N	052° 06.439' W	3736	GB3
MSM121_6-1	2023/09/29 17:32	CTD	42° 25.923' N	052° 01.888' W	3442	
MSM121_7-1	2023/09/29 20:40	CTD	42° 33.999' N	051° 58.001' W	3091	
MSM121_8-1	2023/09/30 00:26	CTD	42° 50.005' N	051° 50.053' W	2249	
MSM121_9-1	2023/09/30 02:47	CTD	42° 58.017' N	051° 46.059' W	1863	
MSM121_10-1	2023/09/30 05:42	CTD	43° 13.991' N	051° 38.000' W	1201	
MSM121_11-1	2023/09/30 07:06	CTD	43° 18.011' N	051° 35.992' W	649	
MSM121_12-1	2023/09/30 09:04	CTD	43° 06.011' N	051° 41.991' W	1571	
MSM121_12-2	2023/09/30 12:02	Mooring	43° 06.111' N	051° 41.916' W	1576	GB1
MSM121_13-1	2023/09/30 17:57	Mooring	42° 42.223' N	051° 53.871' W	2661	GB2
MSM121_13-2	2023/09/30 18:58	Lander	42° 42.002' N	051° 53.995' W	2675	GB2LZ Bottom Pressure
MSM121_13-3	2023/09/30 20:21	CTD	42° 41.007' N	051° 54.345' W	2722	
MSM121_14-1	2023/10/01 18:49	PIES	41° 00.033' N	047° 00.167' W	4110	PIES3
MSM121_14-2	2023/10/01 18:55	CTD	41° 00.033' N	047° 00.168' W	4107	
MSM121_15-1	2023/10/02 22:07	PIES	45° 25.000' N	044° 50.006' W	4528	PIES E4
MSM121_15-2	2023/10/02 22:20	CTD	45° 25.000' N	044° 50.007' W	4525	
MSM121_16-1	2023/10/03 02:04	CTD	45° 32.546' N	044° 57.418' W	4291	
MSM121_17-1	2023/10/03 05:32	C-PIES	45° 40.027' N	045° 04.906' W	4034	C-PIES E3
MSM121_17-2	2023/10/03 05:49	CTD	45° 40.059' N	045° 04.455' W	4026	
MSM121_18-1	2023/10/03 09:11	CTD	45° 47.510' N	045° 12.481' W	3664	
MSM121_19-1	2023/10/03 12:28	C-PIES	45° 55.015' N	045° 20.015' W	3445	C-PIES E2
MSM121_19-2	2023/10/03 12:40	CTD	45° 54.738' N	045° 19.978' W	3452	
MSM121_20-1	2023/10/03 15:34	CTD	45° 59.963' N	045° 25.032' W	3171	
MSM121_21-1	2023/10/03 18:12	PIES	46° 04.986' N	045° 30.044' W	2421	PIES E1
MSM121_21-2	2023/10/03 18:22	CTD	46° 04.980' N	045° 30.106' W	2372	

MSM121_22-1	2023/10/03 20:40	CTD	46° 10.003' N	045° 35.047' W	1497	
MSM121_23-1	2023/10/03 22:28	CTD	46° 15.011' N	045° 39.943' W	876	
MSM121_24-1	2023/10/04 02:47	PIES	46° 15.026' N	044° 45.025' W	1901	PIES D1
MSM121_24-2	2023/10/04 02:54	CTD	46° 15.028' N	044° 44.982' W	1901	
MSM121_25-1	2023/10/04 05:29	C-PIES	46° 04.799' N	044° 34.843' W	3610	C-PIES D2
MSM121_25-2	2023/10/04 05:37	CTD	46° 04.578' N	044° 34.662' W	3622	
MSM121_26-1	2023/10/04 09:30	PIES	45° 50.023' N	044° 19.960' W	4327	PIES D3
MSM121_26-2	2023/10/04 09:37	CTD	45° 50.022' N	044° 19.960' W	4327	
MSM121_27-1	2023/10/04 14:25	C-PIES	46° 05.094' N	043° 44.846' W	4367	C-PIES C3
MSM121_27-2	2023/10/04 14:41	CTD	46° 05.309' N	043° 44.424' W	4360	
MSM121_28-1	2023/10/04 18:18	CTD	46° 09.988' N	043° 49.877' W	4157	
MSM121_29-1	2023/10/04 21:30	CTD	46° 15.000' N	043° 55.012' W	3991	
MSM121_30-1	2023/10/05 00:30	C-PIES	46° 20.027' N	044° 00.015' W	3894	C-PEIS C2
MSM121_30-2	2023/10/05 00:36	CTD	46° 20.026' N	044° 00.013' W	3896	
MSM121_31-1	2023/10/05 03:39	CTD	46° 24.988' N	044° 04.991' W	3552	
MSM121_32-1	2023/10/05 06:13	CTD	46° 28.004' N	044° 08.002' W	3193	
MSM121_33-1	2023/10/05 08:41	CTD	46° 31.015' N	044° 11.005' W	2722	
MSM121_34-1	2023/10/05 10:48	PIES	46° 33.002' N	044° 12.992' W	2279	PIES C1
MSM121_34-2	2023/10/05 10:58	CTD	46° 33.002' N	044° 12.992' W	2276	
MSM121_35-1	2023/10/05 12:53	CTD	46° 34.975' N	044° 15.076' W	1741	
MSM121_36-1	2023/10/05 14:24	CTD	46° 36.418' N	044° 16.548' W	912	
MSM121_37-1	2023/10/05 15:47	CTD	46° 37.896' N	044° 18.108' W	468	
MSM121_38-1	2023/10/06 12:36	CTD	46° 59.971' N	046° 31.977' W	395	
MSM121_39-1	2023/10/06 14:11	CTD	46° 59.980' N	046° 39.978' W	913	
MSM121_40-1	2023/10/06 16:07	CTD	46° 59.948' N	046° 50.007' W	1184	
MSM121_41-1	2023/10/06 17:53	CTD	46° 59.970' N	046° 59.957' W	1150	
MSM121_42-1	2023/10/06 19:33	CTD	46° 59.996' N	047° 09.961' W	874	
MSM121_43-1	2023/10/06 20:56	CTD	46° 59.985' N	047° 16.951' W	413	
MSM121_44-1	2023/10/07 11:48	CTD	48° 14.987' N	044° 59.924' W	630	
MSM121_45-1	2023/10/07 15:03	CTD	48° 23.724' N	045° 00.047' W	666	
MSM121_46-1	2023/10/07 16:49	CTD	48° 32.462' N	044° 59.987' W	851	
MSM121_47-1	2023/10/07 18:40	CTD	48° 41.251' N	044° 59.993' W	1156	
MSM121_48-1	2023/10/07 20:43	CTD	48° 49.972' N	044° 59.973' W	1278	
MSM121_49-1	2023/10/07 22:47	CTD	48° 58.764' N	045° 00.020' W	1572	
MSM121_50-1	2023/10/08 01:00	CTD	49° 07.490' N	044° 59.972' W	2237	
MSM121_51-1	2023/10/08 03:39	CTD	49° 16.261' N	045° 00.018' W	2566	
MSM121_52-1	2023/10/08 06:25	CTD	49° 24.996' N	045° 00.004' W	2846	
MSM121_53-1	2023/10/08 09:15	CTD	49° 33.783' N	045° 00.080' W	3225	
MSM121_54-1	2023/10/08 12:28	CTD	49° 42.501' N	045° 00.044' W	3547	
MSM121_55-1	2023/10/08 19:22	Mooring	49° 51.857' N	044° 58.742' W	3945	FC4
MSM121_55-2	2023/10/08 20:58	PIES	49° 51.950' N	044° 59.220' W	3938	PIES FC4P/PIES1
MSM121_55-3	2023/10/08 21:23	CTD	49° 52.487' N	045° 00.005' W	3927	
MSM121_56-1	2023/10/09 00:35	CTD	49° 59.998' N	044° 59.995' W	3967	
MSM121_57-1	2023/10/09 05:53	CTD	49° 29.375' N	045° 00.051' W	2992	
MSM121_58-1	2023/10/09 12:37	Mooring	49° 25.258' N	044° 59.965' W	2860	FC3
MSM121_59-1	2023/10/09 17:42	Mooring	48° 58.868' N	045° 00.037' W	1573	FC2
MSM121_60-1	2023/10/09 20:39	Mooring	48° 32.747' N	044° 59.991' W	859	FC1
MSM121_61-1	2023/10/10 11:34	Mooring	47° 00.100' N	046° 59.936' W	1149	PASS1
MSM121_62-1	2023/10/11 01:23	PIES	46° 44.996' N	043° 40.000' W	2591	PIES B1
MSM121_62-2	2023/10/11 01:28	CTD	46° 45.003' N	043° 40.009' W	2585	
MSM121_63-1	2023/10/11 06:17	PIES	46° 15.008' N	043° 09.956' W	4281	PIES B2
MSM121_63-2	2023/10/11 06:22	CTD	46° 15.008' N	043° 09.956' W	4280	
MSM121_64-1	2023/10/11 13:40	CTD	47° 04.000' N	043° 19.999' W	1620	Tow-yo Start
MSM121_64-1	2023/10/12 00:18	CTD	47° 06.896' N	043° 16.061' W	2877	Tow-yo End
MSM121_65-1	2023/10/12 00:47	PIES	47° 05.999' N	043° 18.006' W	2535	PIES A1
MSM121_66-1	2023/10/12 05:16	PIES	47° 05.987' N	041° 59.999' W	4224	PIES A2/PIES2

8 Data and Sample Storage and Availability

The raw and processed scientific data collected during MSM121 are stored in the data archives at University of Bremen. They are available to all project partners and upon request to interested cooperating scientists. All scientific data will be submitted to PANGAEA (www.pangaea.de) within one year after the cruise, i.e. by October 2024.

Data	Contact Person	Affiliation	Email
Multibeam Echosounder, Shipboard ADCP, lowered ADCP	Dr. Christian Mertens	Univ Bremen	cmertens@uni-bremen.de
CTD/O_2, SF6, CFC	Dr. Reiner Steinfeld	Univ Bremen	rsteinf@uni-bremen.de

Table 8.1 Overview of data availability

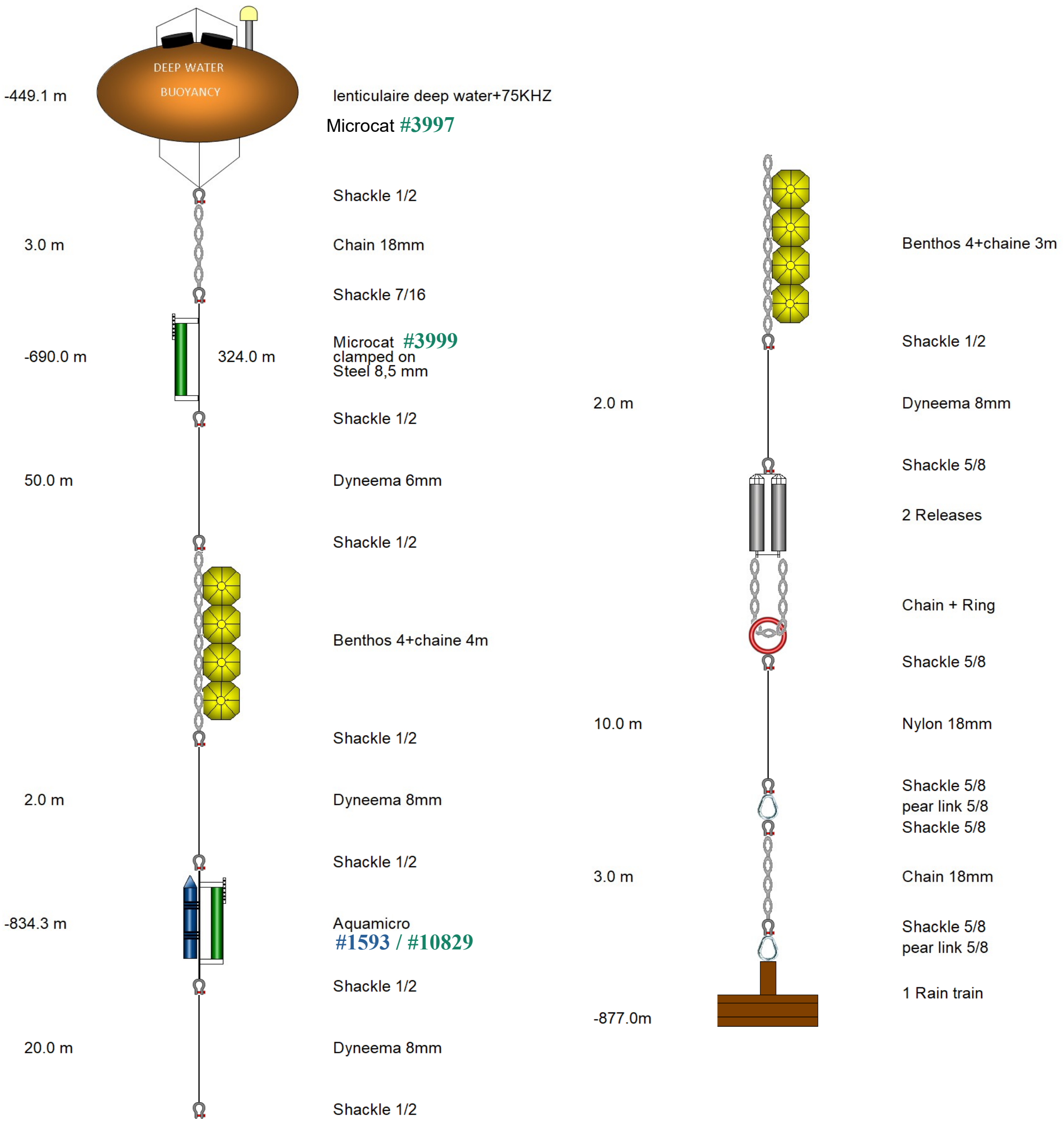
9 Acknowledgements

We thank Captain Ralf Schmidt and the entire crew of the RV MARIA S. MERIAN for the friendly and cooperative atmosphere and their professional technical assistance, which immensely contributed to the success of the expedition. The German Research Fleet Coordination Centre (Leitstelle Deutsche Forschungsschiffe), Markus Gehrken (LPL Projects + Logistics GmbH), and Barbara Kozák (University of Bremen) provided logistical and administrative support. The scientific work conducted during this cruise received funding by the EU Project 101059547 EPOC.

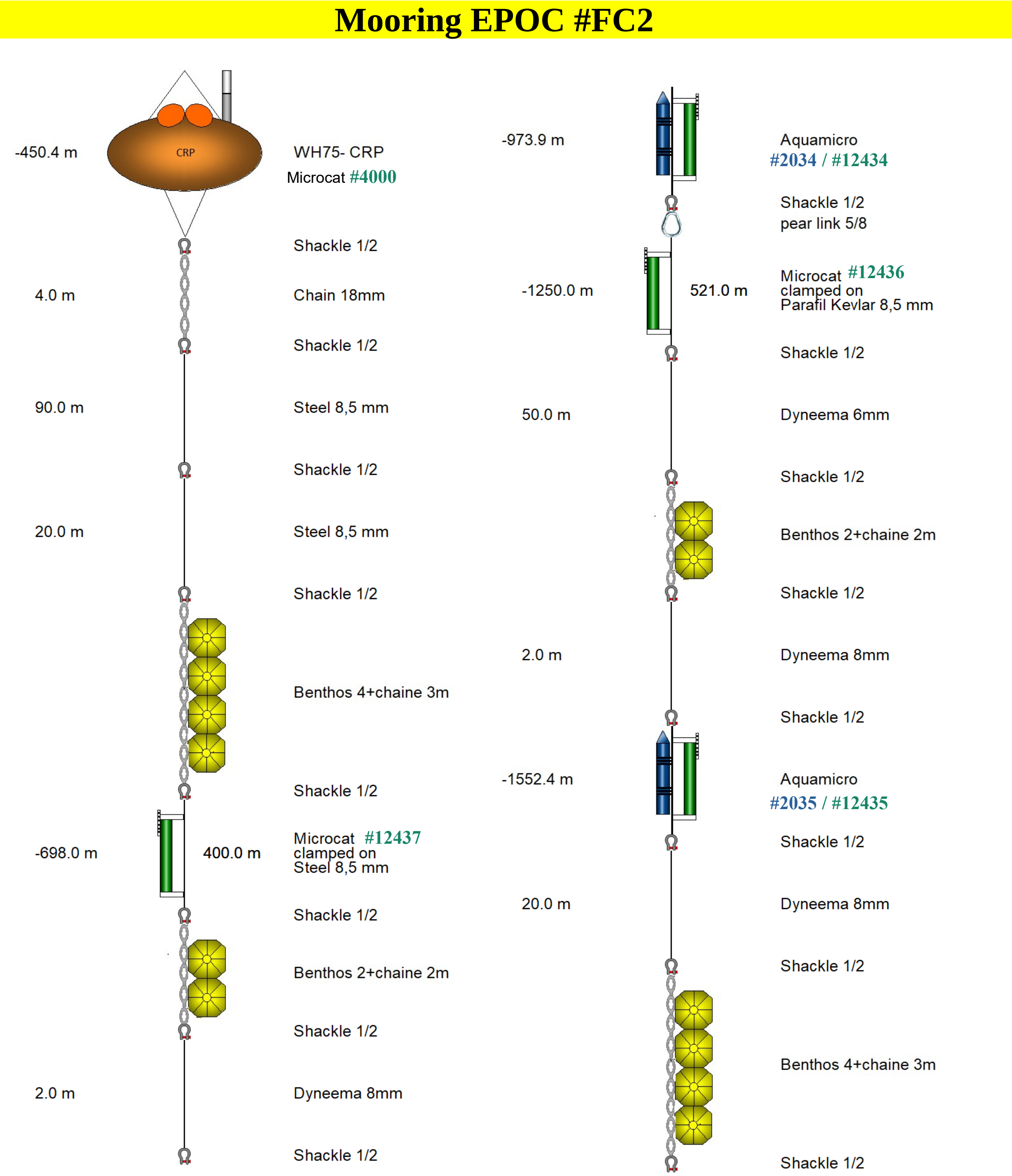
10 Appendix

10.1 Mooring Schematics

Mooring EPOC #FC1

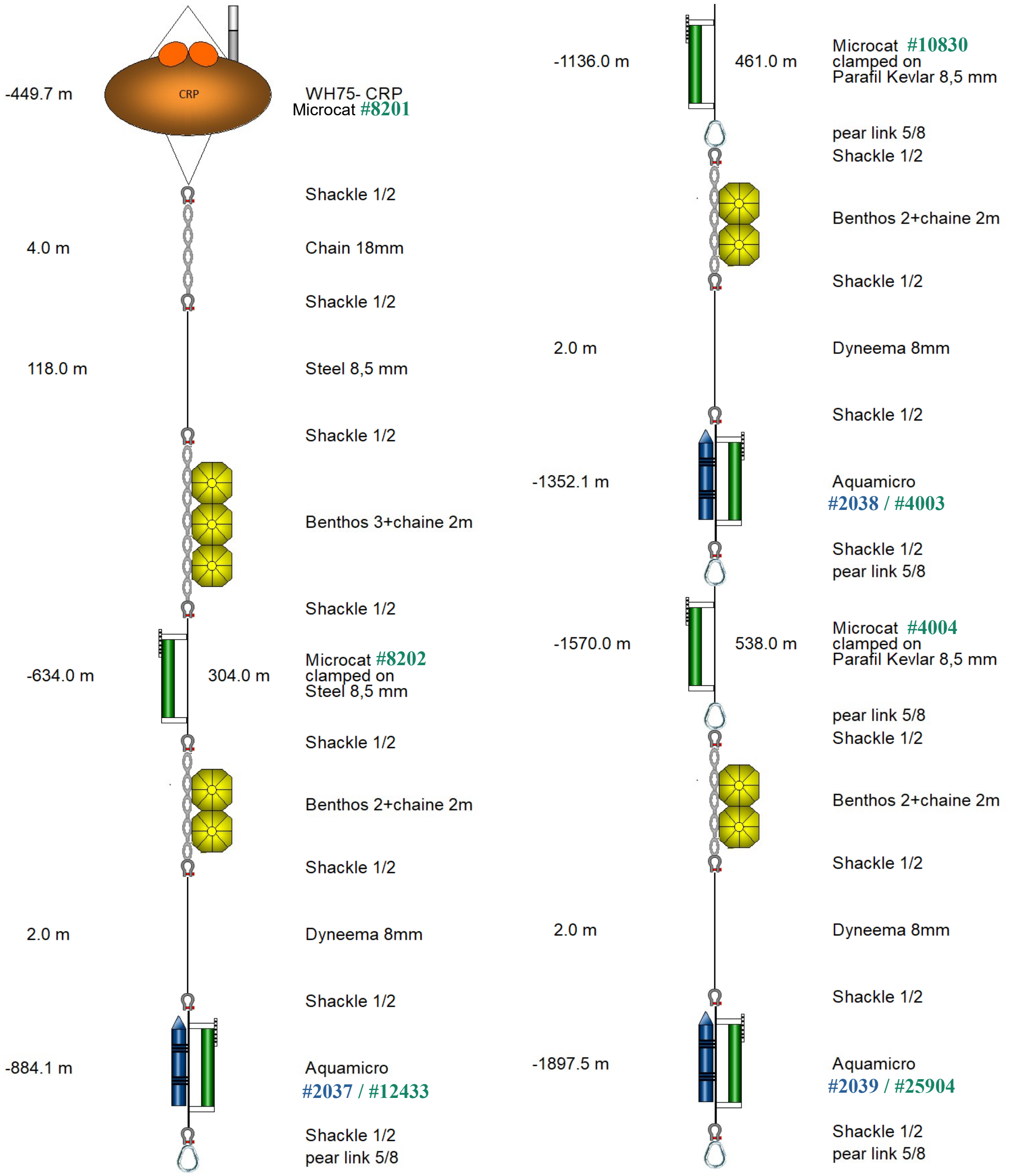


Funded by
the European Union



Funded by the European Union

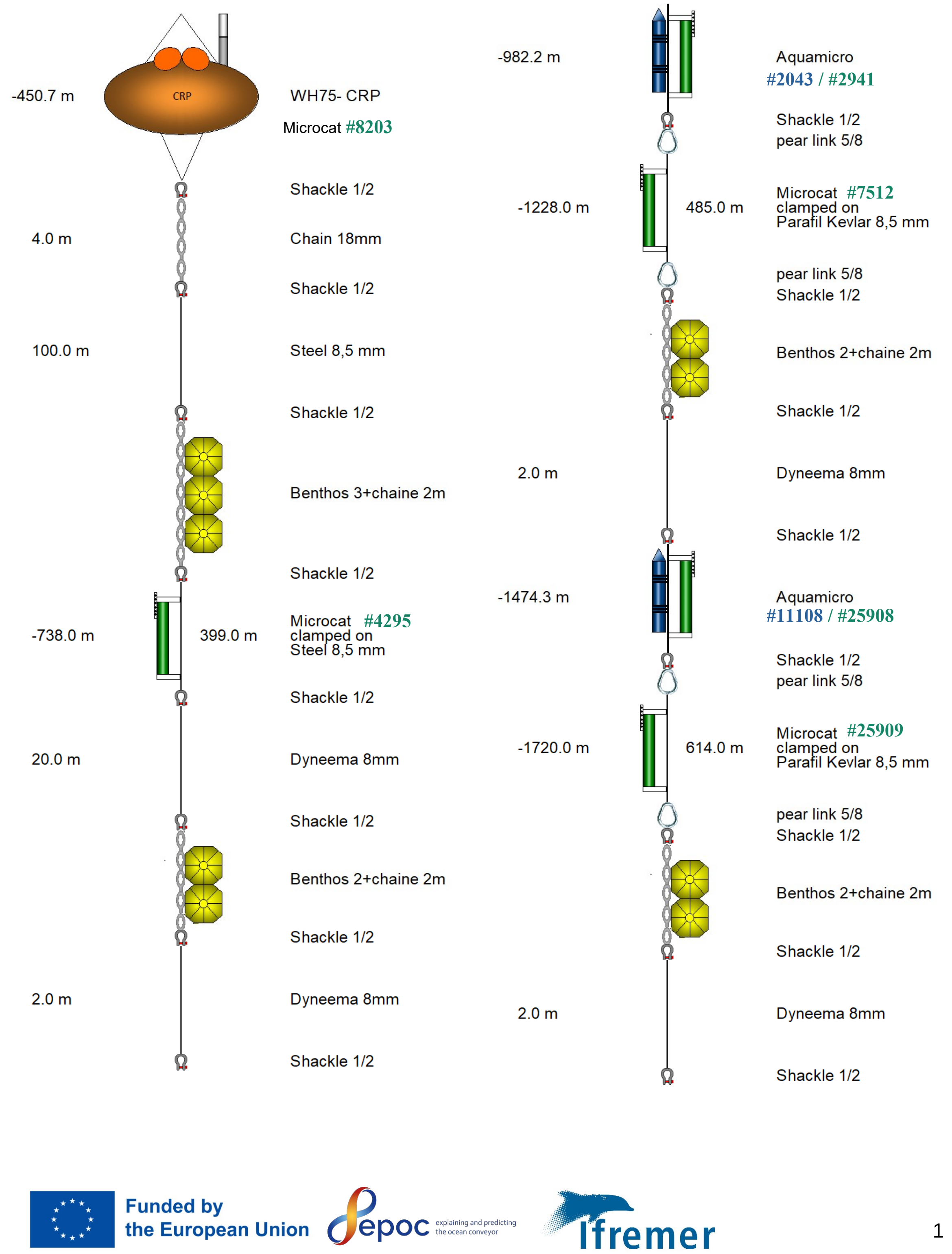
Mooring EPOC #FC3



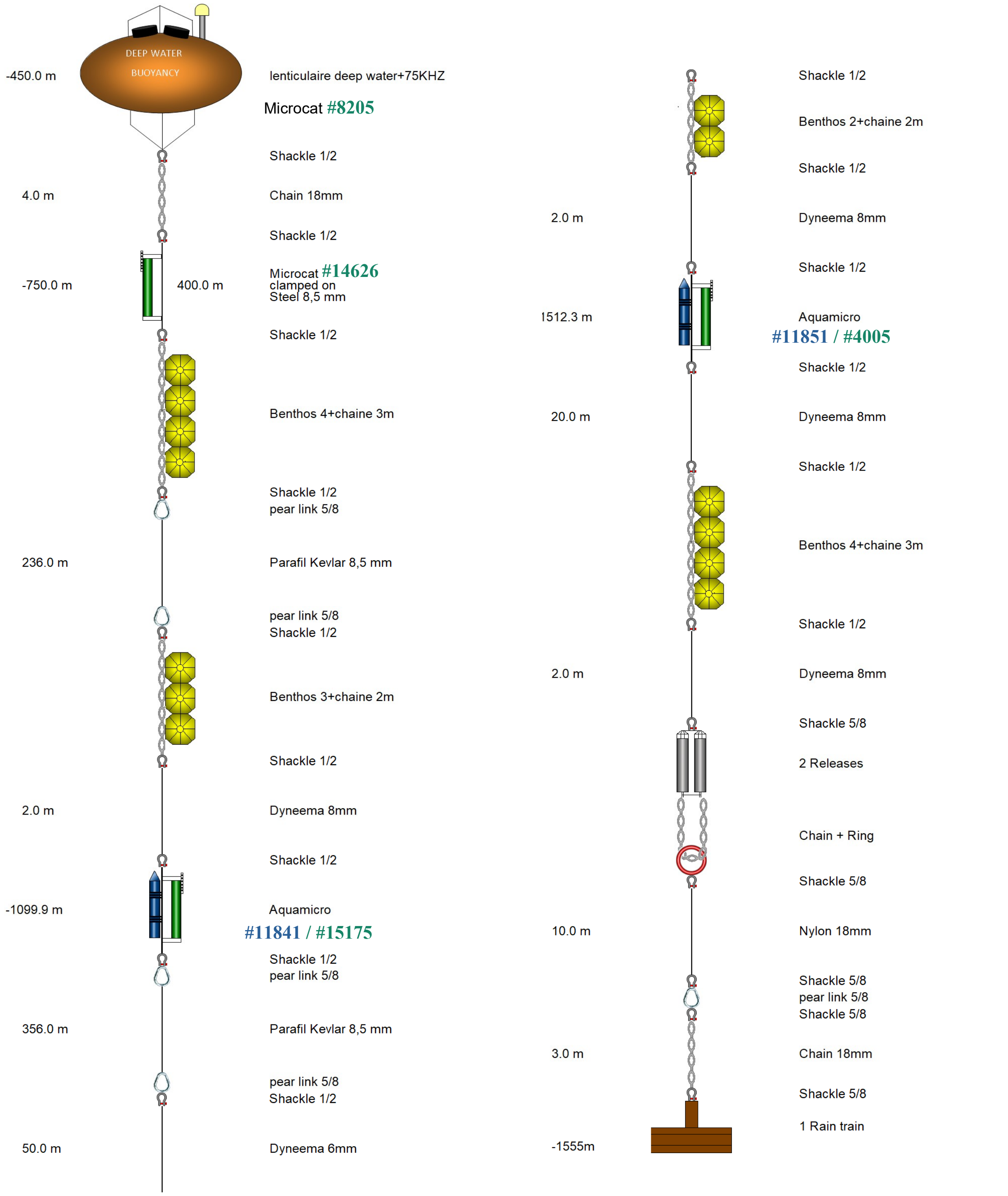
Funded by the European Union

1

Mooring EPOC #FC4



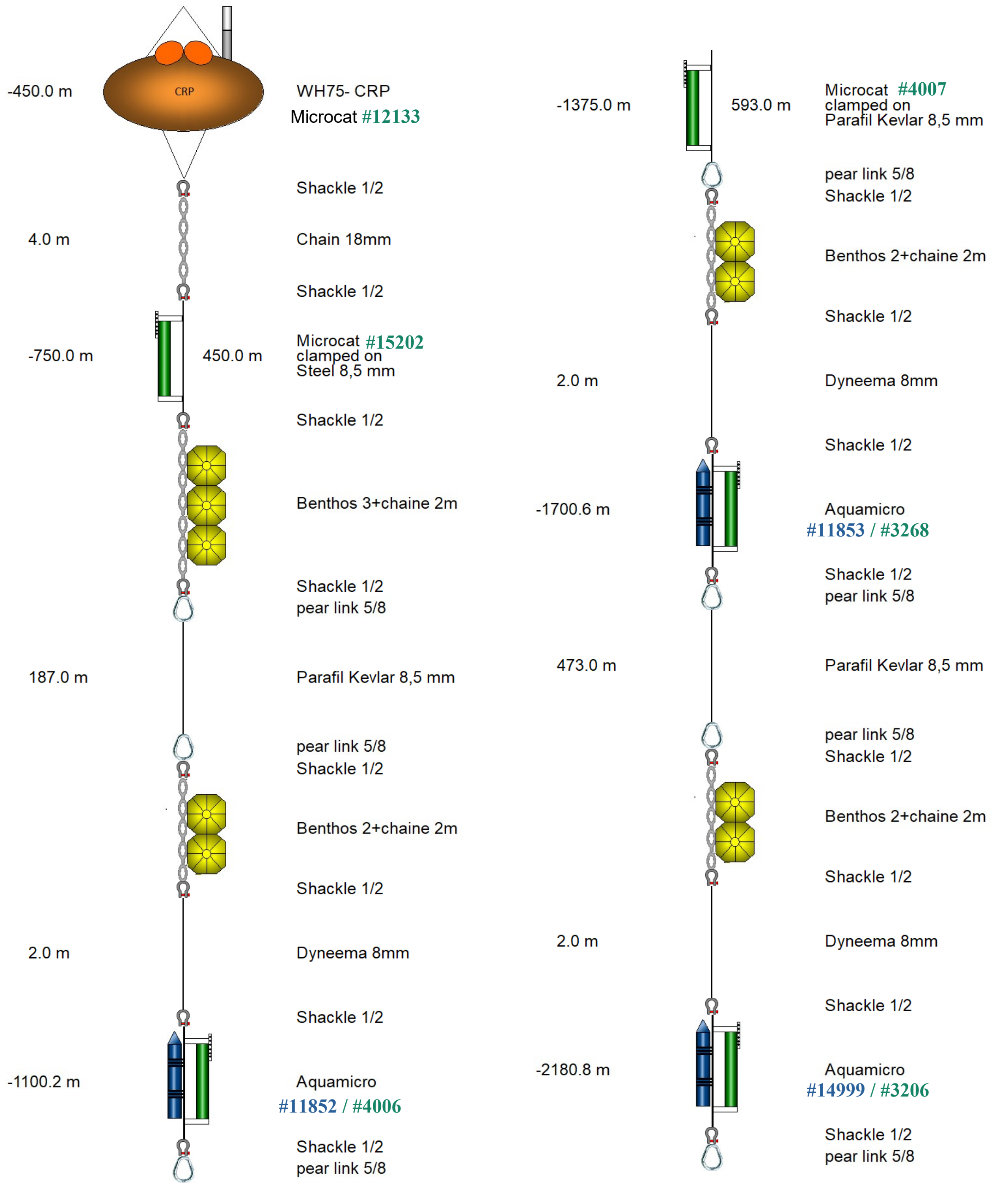
Mooring EPOC #GB1



Funded by the European Union

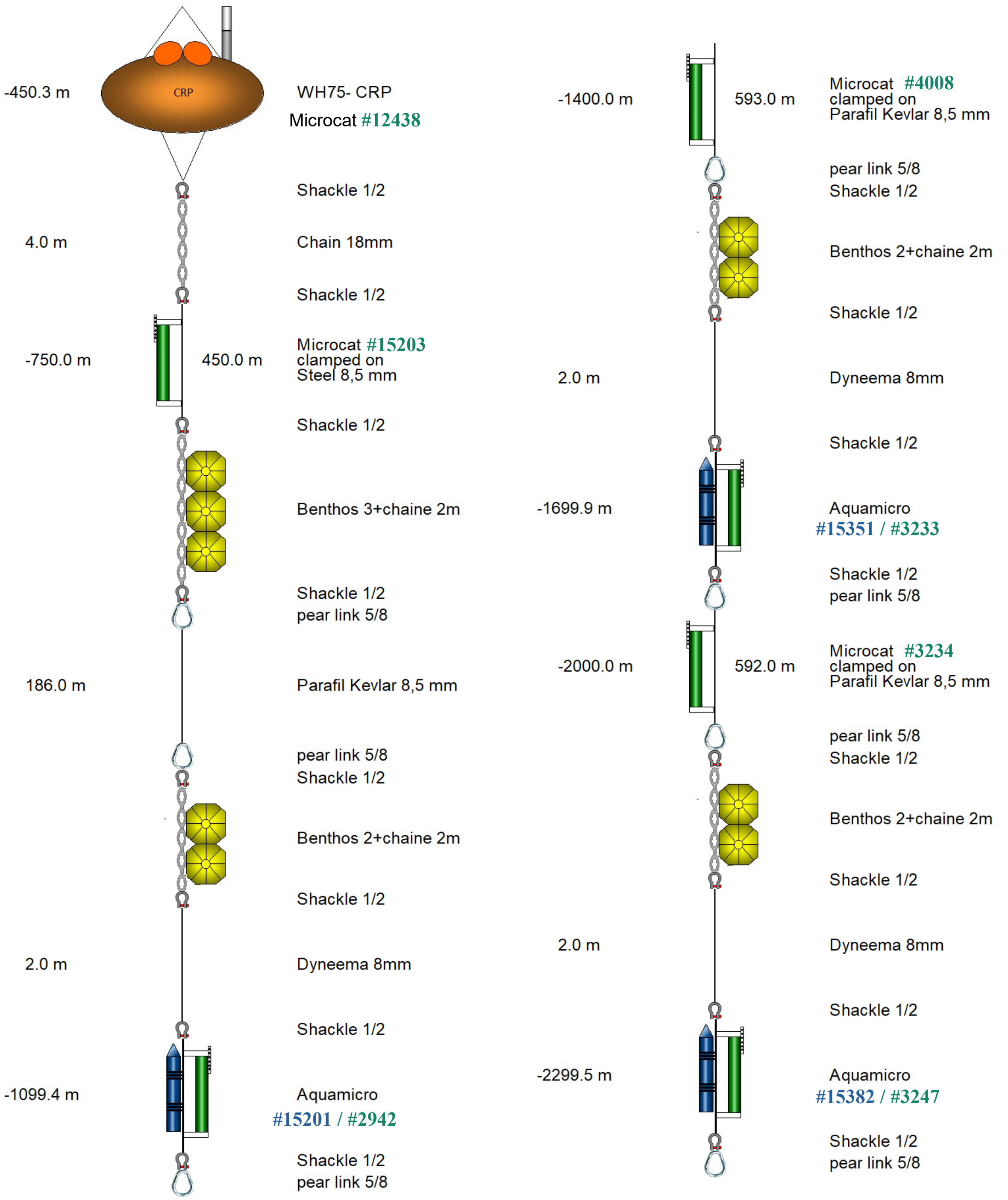
1

Mooring EPOC #GB2



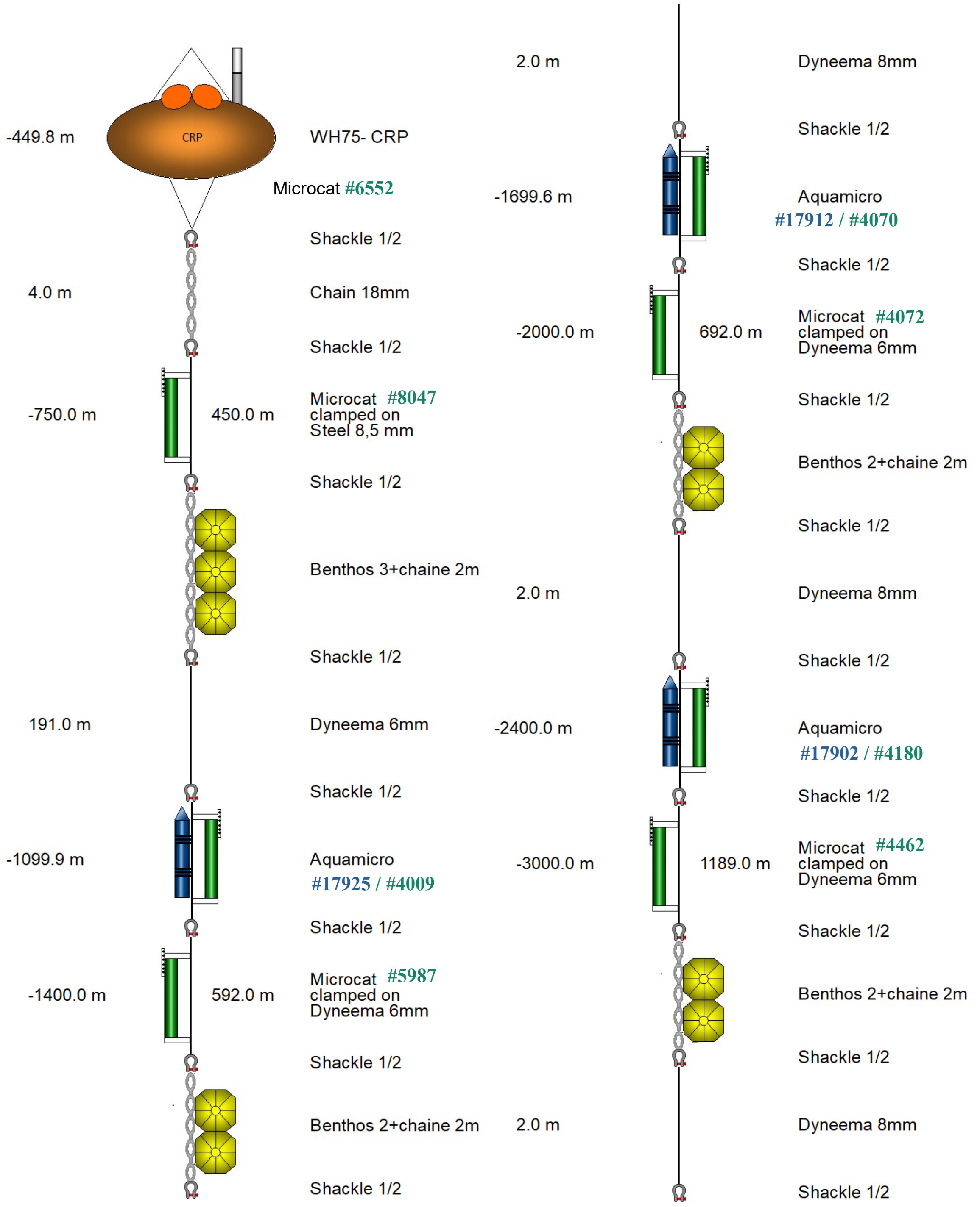
Funded by the European Union
epoc explaining and predicting the ocean conveyor
Ifremer

Mooring EPOC #GB3



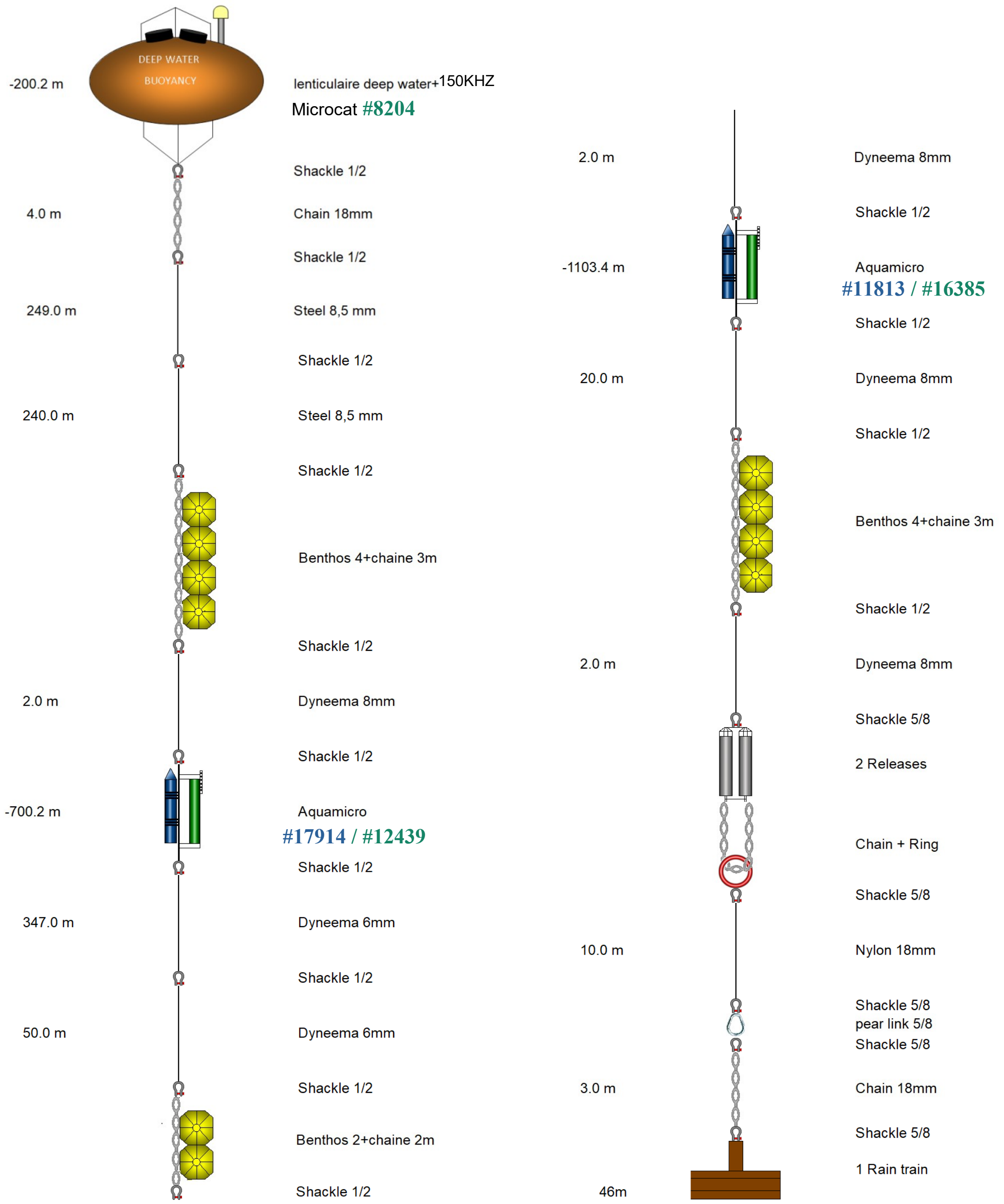
Funded by
the European Union
epoc explaining and predicting the ocean conveyor
Ifremer

Mooring EPOC #GB4



Funded by the European Union
epoc explaining and predicting the ocean conveyor
Ifremer

Mooring EPOC #PASS



Funded by the European Union

GB2LZ Planned 2023