2. HAFOS: MAINTAINING THE AWI'S LONG TERM OCEAN OBSERVATORY IN THE WEDDELL SEA

2.1 Physical Oceanography

Olaf Boebel[1], Jacob Allerholt[1], Carina Engicht[1],
Mario Hoppema[1], Pedro Llanillo[1], Clea Parcerisas[2], Ole Pinner[1], Irene Torrecilla Roca[1],
Stefanie Spiesecke[1], Sandra Tippenhauer[1]

[1]DE.AWI
[2]BE.VLIZ

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Outline and Objectives

Due to its potential to internally store and transport vast amounts of heat and CO_2, the ocean is a key element of the global climate system. Its response to changes in the forcing is expressed and controlled by its stratification, which is governed by the vertical distribution of temperature and salinity. Until the turn of the 21 century, shipborne observations were the only means of obtaining sufficiently accurate vertical profiles of water mass properties, but progress in sensor technology now allows using autonumous systems. The current backbone of the Global Ocean Observing System (GOOS) is the Argo system, which consists of an array of more than 3,000 profiling floats, distributed throughout the world oceans. Provided by an international group of oceanographic institutions, it aims at establishing a real-time data stream of mid- and upper (< 2,000 m) ocean temperature and salinity profiles augmented by a mid-depth oceanic circulation pattern due to the floats' intrinsic drift between profiles.

However, core Argo instrumentation is restricted to oceanic regions that are ice free year-round, as the floats need to surface to be localized and to transmit their profile data via satellite link. HAFOS (Hybrid Antarctic Float Observing System) constitutes an extension of core Argo into seasonally ice-covered waters of the Weddell Gyre, overcoming these limitations through a combination of well tested technologies to close the observational gaps in the Antarctic Ocean (Boebel, 2013, 2017, 2019). To this end, AWI pushed technological developments to extend the operational range of Argo floats into seasonally ice-covered regions by initiating the development of ice-resilient floats featuring an ice-sensing algorithm (ISA; Klatt et al., 2007) which aborts a floats' ascent to the sea surface when the presence of sea ice is likely, as determined from the existence of a layer of near-surface winter water. To be able to (retrospectively) track the floats that continued their mission under sea ice, RAFOS (Ranging And Fixing Of Sound) technology (Rossby et al., 1986) is used, based on an array of RAFOS sound sources.

To determine trends and fluctuations in the characteristics of the main Antarctic water masses (i.e., Warm Deep Water, WDW, and Antarctic Bottom Water, AABW), a set of about a dozen hydrographic moorings has been maintained by AWI and expanded throughout the past 30 years. HAFOS builds on this backbone by having added RAFOS sound sources for under-ice tracking of Argo floats since 2002. Near-bottom recorders continue truly climatological time series as sentinels for climate change in the formation areas of bottom waters, whereas the profiling floats record the water mass properties in the upper ocean layers. Passive acoustic monitoring allows linking marine mammal distribution in the open ocean to ongoing ecosystem changes, thereby complementing the physical measurements with biosphere observations at its highest trophic level. These efforts focus on a region where year-round oceanographic and marine mammal observations are notoriously sparse and difficult to obtain.

HAFOS complements international efforts to establish an ocean observing system in the Antarctic as a legacy of the International Polar Year 2007/2008 (IPY) and as a contribution to the Southern Ocean Observing System (SOOS), which is under development under the auspices of the Scientific Committee of Antarctic Research (SCAR) and the Scientific Committee on Oceanic Research (SCOR).

Work at sea

Most moored oceanographic instruments are, by and large, designed for deployment periods of maximum 3 years before they need to be recovered for maintenance and battery replacement. Hence, one major goal of expedition PS129 was to recover and redeploy moorings deployed during PS117 in 2018/19, to secure the collected data and to continue these observations for another 2-3 years.

The oceanographic studies during PS129 focused on two major areas, the Prime Meridian and the Weddell Sea, continuing more than 30 years of *in situ*-observations in the Atlantic sector of the Southern Ocean. Recovering moored instruments, we obtained time series of water mass properties throughout the oceanic deep and surface layers. For this purpose, moorings featuring current meters, temperature and salinity sensors, sound sources and passive acoustic recorders were recovered (Tab. 2.2 and Fig. 2.1) and (re-)deployed (Tab. 2.3 and Fig. 2.2). Provisioning against any failure of the ultra-short baseline hydroacoustic positioning and recovery system (POSIDONIA), we kept the mini-ROV Fiona (ROV = remotely operated vehicle) ready for ROV-assisted mooring recovery, if need would arise. Mooring work was conducted by a team of 5 crew (first mate, boatswain, crane operator and 2 capstan operators) and 4-5 scientists (2 for instrument handling, 1 or 2 at the winder and a reporter).

To enhance the vertical resolution and to calibrate moored sensors, CTD (Conductivity Temperature Depth) stations were occupied at and in-between the mooring locations. The CTD/water sampler consisted of a SBE911plus CTD system in combination with a rosette water sampler SBE32 with 24 12-litre bottles (Tab. 2.4). To determine the distance to the bottom, an altimeter from Benthos was mounted. A transmissometer from Wetlabs, a SBE43 oxygen sensor from Seabird Electronics and a fluorometer were incorporated in the sensor package. Additionally, two RDI-150 kHz ADCPs (Acoustic Doppler Current Profiler), one pointing upward, one pointing downward were attached to the rosette sampler to measure the current velocity profile. A CTD/L-ADCP section was conducted between Kapp Norvegia and the Antarctic Peninsula, towards which the stations' resolution was enhanced between mooring 257-5 (near 45°W) and the tip of the Antarctic Peninsula (Fig. 2.3) aiming at delineating the export plume of Antarctic Bottom Water. The CTD was operated by a crew of two (winch operator and deck hand) and a scientific CTD watch of two. Data management was done under the auspices of the CTD team leader.

Redeployed moorings host sound sources (Tab. 2.3 and Fig. 2.4), providing RAFOS (Ranging and Fixing of Sound) signals for retrospective under-ice tracking of the ISA-Argo floats deployed during PS129 and passive acoustic recorders to record ambient (biotic and abiotic) sounds. ISA (ice sensing algorithm) and RAFOS receiver equipped Argo floats were launched to capture temperature-salinity profiles in the Weddell Sea proper. Numbering 22 floats (Tab. 2.10 and Fig. 2.5), these receive hydroacoustic RAFOS signals from a total of 9 RAFOS sound sources hosted by the aforementioned moorings, allowing retrospective tracking of their drift under the sea ice and hence localization of the profiles they collected.

Additionally, in support of the international Argo programme, 6 core Argo floats were deployed *en route* for the Bundesamt für Seeschifffahrt und Hydrographie (BSH; Tab. 2.11 and Fig. 2.5) between Cape Town and 60°S. A total of 9 biogeochemical Argo floats (Tab. 2.12 and Fig 2.5) were deployed in support of the American SOCCOM project (Southern Ocean Carbon and Climate Observations and Modeling, https://soccom.princeton.edu).

2.1.1 Oceanographic moorings

Our moorings serve three purposes:

- to host oceanographic instruments that take local measurements at typically hourly intervals, like temperature, salinity or current velocity at the very location of the instrument (Tab. 2.1),
- to host passive acoustic recorders which monitor for marine mammal presence at 10s of km ranges, and
- to host RAFOS sound sources which facilitate the tracking of RAFOS receiver equipped Argo floats roaming freely throughout the Weddell Sea.

Standard mooring design includes Aquadopp velocity profilers and CTD loggers at 800 m (the floats' park depth) and CT loggers near the sea floor (Tab. 2.1). Moorings along the continental shelf break near Kapp Norvegia (EWS001-01 and EWS002-01) and the Antarctic Peninsula (AWI207-12 and AWI261-02) are augmented with additional temperature sensors, ADCPs and bottom pressure sensors to delineate the coastal current's structure.

Tab. 2.1: Moored instrument types, recorded parameters and sampling scheme

Instrument Type	Type	Parameter	typical sample period
SBE 37 SMP	CTD recorder	p, T, S	1800 s
SBE 37 SM	CT recorder	T	1800 s
SBE 39	T (+ p) recorder	p, T	600 s
SBE 53	Bottom pressure logger	p	900 s
SBE 56	Temperature logger	T	60 s
Aquadopp	Current profiler	u, v, w	1800 s

Moorings AWI251-03/04, close to Elephant Island, feature an AZFP (Acoustic Zooplankton and Fish Profiler, ASL), which record the backscatter of acoustic pings emitted at four different frequencies (38 kHz, 125 kHz, 455 kHz, 769 kHz) to detect zooplankton. Furthermore, a 75 kHz ADCP (Acoustic Doppler Current Profiler) is included in that mooring for information on the oceanic currents at the mooring position.

Generally, near each mooring location, a CTD was cast to be able to reference the moored temperature and salinity recorder's accuracy. Due to temporal limitations resulting from the ship-speed constraints imposed on this expedition, calling at the south-westernmost mooring AWI250-3 was not attempted.

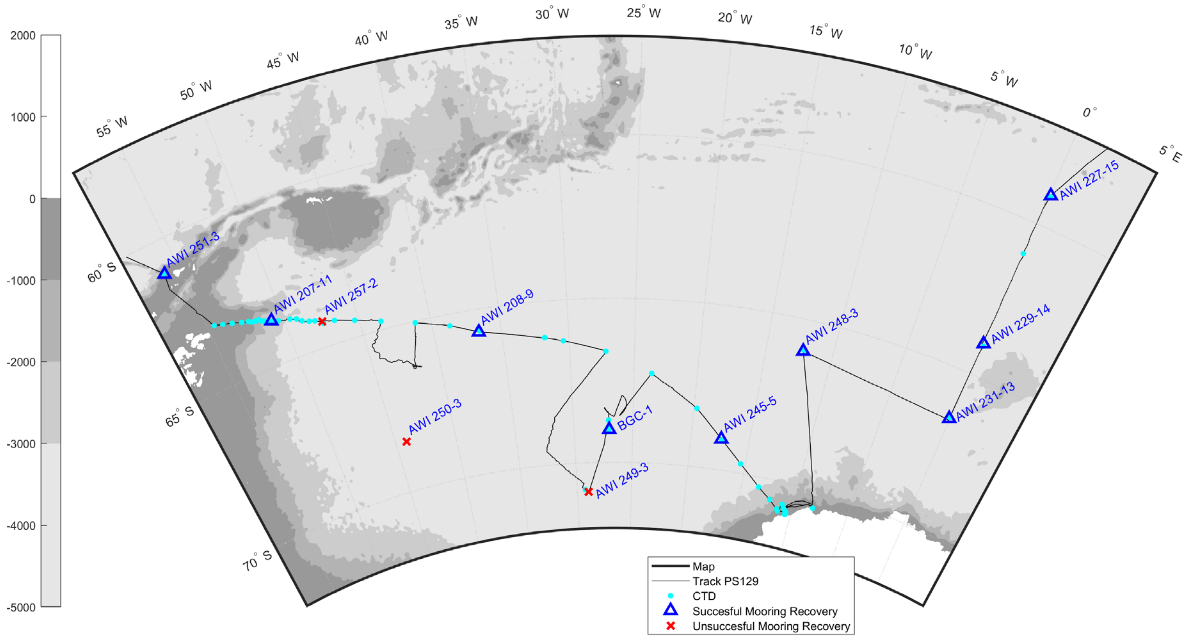

Fig. 2.1: Map of the Weddell Sea depicting the locations of successful (blue triangles) and unsuccessful (red crosses) mooring recoveries during PS129. Moorings are labelled "AWIxxx-nn", with xxx indicating Mooring ID and nn the number of consecutive deployments.

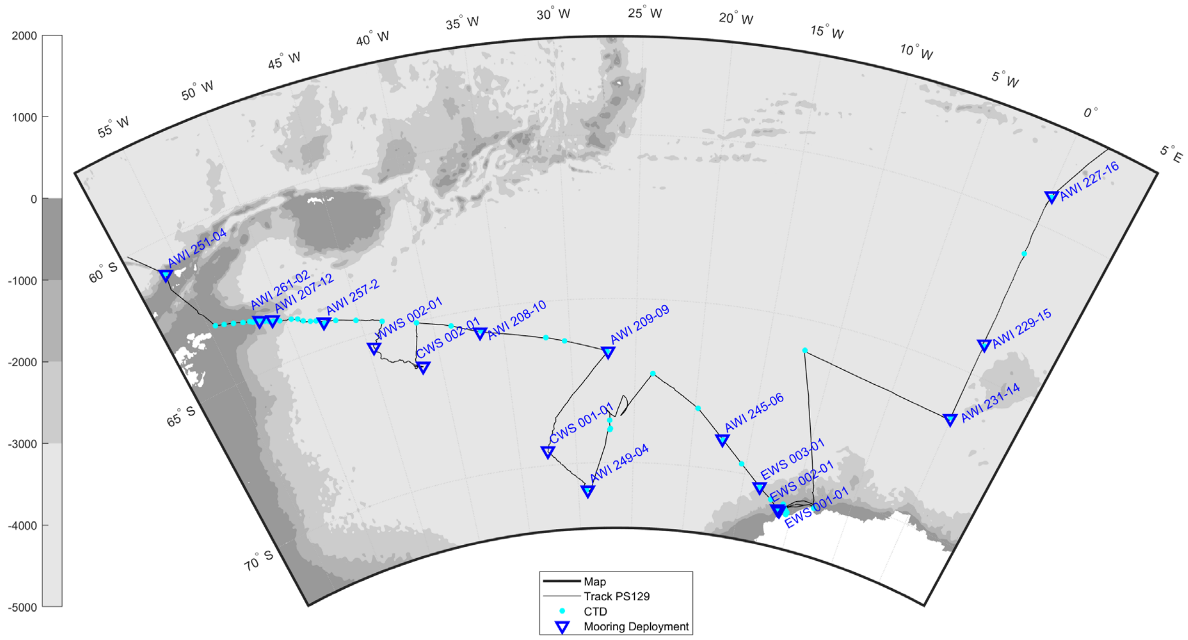

Fig. 2.2: Map of the Weddell Sea depicting the locations of mooring deployments during PS129. Moorings are labelled "ZZZxxx-nn", with ZZZxxx indicating the Mooring ID and nn the number of consecutive deployments.

Tab. 2.2: Instrumentation of moorings recovered during PS129. The column "CTD" gives the station number of the CTD casts carried out near the mooring location at deployment and recovery

For further information see the end of the Chapter.

Tab. 2.3: Instrumentation of mooring deployments during PS129

For further information see the end of the Chapter.

2.1.2 CTD observations

Ship borne CTD/rosette deployments

CTD casts were conducted pursuing three independent objectives:

- to revisit the CTD/CO_2/O_2 section across the Weddell Sea from Kapp Norvegia to the tip of the Anarctic Peninsula (WOCE repeat section SR4) across its entire length after nine years (last occupancy 2010/11),
- to collect temperature and salinity profiles at the mooring positions to tie the moored sensors single point time series to the full depth density profile,
- to revisit the spatially highly resolved repeat CTD section at the tip of the Antarctic Peninsula three years after its last occupation,
- to obtain pre- and post calibrations of the moored sensors.

The CTD/rosette was operated using the standard SeaBird SBE911plus setup, equipped with double sensors for temperature, salinity and oxygen, and one sensor each for pressure, substance fluorescence chlorophyll *a* and beam transmission. In addition, 24 12-litre OTE bottles for water sampling were attached. An altimeter was mounted to monitor the distance to the seafloor. Additionally, a high precision thermometer (SBE35, sn77/sw6345), as well as up and downward looking L-ADCPs were mounted to the rosette; ADCP SN 23293 (sw1309) as master, looking down, and ADCP SN 23292 (sw1258) as slave, looking up. Serial numbers as well as sensor web IDs are given in Table 2.4.

Tab. 2.4: CTD configurations for PS129

Sensor	Serial numbers	Sensor web ID
SBE9/Druck	321	3214
SBE3plus (primary)	1374	5844
SBE4c (primary)	3590	5870
SBE5 pump (primary)	5843	8544
SBE3plus (secondary)	1338	5842
SBE4c (secondary)	3173	4121
SBE5 pump (secondary)	5840	5865
SBE43 (primary)	4070	8542

Sensor	Serial numbers	Sensor web ID
SBE43(secondary)	4062	8543
Transmissometer, CStar	1220	4126
Fluorometer, EcoFLR	1346	5906
Altimeter	51533	4122
SBE35	0077	6345
ADCP down, master	23293	1309
ADCP up, slave	23292	1258

CTD Configuration 2 for PS129, only sensor changes are given here

Sensor	Serial numbers	Sensor web ID
Transmissometer, CStar	814	5913
Altimeter	1229	5904

CTD Configuration 3 for PS129, only sensor changes are given here

Sensor	Serial numbers	Sensor web ID
SBE43 (secondary)	1605	8546

CTD Configuration 4 for PS129, only sensor changes are given here

Sensor	Serial numbers	Sensor web ID
SBE43 (secondary)	0743	5881 or 6182
Altimeter	51533	4122

CTD Configuration 5 for PS129, only sensor changes are given here

Sensor	Serial numbers	Sensor web ID
SBE43 (secondary)	1834	5883

During this expedition, data from 54 full ocean depth CTD profiles were collected (Tab. 2.5). A map of the locations of the CTD stations is provided by Figure 2.3.

Tab. 2.5: CTD casts of PS129

For further information see the end of the Chapter.

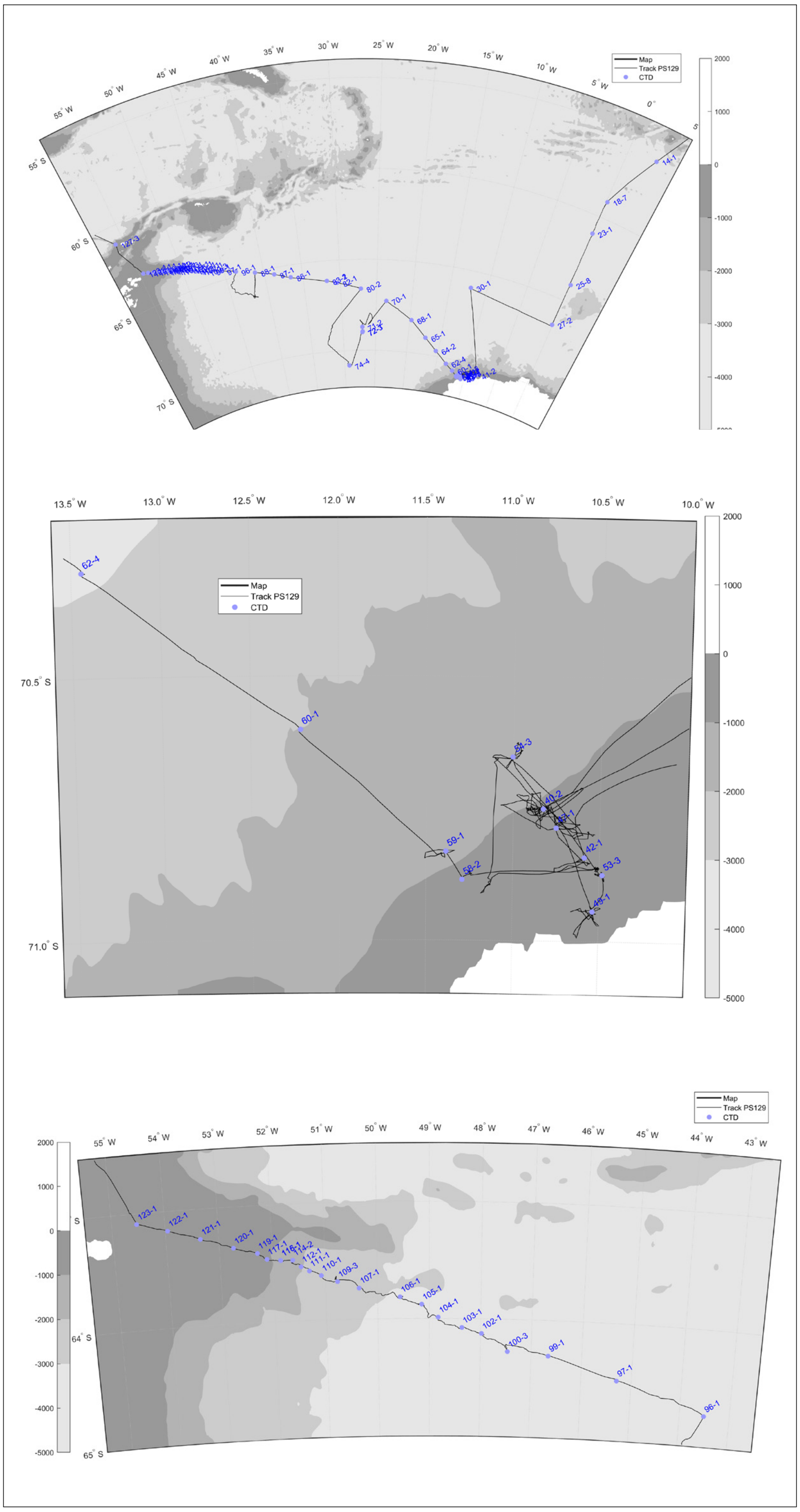

Fig. 2.3: Map of locations of CTD stations (top). Enlarged map of the CTD section near Kaap Norvegia (middle). Enlarged map of the CTD section towards the tip of the Antarctic Peninsula (bottom)

Labels indicate station and cast numbers as given in the station list.

Ocean Floor Observation and Bathymetry System borne CTD measurements

The Ocean Floor Observation and Bathymetry System (OFOBS) is used to assess distribution patterns of larger epibenthic organisms and other objects (see Section 7.3). It carries a still image camera, a forward-facing acoustic camera, a 2-band sidescan sonar system, an Ultra-Short BaseLine system transponder (USBL) and an HD-Video camera. It is lowered to the seafloor and then towed with typically 0.5 kt with an altitude between 1.5 and 10 m above ground. To access the basic physical conditions the observed organisms are living in, a CTD probe was mounted to the OFOBS frame. The CTD was a battery powered, pre-programmed, internally recording SBE-37. A list with station names, positions and file names is given in Table 2.6.

Tab. 2.6: OFOBS CTD deployments

For further information see the end of the Chapter.

2.1.3. CTD-mounted ADCP (L-ADCP)

Set-up

Two 300 kHz RDI Workhorse ADCPs were mounted on the CTD/rosette to act as lowered ADCPs (L-ADCP). The L-ADCP assembly consists of the two 300 kHz ADCPs (SN 23292 – slave, SN23293 – master) and a battery container. When on deck, communication was established to a computer in the winch control room via two cables (for master and slave), which were attached before and after each cast to the ADCPs to start and stop the ADCPs and to download the data. The ADCPs were operated using the GUI of the LADCP tool V1.7 from GEOMAR.

Data collection

L-ADCP measurements were conducted at all CTD stations. The data were downloaded after each cast, time between casts permitting. The master (downward looking device) and slave (upward looking device) data file names consist of the station number (three digits), an abbreviation indicating the viewing direction (UP for upward and DN for downward) and a running number with three digits beginning with 000, representing the file number, in case there are multiple files. For example, at station 4, data is saved in the files "004DN000.000" and "004UP000.000". These files are stored in a folder named alike the station number. In these folders, log files documenting all actions conducted as starting (with configurations), stopping and downloading are kept as well.

When starting a new cast, the ADCP software automatically counts upwards to define the new cast number. This results in the fact that cast numbers are not counting up continuously but have some gaps, in case where the ADCP was started and stopped in between casts. L-ADCP and CTD cast numbers are given inTable 2.5. A battery change was done after L-ADCP cast number 23 and again after cast 31.

Configurations

The settings documented in Table 2.7 were used during the entire expedition. Specifically, we used 20 bins with a bin size of 10 m (i.e., a maximum range of 200 m), beam coordinates, no blanking after transmission, narrow band processing, one ping per ensemble and 1.2 seconds per ensemble.

Tab. 2.7: Configuration file of the Master L-ADCP

```
[LADCP]
last_profile_number=1
base_path=C:\ladcp\scripts\..\
network_path=L:\scientists\ladcp\raw\
cruise_id=PS129
up_installed=1
down_installed=1
total_pings=213259
total_ping_time=37.0
erase_button=enabled
download_files=all
last_action=stop
ntp_server=192.168.20.3
[Master-Commands]
mode_15=1
ambiguity_velocity=250
bin_number=20
bin_length=1000
blank_after_transmit=0
broadband=1
sensor_source=0111101
coordinate_transformation=00111
flow_control=11101
pings_per_ensemble=1
time_between_pings=0
time_per_ensemble=1.2
master_slave=1
wait_ensembles_before_sync=0
master_slave_when_to_sync=011
wait_time_before_sync=5500
power_output=255
[Slave-Commands]
mode_15=1
ambiguity_velocity=250
bin_number=20
bin_length=1000
blank_after_transmit=0
broadband=1
sensor_source=0111101
coordinate_transformation=00111
flow_control=11101
pings_per_ensemble=1
time_between_pings=0
time_per_ensemble=1.2
master_slave=2
master_slave_when_to_sync=011
wait_time_before_start_without_sync=200
power_output=255
```

Data processing

On board, data processing was carried out with the GEOMAR L-ADCP software version 10, which is executed in Matlab. The software combines, if available, data from the L-ADCP, CTD, navigational data, and a vessel mounted ADCP to conduct the velocity inversion method.

The CTD data were provided in two files, one containing data averaged onto 1 dbar and another one averaged onto 1 second. Both files where prepared unsing the programme Manage CTD. For the sADCP data, the output from the GEOMAR sADCP software (OSSI19) was used.

The software package executed in Matlab produces significant amounts of diagnostic output stored in a log file in the log folder and displayed in 16 figures saved in the folder plots. The output not only displays the calculated velocities in zonal (u) and meridional (v) directions, but also additional figures that help to identify error sources and problems of the acquisition process.

2.1.4. HAFOS sound source array

A major goal of this expedition was to reinstall the RAFOS sound source array which is used to retrospectively track the ISA-Apex floats while under ice. All previously moored HAFOS sources had been removed already during *Polarstern* expedition PS117 as, at that time, no ISA floats were present in the Weddell Gyre.

During PS129, a total of 7 sound sources were deployed. We used the opportunity of a complete reinstallation of the array to reduce the temporal spread of signals emitted by the sources from 12:00–14:10 UTC to 12:40–13:20 UTC. This allowed float-side a reduction of listening windows from 11:30–14:30 UTC (180 min duration) to 12:30–13:30 (60 min duration), resulting is significant savings in energy. A summary of sound source activities is given in Table 2.8 as well as in Figure 2.4.

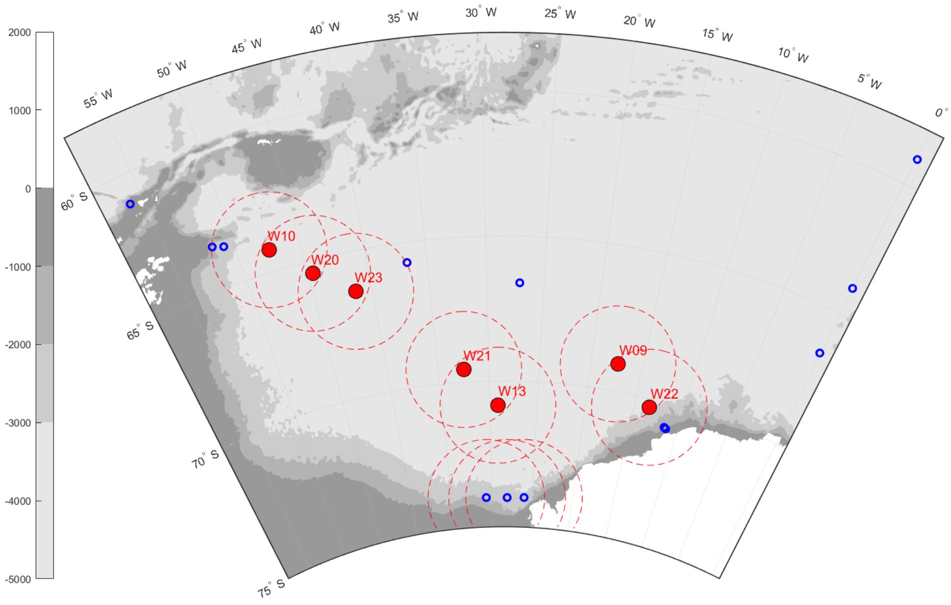

Fig. 2.4: HAFOS sound source array as deployed during PS129 (red dots with red dotted circles at 200 km radius). Presumably active sources deployed near 74°S during PS124 a year earlier are marked by small blue circles with red dotted circles. Moorings deployed during PS129 without sound sources are marked by small blue circles. Top-right to the marked position: sound source array ID

Tab. 2.8: Metadata of RAFOS sound sources deployed during PS129

For further information see the end of the Chapter.

2.1.5 Argo float deployments

During PS129, a total of 22 ice resilient APEX floats, produced by Teledyne Webb Research, U.S.A., were deployed. All floats had been appropriated by AWI and are equipped with identical sensor suits. They feature an adjustable Ice Sensing Algorithm (ISA-2), set to -1.70°C (parameter IceCriticalT) between 40 and 15 dbar (parameters IceDetectionP and Ice EvasionP), with a surfacing response retarded by 11 days (parameter IceBreakupDays, equivalent of one profile). Interim data storage internally saves all profiles that could not be transmitted in real-time due to ISA-triggered aborts of surfacing attempts and transmits these profiles during ice-free conditions. RAFOS technology is used for under ice tracking. For data transmission Iridium SBD is used. The floats were ballasted to drift at a depth of 800 m and acquire profiles from 2,000 m depth upwards every 10 days, for the first 4 profiles every 3 days. The first profile is taken directly after deployment after having sagged to 2,000 m. Floats were launched using the pressure activated autostart option, with and wake-up period of 120 m. The float's boot was filled with seawater prior to deployment, to ensure floats would sink right away after launch and not interfere with any potentially present sea ice (in fact, most floats were launched at or near 100% sea-ice coverage into the ship's swath from the ship's stern. Attempts to enlarge the spot of open water by steering hard starboard proved little helpful, as this introduced an undercurrent which carried the floats to the portside edge of the open water wake and upwards into the sea ice present there.

All floats were subjected to a self-test aboard *Polarstern* a few days prior to deployment. To this end, floats were placed outside the meteorologist's office in good view of open skies. Nevertheless, satellite communication repeatedly did not work on the first try (see Tab. 2.9). To prevent freezing of residual water in the CTD during the around 30 min long satellite communication tests, foot and hand warmers were draped around the CTD, with variable success as indicated by the temperatures reported during the self-test. One float failed to communicate by SailLoop during the test phase and will be returned to the manufacturer. Float deployment information is presented in Table 2.10 and Figure 2.5.

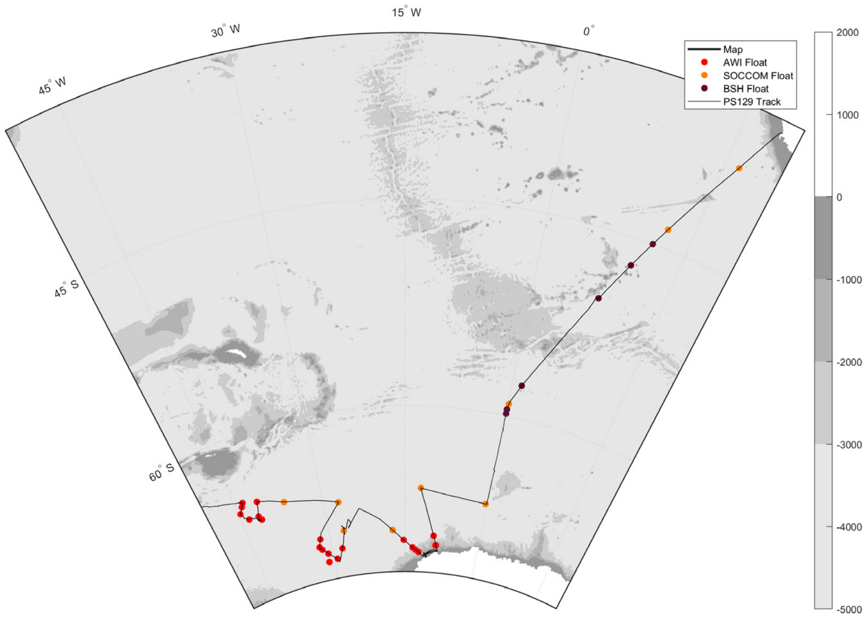

Fig. 2.5: Locations of deployments of floats provided by AWI, BSH and SOCCOM

Tab. 2.9: Ice resilient APEX float tests and clock readings

For further information see the end of the Chapter.

Tab. 2.10: Ice resilient APEX float deployments, all featuring Ice Sensing Algorithm (ISA) and RAFOS receivers

For further information see the end of the Chapter.

2.1.6. Argo float deployments on behalf of BSH / Argo Germany

During PS129, a total of 6 ARVOR-I floats were deployed on behalf of Argo Germany. Four of them are equipped with an adjustable Ice Sensing Algorithm (ISA), set to -1.79°C between 50 and 20 dbar, with a surfacing response retarded by 1 profile. Profiles that could not be transmitted in real-time due to ISA-triggered aborts of surfacing attempts are stored into the float internal memory and transmitted next time the float surfaces. For data transmission Iridium SBD is used. The floats were ballasted to drift at a depth of 1,000 m and acquire profiles from 2,000 m depth upwards 1 day after deployment for the first profile and every 10 days for the next profiles. The first profile is taken 2 hours after activation and after having sagged to 2,000 m. Float identification information given in float profiles can be downloaded on https://www.jcommops.org/board/wa/Platform?ref=xxxxxxx with xxxxxxx standing for the WMO number. Float deployment information is presented in Table 2.11 and plotted in Figure 2.5 (dark red dots).

Tab. 2.11: ARVOR float deployments *Ice Sensing Algorithm (ISA)

For further information see the end of the Chapter.

2.1.7. BGC float deployments on behalf of SOCCOM

During PS129, a total of 9 BGC (biogeochemical) SOCCOM floats were deployed – SOCCOM, Southern Ocean Carbon and Climate Observations and Modeling, is a multi-institutional U.S. programme. Floats were lowered by rope to the sea surface. Float deployment information can be found in Table 2.12 and is plotted in Figure 2.5 (orange dots).

Tab. 2.12: SOCCOM float deployments

For further information see the end of the Chapter.

2.1.8. Salinity calibrations by salinometer

To calibrate the conductivity sensors, water samples for salinity were taken regularly and measured with the Optimare Precision Salinometer (OPS). Prior to measurement, samples where degassed by heating them to 30°C for 1 hour, venting the overpressure and let them adjust to room temperature. In total, 220 salinity samples were measured using the OPS-006 or OPS-007 instruments. As a standard, the OPS-006 is the one to be used by scientists, while OPS-007 is used by the ship's crew. As OPS-006 exhibited a discontinuity in the salinity readings on 3 April 2022, the OPS-007 was used for the subsequent measurements while the OPS-006 was cleaned. Once the OPS-006 showed stable readings again it was reemployed. On 25 April 2022, however, the OPS-006 became unusable as the pre-bath stirrer broke.

Table 2.13 lists all salinity measurements. Out of the 220 salinity measurements, 5 were unusable due to unstable readings of the OPS. For 2 out of these 5 instances, the reason is unknown. To examine the impact of the degassing procedure on the salinity measurements, outgassing was skipped for 3 samples. For those 3 samples, the OPS measurement did not stabilize, indicating that the OPS cannot obtain stable measurements if samples are not degassed properly. In addition to the samples measured on board, 68 samples were shipped to AWI, for later analyses and comparisons between an Optimare Precision Salinometer and an Autosal instrument, the latter of which was used on *Polarstern* cruises earlier in time. Final calibration of the CTD data will be performed using the salinometer measurements together with the post-cruise manufacturer calibration of the sensors.

Tab. 2.13: Salinity measurements by salinometer. Numbers printed red indicate values that exhibited a discontinuity in the OPS reading, resulting in their exclusion from the calibration process.

For further information see the end of the Chapter.

2.1.9. Vessel mounted ADCP (sADCP)

Polarstern is equipped with an Ocean Surveyor 150 kHz (RD-Instruments) Acoustic Doppler Current Profiler (sADCP) to monitor ocean currents. The sADCP was operated using the settings given in Table 2.14. During most of the expedition the sADCP was operated in slave mode, triggered by the K-Synch unit. Pinging was synchronized between the sADCP and the EK-80, which uses four different frequencies (38 kHz, 70 kHz, 120 kHz, 200 kHz) in FM-mode (broadband) and a single 18 kHz ping for echosounding (depth). Zero waiting time was set for the sADCP and EK-80. For the 18 kHz depth sounder, a depth dependent waiting time was set. Before those settings where found, the sADCP was stopped and restarted several times for changing the configuration of the synch-unit as well as EK-80 calibrations.

For protection against ice, the Ocean Surveyor is mounted in a water filled cavity behind a window, in the ship's hull. When steaming through ice, air accumulates inside the window over time, which negatively affects the data quality. During PS129 the air was regularly released by the laboratory electrician.

The data from the sADCP were merged online with the corresponding navigation data (i.e., the vessel's GPS system) and stored on the hard disk using the program VMDAS. Pitch, roll and heading data are converted from NMEA. Current velocity data were collected in beam coordinates to apply corrections during post processing. Processing during the cruise was conducted using GEOMAR s-ADCP software (OSSI19). Final data processing and quality control will be performed at AWI.

Tab. 2.14: Configuration file of the sADCP

```
; Restore factory default settings in the ADCP
cr1h

; set the data collection baud rate to 9600 bps,
; no parity, one stop bit, 8 data bits
; NOTE:  VmDas sends baud rate change command after all other commands in
; this file, so that it is not made permanent by a CK command.
cb411

; Set for narrowband single-ping profile mode (NP), 80 (NN), 4-meter bins (NS),
; 4-meter blanking distance (NF)
WP000
NP001
NN080
NS0400
NF0400
;WV390 (default)

; Disable single-ping bottom track (BP),
BP000

; output velocity, correlation, echo intensity, percent good
ND111100000

; Ping as fast as possible
TP000000

; Since VmDas uses manual pinging, TE is ignored by the ADCP
; and should not be set.
;TE0000000

; Set to calculate speed-of-sound, no depth sensor, external synchro heading
; sensor, pitch or roll being used, no salinity sensor, use internal transducer
; temperature sensor
EZ1011101

; Output beam data (rotations are done in software)
EX00000
; Set transducer misalignment (hundredths of degrees).
; Ignored here but set in VmDAS options.
;EA00000

; Set transducer depth (decimeters)
ED00110

; Set Salinity (ppt)
ES35

;set external triggering and output trigger; no trigger
CX0,0 (either on or off)

;set external triggering and output trigger
;CX1,3 (either on or off)

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

2.1.10. Thermosalinograph

There are two SBE21 SeaCAT thermosalinographs with additional external thermometers SBE38 for minimum thermal contamination from the ship. The two systems are operated in parallel on the same seawater intake. The pumped system is equipped with a flow meter and set to pump 60 L min^{-1}. Position and time information is added via NMEA telegram. The system is located in the ships keel with the water intake at about 11 m depth, depending on the ships draft.

During PS129, the system was running continuously and switched off only for short maintenance and cleaning. For calibration, salinity samples are taken irregularly, depending on the ice conditions. On average, samples are taken every other week and measured with an Optimare Precision Salinometer on board by the ship's laboratory electrician. The sensors are usually operated for one full expedition season (about half a year, depending on expedition schedule) and changed during port calls in Bremerhaven. Once post-cruise calibration of sensors has been performed, the data is processed and calibrated by Fielax GmbH and stored in the PANGAEA data repository.

2.1.11. RAFOS source tuning

A detailed description of the objectives and approach of tuning the RAFOS sources *in situ* is given in the expedition report of ANT-XXIX/2 (Boebel, 2015). During PS129, the frequency response of 7 sound sources was determined using 19 tuning runs: all systems, except one, featured new anodized aluminum resonance tubes and had a total length of 2220-2230 mm. One system had already been tuned on a previous expedition (D0046, end length: 1,900 mm). Due to a refurbishment of this source by the manufacturer, its tuning required checking.

Tuning, i.e., shortening the length of a resonator tube until it resonates at the RAFOS center frequency of 260 Hz, of the new resonator tubes was performed in up to four tuning runs per resonator. Before each shortening, the frequency response of resonators was determined by using up to four consecutive 80-sec long frequency sweeps per run. Start times of sweeps were spaced by 10 minutes to allow the electronics to cool down before starting a new sweep. As the tuning procedure was adapted a number of times during the cruise, the frequency range of each sweep within a run varied.

Before shortening the tubes, the frequency response of the source was determined by using consecutive 80-sec sweeps over a total frequency range from 230-265 Hz. In the first and second tuning step, 3 sweeps were configured to cover the current expected resonance frequency +/- 8 Hz, and the RAFOS frequency. In the third and last tuning step, one sweep from 256-264 Hz and the RAFOS sweep were performed to obtain the final resonance frequency and source level. Details of the steps were adapted during the expedition according to new findings in the resonance frequency behavior (Tab. 2.15).

The sound source's configuration for the tuning was stored on an SD card and set to start on a fictional future date. Prior to the lowering of the sound source, a time approximately 45 minutes before this fictional date/time was set to give the system enough time to be lowered to the measurement depth of 800 m before starting the first sweep.

Sound sources were lowered horizontally to 800 m depth in waters of at least 2,000 m depth using winch #32. A 10-m-long rope with a Sound Velocity Profiler (Valeport) was hanging below the sound source for sound velocity measurements. An additional 25 kg weight was attached below the Sound Velocity Profiler and two 25 kg weights were attached directly underneath the sound source. During the first measurements, the sound sources were directly attached to the winch cable using a sling around the middle part and the electronics of the source.

Starting 18 March 2022, a metal bar was attached to the empty brackets on the opposite side to the electronics with the intention to prevent the sound source from swinging during the tuning measurements. For redundancy of the acoustic recordings, 3 icListen (SN 1413, 1414 and 1415) were attached 40 m above the sound source at 1/8 wavelength spacing directly to the winch cable. Results, however, showed inconsistent sound pressure levels. To minimize potential near-field effects, the distances between the source and the recorders was changed to around 84 m.

Tab. 2.15: Sound source tunings with sweep parameters by step

Event Time	**Reso-nator**	**Electro-nics**	**Run**	**sweep 1 [Hz]**	**sweep 2 [Hz]**	**sweep 3 [Hz]**	**sweep 4 [Hz]**
12.03.2022 18:55	D0047	EI0043	Run 1	230 - 240	240 - 250	250 - 260	
12.03.2022 20:35	D0048	EI0061	Run 1	230 - 240	240 - 250	250 - 260	
13.03.2022 10:48	D0046	EI0066	Run 1	255 - 265	RAFOS		
15.03.2022 19:58	D0046	EI0066	Run 2	257 - 263	RAFOS		
17.03.2022 03:52	D0048	EI0061	Run 2	249 - 255	255 - 261	RAFOS	
18.03.2022 14:11	D0046	EI0043	Run 3	257 - 263	RAFOS		
18.03.2022 15:58	D0048	EI0061	Run 3	257 - 263	RAFOS		
18.03.2022 17:29	D0017	EI0067	Run 1	230 - 238	238 - 246	246 - 254	
03.04.2022 01:07	D0017	EI0058	Run 2	240 - 248	248 - 256	256 - 264	RAFOS
03.04.2022 03:19	D0043	EI0047	Run 1	230 - 238	238 - 246	246 - 254	RAFOS
03.04.2022 05:04	D0018	EI0050	Run 1	230 - 238	238 - 246	246 - 254	RAFOS
04.04.2022 16:46	D0043	EI0047	Run 2	246 - 254	254 - 262	RAFOS	
04.04.2022 18:31	D0017	EI0058	Run 3	246 - 254	254 - 262	RAFOS	
04.04.2022 20:11	D0018	EI0050	Run 2	246 - 254	254 - 262	RAFOS	
08.04.2022 13:06	D0043	EI0047	Run 3	256 - 264	RAFOS		
08.04.2022 21:40	D0018	EI0050	Run 3	256 - 264	RAFOS		
08.04.2022 23:15	D0017	EI0058	Run 4	256 - 264	RAFOS		
15.04.2022 17:00	D0030	EI0066	Run 1	235-243	239.38- 240.90		
17.04.2022 08:08	D0030	EI0066	Run 2	256 - 264	RAFOS		

After completion of each run, recordings from the acoustic recorders were saved from the icListen's internal storage to hard disk. Using Audacity, sweeps belonging to a given sound source were manually cut at their boundaries from the displayed spectrogram and saved as single files.

A python script was used to determine the (current) resonance frequency of the highest root-mean-square amplitude SLmax sweep [dB] (Tab. 2.16). A MATLAB™ script used the current resonance frequency, current tube length and environmental parameters (e.g., sound velocity at tuning depth, water density) to derive the target resonance length and the excess length to be cut. During the first cut, a length of only about two third of the calculated difference was cut, while on the second cut, the remaining calculated length difference was cut. Additionally, 3 boreholes were drilled on each side with a diameter of 12 mm and the center 30 cm from the edge. Isolators were glued into the borehole. After this the last remaining tuning measurement was performed.

Tab. 2.16: Sound source tunings. A block of three lines each represents a single tuning run with the three lines distinguishing the measurements from the three icListen hydrophones. Dist. [m] gives the distance from the source to the hydrophone. Length [mm] gives the overall tube length for both tubes end to end. fpk sweep = frequency of spectral peak, SLmax sweep = maximum band-passed filtered source level during sweep, SL RAFOS = source level during RAFOS sweep re 1 µPa

Sound Source	**electr. ID**	**icListen ID**	**Run**	**f_{pk}. sweep [Hz]**	**SL_{max} sweep [dB]**	**SL RAFOS [dB]**	**Coil**	**Amp.**	**Dist. [m]**	**Length [mm]**	**DateTime**
D0017	EI0067	1413	1	242.5	186.4	NA	off	100	82	2220	202203181802
D0017	EI0067	1414	1	242.5	188.48	NA	off	100	82	2220	202203181802
D0017	EI0067	1415	1	241.0	187.46	NA	off	100	82	2220	202203181802
D0017	EI0058	1413	2	241.0	177.63	168.21	off	95	84.2	2220	202204030147
D0017	EI0058	1414	2	249.0	170.49	167.44	off	95	81.4	2220	202204030147
D0017	EI0058	1415	2	240.5	178.35	167.74	off	95	82.8	2220	202204030147
D0018	EI0050	1413	1	240.0	173.2	168.64	off	95	84.2	2230	202204030545
D0018	EI0050	1414	1	241.5	168.68	167.45	off	95	81.4	2230	202204030545
D0018	EI0050	1415	1	240.0	177.44	170.03	off	95	82.8	2230	202204030545
D0043	EI0047	1413	1	239.0	175	156.92	off	95	82.2	2230	202204030350
D0043	EI0047	1414	1	239.0	172.31	155.82	off	95	81.4	2230	202204030350
D0043	EI0047	1415	1	237.5	174.21	155.46	off	95	82.8	2230	202204030350
D0046	EI0066	1413	1	NA	NA	162.23	off	100	42.8	1900	202203131123
D0046	EI0066	1414	1	NA	NA	161.35	off	100	41.4	1900	202203131123
D0046	EI0066	1415	1	NA	NA	165.44	off	100	40.0	1900	202203131123
D0046	EI0066	1413	2	NA	NA	180.09	on	100	40.0	1900	202203152034
D0046	EI0066	1414	2	NA	NA	176.91	on	100	41.4	1900	202203152034
D0046	EI0066	1415	2	NA	NA	188.46	on	100	42.8	1900	202203152034
D0046	EI0043	1413	3	NA	NA	173.98	on	90	82.0	1900	202203181445
D0046	EI0043	1414	3	NA	NA	168.66	on	90	82.0	1900	202203181445
D0046	EI0043	1415	3	NA	NA	177.11	on	90	82.0	1900	202203181445
D0047	EI0043	1413	1	232.5	170.23	NA	off	100	42.8	2240	202203122106
D0047	EI0043	1414	1	243.0	163.6	NA	off	100	41.4	2240	202203122106
D0047	EI0043	1415	1	238.5	176	NA	off	100	40.0	2240	202203122106
D0048	EI0061	1413	1	241.5	178.26	NA	off	100	42.8	2220	202203121930
D0048	EI0061	1414	1	241.5	175.04	NA	off	100	41.4	2220	202203121930
D0048	EI0061	1415	1	241.5	178.28	NA	off	100	40.0	2220	202203121930
D0048	EI0061	1413	2	259.0	161.15	160.63	off	100	40.0	1964	202203170430
D0048	EI0061	1414	2	256.5	164.88	162.89	off	100	41.4	1964	202203170430
D0048	EI0061	1415	2	256.0	171.24	168.39	off	100	42.8	1964	202203170430
D0048	EI0061	1413	3	NA	NA	168.47	on	90	82.0	1965	202203181634
D0048	EI0061	1414	3	NA	NA	170.04	on	90	82.0	1965	202203181634
D0048	EI0061	1415	3	NA	NA	171.91	on	90	82.0	1965	202203181634
D0017	EI0058	1413	3	246.0	172.36	158.45	off	95	84.2	2006	202204041909
D0017	EI0058	1414	3	249.69	170.07	156.4	off	95	81.4	2006	202204041909
D0017	EI0058	1415	3	245.0	169.66	161.82	off	95	82.8	2006	202204041909
D0018	EI0050	1413	2	248.0	178.39	163.88	off	95	84.2	2010	202204042050
D0018	EI0050	1414	2	250.0	176.13	162.91	off	95	81.4	2010	202204042050
D0018	EI0050	1415	2	250.0	176.52	169.54	off	95	82.8	2010	202204042050

Sound Source	electr. ID	icListen ID	Run	f_{pk}. sweep [Hz]	SL_{max} sweep [dB]	SL RAFOS [dB]	Coil	Amp.	Dist. [m]	Length [mm]	DateTime
D0043	EI0047	1413	2	250.99	175.43	160.38	off	95	84.2	2006	202204041725
D0043	EI0047	1414	2	251.03	173.87	159.44	off	95	81.4	2006	202204041725
D0043	EI0047	1415	2	248.36	172.09	161.74	off	95	82.8	2006	202204041725
D0017	EI0058	1413	4	NA	NA	187.79	on	95	84.2	1845	202204082354
D0017	EI0058	1414	4	NA	NA	186.58	on	95	81.4	1845	202204082354
D0017	EI0058	1415	4	NA	NA	189.81	on	95	82.8	1845	202204082354
D0018	EI0050	1413	3	256.5	181.97	176.41	on	95	84.2	1865	202204082220
D0018	EI0050	1414	3	256.5	179.77	174.78	on	95	81.4	1865	202204082220
D0018	EI0050	1415	3	256.5	183.23	181.62	on	95	82.8	1865	202204082220
D0043	EI0047	1413	3	NA	NA	172.71	on	95	84.2	1890	202204081345
D0043	EI0047	1414	3	NA	NA	171.19	on	95	81.4	1890	202204081345
D0043	EI0047	1415	3	NA	NA	169.89	on	95	82.8	1890	202204081345
D0030	EI0066	1413	1	241.5	178	NA	on	95	84.2	2230	202204151630
D0030	EI0066	1414	1	242.0	174.51	NA	on	95	81.4	2230	202204151630
D0030	EI0066	1415	1	240.5	178.76	NA	on	95	82.8	2230	202204151630
D0030	EI0066	1413	2	NA	NA	163.44	off	95	84.2	1900	202204170650
D0030	EI0066	1414	2	NA	NA	162.95	off	95	81.4	1900	202204170650
D0030	EI0066	1415	2	NA	NA	168.94	off	95	82.8	1900	202204170650

Operational results

2.1.12. Oceanographic moorings

Details of the recovered hydrographic instrumentation and the length of each data record retrieved are listed in Table 2.17. In general, the instruments performed well, providing, with few exceptions, data for the full deployment period.

Tab. 2.17: Recovered hydrographic instruments (34 in total), their condition and data record length

Mooring	Instrument Type	SN	Data record length [days]	Recorded Full period (Y/N)	Type of failure	Physical condition from visual inspection at recovery
227-15	SBE37	12479	1166	Y	-	Good
229-14	SBE37	2098	1168	Y	-	Good
229-14	SBE37	2385	1168	Y	-	Good
229-14	SBE37	2382	1168	Y	-	Good
229-14	SBE37	2396	1168	Y	-	Good
229-14	SBE37	9492	1168	Y	-	Good
229-14	SBE37	9494	1168	Y	-	Good
229-14	SBE37	9495	1168	Y	-	Good
229-14	SBE37	9496	1168	Y	-	Good
229-14	SBE37	9497	1168	Y	-	Good
229-14	SBE37	12481	1168	Y	-	Good

Mooring	**Instrument Type**	**SN**	**Data record length [days]**	**Recorded Full period (Y/N)**	**Type of failure**	**Physical condition from visual inspection at recovery**
229-14	Aquadopp	12654	1168	Y	-	Good
229-14	Aquadopp	12658	1168	Y	-	Good
231-13	SBE37	10944	1175	Y	-	Good
245-5	SBE37	8124	590	N	Recording interrupted	Good
248-3	SBE37	8123	151	N	Recording interrupted	Good
BGC-1	SBE37	449	379	Y	-	Good
BGC-1	SBE37	2100	379	Y	-	Good
BGC-1	SBE56	6513	379	Y	-	Good
BGC-1	SBE56	7824	379	Y	-	Good
BGC-1	SBE56	7825	379	Y	-	Good
208-9	SBE37	9841	1176	Y	-	Good
208-9	SBE37	3812	0	N	No data recorded	Good
208-9	Aquadopp	12685	1177	Y	-	Good
207-11	Aquadopp	12745	1178	Y	-	Good
207-11	SBE37	6928	1177	Y	-	Good
207-11	SBE37	9847	1177	Y	-	Good
207-11	SBE37	10934	1177	Y	-	Good
207-11	SBE37	10937	1177	Y	-	Good
207-11	SBE37	10943	1177	Y	-	Good
207-11	SBE39	8641	1177	Y	-	Good
207-11	SBE39	8642	1177	Y	-	Good
207-11	SBE39	8643	1177	Y	-	Good
251-3	SBE37	2096	1177	Y	-	Good

2.1.13. *In-situ* calibration of moored instruments

All Seabird® instruments (SBE37ct, SBE37ctp, SBE39plus, and SBE56) were compared *in situ* with the 911plus CTD system prior to mooring deployment or after recovery. Up to 15 units were attached at a time to the frame of the rosette water sampler. For the *in situ* calibration, the sampling interval was set to 10 seconds and programmed to begin sampling prior to the CTD reaching its maximum depth. The CTD/rosette was stopped at two different depths exhibiting low stratification for 5 minutes to obtain approximately 30 records for comparison with the CTD reading.

During PS129, the following modifications have been applied to the standard calibration process of moored instruments:

1. For the instruments without pressure sensor (SBE56, old SBE37):
    a. Interpolation of CTD pressure by using timestamps as the reference between CTD and instruments.

b. Correction of the actual pressure effect on the conductivity, c, according to equation below as suggested by Povl Abrahamsen, BAS[1].

$$c_{corr} = c_{instr} \cdot \frac{1+(\kappa_T \cdot T_{inst}) + (\kappa_p \cdot p_{ref})}{1+(\kappa_T \cdot T_{inst}) + (\kappa_p \cdot p_{interp})}, \text{ with}$$

c_{corr}	the corrected conductivity;
c_{instr}	the instrument's conductivity reading;
κ_T	the correction coefficient for temperature effects on conductivity, $3.25 \cdot 10^{-6}\ °C^{-1}$;
κ_p	the correction coefficient for pressure effects on conductivity, $-9.57 \cdot 10^{-8}\ dbar^{-1}$;
T_{inst}	the intruments temperature reading during the calibration period [°C];
p_{ref}	for SBE37ct (without pressure sensor), the reference perssure , eqalling 0 dbar (zero);
p_{interp}	for SBE37ct (without pressure sensor), the interpolated pressure during the measument period [dbar].

This correction reduces the conductivity offsets between instrument and CTD by up to one order of magnitude (for example the offset of SN238 was reduced from 0.0819 to 0.0047, and for SN239 from 0.0212 to 0.0090).

2. The CTD file bin-averaged every 1 second is now preferred over the CTD file bin-averaged every 1 dbar to compute the offsets of the moored instruments as this allows reconstructing the pressures of moored instruments without pressure and also to obtain a more accurate (time) mean of the CTD values during the calibration stop. In contrast, the standard calibration process computed the offsets to the value of a selected CTD pressure level (bin-averaged by 1 dbar and thus time independent) instead. This was less accurate than using the mean of the actual CTD values measured during the 5 mins calibration stop. Both the CTD and the attached instruments are oscillating in depth during the calibration stop and thus, using the actual time dependent sampling points to compute their offsets is more advisable.

3. Correct for the cropping issue limited to 8 instruments. As several calibration casts were done with more than 8 instruments, this meant that the truncation of the values selected from the calibration stop would not be exactly the same for all the instruments (the cropping needed to be done more than once). This is solved by a modification in the main routine (guiSBEvsCTD.m) that allows for truncating the time series of up to 18 instruments at the same time.

   Further modifications: Addition of the SBE56 instrument type, inclusion of the times of the CTD and attached instruments, calibration plots with time in the X-axis instead of sampling counts and including the actual CTD values and mean along the calibration stop.

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[1] More details in SeaBird's Application Note nº 10 (May 2013, "Compensation of Sea-Bird Conductivity sensors").

Tab. 2.18: Comparison for Seabird sensors SBE37 moored during PS117. Columns CTD and PRES indicate the corresponding station number and the CTD pressure during the 5-minute stop. Xcorr = Xreading + ΔX, with X = temperature (t), conductivity(c) or pressure (p)

Mooring	Type	SN	CTD	Δp [dbar}	ΔT [ºC]	Δc [mS cm^{-1}]	ΔS [psu]	pres [dbar]
227-16	SBE37	1232	none					
227-16	SBE37	10933	none					
229-15	SBE37	238	018-07	R	-0.0059	0.0047	0.0124	4680
229-15	SBE37	10929	018-07	-8.5	0.0017	0.0069	0.0105	4680
229-15	SBE37	10930	018-07	-7.4	0.0025	0.0063	0.0085	4680
229-15	SBE37	10931	018-07	-7.7	0.0012	0.0086	0.0129	4680
229-15	SBE37	10932	018-07	-7.3	0.0013	0.0039	0.0066	4680
231-14	SBE37	239	018-07	R	-0.0006	0.0090	0.0121	4680
231-14	SBE37	9848	018-07	-8.2	0.0020	0.0056	0.0084	4680
229-15	SBE37	225	023-01	R	0.0013	0.0110	0.0125	5465
229-15	SBE37	230	023-01	R	-0.0041	0.0102	0.0174	5465
EWS01-01	SBE37	10928	023-01	-9.1	0.0016	0.0055	0.0089	5465
EWS01-01	SBE37	10940	023-01	-9.1	0.0021	0.0066	0.0096	5465
EWS01-01	SBE37	10941	023-01	-9.1	0.0011	0.0065	0.0106	5465
EWS01-01	SBE37	10942	023-01	-10.3	0.0015	0.0053	0.0091	5465
EWS01-01	SBE56	7826	040-02	R	0.0010	-	-	918
EWS01-01	SBE56	7827	040-02	R	0.0005	-	-	918
EWS01-01	SBE56	7828	040-02	R	0.0005	-	-	918
EWS01-01	SBE56	7829	040-02	R	0.0010	-	-	918
EWS02-01	SBE37	2088	023-01	-9.3	0.0022	0.0018	0.0036	5465
EWS02-01	SBE37	9490	023-01	-4.4	0.0011	0.0047	0.0065	5465
EWS02-01	SBE37	10946	023-01	-9.0	0.0009	0.0042	0.0078	5465
EWS02-01	SBE37	10947	023-01	-7.6	0.0012	0.0056	0.0087	5465
EWS02-01	SBE37	11420	023-01	1.0	0.0006	0.0066	0.0073	5465
EWS02-01	SBE56	7830	040-02	R	0.0008	-	-	918
EWS02-01	SBE56	7831	040-02	R	0.0013	-	-	918
EWS02-01	SBE56	7833	040-02	R	0.0009	-	-	918
EWS02-01	SBE56	6368	040-02	R	-0.0002	-	-	918
EWS02-01	SBE56	6986	040-02	R	-0.0048	-	-	918
EWS02-01	SBE56	6988	040-02	R	0.0106	-	-	918
EWS02-01	SBE56	6989	040-02	R	-0.0048	-	-	918
EWS03-01	SBE37	224	023-01	R	-0.0001	0.0118	0.0152	5465
EWS03-01	SBE37	3814	060-01	1.5	0.0008	0.0045	0.0041	1907
245-6	SBE37	218	023-01	R	-0.0014	0.0140	0.0193	5465
245-6	SBE37	9838	023-01	-6.2	0.0007	0.0133	0.0185	5465
249-4	SBE37	9832	023-01	-9.3	0.0005	0.0069	0.0119	5465
249-4	SBE37	235	030-01	R	-0.0008	0.0107	0.0145	5107
208-10	SBE37	442	030-01	R	0.0037	0.0108	0.0098	5107
208-10	SBE37	9487	030-01	-5.1	0.0013	0.0068	0.0093	5107
209-09	SBE37	440	030-01	R	-0.0004	0.0096	0.0127	5107
209-09	SBE37	9491	030-01	-5.8	0.0018	0.0055	0.0074	5107

Mooring	Type	SN	CTD	Δp [dbar}	ΔT [ºC]	Δc [mS cm^{-1}]	ΔS [psu]	pres [dbar]
208-10	SBE37	442	030-01	R	0.0037	0.0108	0.0098	5107
208-10	SBE37	9487	030-01	-5.1019	0.0013	0.0068	0.0093	5107
CWS01-01	SBE37	233	064-02	R	0.0005	0.0124	0.0154	4819
CWS01-01	SBE37	2090	064-02	-4.7	0.0006	0.0066	0.0097	4819
CWS01-01	SBE37	2090	064-02	-4.7	0.0006	0.0066	0.0097	4819
CWS02-01	SBE37	444	064-02	-0.2	-0.0041	0.0107	0.0181	4819
CWS02-01	SBE37	2101	064-02	-5.1	0.0009	0.0059	0.0086	4819
WWS02-01	SBE37	9488	064-02	-5.8	0.0013	0.0058	0.0085	4819
WWS02-01	SBE37	232	064-02	-0.2453	-0.0011	0.0112	0.0157	4819
257-3	SBE37	435	080-02	0.0	-0.0090	0.0106	0.0232	4924
257-3	SBE37	7690	080-02	0.8	0.0018	0.0080	0.0079	4924
207-12	SBE37	2089	064-02	1.3	0.0012	0.0046	0.0040	4819
207-12	SBE37	11421	064-02	0.4	0.0018	0.0066	0.0064	4819
207-12	SBE37	2094	064-02	-8.7	0.0016	0.0095	0.0140	4819
207-12	SBE37	2234	064-02	-1.5	0.0015	0.0089	0.0103	4819
207-12	SBE37	2099	064-02	-4.2	0.0000	0.0033	0.0059	4819
207-12	SBE39	7860	080-02	-6.4	0.0014	-	-	4924
207-12	SBE39	7861	080-02	2.7	0.0012	-	-	4924
207-12	SBE39	7862	080-02	-6.0	0.0014	-	-	4924
261-02	SBE37	9840	080-02	-6.2	0.0009	0.0057	0.0089	4924
261-02	SBE37	2092	080-02	-4.8	0.0021	0.0052	0.0064	4924
261-02	SBE37	2093	080-02	-5.8	0.0016	0.0062	0.0086	4924
261-02	SBE37	9834	080-02	-6.7	0.0016	0.0051	0.0076	4924
261-02	SBE37	12478	080-02	-8.3	0.0011	0.0011	0.0036	4924
261-02	SBE56	6990	040-02	-	0.0012	-	-	918
261-02	SBE56	6991	040-02	-	0.0011	-	-	918
261-02	SBE56	7068	040-02	-	0.0039	-	-	918
261-02	SBE56	7069	040-02	-	0.0008	-	-	918
251-04	SBE37	2395	060-01	1.6	0.0018	0.0038	0.0022	1907

R: Pressure reconstructed from the CTD pressure

Tab. 2.19: Offsets for Seabird sensors SBE37 and SBE39 recovered during PS129. Their temperature and conductivity data were adjusted based on a linear interpolation between pre- (dt1, dc1) and post recovery (dt2, dc2 dp2) offsets. For pressure the post recovery offset was applied as a constant offset. Xcorr = Xreading + ΔX, with X representing temperature (T), conductivity(c) or pressure (p)

MOORING	Type	SN	ΔT1 (ºC)	Δc1 (mS/cm)	Δp1 (dbar)	Δt2 (ºC)	Δc2 (mS/cm)	Δp2 (dbar)
227-15	SBE37	12479	0.0012	0.0079	-4.5	0.0012	0.0060	-4.4
229-14	SBE37	2098	0.0011	0.0034	-4.4	0.0006	-0.0002	-7.5
229-14	SBE37	2396	0.0016	0.0109	-	0.0019	0.0059	-0.02
229-14	SBE37	9492	-0.0001	0.0017	-3.4	0.0001	0.0071	-7.0
229-14	SBE37	9494	0.0006	0.0010	-3.3	0.0011	0.0039	-7.4

MOORING	Type	SN	ΔT1 (ºC)	Δc1 (mS/cm)	Δp1 (dbar)	Δt2 (ºC)	Δc2 (mS/cm)	Δp2 (dbar)
229-14	SBE37	9495	0.0009	0.0038	-1.0	0.0011	0.0057	-6.0
229-14	SBE37	9496	0.0008	0.0038	-3.7	0.0010	0.0126	-8.1
229-14	SBE37	9497	0.0008	0.0044	-4.4	0.0012	0.0048	-9.1
229-14	SBE37	12481	0.0012	0.0044	-3.4	0.0012	-0.0035	-7.9
229-14	SBE37	2385	0.0003	0.0208	-	0.0005	0.0044	-
229-14	SBE37	2382	0.0022	0.0220	-	0.0019	0.0046	-
231-13	SBE37	10944	0.0003	0.0009	-5.7	0.0003	-0.0001	-10.8
245-5	SBE37	8124	0.0011	0.0048	-1.6	0.0014	0.0038	-5.2
248-3	SBE37	8123	0.0014	0.0029	0.6	0.0019	0.0031	-2.8
BGC-1	SBE37	449	-	-	-	-0.0050	0.0081	R
BGC-1	SBE37	2100	-	-	-	0.0013	0.0072	-8.4
BGC-1	SBE56	6513	-	-	-	0.0750	-	R
BGC-1	SBE56	7824	-	-	-	2.3101	-	R
BGC-1	SBE56	7825	-	-	-	0.4178	-	R
208-9	SBE37	9841	0.0014	0.0010	-4.7	0.0020	-0.0014	-5.1
208-9	SBE37	3812	0.0013	0.0060	3.3	no data	no data	no data
207-11	SBE37	6928	0.0011	0.0110	-	0.0036	0.0075	-
207-11	SBE37	9847	0.0017	0.0041	-1.3	0.0032	-0.0755	-0.7
207-11	SBE37	10934	0.0007	0.0054	-4.3	0.0031	0.0039	-1.5
207-11	SBE37	10937	0.0012	0.0096	-2.6	0.0027	0.0040	-2.4
207-11	SBE37	10943	0.0018	0.0035	-6.1	0.0025	0.0008	-3.0
207-11	SBE39	8641	0.0016	-	-5.4	-0.0018	-	-2.1
207-11	SBE39	8642	0.0012	-	-7.4	-0.0051	-	-2.3
207-11	SBE39	8643	0.0008	-	-7.2	-0.0045	-	-2.8
251-3	SBE37	2096	0.0008	0.0057	-4.3	-0.0036	0.0168	0.4

2.1.14. Salinity calibrations by salinometer

On board comparisons between salinometer-based salinity measurements of water samples and concurrent *in situ* CTD data exhibited conspicuously large deviations for both conductivity sensors for some measurements between 10 and 17 April 2022, both with regard to time as well as pressure (Fig. 2.6).

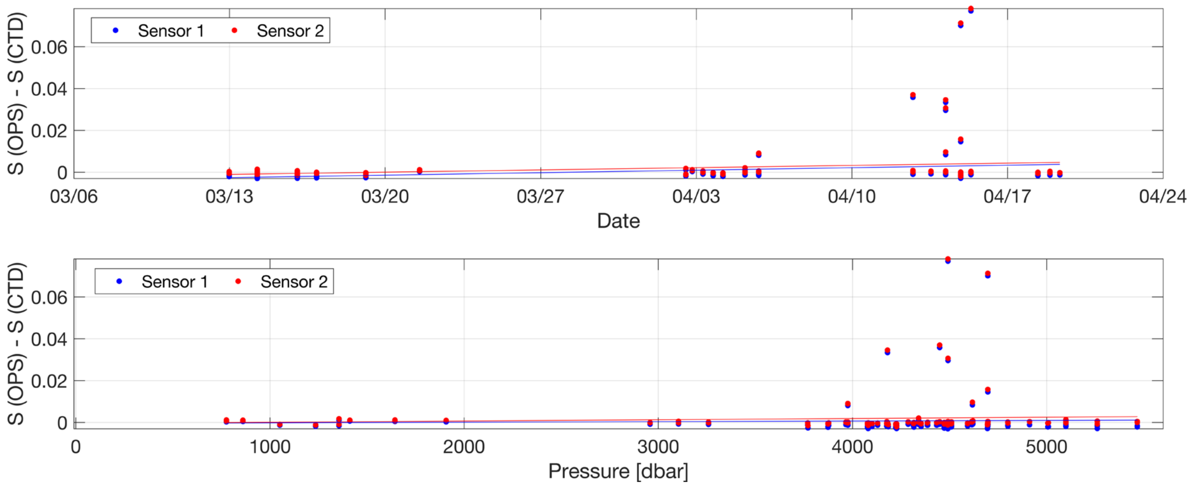


Fig. 2.6: Deviation in salinity between OPS measurements and in situ CTD measurements versus date (top) and pressure (bottom) for the primary (blue) and secondary (red) sensors (all samples). Conductivity sensor #1 = SBE4c #3590; Conductivity sensor 2 = SBE4c #3173

Concurrent spreads like these point towards issues with the sampled water rather than the sensors, which is why we excluded theses measurements from the preliminary onboard evaluation.

After the failure of the OPS-006 on 3 April 2022, measurements continued and 5 further samples were measured. Those 5 samples show a systematic offset with regard to all other samples and are thus excluded from the calculation of offsets applied of the CTD data. Furthermore, 9 samples showed exceedingly large deviations >0.008, whereas the average deviation was 0.001. The reason for the larger deviation is unknow but contamination during sampling is the most likely cause. Those 9 samples were also not taken into account for correcting the CTD sensor data.

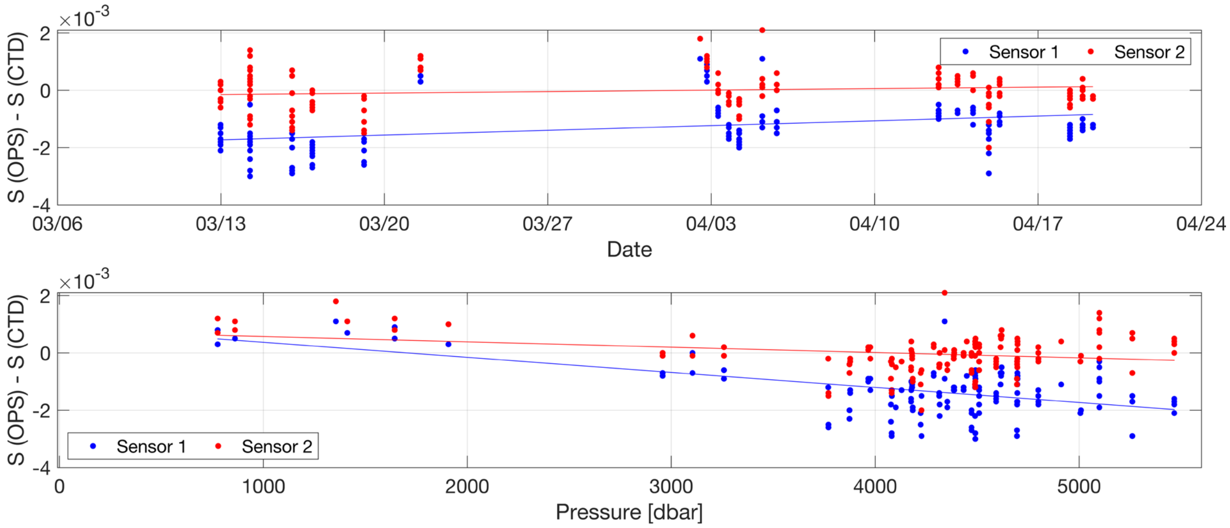


Fig. 2.7: Deviation in salinity between OPS measurements and in-situ CTD measurements versus date (top) and versus pressure (bottom) for primary and secondary sensor after a first quality check and removal of erroneous OPS measurements

Analysis of the prevailing data (Fig. 2.7) reveals that sensor #1 (blue) exhibits a slightly larger temporal drift as well as a larger pressure dependency compared to sensor #2 (red). Thus, sensor #2 will likely be chosen as the better performing one and the data of channel 2 will likely be used for the final data set. After further control for suspicious OPS measurements the final calibration of the CTD data will be performed on the basis of the remaining salinometer measurements together with the post-cruise manufacturer calibration of the sensors. Sensors will be sent to SeaBird for post-expedition calibration, which will be applied to data prior to publication of the final data in PANGAEA.

2.1.15. CTD-mounted ADCP (L-ADCP)

Overall, the obtained information resembled the scientific assumptions and agreed well with vessel mounted ADCP data. Most of the time, the error of the velocities was on the order of 5 to 10 cm s^{-1}. Thus, data should be handled with care and post-processing is required. Table 2.20 summarizes which casts suffered from one or more warnings:

- large compass differences (> 15°), due to the high latitude of the study area
- the routine does not only perform the velocity inversion, but calculates a solution based on the shear method as well. If both disagree substantially, the error estimate is larger.

Reprocessing the data with a different setting may change these problems.

Tab. 2.20: List of common problems of L-ADCP casts by station number

For further information see the end of the Chapter.

2.1.16. RAFOS source tuning

Figure 2.8 gives an overview of each source's frequency response curve for runs 1 through 4, (unconventionally) from right to left. Each row represents a specific RAFOS sound source. The graphs plot source levels (estimated using a $20 \cdot \log_{10}(r)$ propagation loss from the received levels, with r the distance source to hydrophone, given in colored labels at the top right of each plot) versus the tone's momentary frequency. Using about 40 m hydrophone source distance ($7 \cdot \lambda$) resulted, with one exception (D0048, first run), in rather inconsistent measurements between hydrophones (spaced by 1.4 m, i.e., about $\lambda/4$ of the 260 Hz wave (λ = 5.8m). Changing the distance about 80 m, and mechanically fixing the source's axis at a right angle towards the hydrophones provided more consistent results. Final source level measurements, when transmitting a true RAFOS sweep and resonance coil on, varied between 170 and 180 dB re. 1µPa with one noteworthy outlier just below 190 dB re 1µPa.

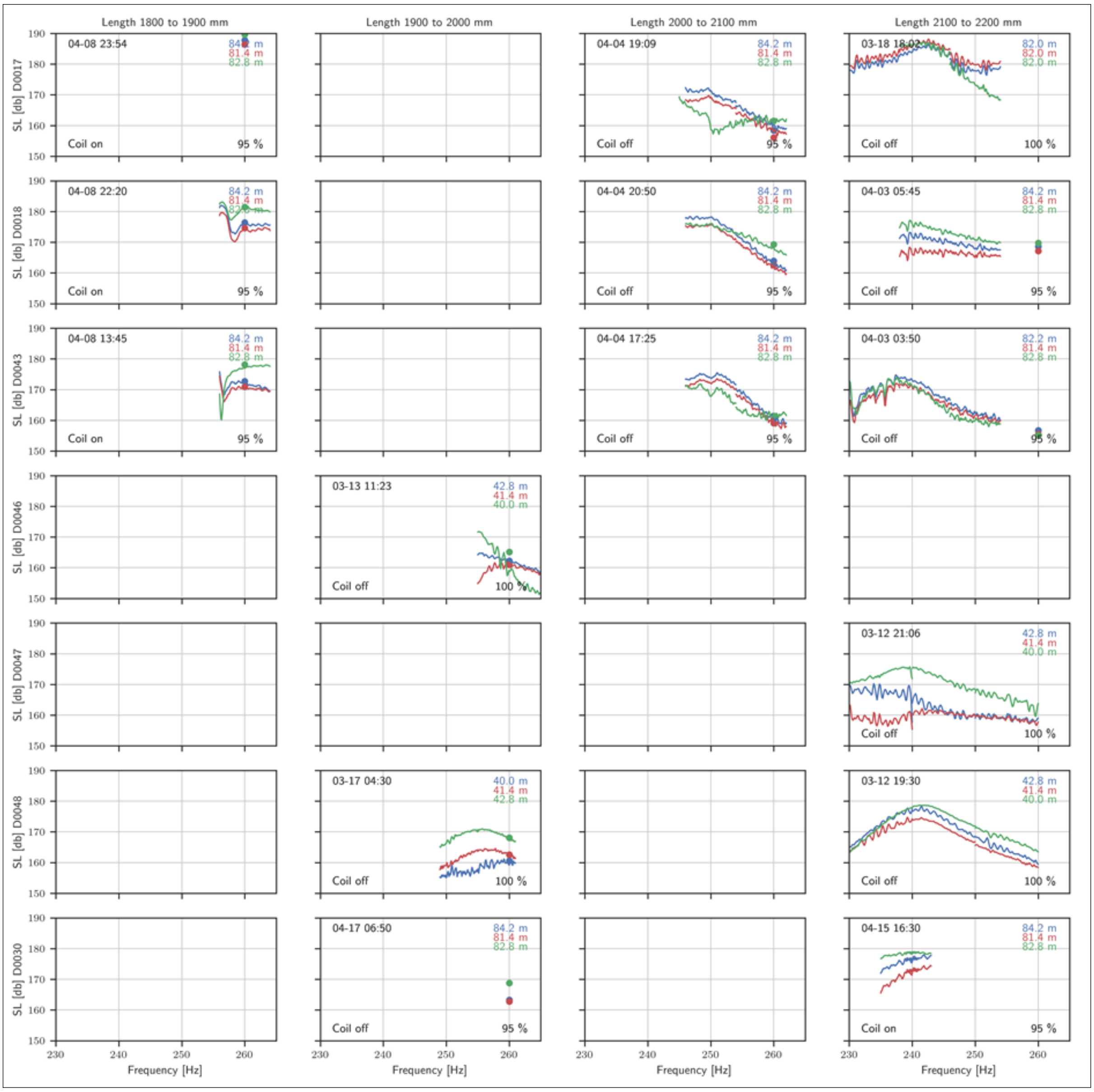


Fig. 2.8: Resonance curves of develogic RAFOS sources sorted by sound source (rows) and tube length (columns), becoming progressively shorter from right to left. Colored curves indicate the sound pressure level as received by the three hydrophones; 1413 = blue, 1414 = red, 1415 = green. Distances between hydrophones and source are listed in each plots' legend.

2.1.17. Use of MiniROV vLBV300 (Fiona) for mooring recovery

Experience showed, that, on occasion, acoustic releases fail to open the clutch to the anchor chain when acoustically commanded to do so. The reasons for this are manifold, including, e.g., electronic failure of the releases' electronics, low batteries or a mechanical jamming of the clutch by biofouling or anode residues. The risk of such failures increases with time. To nevertheless be able to recover such moorings, the Seabotix vLBV300 (vectorized Little Benthic Vehicle) ROV "Fiona" had been acquired and successfully deployed on *Polarstern* expeditions PS103 and PS117.

Learning from the experiences made during these expeditions, we moved the spool holding the recovery rope from underneath the ROV (which caused excessive pitching during high ROV speeds during PS117) to behind where it creates less drag when moving forward at increased speeds while beating a current. Additionally, moorings now feature acoustic Posidonia transponders in the 200 to 300 m depth range, such that the mooring location is more precisely known during the search phase with the ROV's sonar and video.

During PS129, two occasions offered themselves for deployment of Fiona when moorings were positioned underneath a sea-ice cover of nearly 100%. However, temporal constraints resulting from the speed constraints imposed on this expedition, in the end prohibited the use of Fiona. Fiona had nevertheless been set up proactively, resulting in some additional experience with the IT network setup, which is described below.

Amendment to notes in expedition report of PS117 regarding communication setup

Please refer to the PS117 expedition report for a detailed starter on how to set up communication between the navigational computer (the Integrated Navigation Control Console, INC or an external laptop). This paragraph builds on that description and provides additional information only.

The navigational software SeaNetPro requires the following navigation data to be provided as serial input:

- the ship's position
- Fiona's position via GAPS
- the mooring position via Posidonia, possibly 2 units (release and transponder).

The ship's georeferenced position is continuously being tracked by the ship's navigational system. The ship's server continuously sends NMEA datagrams:

$GPGGA,155901,**5837.290,S,05946.345,W**,2,9,1,48.6,M,19.8,M,,,,*55

$GPHDT,**319.8,T***36

$PSRPS**,-1.149,-0.738**,8.03*6A

The $GPGGA telegram provides position.

The $PGHDT telegram provides the heading

The $PSRPS telegram provides roll and pitch, though it is unclear how SeaNetPro makes use of this information.

The UDP broadcast for ship position and heading is custom telegram set up by the sysman, containing the datagrams GPHDT and GPGGA.

Fiona's location relative to the GAPS head is continuously being tracked with the GAPS short baseline navigational system. Fiona bears an Applied Acoustic GAPS compatible Mini-beacon (transponder) which responds by sending a ping upon reception of an interrogation ping, while shipside the GAPS antenna is being deployed through the moonpool. GAPS sends HPR400 datagrams, like

$PSIMSSB,231407.73,B01,A,,**C,H**,M,**29.65,-65.86,1593.59**,1.83,T,1.055685,0.00*66

C indicates the use of cartesian coordinates, and H the Vessel being heads up (bow = north) with the first (bold) value the Starboard distance, and the second (bold) value the Forwards distance.

The mooring's absolute location is continuously being tracked with the POSIDONIA short baseline navigational system by sending pings to (both) acoustic release (near the bottom) and acoustic transponder (at 200-300 m depth). POSIDONIA sends $PTSAG datagrams, like

$PTSAG,#755615,230823.957,22,04,2022,**0,6328.66281,S,05136.85417,W**,F,0011.70,1,9999.00*12

$PTSAG,#755625,230823.424,22,04,2022,**1,6328.61924,S,05136.85302,W**,F,1750.71,1,9999.00*1B

with ID = 0 usually referring to the ship-borne Posidonia head (embedded in the hull) and ID = 1 or ID = 2 to the respective (moored) transponder. The ship's and Posidonia ID = 0 positions should move in parallel, separated by the offset between the Posidonia Window and the ships inertial navigation systems position.

This information is provided via datagrams sent by Ethernet to the navigational computer (INC or Laptop) with SeaNetPro ingesting datagrams sent to the respective ethernet port's IP-Address via virtual com ports. Because the Ethernet port is being recognized by the INC-PC as an Ethernet connection, software is required to feed the incoming datagrams to the SeaNetPro software. For this, the emulation (by the programme com0com2) of serial ports is required, as well as a programme (udp2serial) that redirects the input from the Network ports to the emulated serial ports (Fig. 2.9).

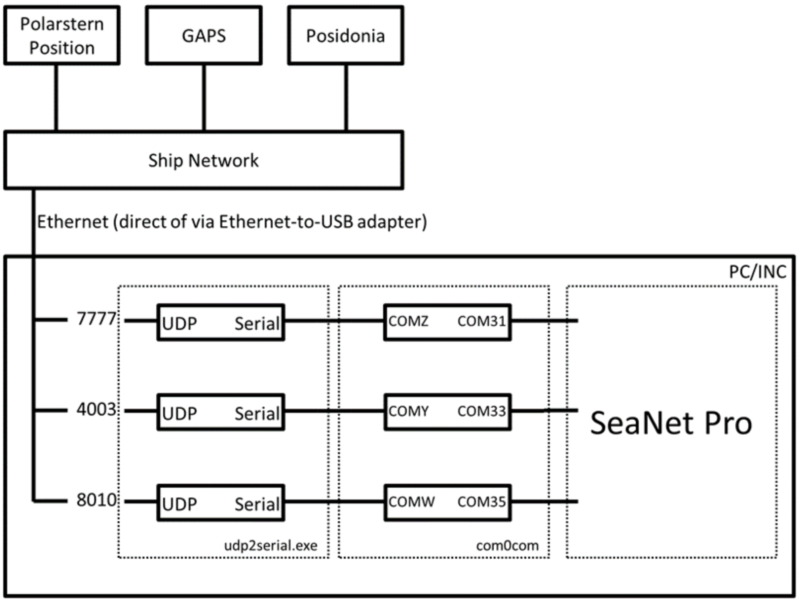


Fig. 2.9: Flow chart of navigational information

During PS117, a UDP broadcast to either the INC or the separate navigation PC was employed. However, during PS129 we could not find a USB-Ethernet adapter that worked with the INC. Hence, we relied on the navigational Laptop only (with com0com[2] and SeaNetPro installed there). In com0com three port pairs were established (Fig. 2. 9):

---

[2] Null-modem Emulator, creates an unlimited set of virtual COM Port Pairs and connects these with a virtual Null-modem cable. This allows to connect 2 COM based applications with the output of one being the input of the other, and vice-versa.

- Ship GPS position: COMZ ⇔ COM31
- GAPS (ROV) position: COMY ⇔ COM33
- Posidonia (mooring) position: COMW ⇔ COM35

On SeaNet Pro side, the setup was (Utilities → COM Setup):

GPS	COM31	Baud rate 9600
NAV Beacon B16	COM33	Baud rate 9600
NAV Beacon B17	COM35	Baud rate 9600

To establish the routing from Ethernet to the emulated COM ports, a C# programme (udp2serial.exe, written during PS117) binds itself to the given UDP (User Datagram Protocol[3]) port and forwards anything to the respective serial port. The source code can be found in the PS117 expedition report. For every port pair given above, a new process of the udp2serial.exe programme has to be started, i.e., three in total. This programme can be started via command line (e.g., "udp2serial.exe 7778 COMZ") or interactively when only issuing udp2serial.exe in a command window.

The UDP setup was as follows:

- Ships UDP port 7778 (navigation PC)
- GAPS UDP port 4003
- Posidonia UDP port 8010

It is recommended to request the "sysman" (computer network operator) to reset the network buffer on your IP for GAPS and Posidonia. This is to make sure that there is no delay in the datagrams received to the current state.

Problems and diagnostics

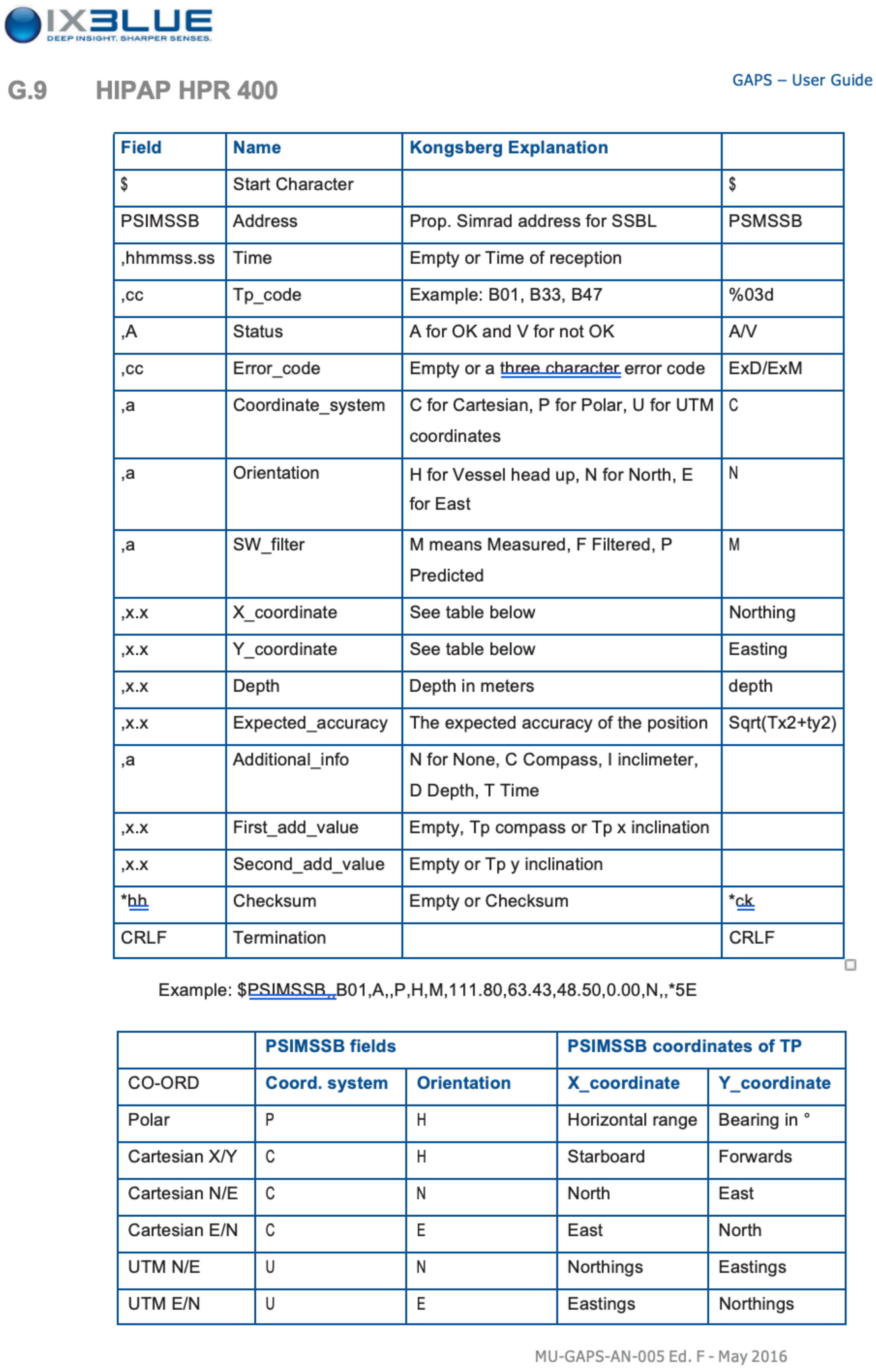
<u>Network problems</u>: On PS117, datagram problems existed when using the ships position and heading broadcast to UDP ports 7777 to two different PC's (INC and navigation PC). The problem may be overcome by using port 7777 on the INC and port 7778 on the navigation PC.

To check if anything is received on the INC or navigational PC, the software NetCat can be used. In case of the ships position and heading in our setup, the following call has been used from a console window: ncat.exe –ul 7778. The programme ncat.exe is provided with Fiona's documentation. Now all UDP packets that are received on this port are being printed to the terminal.

---

[3] User Datagram Protocol (UDP) is a communications protocol that is primarily used to establish low-latency and loss-tolerating connections between applications on the internet. UDP speeds up transmissions by enabling the transfer of data before an agreement is provided by the receiving party.

Tab. 2.21: GAPS HIPAP PPR400 protocol (MU Posidonia AN-001-1 – November 2019)



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G.9 HIPAP HPR 400

Field	Name	Kongsberg Explanation	
$	Start Character		$
PSIMSSB	Address	Prop. Simrad address for SSBL	PSMSSB
,hhmmss.ss	Time	Empty or Time of reception	
,cc	Tp_code	Example: B01, B33, B47	%03d
,A	Status	A for OK and V for not OK	A/V
,cc	Error_code	Empty or a three character error code	ExD/ExM
,a	Coordinate_system	C for Cartesian, P for Polar, U for UTM coordinates	C
,a	Orientation	H for Vessel head up, N for North, E for East	N
,a	SW_filter	M means Measured, F Filtered, P Predicted	M
,x.x	X_coordinate	See table below	Northing
,x.x	Y_coordinate	See table below	Easting
,x.x	Depth	Depth in meters	depth
,x.x	Expected_accuracy	The expected accuracy of the position	Sqrt(Tx2+ty2)
,a	Additional_info	N for None, C Compass, I inclimeter, D Depth, T Time	
,x.x	First_add_value	Empty, Tp compass or Tp x inclination	
,x.x	Second_add_value	Empty or Tp y inclination	
*hh	Checksum	Empty or Checksum	*ck
CRLF	Termination		CRLF

Example: $PSIMSSB,,B01,A,,P,H,M,111.80,63.43,48.50,0.00,N,,*5E

	PSIMSSB fields		PSIMSSB coordinates of TP	
CO-ORD	Coord. system	Orientation	X_coordinate	Y_coordinate
Polar	P	H	Horizontal range	Bearing in °
Cartesian X/Y	C	H	Starboard	Forwards
Cartesian N/E	C	N	North	East
Cartesian E/N	C	E	East	North
UTM N/E	U	N	Northings	Eastings
UTM E/N	U	E	Eastings	Northings

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Preliminary results

2.1.18. CTD measurements

Extending our long-term ocean-bottom temperature time series by another 3 years, we reoccupied the 61°S 0°E position for the 16th time, now having 30 years of observations (1992 – 2022). The temperature profile shows the near-linear continuation of the warming in the aged Weddell Sea Bottom Water (WSBW, Fig. 2.10). In the bottom layer of the WSBW, below a depth of 5,300 m, the temperature increased from -0.8435°C (1992) to -0.7759°C during PS129, which corresponds to an increase of 0.0225°C per decade.

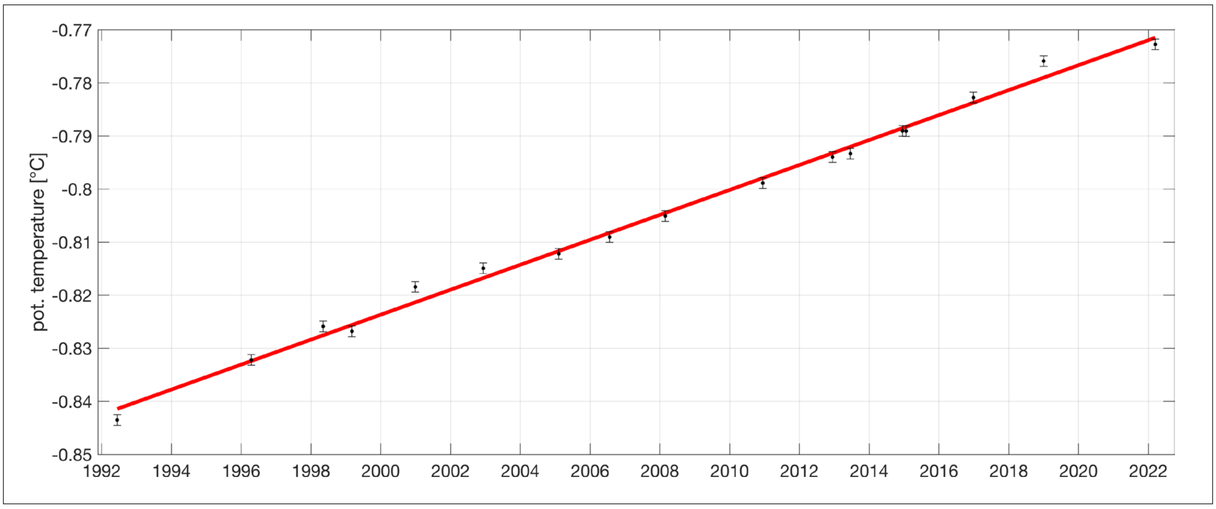

Fig. 2.10: Potential temperature record from past and current CTD casts at nominally 61°S, 0°E. Error bars indicate the measurement accuracy of the temperature sensor (final calibration pending).

Being confronted with significant losses of station time, the decision was taken that the completion of the Weddell Sea hydrographic section SR4 would be given highest priority. While the station spacing had to be stretched somewhat in the open ocean region (Fig. 2.11) a shelf-to-shelf hydrographic section was acquired nevertheless.

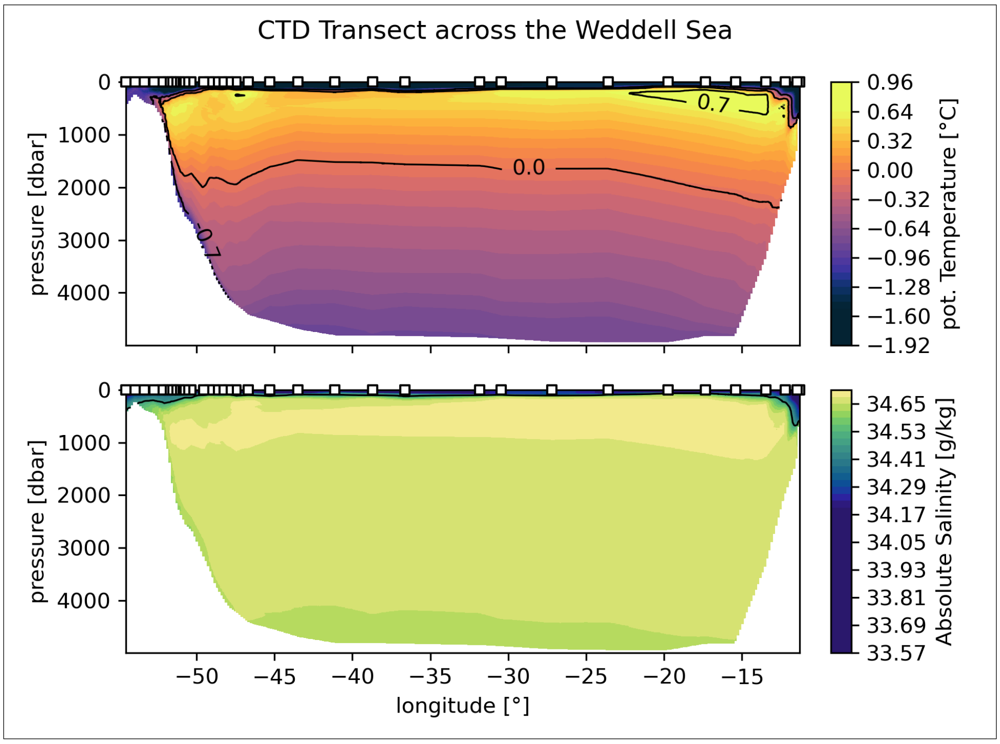

Fig. 2.11: CTD section along SR4 during PS129. In deep waters, station spacing is nominally 60 nmi, while the western outflow region is sampled at a significantly higher rate.

Towards the tip of the Antarctic Peninsula, 20 CTD casts were taken at enhanced horizontal resolution between 46°W to 55°W (Fig. 2.3), repeating a section being occupied there since 1998, resulting in 34 years of coverage.

The surface layer exhibits Antarctic Surface Water offshore and Shelf Water onshore (Fig. 2.11 and Fig. 2.12). Below that, the Warm Deep Water (WDW, with potential temperature >0°C) is centered around 1,000 m depth. It is fed from the ACC, entering the Weddell Sea upstream of the Prime Meridian. The Weddell Sea Deep Water (potential temperature between 0° and -0.7°C) is located below the WDW. The thin sliver of bottom water colder than -0.7°C (Fig. 2.12) at the continental slope is indicative of newly formed Weddell Sea Bottom Water flowing northward along the slope.

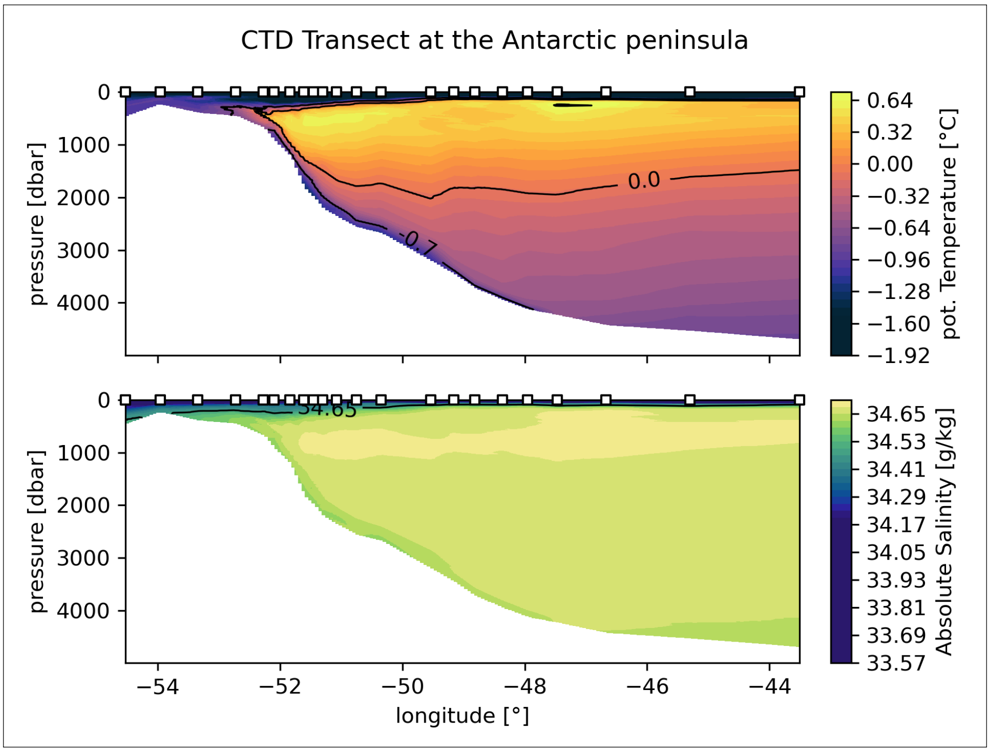

Fig. 2.12: Section of potential temperature and salinity at the tip of the Antarctic Peninsula

2.1.19. Velocity profiles by L-ADCP

Throughout the expedition, L-ADCP measurements were preliminarily analyzed. The SR4 section, with reduced station spacing up the continental slope east of the Antarctic Peninsula confirmed the expected flow patterns (Fig. 2.13). The L-ADCP measurements near the Antarctic Peninsula reveal that the velocity fronts near the 2,000 m isobath are barotropic (Fig. 2.14) while those farther offshore exhibit a strong baroclinicity. However, these preliminary plots have not been corrected for tidal contributions; they only serve to demonstrate data availability.

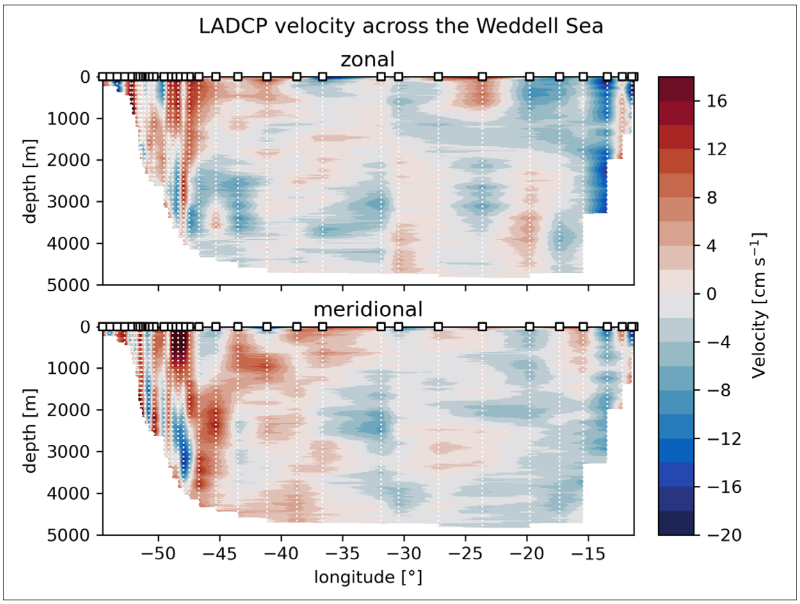

Fig. 2.13: Sections of zonal (top) and meridional (bottom) velocities measured by the L-ADCP along the complete SR4 hydrographic section

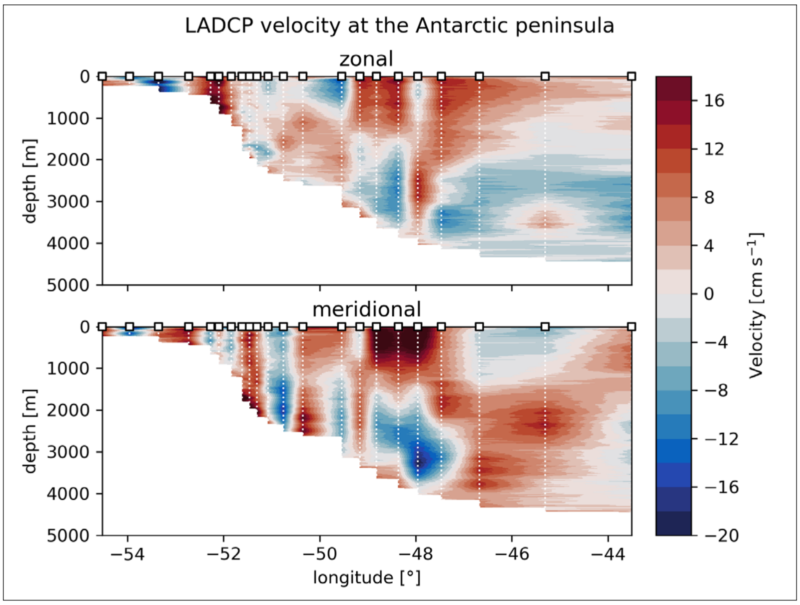

Fig. 2.14: Sections of zonal (top) and meridional (bottom) velocities measured by the L-ADCP along the SR4 hydrographic section off the Antarctic Peninsula (zoom-in of Fig. 2.13)

2.1.20. Thermosalinograph

The thermosalinograph captured the expected hydrographic features (Fig. 2.15). Warm, saline waters reflecting the Agulhas influence near Cape town, a strong reduction in salinity and temperature when crossing the Subtropical Front (characterized by the 10°-isotherm intersecting the sea surface) in the second half of 7 March 2022 and the dominance of sub-zero waters in the southern Weddell Sea. There are two specific observations to be mentioned: 1) the frontal crossing in the first half of 20 March 2022 (with float PS129_01 launched just north of it, and PS129_02 and PS129_03 south of it) at the location of the continental shelf break front; 2) the two instances of increased temperatures on 4-6 April and 13-16 April 2022, when the ship operated to the north of the sea-ice edge.

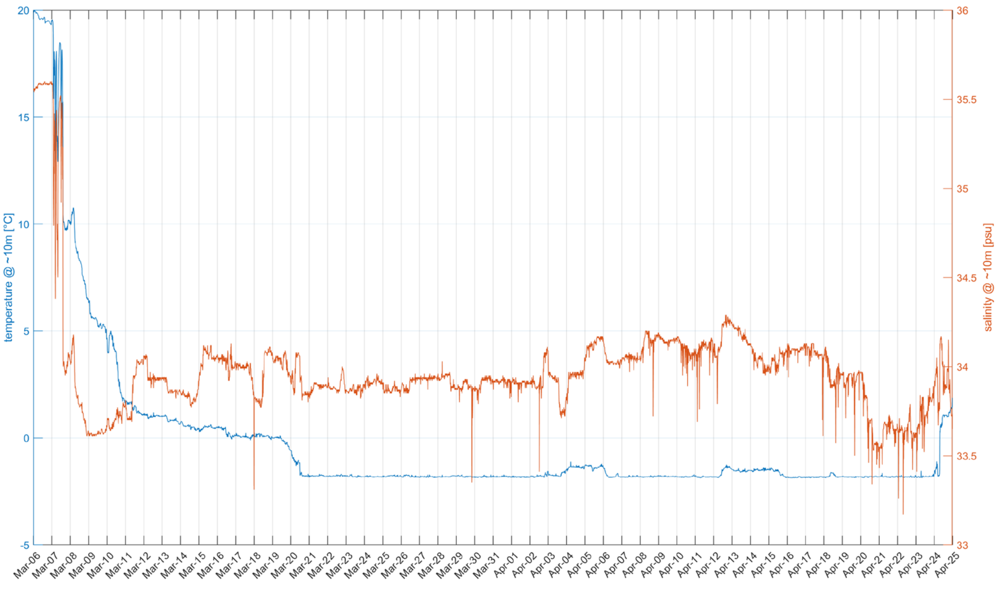

Fig. 2.15: Time series of temperature and salinity as measured by thermosalinograph from sea water continuously drawn at about 11 m depth

Data management

Data from moored oceanographic instrumentation will be uploaded into World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) after final processing, calibration and quality control. It will be publicly available by latest April 2024. By default, the CC-BY license will be applied.

All data (CTD-, OBOFS-, sADCP- and L-ADCP data) will be uploaded into PANGAEA after final processing, calibration and quality control. It will be publicly available by latest April 2024. P.I.: Sandra Tippenhauer

Float data is available in quasi real time through https://www.ocean-ops.org/board/?t=argo, or https://fleetmonitoring.euro-argo.eu/dashboard?Status=Active. Delayed mode data will be made available through the respective data centres.

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In publications based on this expedition, the **Grant No. AWI_PS129_01** will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

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