Physical Process Cruise 2018

Cruise Report

The Nansen Legacy Report Series 2/2020

Physical Process Cruise 2018

Cruise 2018709

R.V. Kronprins Haakon

Longyearbyen-Longyearbyen

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Contents

1. Background

The cruise KH 2018-709 aboard the Research Vessel *Kronprins Haakon* is the second process cruise of the project the Nansen LEGACY. LEGACY is the Norwegian Arctic research community's joint effort to establish a holistic understanding of a changing marine Arctic climate and ecosystem. The project will provide a scientific knowledge base needed for future sustainable resource management in the transitional Barents Sea and the adjacent Arctic Basin. It is a collaborative project between ten Norwegian research institutions, and will run between 2018 and 2023. Activities in the project will include international cooperation, and several cruises mainly with the new, ice-going research vessel *Kronprins Haakon*. The first LEGACY cruise aboard *Kristine Bonnevie* conducted ocean mixing process studies in July 2018 in the region west and north of Svalbard. KH 2018-709 is a follow-up cruise.

The cruise contributes to task T1-2, on process studies to investigate the atmospheric, oceanographic, radiative and other physical controls on sea ice and stratification, with a general aim to identify and quantify the processes that control the heat budget north of Svalbard and in the Barents Sea. The field programme of Task 1-2-1 includes the previous summer cruise, the present cruise, as well as other planned cruises with coordinated deployments of moorings, gliders and AUVs, to capture the role of frontal processes, tides, background shear and wind energy in turbulent mixing distribution within the ocean and interactions and feedback with sea ice cover. More specifically, the cruise contributes to

Task 1-2.1, Oceanic processes. Deliverable D1-2.1.1.

Task 1-2.2, Sea ice and snow processes. Deliverable D1-2.2.1.

Task 1-2.3, Atmospheric processes. Deliverable D1-2.3.1.

The cruise KH 2018-709 aims to deploy oceanographic moorings and gliders, an AUV, a remotely piloted unmanned aircraft, controlled meteorological balloons, collect underway measurements from ship-mounted ocean current profilers, wind profilers, radiometer and wave sensors, and collect ocean stratification, currents, and microstructure profiles along selected transects across the north Spitsbergen shelf and slope. Additionally, wave sensors are deployed at ice floes from ice edge into pack ice. This report provides an overview of the methods employed and the data collected.

2. Survey area

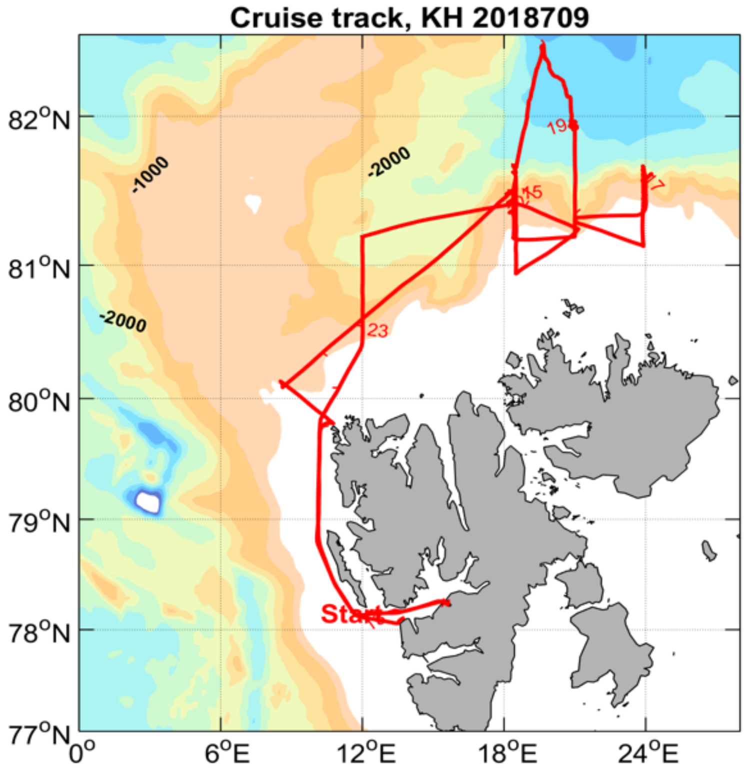
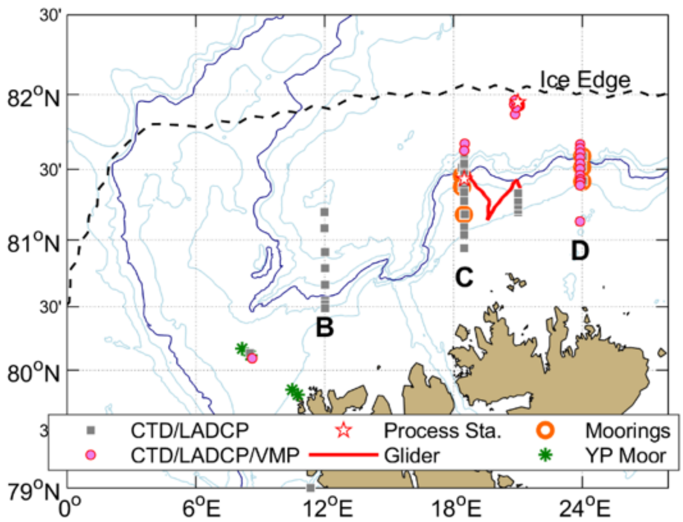


Figure 1. Cruise track of KH 2018709. Day of September is indicated. Bathymetry from ETOPO2.



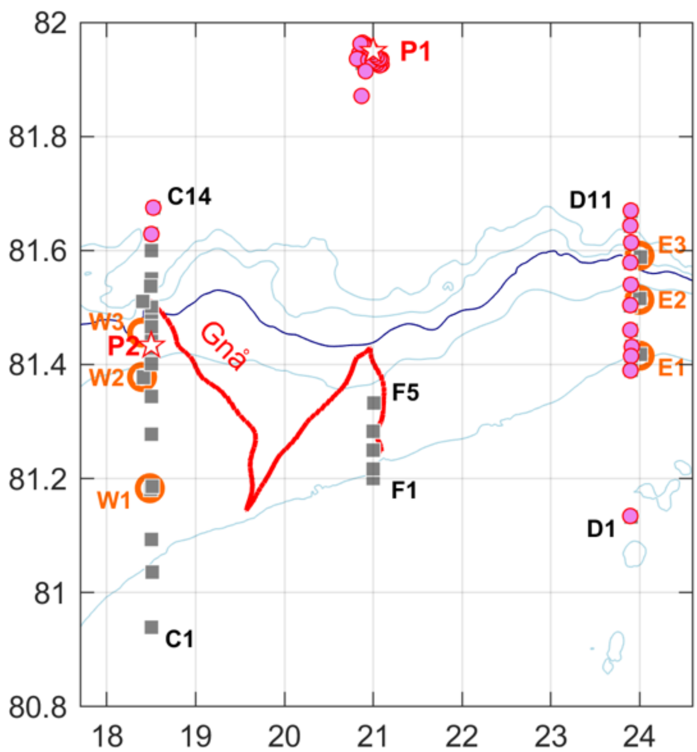


Figure 2. Station map, KH 2018709. Ice edge (15% concentration) is for 20 September 2018. The stations in Isfjorden are not shown. The region between Sections C and D are zoomed in on the right.

The cruise took place between 12 and 24 September 2018 with port calls Longyearbyen - Longyearbyen. The main operations are listed below (in no particular order). A timeline of events is given in Appendix II. The cruise track is shown in Figure 1.

- The main operations conducted during the cruise
- Deploy 6 oceanographic moorings
- Recover 3 moorings (REOCIRC project)
- Conduct CTD/LADCP and ocean microstructure (VMP) profilings
- AUV, adaptive routines for mapping and sampling of water properties across fronts
- Cruise duration sampling from the glider Gná with microstructure sensors
- Deploy 1 Seaglider for a long-term mission
- Deploy 4 wave sensors on sea ice, and measure ice thickness
- Daily radiosondes
- Release of 2 controlled meteorological balloons (CMET)
- Continuous atmospheric measurements using a LIDAR and a microwave radiometer
- Deploy a remotely piloted unmanned aircraft for atmospheric measurements)
- Deploy 3 SVP drifters
- Continuous measurements of surface waves using a bow mast

In total 68 CTD (conductivity temperature depth), 63 LADCP (lowered acoustic Doppler current profiler), and 45 microstructure profiles were collected. The shipboard ADCP (SADCP) sampled continuously, for 12 days, throughout the cruise. In total, 67 and 48 water samples were drawn for salinity and oxygen concentration calibration, respectively. A station map is shown in Figure 2.

A complete list of CTD and microstructure stations is tabulated in Appendix II. Instrument and sampling details are given in the following sections.

Environmental conditions during the cruise are shown using data from the ship's weather mast (sensors at 22 m height) (Figure 3), and from AOTIM5 tides inferred at process station 2 position (Figure 4). Ice edge on 20 September was approximately at 82°N (dashed line in Figure 2).

3. Activity reports

3.1. Environmental conditions

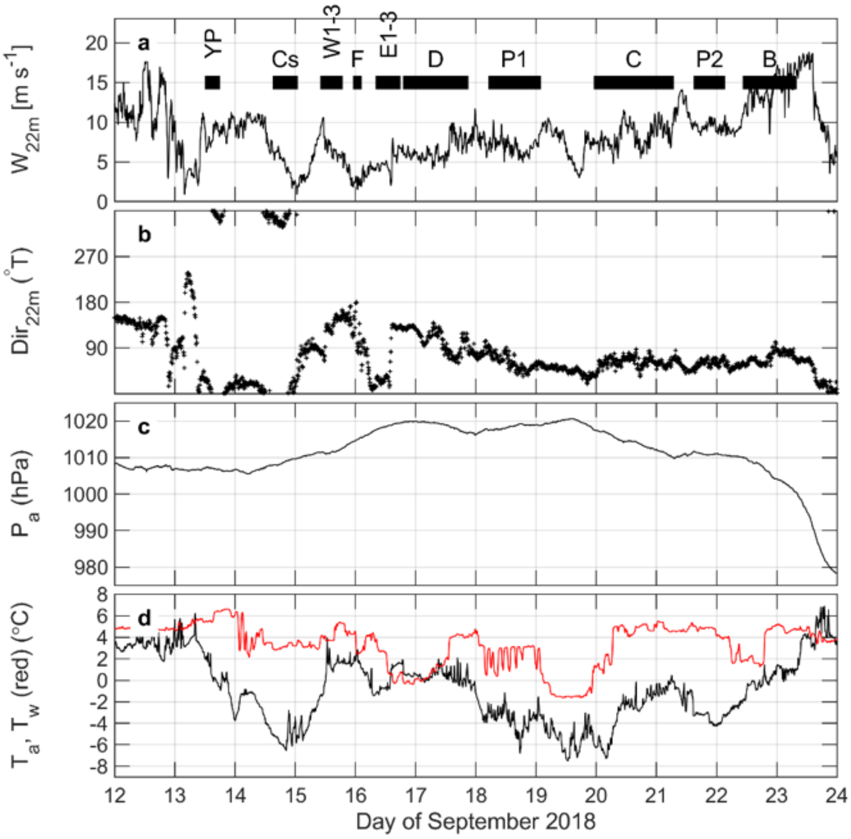


Figure 3. 10-minute averaged data from the ship's log: a) wind speed, b) direction, c) atmospheric pressure measured at 22-m height, and d) near-surface water (red) and 22-m height air temperature. Duration of activities (sections and process stations) are indicated at the top.

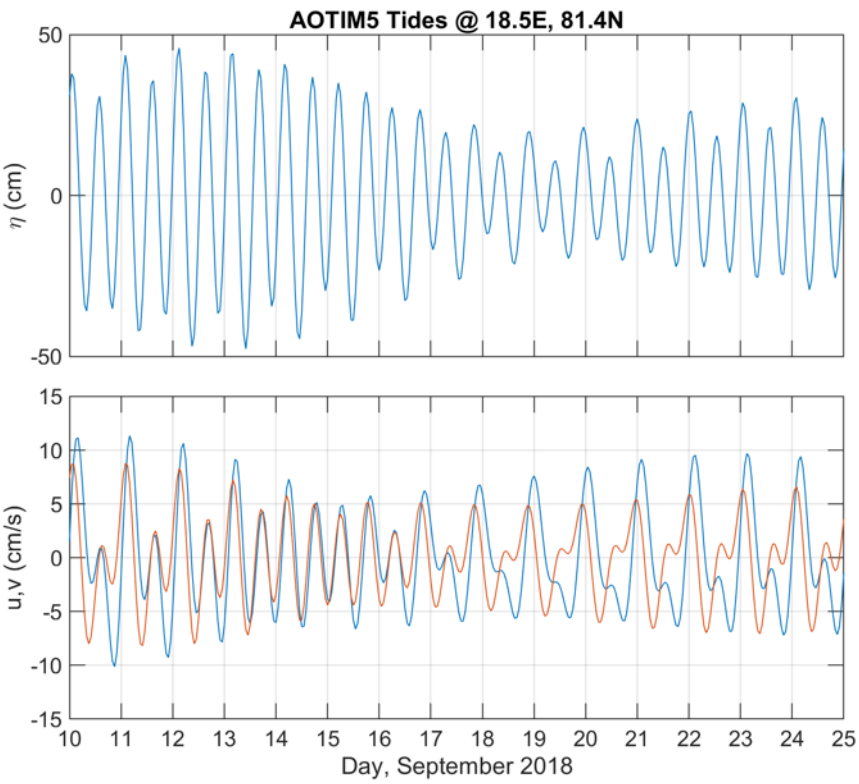


Figure 4. Tidal elevation and currents during a spring-neap cycle covering the cruise period, inferred from the AOTIM5 model near Process Station 2 (at 18.5E and 81.4N).

3.2. Methods and Instruments: Oceanography

3.2.1. Hydrography and water sampling

The hydrographic work was carried out using a CTD-water sampling package from SeaBird Inc., acquiring data during both down and upcast. The package consisted of a SBE 911plus CTD (underwater unit SBE9plus SN 141612, deck unit SBE11 SN 1121) with sensors listed below. The Benthos altimeter (200 kHz) allowed profiling close to the bottom. The CTD was equipped with a 24 position SBE 32 Caroussel (SN 1222). Until 15 September, the rosette was fitted with 24 10-litre bottles, and then after 12 10-litre sampling bottles for salinity calibration at all stations, and with 4 more bottles in selected stations for water samples for dissolved oxygen calibration. In total 68 CTD-stations were taken, recorded in files sta0094 to sta161. At all stations, water samples for salinity calibration were collected at the deepest sampling level. At 6 stations, 48 samples in total were drawn at selected levels for oxygen concentration analysis. The CTD rosette, together with LADCPs (Section 3.2.2), is shown in Figure 5. Their locations are listed in Appendix II. Station positions are shown in Figure 2.

Table 1. Sensor details installed on the CTD rosette.

Sensor	SN	Calibration/Service date
Temperature	6275	06.12.2017
Conductivity	4726	06.12.2017
Pressure	141612	19.12.2017
Temperature, 2	6289	06.12.2017
Conductivity, 2	4727	06.12.2017
Altimeter, Benthos PSA-916	73084	24.12.2017
Oxygen, SBE 43	3636	05.12.2017
Fluorometer, Wet Labs ECO-AFL	1547	23.10.2017
Transmissiometer, Wet Labs C-Star	1838 DR	
Fluorometer, Wet Labs ECO CDOM	4885	
RDI WH300 L-ADCP, downward	24474	
RDI WH300 L-ADCP, upward	24472	

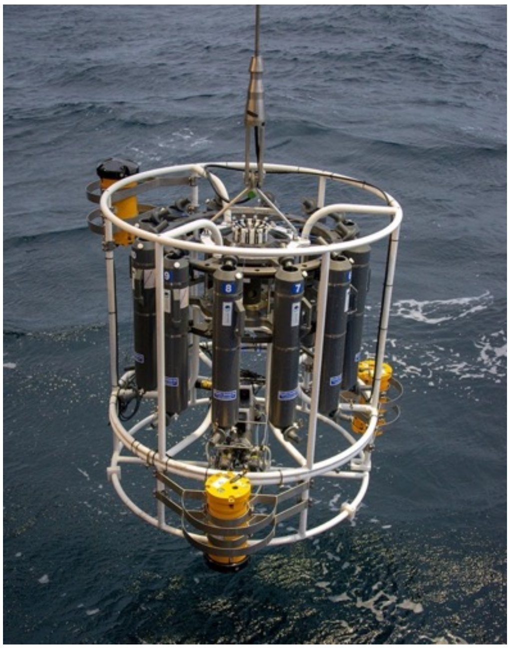


Figure 5. The CTD rosette together with the CTD sensors, 10-liter Niskin bottles, a down and uplooker ADCP, and a benthos altimeter installed. The transducers of both ADCPs and the altimeter have a non-obstructed path. The third yellow pressure case is for the LADCP batteries. The position of the lead weights and the ADCPs are adjusted to have a negligible tilt of the entire system.

Data processing - SBEDataProcessing-Win32, standard Seabird Electronics software for Windows (version 7.23.2), is used for post-processing of the CTD data. Only data from downcasts are used to avoid turbulence caused by rosette package on the upcast. Raw data (pressure, temperature and conductivity from dual sensors) are converted to physical units using calibration files modified for air pressure and conductivity slope factor (DATCNV). Outliers, differing more than 2 and 20 standard deviations for the first and second pass, respectively, from the mean of 100 scan windows are flagged and excluded from analysis (WILDEDIT). WILDEDIT flags only the bad data point of each parameter, and does not flag the entire scan. The thermal mass effects in the conductivity cell are corrected for (CELLTM, with parameters alpha = 0.03 and 1/beta = 7.0). Pressure is low-pass filtered with a time constant of 0.15 s. Following the SBE recommendation, the conductivity or temperature signals were low-pass filtered. Auxiliary sensors (oxygen, CDOM, flC, Trans) were filtered using a time constant of 0.03 s. Scans when the CTD package moved less than the set minimum fall rate of 0.25 m s^{-1} are flagged to remove pressure reversals due to ship heave (LOOPEDIT). Data are then averaged (BINAVG) into 1-dbar vertical bins and 1-s temporal bins (the latter is for the LADCP data processing). In the final (converted and bin-averaged) data files, temperature is saved using the ITS-90 scale, and salinity on the practical salinity scale (PSS-78). Pressure, temperature, and salinity data are accurate to ±0.5 dbar, $\pm 2\times10^{-3}$ °C, and $\pm 3\times10^{-3}$, respectively.

Conductivity correction from salinity bottle samples - A total of 67 salinity bottle samples are analyzed at IMR with a Guildline Portasal 8410 salinometer. Salinity and conductivity values from each bottle are merged with the corresponding CTD data. Bottle conductivity is calculated from bottle salinity and CTD temperature and pressure. Following the procedure recommended by UNESCO [1988], only data within the 95% confidence interval are used to correct the calibration of the CTD conductivity. Histogram of $\Delta C = C_{CTD} - C_{Bot}$, difference of conductivity measured by CTD and inferred from bottle salinity, is approximately normally distributed Following the recommendations given by Seabird Electronics, the conductivity values are corrected by the formula, $C_{new} = m\ C_{old}$, where m is the slope calculated by

$$m = \frac{\sum_{i=1}^{n} a_i \times b_i}{\sum_{i=1}^{n} a_i \times a_i}.$$

Here a_i and b_i are the CTD conductivity and the bottle conductivity, respectively and n is the total number of bottles. The results from all samples are shown in the following two figures.

For unknown reasons, there is an offset (jump) in salinity differences between the samples and the profiling measurements. The jump occurs at station 135 (sample number 42). The data set is thus subsampled and analysed separately prior and after the jump (plots not shown). Slope corrections needed were obtained to be 1.00078 and 1.00024 until Station 135 (41 samples) and from Station 135 and on (27 samples), respectively. However, we found a simple salinity offset correction more suitable for the purpose ($S_{new} = S_{old}$ + offset). Until Station 135 a salinity offset of 0.03 and from Station 135 and on a salinity offset of 0.009 was obtained. RMS salinity difference 0.0074 and 0.0029, respectively. These RMS differences are approximately identical to that would be obtained from the slope correction.

The offset of 0.03 is not in agreement with the calibration history of this CTD system. It nor agrees with the water mass properties of the deep waters when compared to the earlier LEGACY cruise. In conclusion, we ignore the samples until Station 135 and produce the final data set using a salinity offset of 0.009.

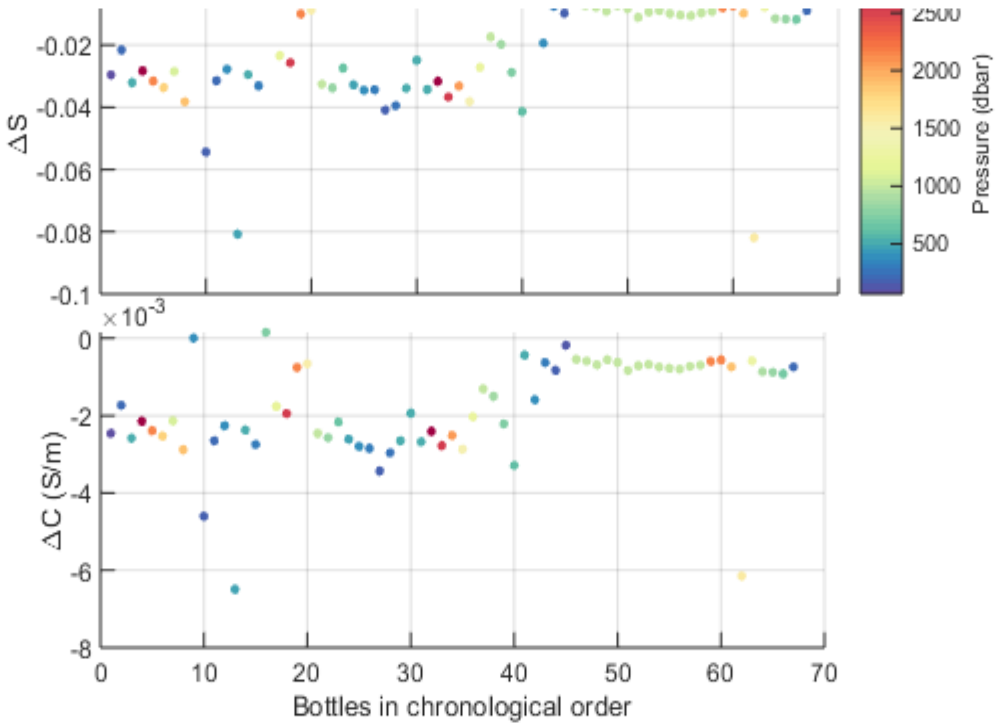


Figure 6. Difference between CTD-derived and bottle data: upper panel, salinity, lower panel, conductivity.

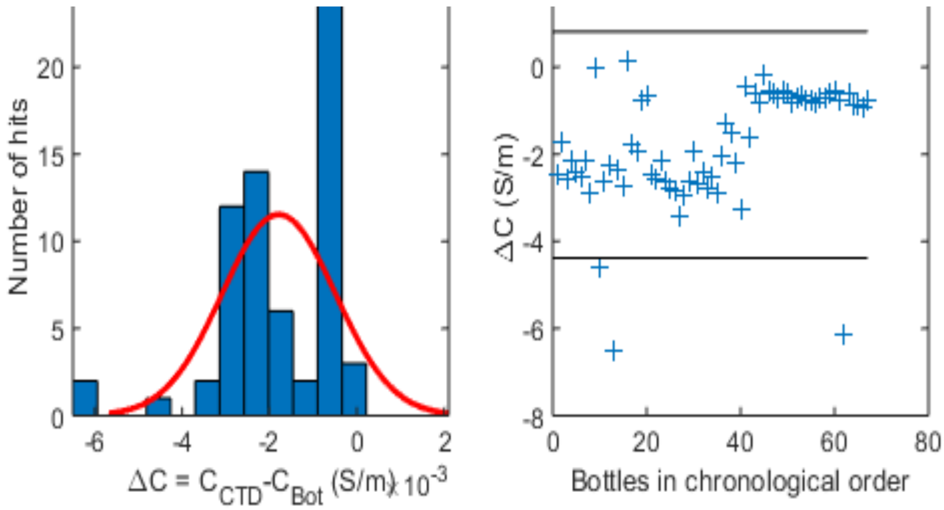


Figure 7. (Left) Histogram of CTD-derived and bottle conductivity differences. Red curve is the normal-distribution fit for the sample mean and standard deviation. (Right) ΔC in chronological order with 95% confidence intervals on the mean indicated (black envelopes).

Samples for oxygen calibration - During the cruise, 48 water samples were taken at several depth levels at 6 CTD stations (CTD-stations 117 to 122) on 17 September, and analysed for dissolved oxygen. The Winkler titration method with visual detection of the end point was used. Of the 48 samples, 2 duplicates and 4 outliers were excluded from the analysis. The dissolved oxygen concentrations obtained by the Winkler method (Ox sample) were not significantly different than the concentrations measured by the CTD dissolved oxygen sensor (Ox CTD) (Figure 8). The difference between the two varied around zero and the mean offset was -0.01 ml L^{-1}. This is within the measurement uncertainty; however, we applied this offset correction to the concentrations measured by the CTD sensor. A more detailed, multiple-parameter calibration, for dependency on pressure was not deemed necessary.

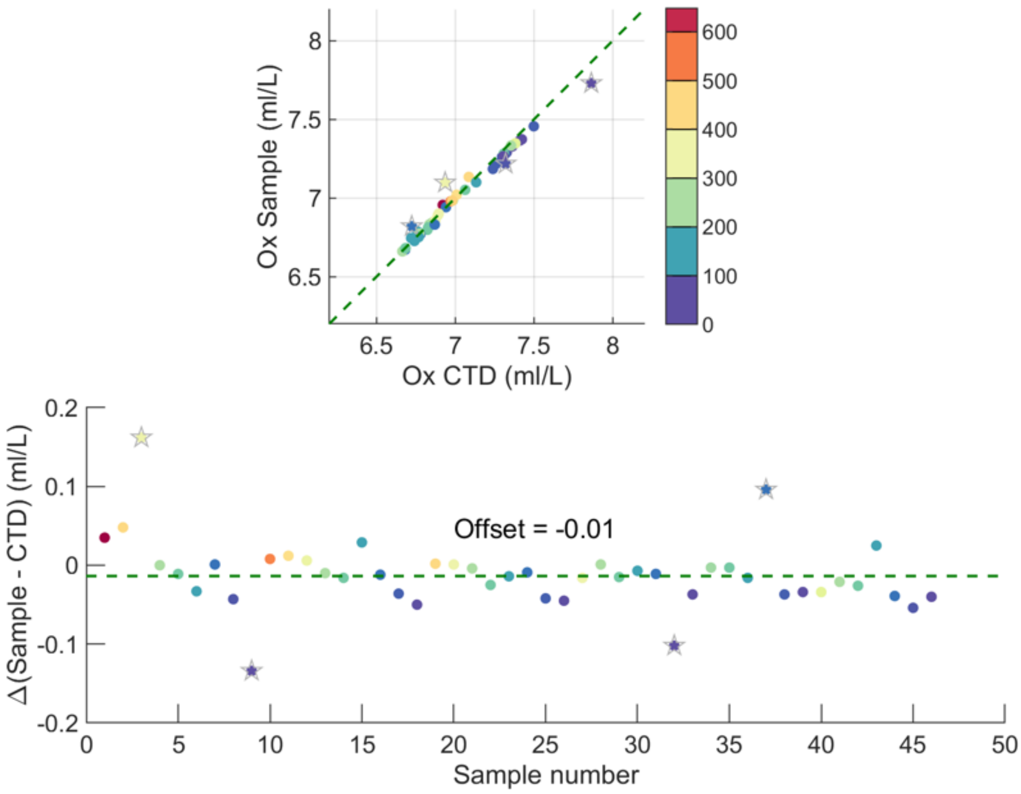


Figure 8. (upper panel) Scatter plot of CTD-measured oxygen values against oxygen samples analyzed on board, color coded with sample depth. (lower panel) difference between the sample reading and the CTD reading. After excluding 4 outliers (pentagrams), the average offset is -0.01.

3.2.2. Current Profiling: Lowered-ADCP (LADCP)

Two LADCP-profilers (RD Instruments) were mounted on the CTD rosette in order to obtain current profiles (Figure 5). The ADCPs are 6000-m rated, 300 kHz Sentinel Workhorses. While the pressure cases can hold batteries (i.e., not head only), we did not install batteries and instead used an additional battery canister with two battery packs. All 3 units are installed on the rosette in a balanced distribution to ensure minimum tilt. The battery canister was sufficiently away from the instruments. This ensures that when battery is changed, no compass re-calibration is necessary. Fresh batteries were installed before the cruise and were not replaced during the cruise.

Each ADCP has the L-ADCP option installed. The ADCPs were configured to sample in master/slave mode to ensure synchronization. The master ADCP pointed downward (SN 24474) and the slave ADCP pointed upward (SN 24472). The compass of each instrument was calibrated on land in their respective orientation prior to the cruise before KH2018709 and the resulting compass errors were 1-2°. Between the two cruises, batteries were replaced, but no new compass calibration was conducted (because the battery canister is sufficiently away from the instruments and will not affect the compass). In total 64 profiles of LADCP was taken. Communication with the instruments, start & stop of data acquisition and data download were done using the BBTalk software. PC time (UTC) was transferred to each instrument before each cast. The vertical bin size (and pulse length) was set to 8 m for each ADCP. Single ping data were recorded in narrow bandwidth (to increase range), in beam coordinates, with blank distance set to zero. The data from the first bin are discarded during post processing. In order to mitigate a possible influence of previous pinging, especially close to steep slopes, staggered pinging with alternating sampling intervals of 0.8 s and 1.2 s were used. The altimeter worked reliably and no sign of degradation of LADCP data quality was observed. The command files for the master and slave LADCPs are given in Appendix II.

The LADCP data are processed using the LDEO software version IX-13 based on *Visbeck* [2002]. For each master/slave profile data, synchronized time series of CTD and navigation is used. The NMEA GPS stream is automatically stored in the CTD .hex files with each scan, and are post-processed as 1-s bin averages, similar to the ADCP ping rate. LADCP-relevant processing of the CTD data included the identical steps in the SBE-Data Processing software. 5-minute time averaged profiles from the VM-ADCP are included for additional constraint on the inversion of the LADCP data (while this is done at the time of reporting, the data presentation is based on figures produced during the cruise and does not include the VM-ADCP constraint).

3.2.3. Current Profiling: Shipboard ADCP (SADCP)

There are four shipboard acoustic Doppler velocity profilers (SADCP) on board Kronprins Haakon, two 38 kHz and two 150 kHz RDI Ocean Surveyors. One of each are located on a drop keel (3.4 m), and the other ones are in the hull, flush mounted. The draft of the ship is 8.4 m. Flush mounted ADCPs are protected with an acoustically transparent window, allowing for profiles when moving through sea ice.

<u>Drop keel:</u> 150 kHz, SN 670821, transducer alignment angle 44.67°
38 kHz, SN 671825, transducer alignment angle 45.56°
<u>Flush mounted:</u> 150 kHz, SN 670822, transducer alignment angle 46.42°
38 kHz, SN 671824, transducer alignment angle 46.88°

SADCP continuously collected velocity profiles below the ship, using the VmDAS software. The command files for the SADCPs are given in Appendix II. The 38 kHz SADCPs were set to Narrowband mode, 65 bins of 24-m vertical thickness and 16 m blank distance. The 150 kHz SADCPs were set to Narrowband mode, 65 bins of 8-m vertical thickness and 6 m blank distance. Bottom tracking was disabled. Final post-processing of the drop keel SADCP (150kHz and 38Khz) has been done by using the CODAS package maintained at https://currents.soest.hawaii.edu. Typical processed horizontal velocity uncertainty is 2-3 cm s^{-1}. The flush mounted SADCPs have not been processed with the CODAS package

3.2.4. Microstructure Profiling

Ocean microstructure measurements were made using the vertical microstructure profiler VMP2000 SN009. Profiles were collected until 20 September, when the VMP winch broke and we had to terminate the operations. In total 51 deployments were made, some were aborted short casts, resulting in 45 microstructure profiles. A complete list of casts is provided in Appendix II. Operation and deployment methods for the VMP system are described below. VMP data reported here are from preliminary processing conducted during the cruise. Data will be post-processed to high-quality for analysis. The processing is based on RSI's ODAS MATLAB software v 4.01.

The VMP2000 is 2000-m depth rated, loosely tethered vertical microstructure profiler (http://www.rocklandscientific.com), for the measurement of dissipation-scale turbulence to depths down to 2000 m. It is equipped with high-accuracy conductivity temperature depth (CTD) sensors (P Keller, T, SBE-3F, C, SBE-4C with pump SBE-5T), microstructure velocity probes (shear probes), one high-resolution temperature sensor (FP07-38-1 thermistor), one high-resolution micro-conductivity sensor (SBE7-38-1 micro-C), and three accelerometers. VMP samples signal-plus-signal-derivative on thermistor, micro-conductivity and pressure transducer, and derivative for shear signals, which is crucial for turbulence measurements, especially for the temperature microstructure. Data are transmitted in real time to a ship-board data acquisition system. VMP has an overall length of 2 m with 40/3.5 kg weight in air/water and with a nominal fall rate of 0.6 m/s.

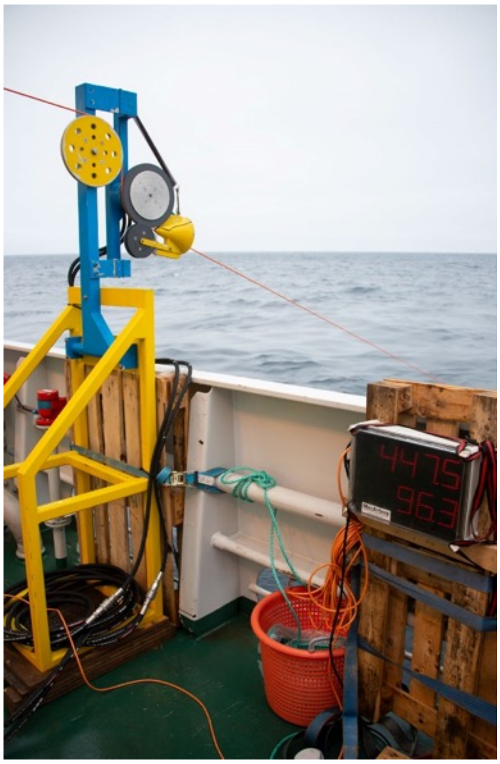


Figure 9. The set-up, on deck, of the VMP microstructure profiling system. The hydraulic winch (above); the cable is fed through a block strapped fixed at higher deck in the middle, and fastened by straps to the deck to avoid swings due to wind and ship's roll. The tether then is fed into the line-puller (right) fastened to the ships' railing. In addition to the winch operator, a second person observes the cable in water during the deployment, and assists with deployment and recovery.

Deployments were made using a Sytech Research Ltd. CMK-2 Hydraulic winch with Linepuller (an active line pay out system that makes it possible to perform rapid repeated profiles) and 2500 m deployment cable. Initially, we used the ship's hydraulics for the VMP winch, bypassing the hydraulic/electric motor. After several days of operation, we were informed that the winch lead to problems in the ship's hydraulics system. We then had to use our stand-alone electric motor, which worked satisfactorily. The winch and line puller system was designed to feed cable over the side of the ship, allowing the profiler to free-fall through the water column. On 20 September, however, the VMP winch broke and we had to terminate the operations.

Sampling was made from the starboard side, while drifting. We placed a block between the winch and the linepuller. The block is suspended from the main crane. The block is slightly (10-30 cm) above the linepuller level, ensuring that the cable does not jump off the linepuller. The block is strapped to the deck. Additionally, the block is tied (by rope) to the winch, to avoid excessive wagging. The setup worked very well. The VMP is deployed and recovered using the secondary (smaller) crane, behind the main crane (holding the block). Approximately 2-m long rope is attached to the upper end of the VMP and strapped (using cable ties and tape) along the bottom part of the VMP cable. The rope ends with an eye, which is used to lift the VMP. The instrument is guided directly to its stand, secured close to the railing. The operation worked well.

Sensors on VMP2000: sbeT: 4788, sbeC: 3340; Measured pressure offset is approximately 1.5 m (4 m actual depth is sensed as 2.5 dbar). S1 is oriented vertical, S2 is oriented horizontal.

casts	**S1**	**S2**	**T1**	**T2**	**C1**
1	M1109	M546	T808	-	-
2-5	M1109	M546	T808	T1001	C200
6-7	M1109	M1112	T808	T1001	C200
8-51	M1109	M1112	T808	T809	C206

Figure 10. (Left) The VMP profiler during deployment. The brushes provide the drag for the profiler. Drag, together with the buoyancy elements (yellow) set the nominal sink velocity of the profiler. Note the recovery line attached to the cable which allows recovery by a crane without damaging the cable. (Right) The hydraulic line-puller.

3.2.5. Gliders

During the cruise, a Kongsberg Seaglider and a Teledyne Webb Research Slocum glider were deployed near 81N30'-18E30'. The Seaglider will be recovered in December, while the Slocum was recovered during the cruise. The Slocum glider (Gnå) was equipped with an unpumped Seabird CTD, a Wetlab ECO-puck (Fluorescence and Turbidity), Andreraa Optode for oxygen and a Rockland Scientific Microrider. It was deployed on September 14 (11:00 UTC) and successfully recovered one week later on September 21, at around 12:00 UTC at 81N15'-21E00'.

The MicroRider is a self-contained turbulence instrument package, fitted with two velocity shear probes (SPM-38), two fast response thermistors (FP07), one micro conductivity probe (SBE7-38-1) and high-resolution pressure, acceleration and tilt sensors. The following sensors were installed:

SH1: M835, oriented vertical
SH2: M834, oriented horizontal
T1 : T873
T2 : T874

Sampling rate for the turbulence sensors is 512Hz, while the slow-response sensors sample at 64Hz. Sensors were protected by a probe guard designed not to disturb turbulence measurements, but greatly reducing the risk of breaking sensors during recovery. The MicroRider is powered by the glider's battery, but stores data separately on a flash card. For details, see *Fer et al. [2014]*.

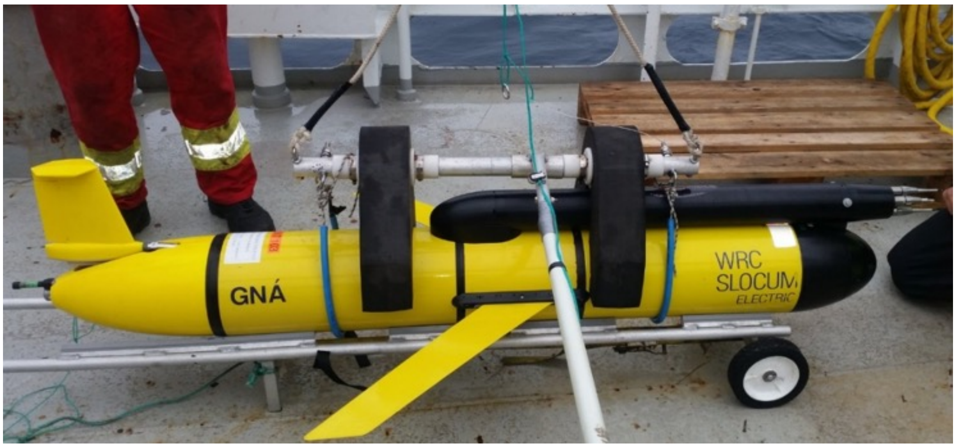


Figure 11. Photo of the glider Gná mounted with MicroRider, on the transportation trolley, together with the deployment tool.

The glider was deployed from the aft deck of the ship using a crane and a deployment tool kindly provided by French collaborators from IFREMER. Initially designed for the deployment of Spray gliders, it could easily be adapted to the shape the Slocum glider carrying a Microrider. Two straps holding the underside of the glider are connected to a quick release, easily opened by pulling a string from the end of the steering pole (see photographs) for a simple and safe deployment. It is important that the ship is moving at a few knots to quickly move away from the glider once released.

Recovery is challenging, and as a result, microstructure sensors were often damaged on previous cruises. We have now constructed a tool to ease recovery and operated now several times with success. The recovery tool consists of a hexagonal frame with a net, attached by four ropes to a big marionette that is held by a ship crane (see photographs). The framework is made out of hollow steel pipes. To add weight to the hexagonal frame we use a long linked steel chain, tightened to hold the parts together. Bolts are inserted at the joints to prevent the frame from twisting. The hex-frame is lowered below the glider, and fenders attached to the frame make it follow the wave movement rather than the ship movement. The rope connecting the frame to the marionette is approximately 4m long, allowing the marionette to stay safely above water, while the net goes below the glider. A rope is attached to the hexagonal frame to help control the frame movement and direction. Approaching the glider slowly from behind, the marionette is lifted when the glider is safely inside the hexagonal frame net.

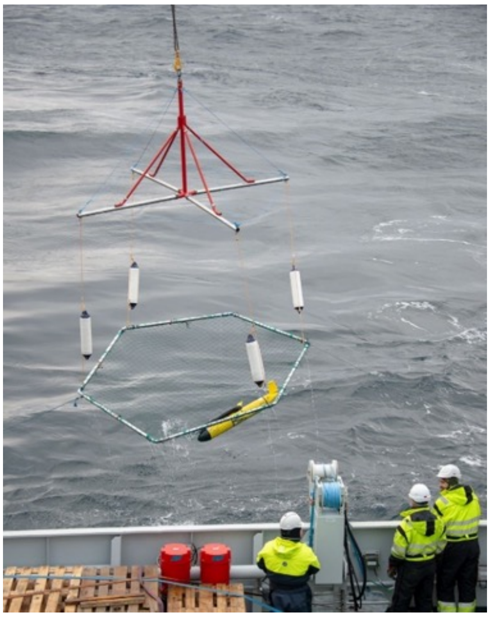


Figure 12. Glider deployment and recovery. (Pictures by Rudi Caeyers).

A first test dive to 30m was successfully done within the range of the Freewave radio signal. A second dive to 100m was then done in order to observe the flight behavior of the glider and further decide on fixed battery position to set to achieve stable dives with ±20-25 degree pitch angle. Fixed battery positions are necessary to prevent perturbations of the glider flight required for the Microrider.

Once the battery positions were fixed, the glider was set to glide down to 400m maximum by pumping ±260 cc. It showed very good flight performance (Fig. 14). All sensors worked well, recording values of temperature, conductivity, pressure, oxygen, fluorescence and turbidity along the glider track. After being successfully recovered, the Microrider mounted on the glider showed important signs of corrosion. After investigation, this happens to be caused by a leak of the power connection from the glider to the instrument. The Microrider stopped recording data after 4 days at sea, collecting data during about 60 dive/climb cycles. Further investigations are required to assess about the quality of the recorded data.

3.2.6. Autonomous Underwater Vehicle - LAUV Harald

The autonomous underwater vehicle (AUV) used on the Legacy cruise is a Light AUV (LAUV) named Harald, which is configured as a water column profiling AUV. The vehicle is 2.4 meters long with a diameter of 15 cm and a weight of about 32 kg. The vehicle has a large battery bank, which allows missions of up to 24 hours at a speed of 1 meter per second. The depth rating of the vehicle is up to 100 meters.

Figure 13. LAUV Harald after departure for the LEGACY cruise

The vehicle uses several communication interfaces, such as Wi-Fi, GSM/4G and acoustics. However, on operations in the Arctic, the most suitable communication interface is the iridium satellite modem. The payload sensors on LAUV Harald consist of:

Nortek 1000 KHz DVL.
SeaBird SBE 49 FastCat CTD.
Wetlabs EcoPuck Flurometer (Chl-a, CDOM, TSM).
Anderaa 4831F Oxygen optode.

Detailed specifications for the payload sensors are found in Figure 14. The vehicle also has an onboard user computer, which is used for running autonomy programs, that utilizes sensor data to command the AUV.

Type	Resolution	Accuracy	Sampling interval	Range	Measuring
Aanderaa's Optode 4831 oxygen sensor	< 1 µM	< 8 µM	2 sec - 255 min	0-500 µM	Oxygen
	0.01 °C	+/- 0.03°C	2 sec - 255 min	-5°C to +40°C	Temperature
WetLabs Triple-Measurement Meter EcoPuck	-	-	0.25 sec	0-375 ppb	Dissolved organic matter
	-	-	0.25 sec	0-30, 0-50 µg/L	Chlorophyll
	-	-	0.25 sec	0-5 1/m	Optical backscatter
SeaBird SBE 49 FastCAT	0.00005 S/m	+/- 0.0003 S/m	0.0625 sec	0 to 9 S/m	Conductivity
	0.01 °C	+/- 0.002 °C	0.0625 sec	-5°C to +35°C	Temperature
	0.002% of full scale range	+/- 0.1% of full scale range	0.0625 sec	0 to >=100m	Pressure

Figure 14: Payload sensor specification on LAUV Harald.

During the Legacy cruise, a total of 6 missions have been conducted with the LAUV Harald. A summary of the missions can be found in the table below.

Name	Date	Time	Position	Distance	Duration
msn_1_ctdcal	20180914	19:51	81.604, 18.490	0.6 km	8 min
msn_2_ctd_transect_1	20180914	20:00	81.604, 18.490	10.4 km	91 min
msn_3_ctd_transect_2	20180916	00:55	81.189, 21.065	8.3 km	83 min
msn_4_trex_1	20180918	07:15	81.921, 21.008	24.4 km	238 min
msn_5_trex_2	20180918	16:11	81.921, 21.008	11.3 km	112 min
msn_6_trex_3	20180918	18:34	81.921, 21.008	5.3 km	56 min

The data from the AUV is stored as a custom binary format, and requires custom software for reading. For reference, the full raw data for the AUV is added, along with the configuration files, terminal output and DVL raw data. In addition, a selected set of exported CSV-files are available for all missions listed above. The CSV-files include:

Chlorophyll	EstimatedState	NavigationUncertainty
Conductivity	EulerAngles	OpticalBackscatter
Depth	GpsFix	Salinity
DissolvedOrganicMatter	GroundVelocity	Temperature
DissolvedOxygen	NavigationData	WaterVelocity

3.2.7. Surface Drifters

Three Surface Velocity Program (SVP) drifters, manufactured by MetOceans, have been deployed during the cruise. The upper hull of the surface unit incorporates the Iridium and GPS antennas as well as a console port for user interface. The SVP has been designed to transmit the acquired data over the Iridium satellite network for a period of 12 months. Data is acquired and transmitted every 30 minutes, and to the Global Telecommunication System (GTS) every three hours. The unit is outfitted with a Lithium Battery which supplies enough power to operate the unit for 6 to 12 months of uninterrupted data collection.

The SVP contains:

USS PR303J2 Sea Surface Temperature Sensor

PTB110 Barometric Pressure Sensor

Iridium 9602 short burst data modem and antennas

Control electronics

Jupiter 32 GPS module and antenna

The three drifters have been deployed at the following dates and locations.

Name	**Date**	**Lat**	**Lon**	**IMEI**
AEN-SVP-01	14-09-2018 17:30UTC	81.60 N	18.50E	300234066265160
AEN-SVP-02	22-09-2018 21:00UTC	80.67	12.05E	300234066261180
AEN-SVP-03	18-09-2018 11:26UTC	81.92N	20.98E	300234066268180

3.2.8. Bow wave sensor

An ultrasonic sensor (Banner Engineering QT50ULBQ6) was mounted at the bow of the ship on a 6m long steel rod pointing downwards towards the water /ice (Figure 15). The sensor measured the distance to the surface of the water / ice. In addition, a high accuracy, thermally calibrated IMU equipped with a Kalman filter (Vectornav VN100) was located at the same location at the bow of the ship and measured the acceleration of the mounting point of the sensor. This combined ultrasonic and acceleration measurement was active during the whole cruise.

Figure 15. The ultrasonic sensor measuring distance to the surface of the water / ice.

Using the data from the ultrasonic sensor and the IMU, the elevation of the water or ice surface, compensated from the motion of the ship, can be computed. From this information, the power spectrum density of the waves and significant wave height can be recovered. In the case when the boat is steaming, Doppler shift redistributes the energy across the range of wave frequencies and only the significant wave height should be used. In the case when the boat is still, both the significant wave height and the wave power spectral density are reliable. As the ultrasonic sensor was planned for use in the ice, it was calibrated using its self-calibration feature. The range obtained is then fixed at [-0.5, +0.5] meters around the mean water level. This is too little in the open ocean when large wave activity is present, and therefore some signal saturation is observed and must be compensated for in the ocean.

The data from the measurements, both ultrasonic gauge and IMU, is saved in the folder of the cruise in '.csv' format (zipped). In addition, pre-processed results in 'pkl' format are also stored. For more information, contact Jean Rabault or Malte Muller.

3.2.9. Measurements of waves in ice

An array of 4 instruments measuring waves in ice were deployed on September 19th. Each wave in ice sensor is composed of a solar panel, battery and power managing unit for providing energy, a high accuracy thermally calibrated VN100 IMU for performing the measurements, a microcontroller-based logger including a SD card and a GPS chip to log the data, a microcomputer for in-situ data processing, and an Iridium modem with active antenna for satellite communications. The instruments were deployed on 4 different ice floes, at different depth inside the marginal ice zone (see Figure 16). Around each 4.5 hour, each sensor wakes up, performs measurements of waves for 30 minutes, computes the wave power spectral density, and sends through Iridium the GPS position of the logger and an under sampled wave energy spectrum. These instruments will be useful for tracking ice drift, wave attenuation in the ice, and the wave spread in the ice. Expected lifetime is up to 2.5 months running on battery, or unlimited as long as enough solar energy is available, and as long as the ice under does not break up. The array was deployed in the following way:

Sensor 1 on an isolated ice floe (diameter around 10 meters), in the outer marginal ice zone.
Sensor 2 on an ice floe surrounded by grease ice and pancake ice (diameter around 10 meters), around 5 kilometers inside the marginal ice zone.
Sensor 3 at the beginning of the continuous drift ice.
Sensor 4 inside the closed drift ice.

Figure 16. One of the wave-in-ice sensors deployed on a large ice floe. The main case containing the instrument, its solar panel, and the additional buoy around it are visible.

3.3. Methods and Instruments: Meteorology

3.3.1. Radiative Flux Measurements

A portable station has been used to study the temporal variations of surface radiative fluxes. The sensors are mounted on a 4-meter long horizontal pole, reaching out at Deck 6, approximately 11.5 meter above the surface (Figure 17). The station includes a Kipp & Zonen CNR 4 surface net radiometer. It measures broadband electromagnetic radiation shortwave (0.3-3 micrometer) and longwave (4-50 micrometer) bands at the surface (incoming and outgoing). The shortwave measurements include visible light, but excludes the most UV-radiation. The instrument has also an internal temperature sensor for internal correction of the longwave radiation. This is taken care of in the logger. The CNR4 is ventilated and heated when connected to an external power source. The surface skin temperature is measured using two IR radiometers (Apogee SI-411 SDI-12 and Campbell Scientific IR120 IR), mounted on a horizontal pole as shown. The main IR radiometer (CS IR120 IR) points downwards to the surface with an angle of about 35 degrees (relative to the vertical), for measuring the surface skin temperature. The second IR radiometer (Apogee SI-411) points directly upwards for measuring the sky temperature, which is used for atmospheric correction of the surface skin temperature measured by the main IR radiometer. Geographic position is measured by a Campbell Scientific GPS16X-HVS GPS sensor. The Memsic XTLA tilt sensor measures the tilt of the sensor induced by the ship motion. It is used to correct the radiation data from CNR 4.

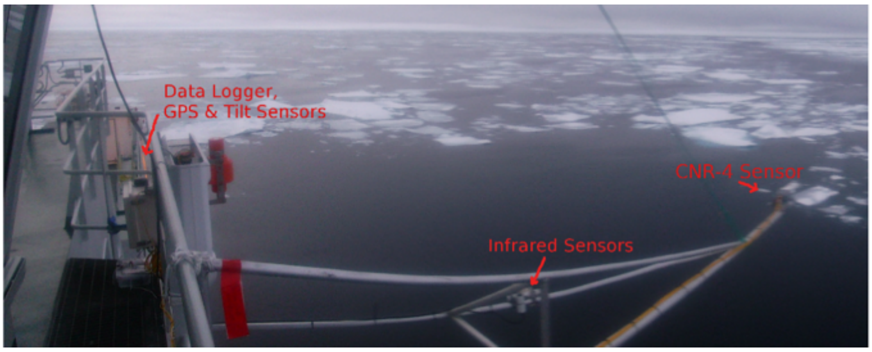


Figure 17. Horizontal pole with the CNR4 radiation, infrared, GPS, and tilt sensors. Picture from Deck 6, beside the bridge.

Figure 18. (Left) Portable data logger with battery and LCD monitor, memory card reader and switches controlling the ventilator and heating for the CNR4 instrument (indicated by circle). (Right) Horizontal pole with the CNR4 radiation instrument mounted on Deck 6.

3.3.2. SUMO – UAV

While SUMO operations have occurred onboard ships in the past, they have always been challenging. Though launching and mission operations can take place mostly as normal, the difficulty in the landing procedure is vastly increased. In the past, expert RC pilots have made landings on helipads, though even these have been rough and potentially damaging to the aircraft. To make this landing procedure more accessible to scientific pilots, a net landing system was designed and built by Lindenberg und Mueller GmbH & Co. KG (Figure 19).

Figure 19. SUMO RPAS coming in for a net landing. The net is secured with sandbags and rope.

The dimensions of the net, 4 x 4 m, have been specifically chosen to balance logistical (weight, transport, setup) and operational (ease of hitting the net) considerations. While other net landing rigs have used taunt nets, this current design incorporates a more flexible net, which helps to absorb more energy upon aircraft impact. The frame of the net also incorporates the use of mostly steel, for strength, with fiberglass rods, for further energy absorption. This necessity of energy absorption/distribution is very important for platforms such as SUMO, as its EPP construction makes it less rugged during net landings, compared to other fiberglass craft. Alongside the net, a "shoe" and hook apparatus was built for the net capture. This shoe fits snugly over the nose of the SUMO, and has a 3D printed, 4-barbed hook at the front. The shoe is then secured to the fuselage, and will subsequently help to more evenly distribute energy during impact. Upon impact with the net, the hook penetrates, while slightly stretching, the mesh (~35 mm), which allows for the barbs (~32 mm) to prevent the SUMO from bouncing/falling off. The net has been built in a very modular and mobile fashion, being able to be taken as checked luggage on flights.

The largest departure from normal SUMO operations is in the landing procedure. As landing requires an approach vector into the mean wind direction, and the net is secured to the helipad, the orientation of the ship must be in a way that allows for landing. Additionally, since landings along the longitudinal axis of the ship could potentially pose a safety risk (superstructure of the ship is blocking approach vector/"go-around" path), only approach vectors from port or starboard should be attempted. An automated approach procedure was written into the autopilot software ("Paparazzi"), which aligns the SUMO along a manually set path between a downwind approach point (AF) and a "touchdown" point (the helipad). Communications between SUMO operators and the bridge/ship are critical as the current heading of the ship has to be known, in order to properly set AF.

Though landing is significantly more complicated during ship-board SUMO operations, take-off difficulty is greatly reduced. The elevated height of the helipad (~10 m on RV Kronprins Haakon) adds substantial time for SUMO to drop while building up speed and lift. Once in the air, most normal SUMO missions can take place. For this cruise, SUMO was limited to operations below 120 m ASL, therefore the deployment strategy focused on procedure/mission building and horizontal measurements. Beginning with the latter, standard, oval patterns (referred to as "racetracks") were flown 80 m above a heterogeneous, sea-ice/open-water surface, with the IR thermopile measuring surface temperature (average over an ~80 m circle), while air temperature and humidity were simultaneously measured. These racetracks had straight sections of approximately 300 m, and were separated by 250 m. This pattern was tested with two variations: straight sections perpendicular to the mean wind, and also parallel; both methods were performed upwind of the research vessel. These variations were done to determine if one was superior in identifying internal boundary layer structures that would be created due to the different surface types.

Low-level vertical profiles from 40 to 120 m were flown, with two horizontal circles every 20 m (vertical), to allow for sensor stabilization. Using this pattern and the onboard GPS, a vertical profile of the mean horizontal wind can also be calculated.

Five SUMO flights were held across three days. An additional test flight was held earlier in the cruise, but conducted no scientific operations due to technical concerns with the propeller. A summary of flight details can be found in Table 2. All flights were done with SUMO#1.

Table 2. Summary of SUMO flights conducted. All flights done with SUMO#1.

#	Date	Time (UTC)	Location	Winds (°, m/s)	Missions
0	16-SEP-2018	18:22	81.59N, 24.02E	135, 7	Test flight
1	17-SEP-2018	06:43	81.57N, 23.90E	120, 5	Profile (up & down)
2	17-SEP-2018	09:09	81.54N, 23.90E	110, 6	Profile (up & down)
3	18-SEP-2018	11:34	81.56N, 20.53E	80, 6	Racetracks, profile (up)
4	19-SEP-2018	15:38	82.32N, 19.47E	45, 4	ICE: Profile (up), racetracks
5	19-SEP-2018	18:00	82.19N, 19.23E	45, 4	ICE: Profile (up), racetracks

3.3.3. Windcube LIDAR

The Windcube LIDAR system uses the Doppler shift of emitted infrared laser pulses to calculate the 3D wind profile. Laser pulses are emitted from four beams, horizontally orthogonal to the four sides of the instrument and directed 28 degrees from vertical, alongside an additional fifth beam directed vertically. The determined radial velocities along each beam can then be transformed into standard U, V, & W components (easterly, northerly, & vertical, respectively), at preset altitudes. The V2 Offshore model, used in this deployment, also takes into account angular changes in pitch, roll, and yaw while calculating the wind profile, by utilizing an integrated IMU.

This particular Windcube has previously been deployed in exactly the same fashion, having been on board the RV Alliance during the Iceland-Greenland Seas (IGP) project. However, translational effects of the ship's movement are not taken into this corrected calculation. As the unit also has precise differential GPS, recorded position data used in conjunction with the corresponding timestamp should provide a background velocity that can be subtracted from the calculated winds. As this effect is only present while the ship is moving, low-level SUMO profiles are planned for comparison, being made while enroute.

3.3.4. HATPRO Microwave Radiometer

The HATPRO Microwave Radiometer monitors several frequency bands, each with different atmospheric opacities, and can give temperature and moisture profiles up to 10 km. The system has two, alternating measurement modes: the aforementioned multiple frequency up to 10 km with a purely vertical beam, and an angular based Boundary Layer (BL) mode which relies on the assumption of horizontal homogeneity and the use of fewer bands at increasing angles to obtain a vertical profile, with higher resolution near the surface. While the pitch/roll of the ship should have a minimal effect on the vertical mode (maximum height errors on the order of 20 m), the BL mode relies heavily on a stable platform, which a heaving ship can seldom provide. One approach, taken by a recent cruise to the Greenland-Iceland Seas (IGP project), is to mount the instrument on a self-leveling platform, thereby emulating a deployment on stable, motionless ground. If such an apparatus is unavailable, alternative setups must be considered.

Figure 20. Windcube LIDAR and HATPRO microwave radiometer installations. The equipment was installed towards the aft of Deck 6, Port side. Port side gallow can be seen in the background.

Windcube LIDAR system provides high frequency angular information and was already planned for deployment on the same cruise, it was decided to install the instruments side-by-side, and to use this angular information as a correction in the post-processing of the HATPRO data. The two instruments were aligned to be as parallel as possible, with the horizontal field of view of the HATPRO directed towards aft (Figure 20). Additionally, the ship itself also records pitch and roll measurements, which can also be used as a lower frequency alternative. While lower level measurements can be compared to SUMO flights, upper level measurements can be compared with the daily radiosonde launch.

3.3.5. Controlled Meteorological Balloons

Controlled Meteorological (CMET) balloons provide 4D observations of air temperature, wind speed, wind direction and air humidity. CMETs are developed by Prof. Paul Voss, Smith College, MA, USA and can fly for multiple days in the troposphere with altitude controlled via satellite link [*Voss et al.*, 2013]. Altitude control is achieved by the dual balloon design (high-pressure inner and low-pressure outer balloon) between which helium is transferred by a miniature pump−valve system. Commands sent through an Iridium satellite link can set target altitude (typically 0−3500 m), control band (~ 50–500 m with the higher band using less power), vertical velocity (~0.5–1.5 m/s^{-1}), termination countdown timer and numerous other operational parameters. The CMETs have the ability to perform automated soundings between two specified pressure altitudes.

The 215g CMET payload (excluding balloon envelopes) includes the control electronics, GPS receiver, satellite modem, pump-valve system, lithium polymer battery, photo-voltaic panel, aspirated T-RH sensor and a vacuum-insulated pouch for the payload. The payload temperature is maintained within acceptable operating limits (typically +20^{o}C above ambient) even at altitudes of several kilometres in the Arctic. An aviation-grade pressure sensor (Freescale 25 MPXH6115A) coupled to a 16 bit analog-to-digital converter (Analog Devices AD7795) provides altitude information to the balloon's control algorithm every 10s during flight. As part of data post-processing, this pressure derived altitude is corrected for pressure offsets using the 30 in-flight GPS altitude (Inventek ISM300X). GPS latitude and longitude provide the in-flight CMET coordinates and are also further analysed post-flight to determine wind speeds in eastward (U) and northward (V) directions. Temperature is measured using a thermistor (General 35 Electric MC65F103A) in a 10 k-Ohm divider circuit coupled to the aforementioned analog-to-digital converter. A capacitance humidity sensor (G-TUCN.34 from UPSI, covering 2 o 98 % RH range over −40 to +85 ^{o}C generates a signal which is a function of the ambient relative humidity (RH) 40 with respect to water. For the first time, the RH sensors were calibrated using a Licor 7000 CO2/H20 NDIR analyzer.

Figure 21. Launch of Controlled Meteorological Balloon from RV Kronprins Haakon on 19. September 2018.

CMETs are easy to launch (requiring just 1−2 people with standard meteorological balloon skills: launches have been achieved under a wide range of surface winds to date) and are similar in size to a standard meteorological balloon. CMETs typically rise and sink 1m/s and has a sample rate of 10 s, providing detailed profiles. For further details of the CMET balloon, payload design and balloon flight engineering see Voss et al. (2013) and http://www.science.smith.edu/cmet/flight.html.

During this cruise, two CMET balloons were launched (Table 3)). Due to high RH during the entire cruise, icing was a major challenge during these flights, and caused relatively early terminations.

Table 3. Meta data for CMET Launches

Balloon Name	Lat [°N]	Lon [°E]	Launch date and time (UTC)	Termination date and time (UTC)	Max altitude [masl]
Olav	81.95	20.78	18 Sept 13:27	18 Sept 15:11	770
Märtha	81.43	18.47	21 Sept 16:41	21 Sept 20:14	3438

Radiosonde measurements

On behalf of the *Deutscher Wetter Dienst*, Vaisalla radiosondes were launched daily, to collect profiles of air temperature, wind speed, wind direction and air humidity. The sondes are launched from a specialized container at the vessel at about 1045 UTC. The sondes rise quickly to about 20 000 – 30 000 masl before they explode. Although the vertical resolution is somewhat coarse, the radiosondes provide valuable data for meteorological model validation. Figure 22 shows the location of the radiosonde launches.

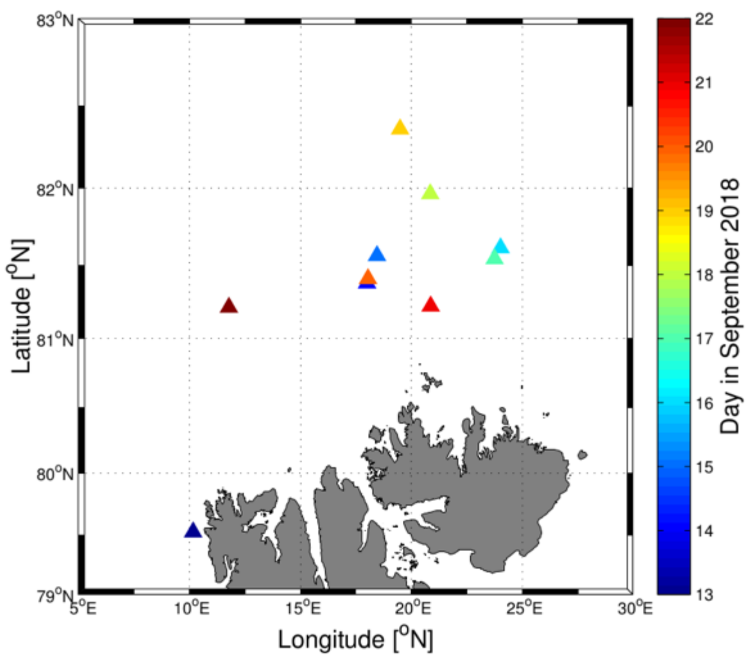


Figure 22. Map of ship locations during radiosonde launches (triangles) during 13-22 September.

3.4. Moorings

3.4.1. The Nansen LEGACY moorings north of Svalbard

Two mooring arrays, each consisting of 3 moorings, were deployed across the slope north of Svalbard at approximately 400, 700 and 1200 m isobath. The deployment time, depth and locations are listed in Table 4. A detailed drawing of the moorings with instrumentation and serial numbers is given in Figure 23 (array E) and Figuer 24 (array W). Mooring W1 also includes the PEANUTS mooring package in the upper 80 m, detailed in the next section.

Table 4. Oceanographic mooring deployment details.

Mooring	Latitude	Longitude	Depth (m)	Deployed (UTC)
W1	81N10.979	18E29.052	401	15.09.2018 , 1820
W2	81N22.686	18E23.789	727	15.09.2018 , 1420
W3	81N27.356	18E23.730	1202	20.09.2018, 1810
E1	81N24.925	24E0.0	300	16.09.2018, 0745
E2	81N30.813	23E59.853	706	16.09.2018 , 1120
E3	81N35.453	23E59.982	1222	16.09.2018 , 1445

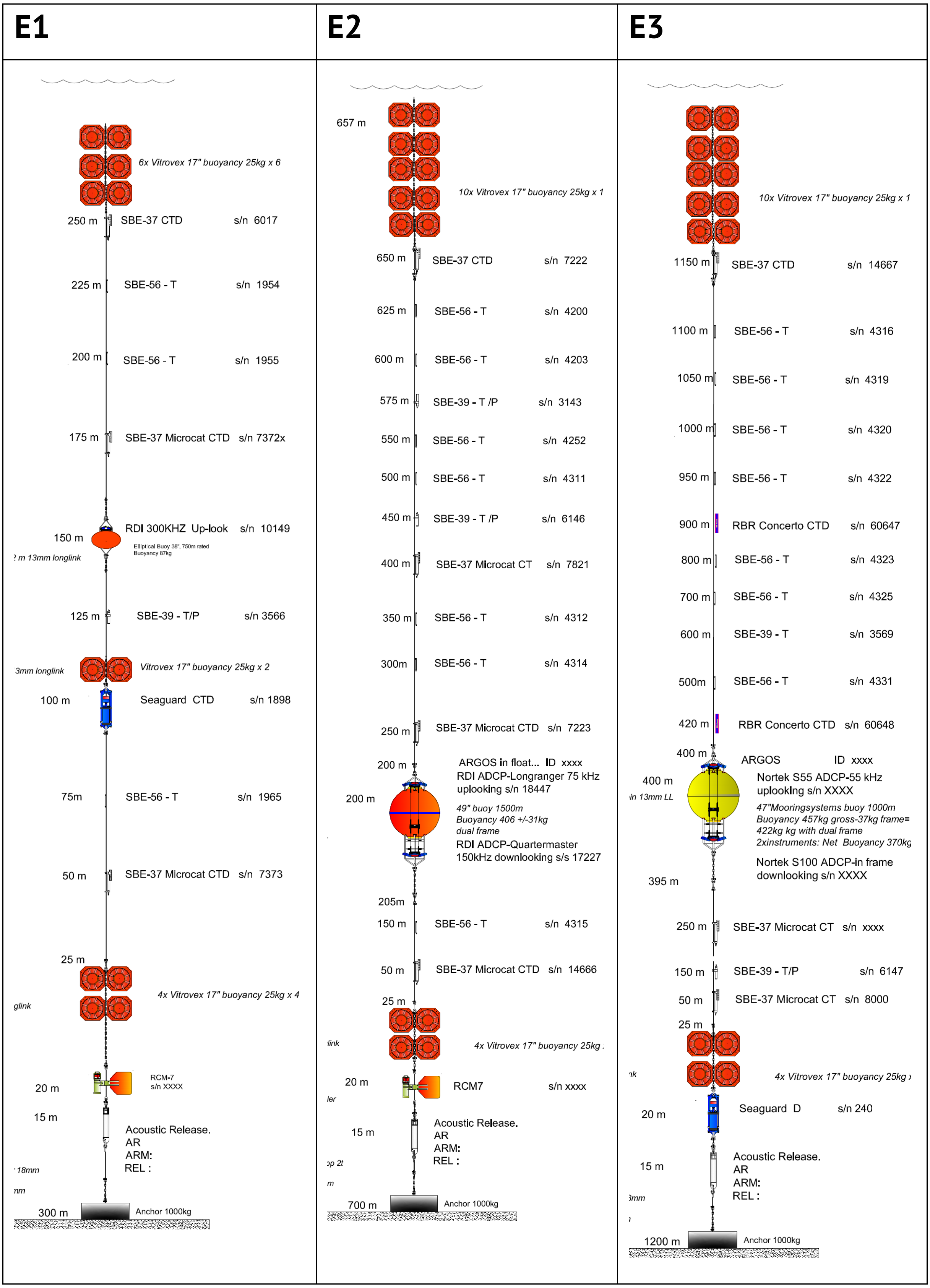


Figure 23. LEGACY mooring array E, north of Svalbard

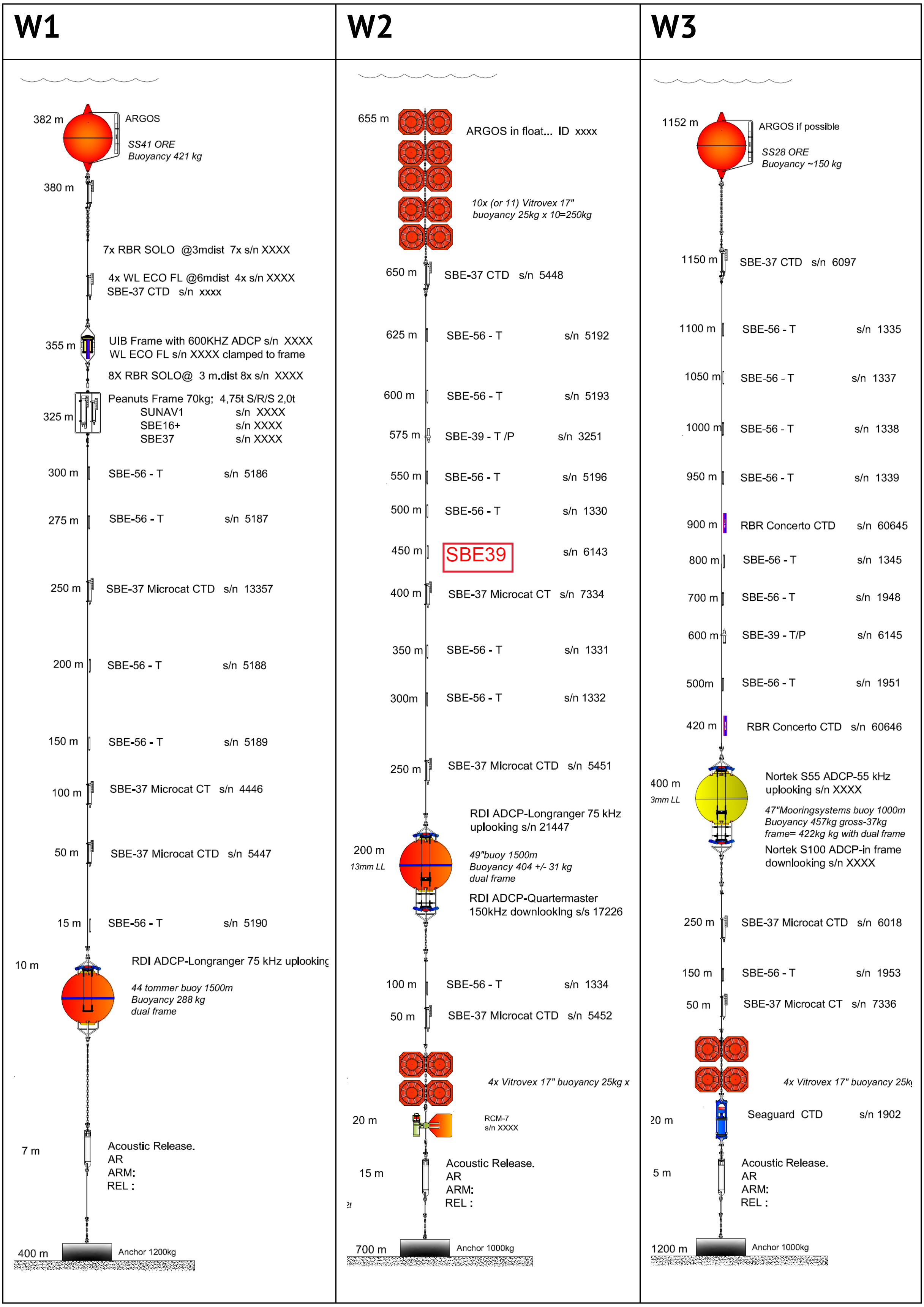


Figure 24. LEGACY mooring array W, north of Svalbard

3.4.2. PEANUTS mooring instruments

The instrumentation in deployed in the upper 80 m of sen Legacy mooring W1 is supplied by NOC and Bangor University as part of the PEANUTS (primary production driven by escalating Arctic nutrient fluxes) project. The instruments deployed on Nansen Legacy mooring W1 aim to quantify turbulent mixing rates at the base of the surface mixed layer over a seasonal cycle, quantify nutrient fluxes, measure nitrate concentrations and fluorescence-derived chlorophyll-a concentration below the mixed layer over a seasonal cycle.

The instrumentation was deployed in approximately 400 m of water at the location 81°N10.979', 18°E29.052', on Saturday 15/09/2018 at 1820 UTC. It was deemed a risk to the ship to verify the final depth of the mooring using the echo-sounder, therefore those depths indicated on the following diagram (Figure 25) are estimates.

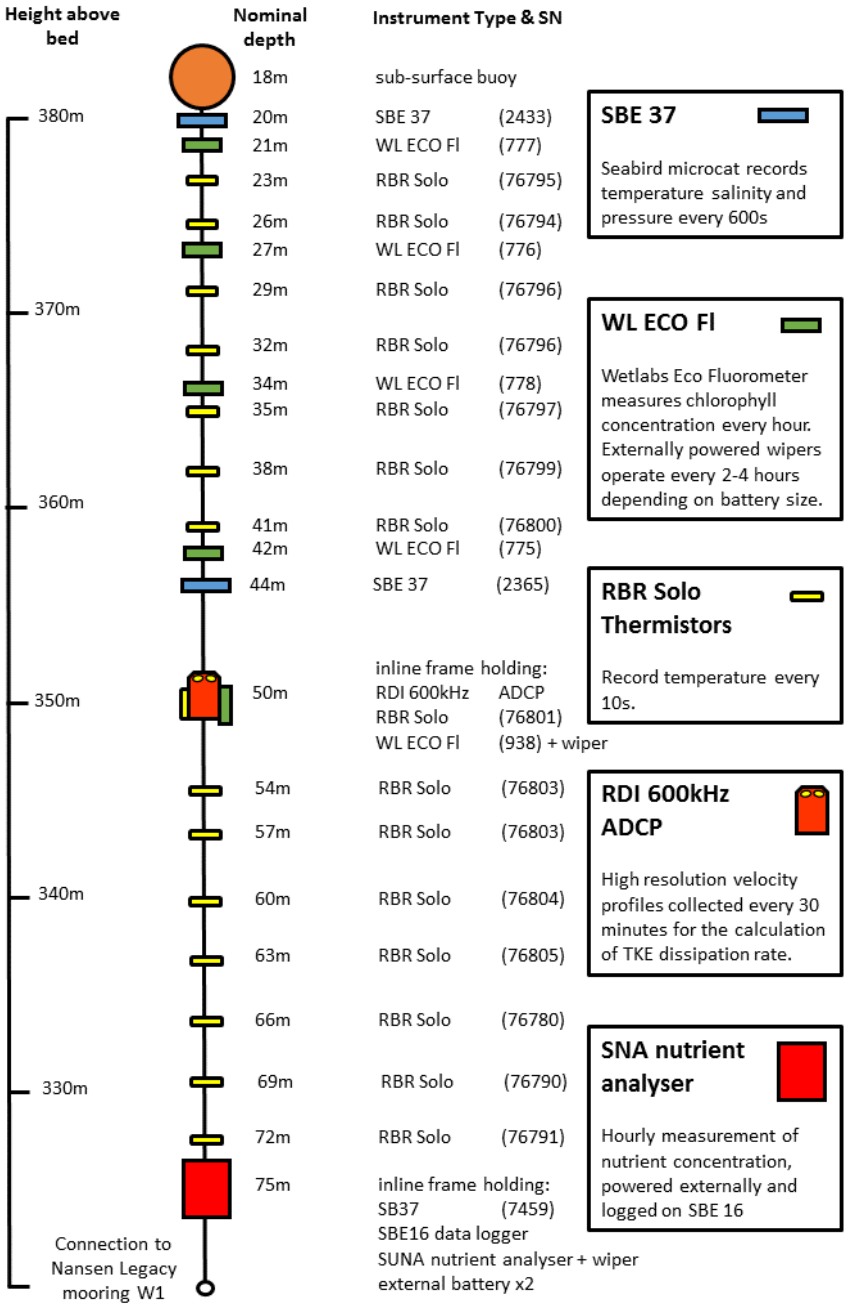


Figure 25. PEANUTS mooring instruments.

3.4.3. REOCIRC moorings on the Yermak Plateau

For independent and integrated measure of the Atlantic Water volume flux and heat input to the Arctic Ocean three precision Ocean Bottom Pressure (OBP) recorders have been deployed (YP1-YP3, Figure 26) across the south-eastern Yermak Plateau for 3 years over 4-year period. The location at the northwestern corner of Spitsbergen was chosen in order to capture the water transport in the Svalbard branch (SB) – the barotropic continuation of the West Spitsbergen Current (WSC) with a slope-confined flow path straight into the Arctic Ocean. Data from current meters (Aanderaa SeaGuard, YPC), together with SBE MicroCat CTD time series, Vemco temperature loggers and the bottom pressure data, results in an integrated barotropic velocity time series for the northward flowing Atlantic Water in the Svalbard branch. The REOCRIC-section is also the most suitable section for an integrated effect of freshwater discharged from land in the coastal current.

Three moorings (YP1, YP2, YPC, Figure 26) were recovered on the second day (Table 5) of the sen Legacy cruise KH2018709 on a calm day with favorable sea state and good visibility. The release of all three moorings was executed according to plan and the haul on deck went smoothly except the longer YPC mooring where the line was entangled after being hocked to the drop keel. All instruments were brought safely on board and they had collected data until recovery. We had to leave behind YP3 for a later recovery on the cruise due to poor light conditions and visibility.

Table 5. Position, deployment depth, deployment time and recovery time for the REOCIRC moorings

Mooring	Latitude	Longitude	Depth (m)	Deploy (UTC)	Recover (UTC)
YP1	79 48.09	010 45.59	31	03.10.17, 06:56	13.09.18, 12:45
YP2	79 50.60	010 29.98	111	03.10.17, 08:20	13.09.18, 13:45
YPC	80 07.95	008 32.20	515	03.10.17, 12:50	13.09.18, 18:15
YP1	80 10.48	008 09.28	549	03.10.17, 14:46	-

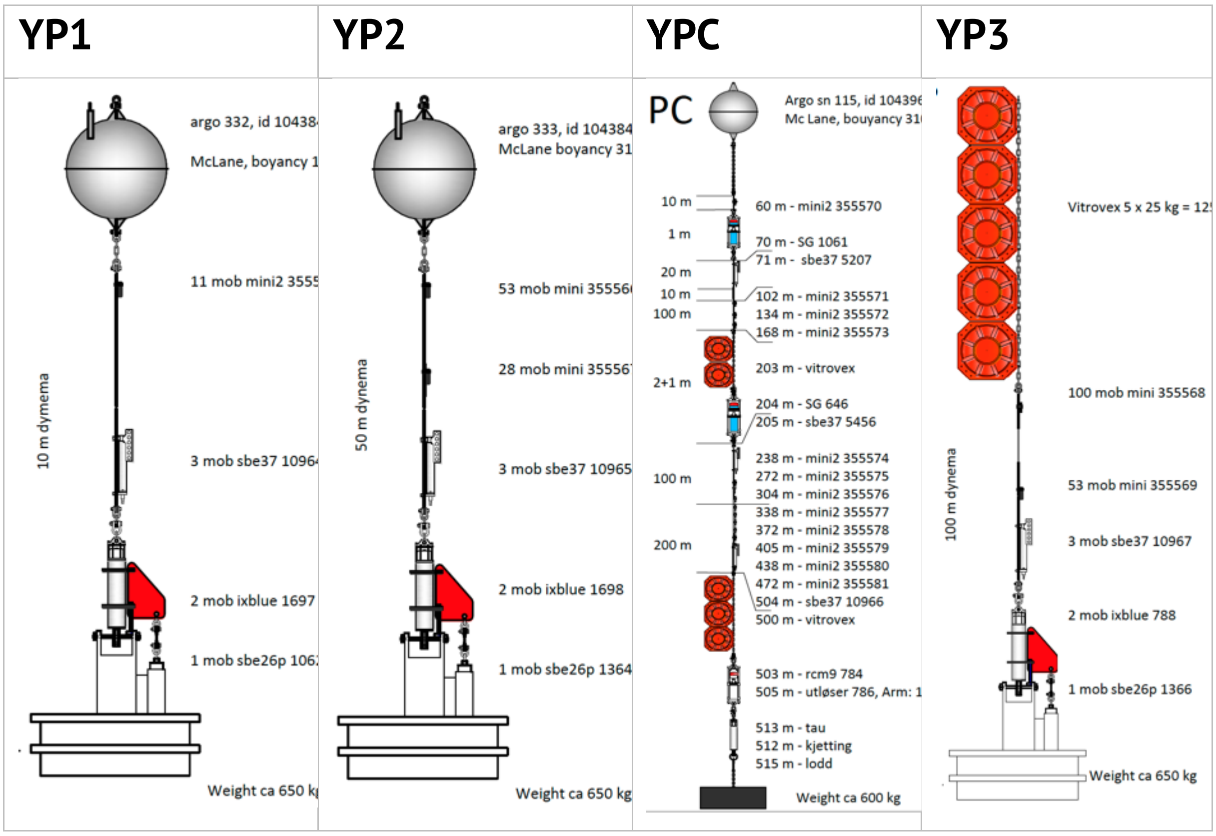


Figure 26: REOCIRC mooring design with instrument setup and deployment depth specifications.

3.5. Presentation of Data

Below we present selected plots from the CTD, LADCP, SADCP and VMP2000 profiles at sections and repeat stations. In the figures the CTD salinity is not corrected against bottle samples, but oxygen is. Current profiles are *in situ* (not detided nor corrected for magnetic declination). LADCP profiles are processed without SADCP data. VMP2000 data are not screened carefully for outliers and glitches, other than the automated despiking carried out during the processing.

3.5.1. CTD

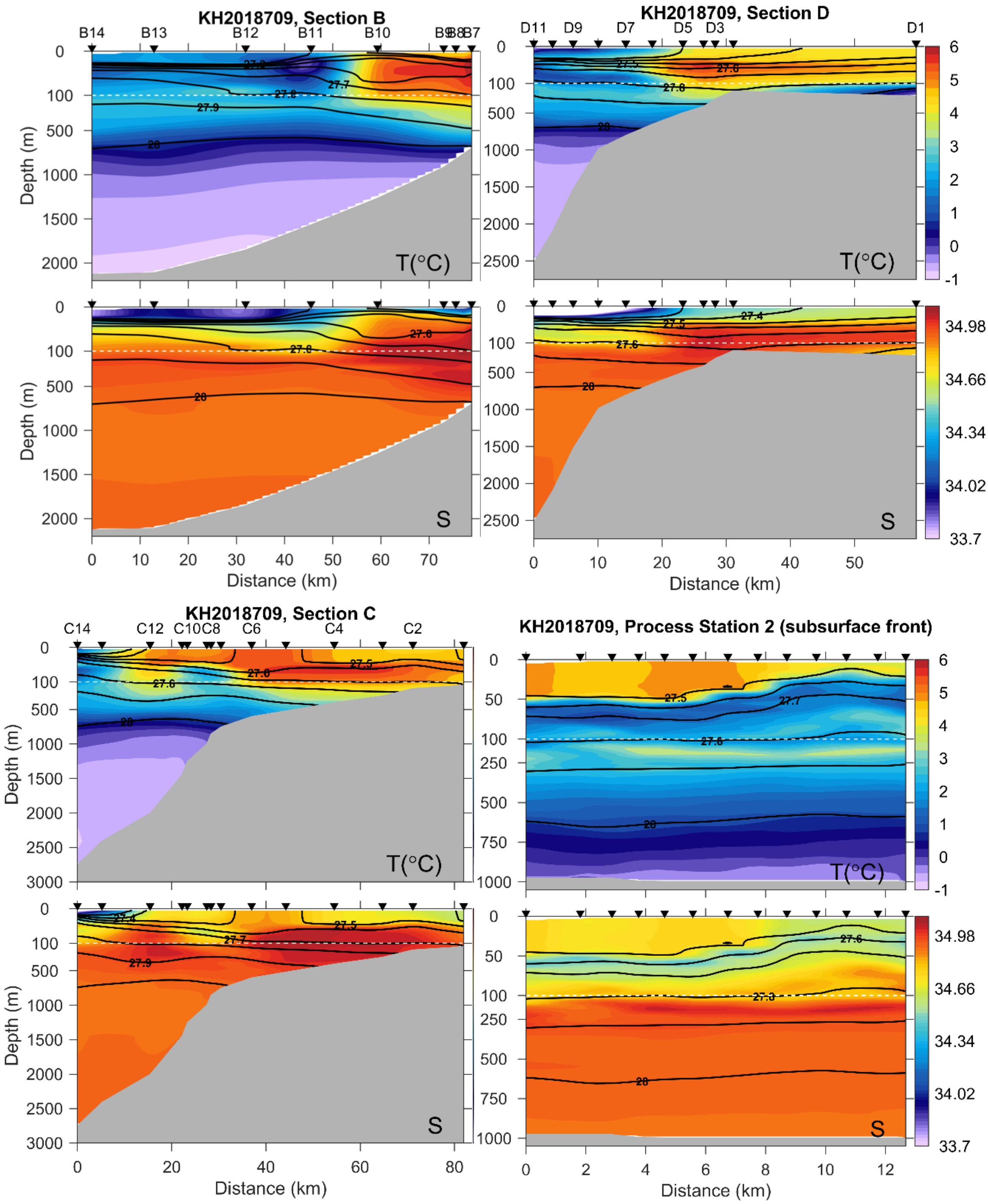


Figure 27. Contours of temperature (*T*) and salinity (*S*) for selected sections. Potential density anomaly (σ_θ) surfaces are also shown (black). Distance is relative to the outer (deepest) station of each section. Note the change of scale at 100 m depth.

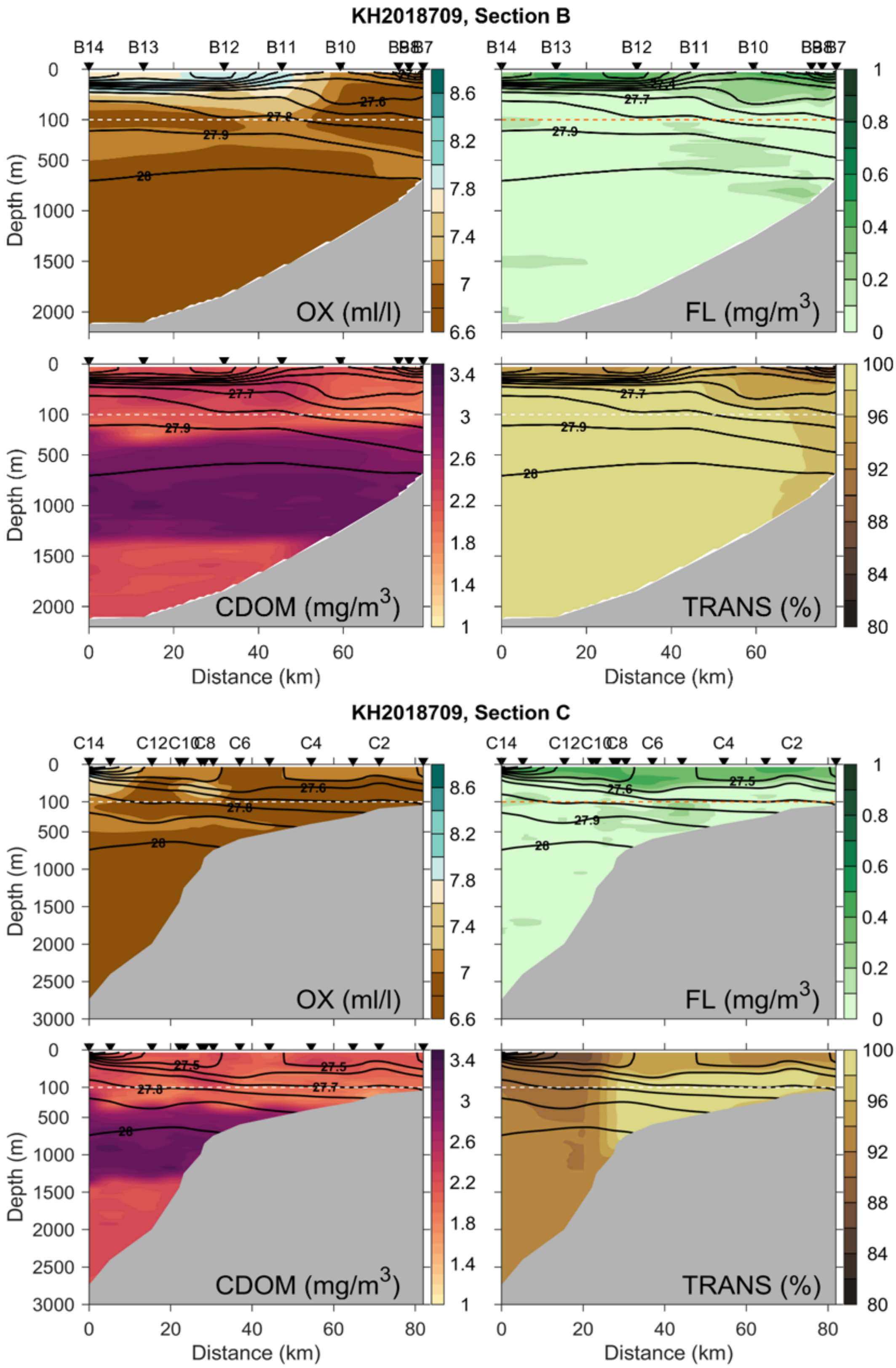


Figure 28. Contours of dissolved oxygen (OX), fluorescence (FL), CDOM and transmissivity (TRANS) for selected sections. Potential density anomaly (σ_θ) surfaces are also shown (black). Distance is relative to the outer (deepest) station of each section. Note the change of scale at 100 m depth.

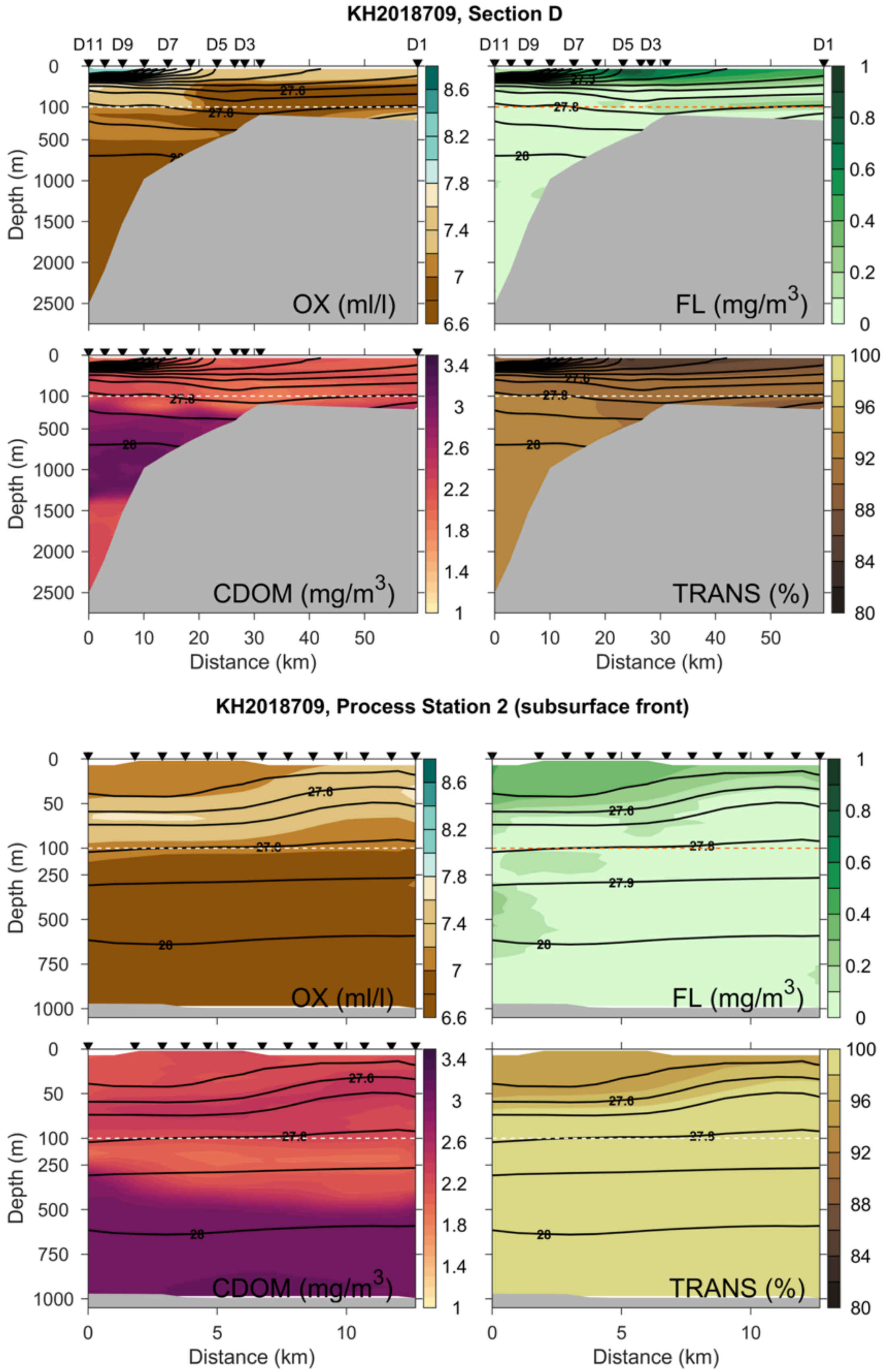


Figure 28, continued.

3.5.2. LADCP

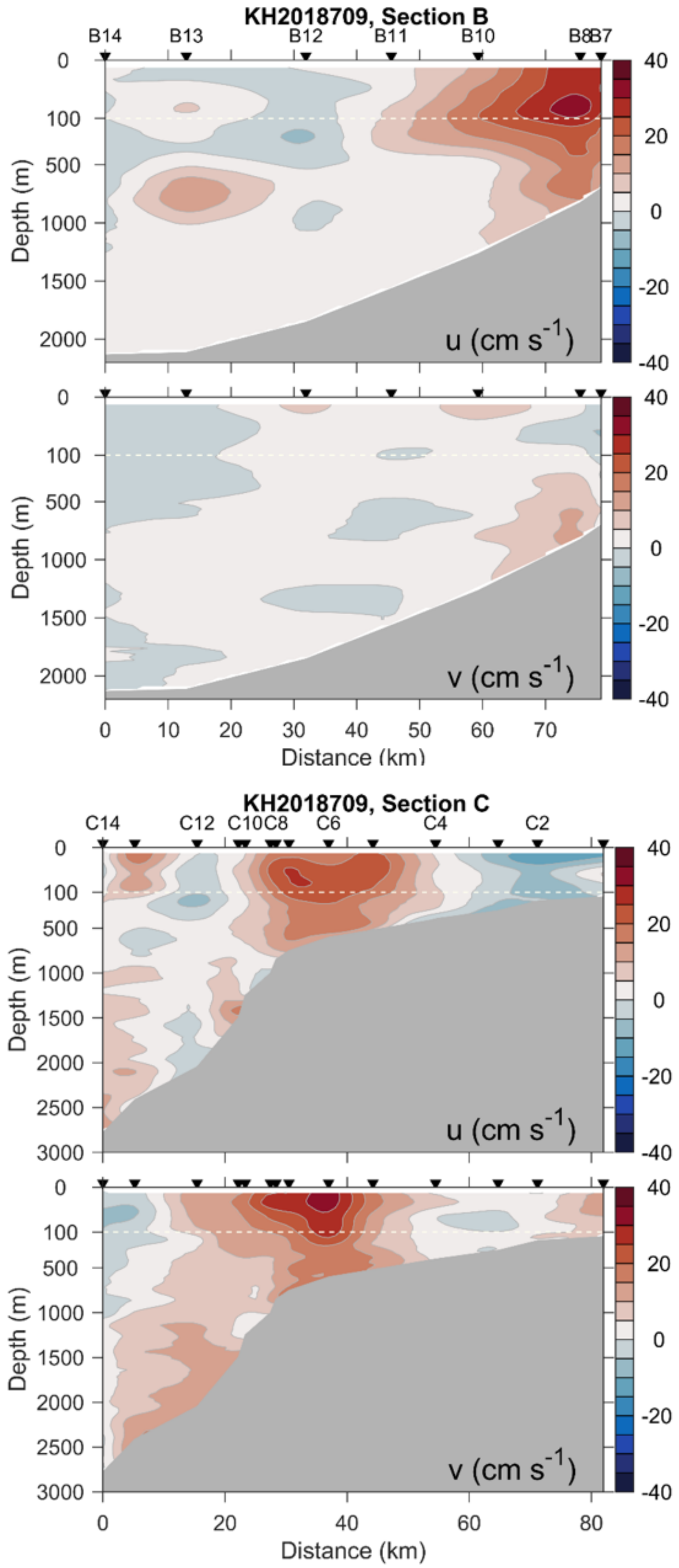


Figure 29. East (u) and North (v) velocity distribution for selected sections. Distance is relative to the outer (deepest) station of each section. Note the change of scale at 100 m depth.

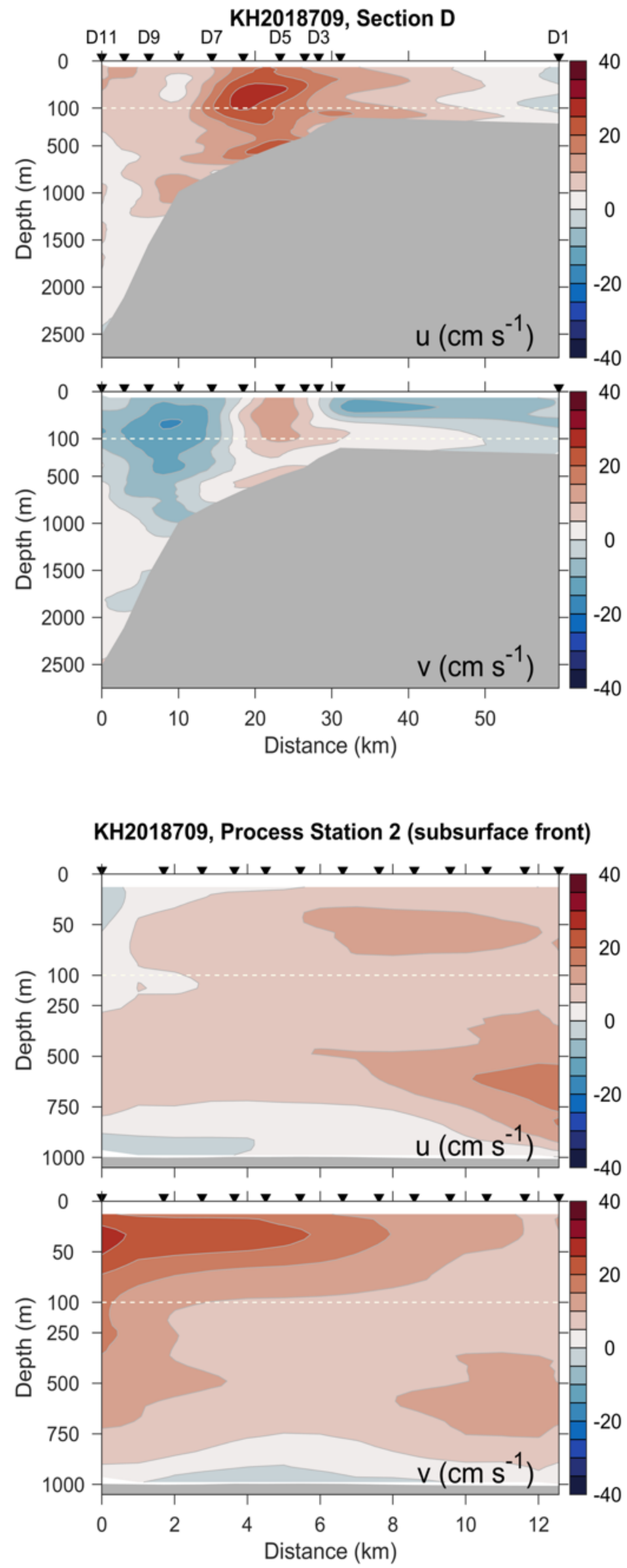


Figure 29, continued.

3.5.3. SADCP

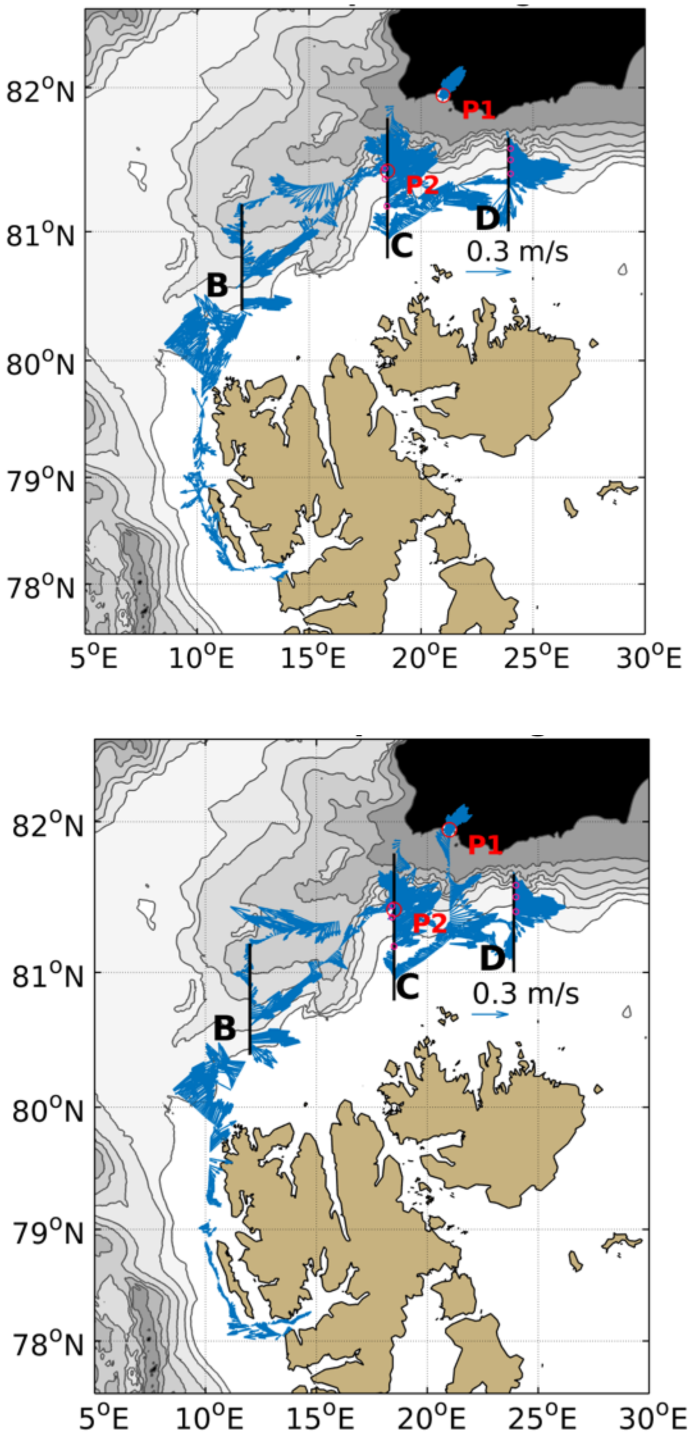


Figure 30. Vector plot of 25-300 m depth-averaged currents from the SADCP (upper: 38 kHz Drop keel (DK); lower: 150 kHz DK). Sections and process stations are indicated

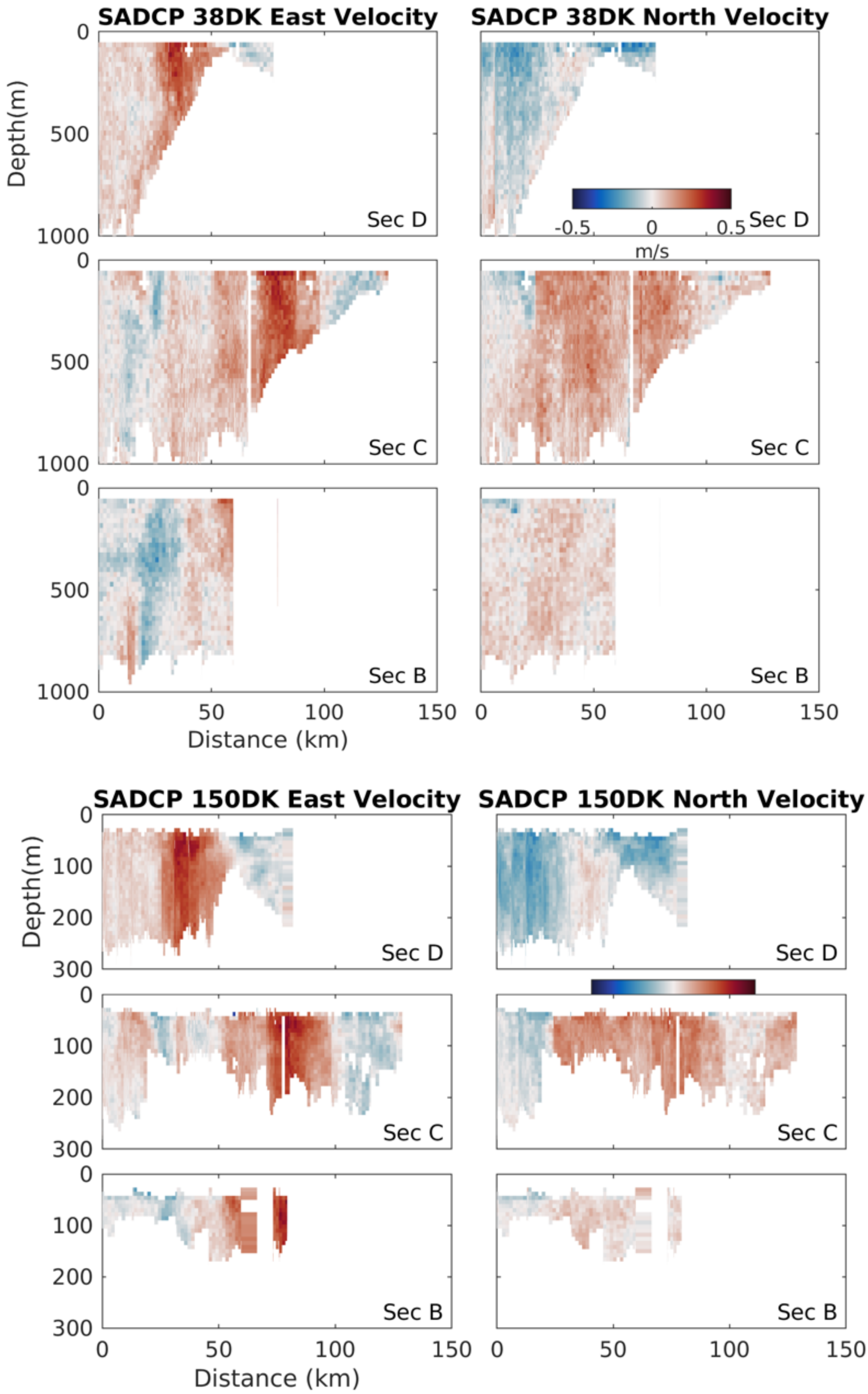
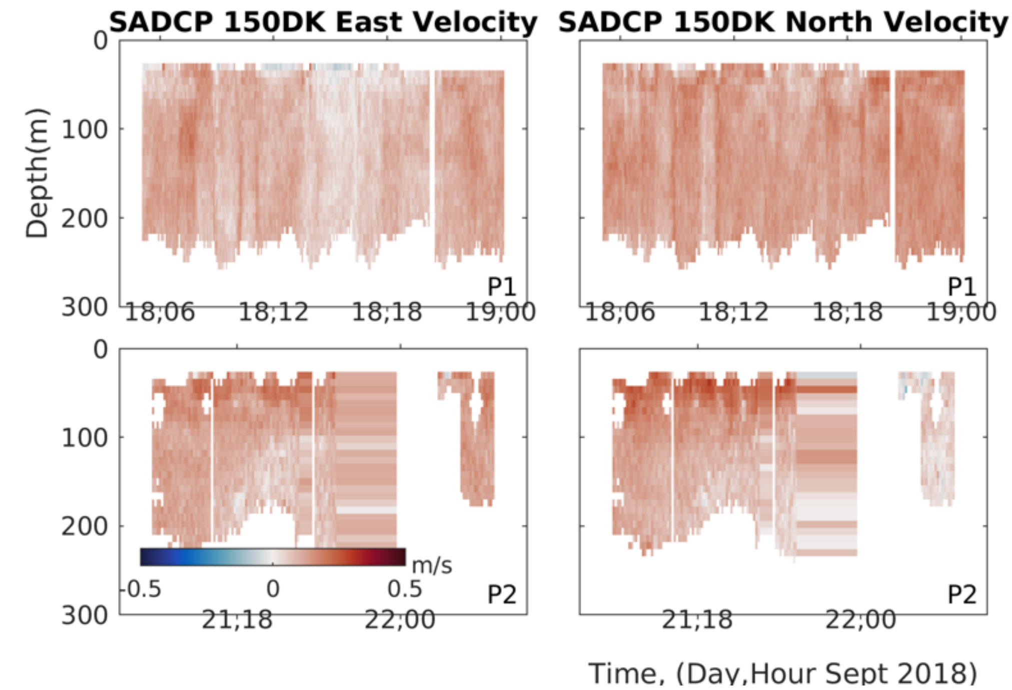


Figure 31. East and north components of the velocity measured by the SADCP in Sections B, C and D, by (upper panels) the 38 kHz ADCP and (lower panels) the 150 kHz ADCP. The horizontal distance is arbitrarily referenced from deep waters toward the continental shelf on the right. Axis and color scales are identical in all panels.



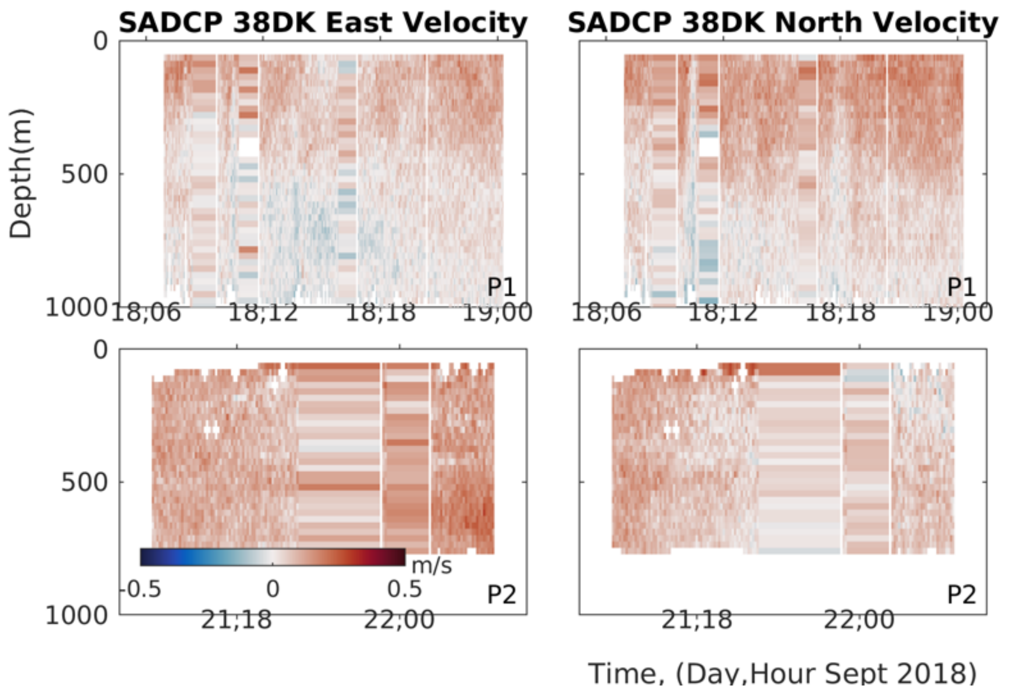


Figure 32. East and north components of the velocity measured by the SADCP in Repeat Stations, RS1 and RS2 for approximately 24 hour duration. Time is given as DD, HH of July 2018.

3.5.4. Microstructure

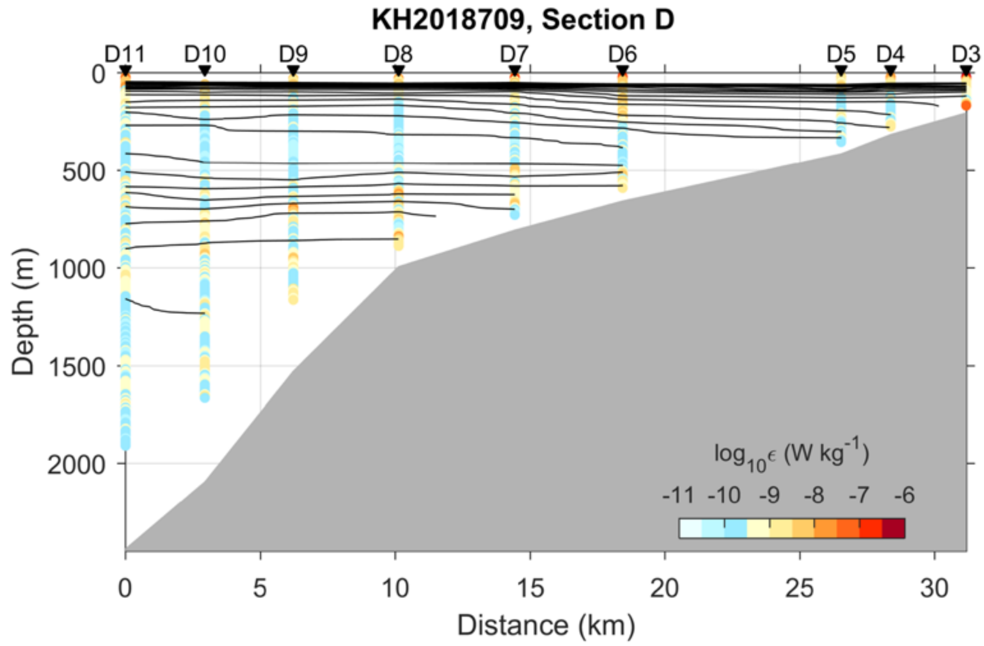


Figure 33. Distribution of dissipation rate (ε, color) and σ_θ (black, CI=0.02 kg m-3), measured by the sensors on the VMP, for Section D. σ_θ is not gridded or smoothed. ε is vertically averaged over 5 m. Distance is relative to the outer (deepest) station of each section.

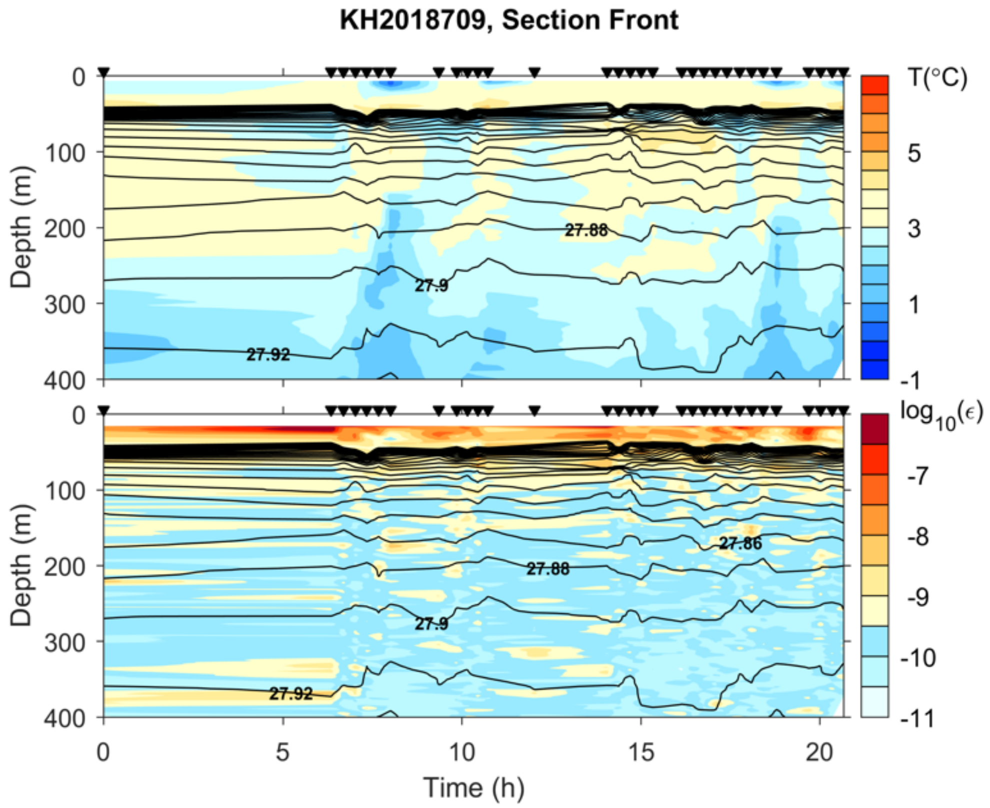


Figure 34. Process Station 1 (Front). Top: temperature (color) and σ_θ (black, CI=0.02 kg m^{-3}). Bottom: dissipation rate (ε, color) and σ_θ (black), measured by the sensors on the VMP. No gridding or smoothing applied.

3.5.5. Slocum Glider

During its 7-day mission, the glider traveled about 135 km (average speed over ground of 20 km per day). It completed three crossings of Atlantic Water slope current flowing eastward centered around the 500-1000m isobath (Figure 35) Depth-average currents often reached values around 30-40 cm/s, deflecting its path in the direction of the flow toward the east. Despite this strong dynamical environment, the glider managed to reach the prescribed waypoints without much trouble. Three sections of about 30-50km from the current core were successfully carried out.

The glider showed very good flight performance (Figure 36). Pitch angle was stable and close to the targeted value during dives and climbs. Roll was insignificant. Vertical velocity through water was about 15 to 20 cm/s. All sensors worked well, recording values of temperature, conductivity, pressure, oxygen, fluorescence and turbidity along the glider track (Figure 37).

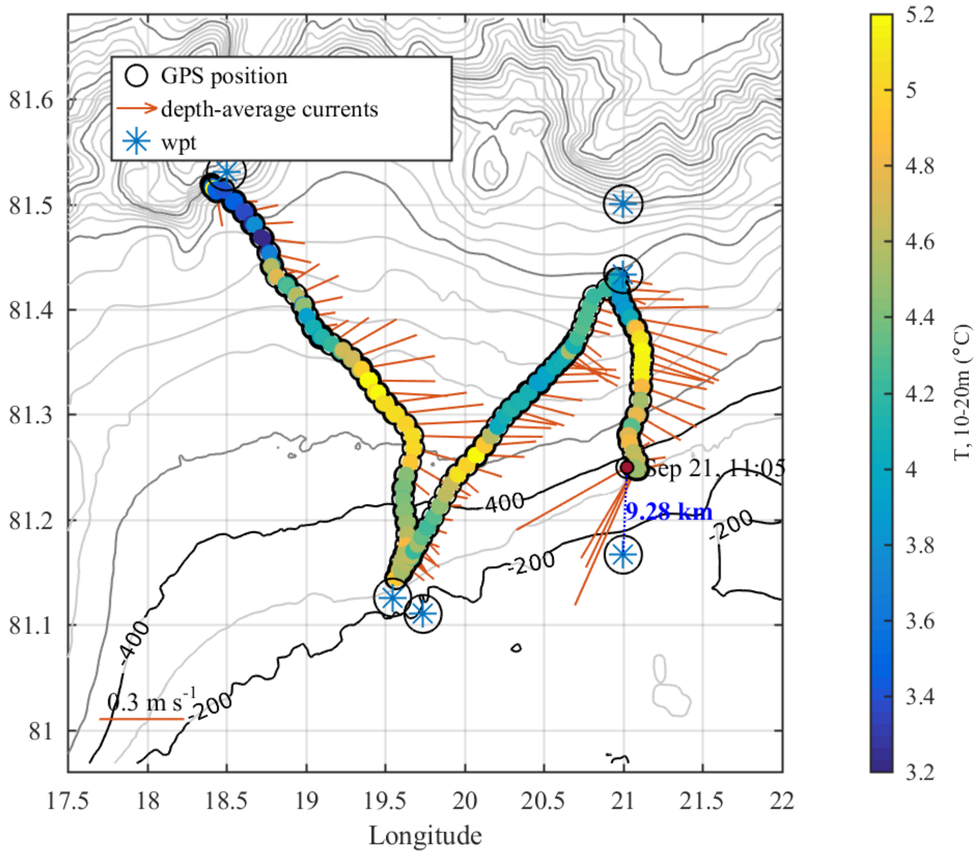


Figure 35. Map of the Slocum glider trajectory successfully deployed during the cruise. The colors indicate water temperature recorded between 10 and 20m. Depth-average currents are shown by the red sticks. Blue stars are the different waypoints used during the missions

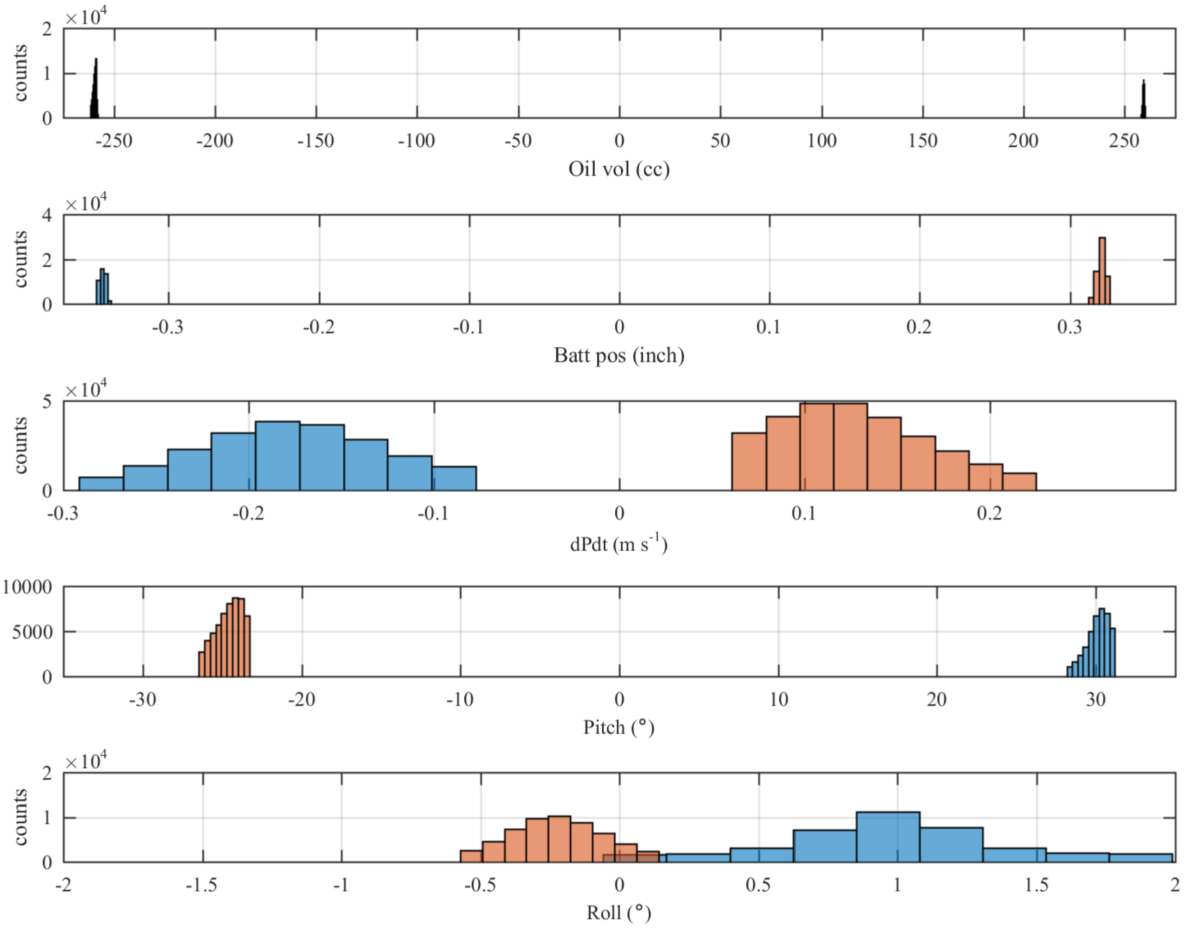


Figure 36. Histograms of (from top to bottom): pumped oil volume, battery position, vertical displacement, pitch and roll angles. Blue (resp. red) color refers to dives (resp climbs) of the glider. No data at surface or during turning points, defined as vertical displacement <5 cm/s, are excluded.

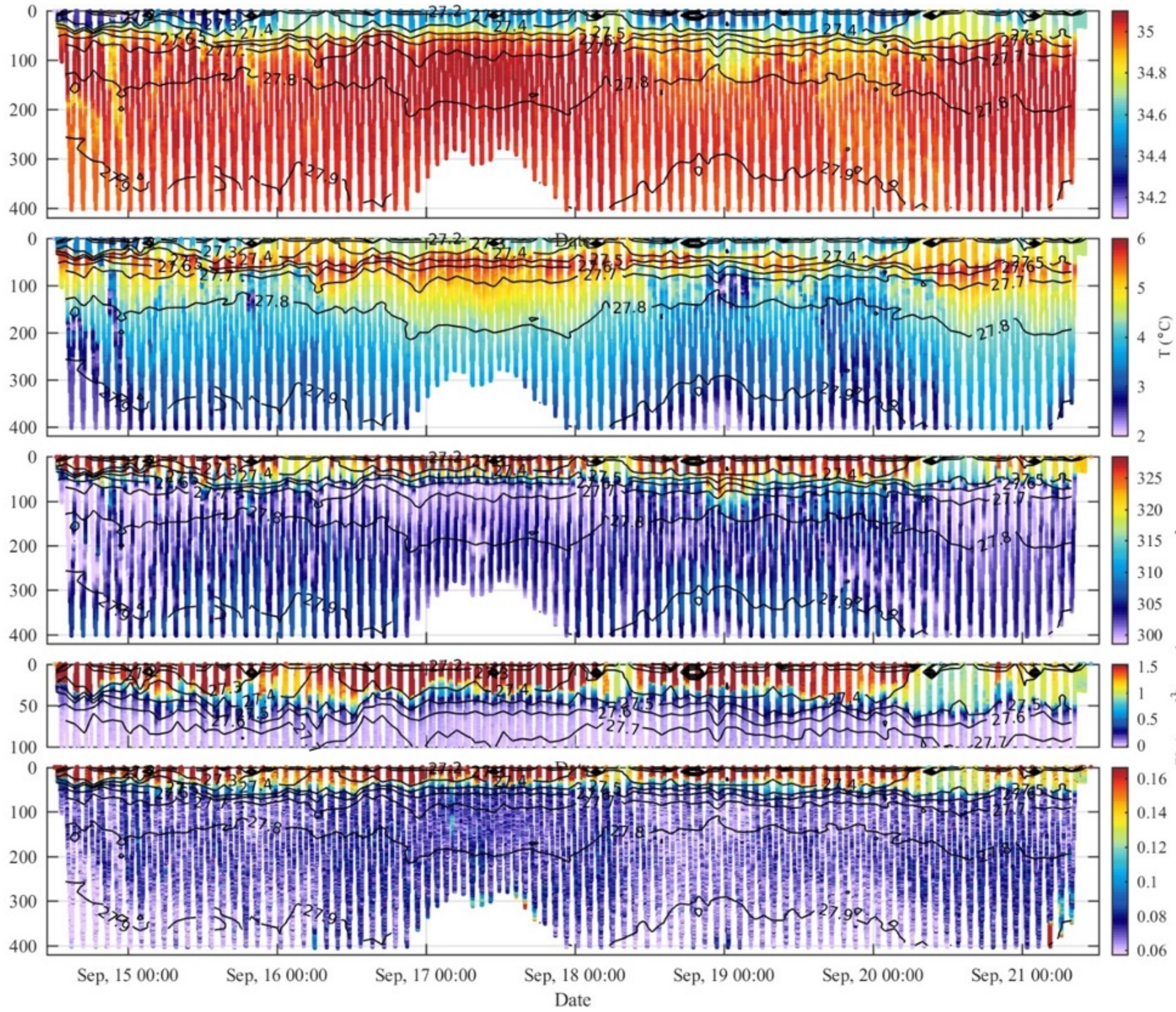


Figure 37. Depth-Time plots of (from to bottom): Practical Salinity, In situ Temperature, Dissolved Oxygen, Chlorophyll Fluorescence, Turbidity. Black lines show potential density lines.

3.5.6. AUV

The AUV was successful in tracking the front, making six crossings before returning to the home location (81.920633, 21.0021). Both the temperature and salinity confirm that a front was present, with temperature differences as high as five degrees (over the full water column), and salinity change from 34.5 to 33 g/kg. As the top layer was used for adaptation (0.5 - 8 m) the temperature changes seen was less, around two degrees. The following plots are showing the different variables overlaid on a 2D plot covering depth and traveled distance. The plots are made using Ocean Data View (ODV, https://odv.awi.de/).

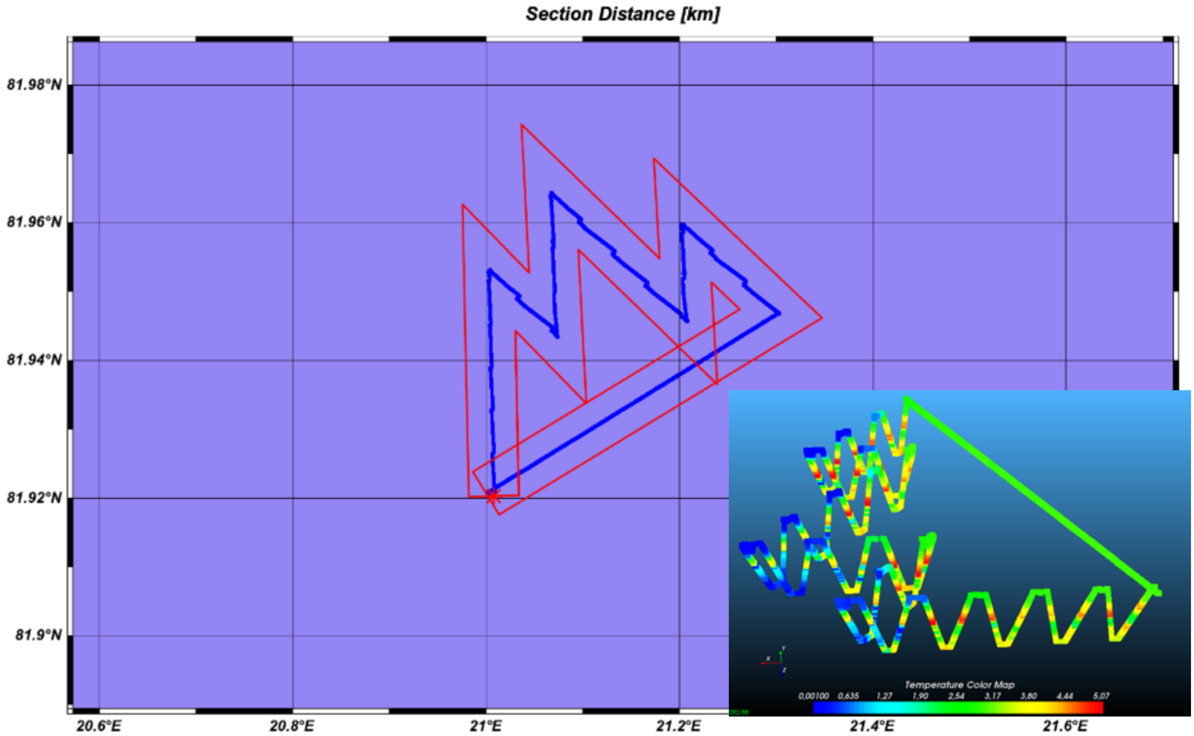


Figure 38: The TREX mission seen from above. The AUV crosses back and forth in a zig-zag pattern across the front. The AUV path is the blue line, while the red line is the section used for plotting in Ocean Data View. The AUV does 6 crossings before tracking back to the start location. A 3D representation can be seen in the lower left corner.

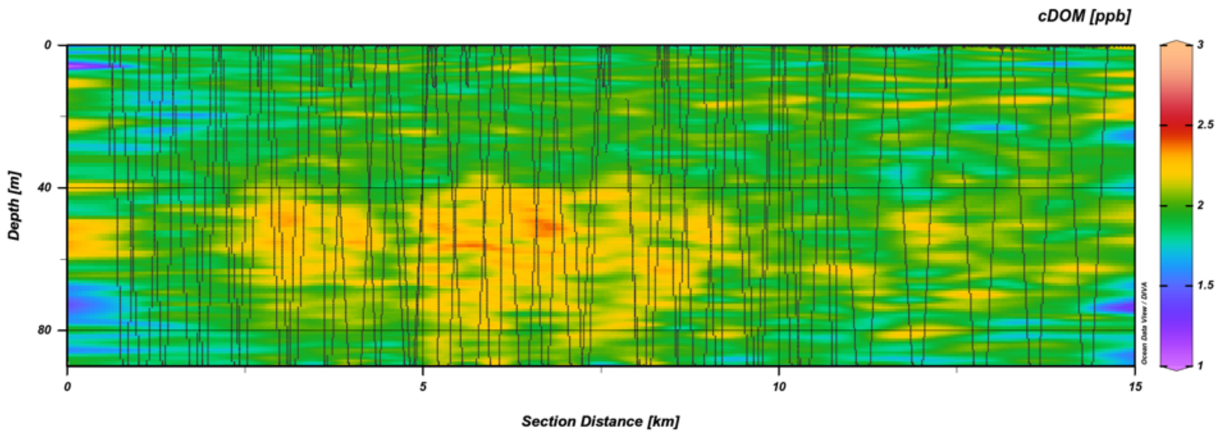


Figure 39: The color dissolved organic matter (cDOM) from the sampling profile. Some hot spots can be seen at 45-50 m.

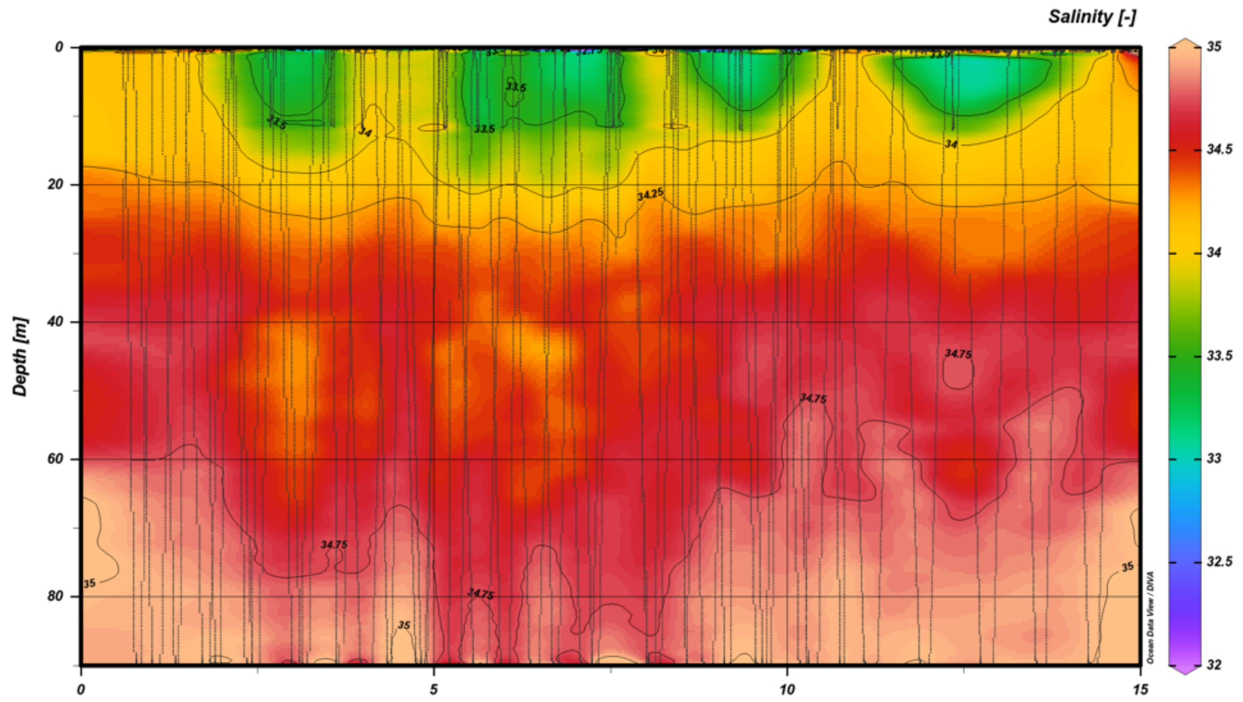


Figure 40: Salinity Profile from the TREX adaptive sampling mission. The AUV crosses back and forth from saline to fresher waters.

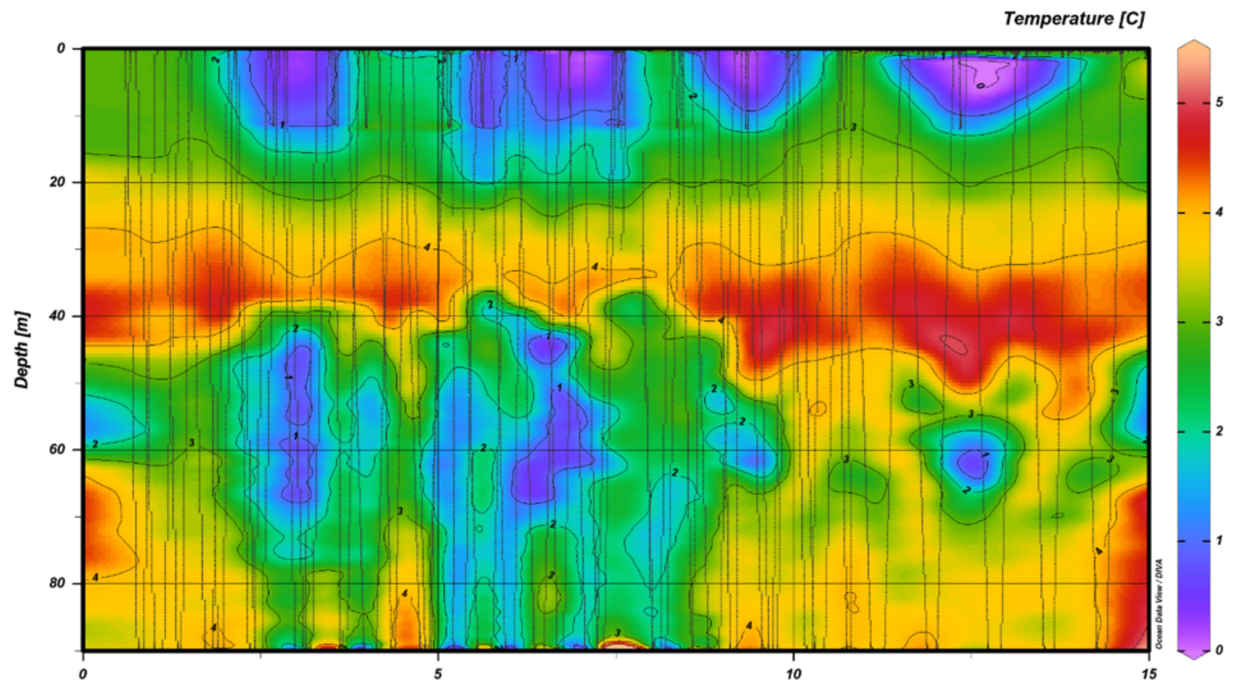


Figure 41: Temperature Profile from the TREX adaptive sampling mission. The AUV crosses back and forth from warm to cold waters.

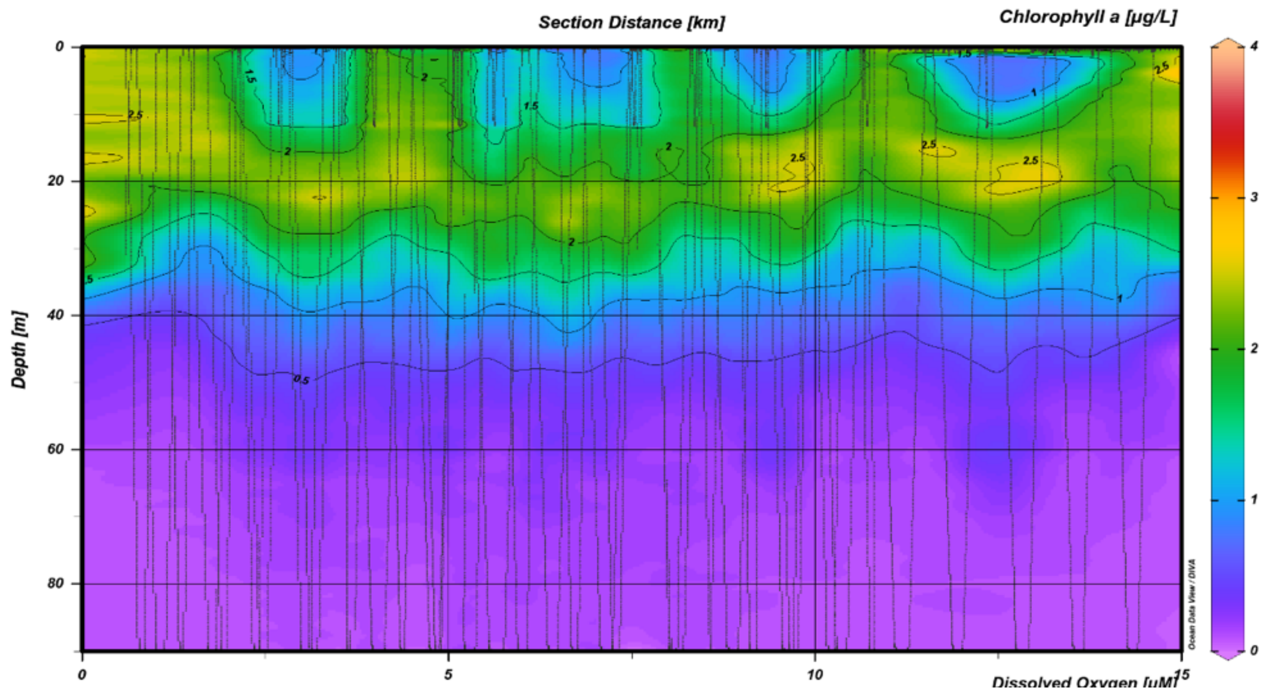


Figure 42: Chlorophyll profile from the TREX adaptive sampling mission. Higher values in shallow, as well as fresh waters.

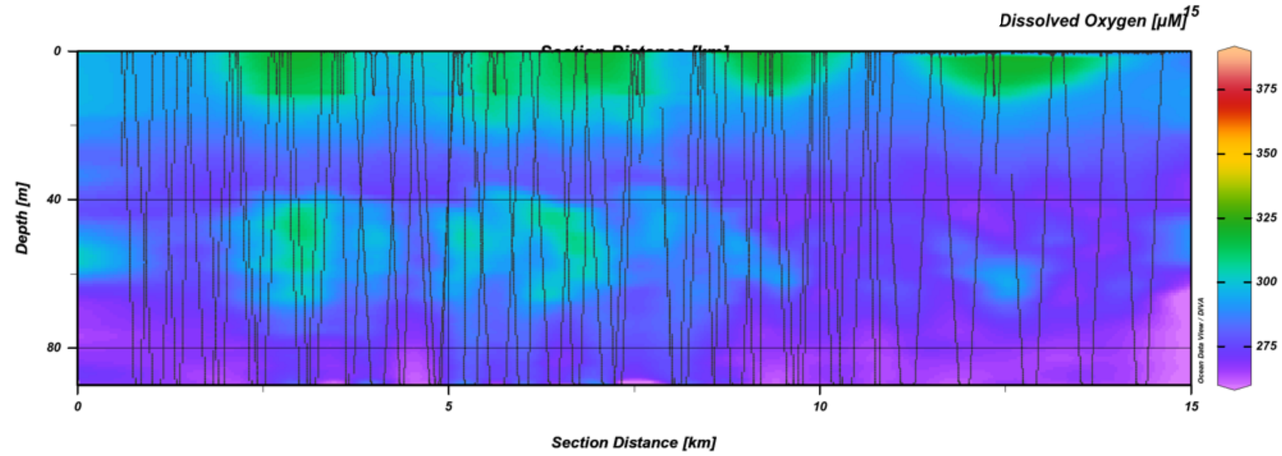


Figure 43: Dissolved oxygen profile from the TREX adaptive sampling mission. Higher values visible in the fresher and colder regions.

3.5.7. Bow wave sensor

The results obtained can be used for comparison with meteorological previsions in the region. An overview of the measurements over part of the cruise (together with a summary of the AWS parameters obtained from the boat which are relevant for the understanding of the data) is presented in Figure 44.

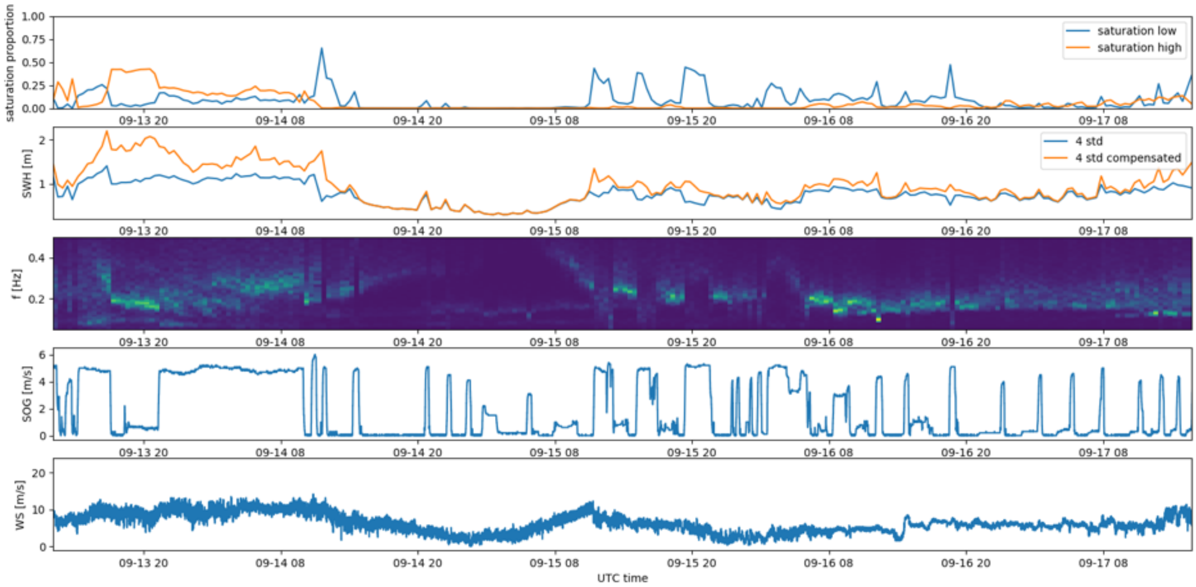


Figure 44. An overview of some of the data obtained from the bow-mounted wave instrument, compared with the motion of the ship and wind measurements (AWS data)

3.5.8. Radiative Flux

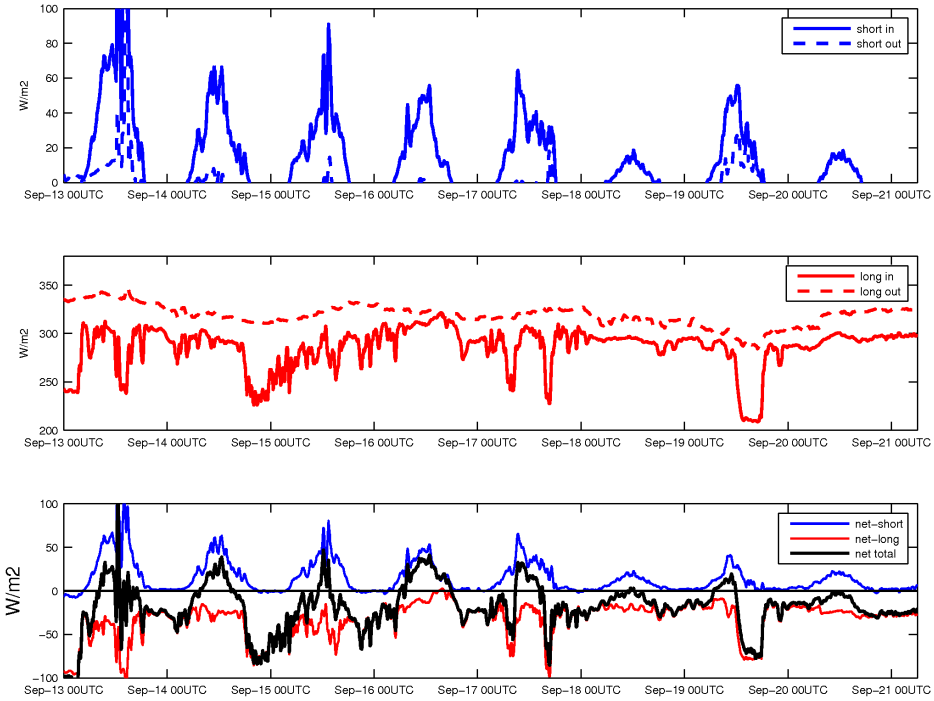


Figure 45. Radiative Flux Measurements. (top) Incoming (solid) and outgoing (dashed) shortwave radiation (middle) Incoming (solid) and outgoing (dashed) longwave radiation (c) the net budget of short- and longwave radiation (red and blue) and the total radiative budget (black).

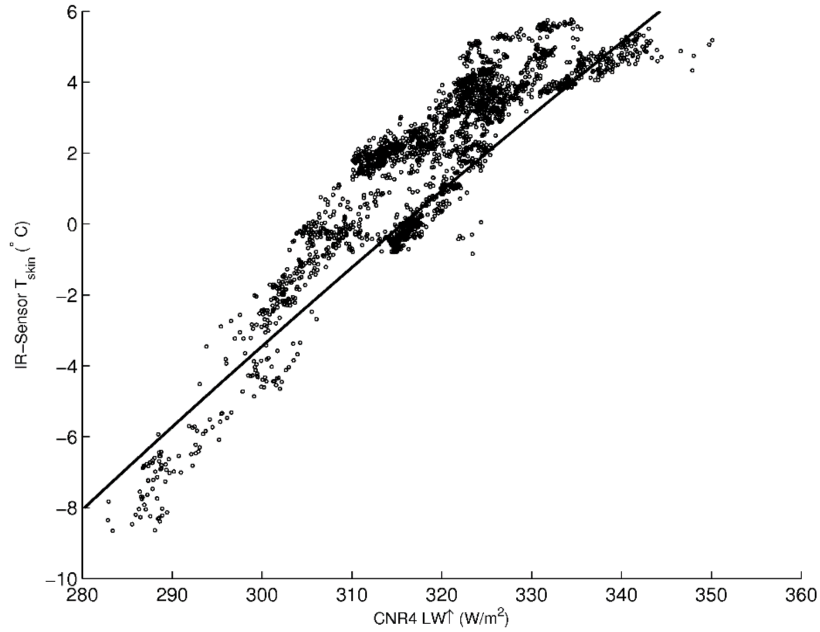


Figure 46. Surface skin temperature measured by the infrared sensor versus longwave outgoing radiation measure by CNR4. Black line indicates the relation $LW = T_{skin}^4\sigma$, where σ is the Stefan Boltzmann constant.

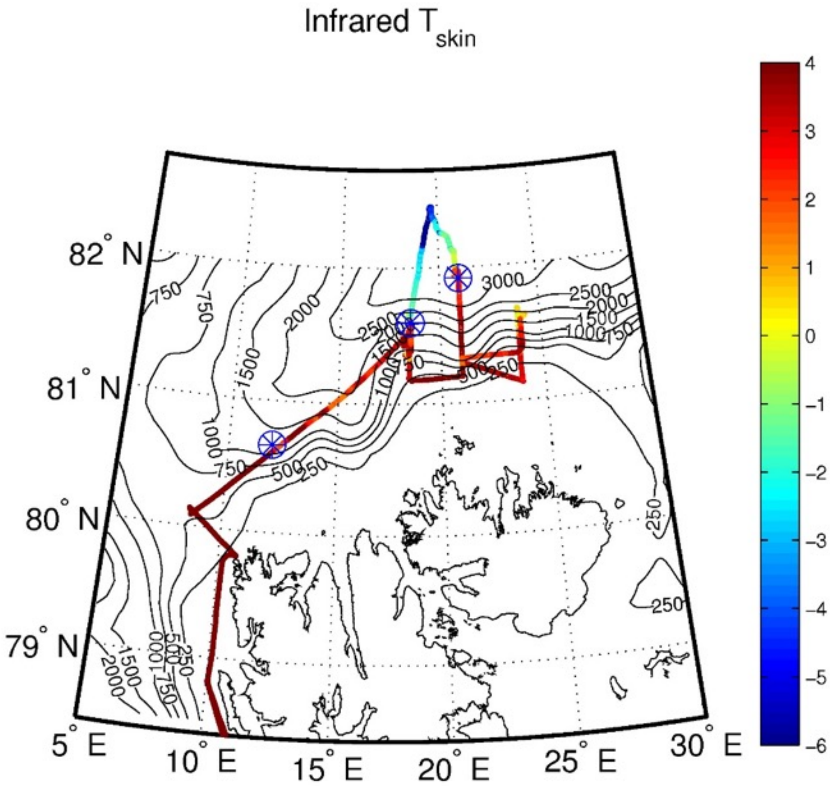


Figure 47. Geographical map showing skin temperature along the cruise track. Stars denote the locations of SVP deployments.

3.5.9. SUMO – UAV

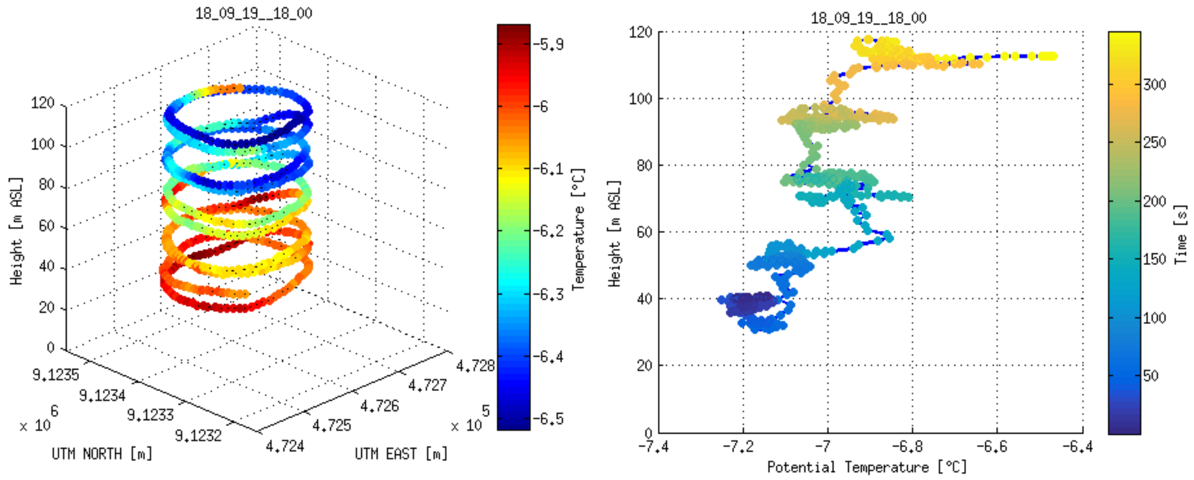


Figure 48. (left) 3D SUMO profile. Colorbar represents temperature. (right) Vertical profile of potential temperature. Colorbar represents time.

Figure 48 (left) displays the 3D flight path of an upwards profile, taken on Flight #5, with color representing temperature. The circular pattern taken by the SUMO assumes horizontal homogeneity over the diameter of the circle (~250 m), though has some noise due to the response time of the sensor used, and slight variability in altitude during flight. This noise is also present in **Figure 48** (right), however plotting the signal – as potential temperature – versus height shows the slightly stable or near-neutral profile of the boundary layer, capped with a sharp increase revealing the bottom of the inversion. Unfortunately, the total strength of the inversion is unknown, as the flight was unable to sample higher. The inversion base is also present during Flight #4, which similarly to Flight #5, occurred over the sea-ice/open-water, however was not present during the flights over the open ocean.

While the data obtained during the racetracks will require further processing to be interpreted correctly, initial results look promising. Temperature gradients across the sea-ice/open-water appear to be present in the raw data, and how these gradients spatially relate to the measured air temperature and humidity will be subject to further investigation. **Figure 49** shows an example of a racetrack pattern flown during Flight #5, with the straight sections nearly parallel to wind direction.

Compared to land-based SUMO operations, ship-board operations had a much narrower window of opportunity. If there were poor flying conditions at the planned flight time, it was not possible to simply postpone the launch until the weather changed; that flight window was no longer available, and the next might be hours away. Trying to maximize cruise efficiency by finding overlapping needs of operations was not trivial and each scientific operation taking place had its own requirements in regards to ship orientation and speed, including SUMO. For this cruise, SUMO operations and VMP operations had very similar – but not exact – requirements. While both needed winds from the Starboard side, the ship was allowed to drift away from the VMP drop site, thereby requiring a SUMO landing on a moving target. There existed opportunities to fly outside of VMP operations, and while some were taken, others were impossible due to weather conditions. Fog – and therefore the heavy risk of icing – was common during the first days of the cruise, while strong winds persisted in the final days. Given the time and location of the observation environment, these conditions were not unexpected, but more so unfortunate in their timing.

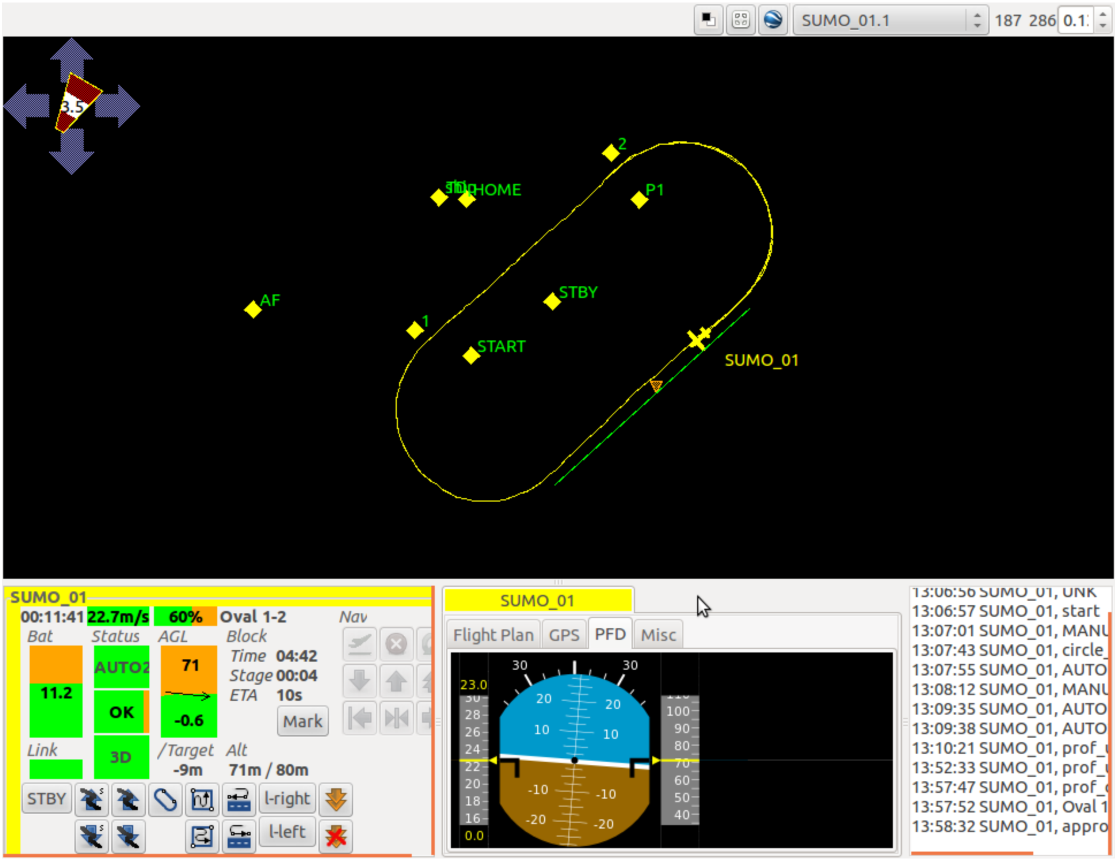


Figure 49. Screenshot of ground control station monitor, showing racetrack pattern in progress.

3.5.10. Remote Sensing: LIDAR and Microwave Radiometer

3.5.10.1. Windcube LIDAR

The Windcube LIDAR operated continuously from midday 12 Sep until afternoon of 23 Sep. Despite running continuously, the dataset obtained does have spatial and temporal gaps, as data is automatically flagged as “poor” based off of a threshold signal-to-noise ratio. **Figure 50** (left) shows a full profile up to 290 m, with points above 160 m displaying decreasing “Data Availability” (colorbar). **Figure 50** (right) shows wind direction with height, for the same profile. Though there do exist some data gaps due to availability, the IMU dataset is full and complete and is available for use to attempt the correction of the HATPRO dataset. Unfortunately, it was not logistically possible to fly SUMO profiles during ship movement for comparisons sake.

Additionally, at 1420UTC on 14Sep, the Windcube orientation was adjusted to better match the coordinate axis of the ship/HATPRO. Beam 1 was still directed due aft.

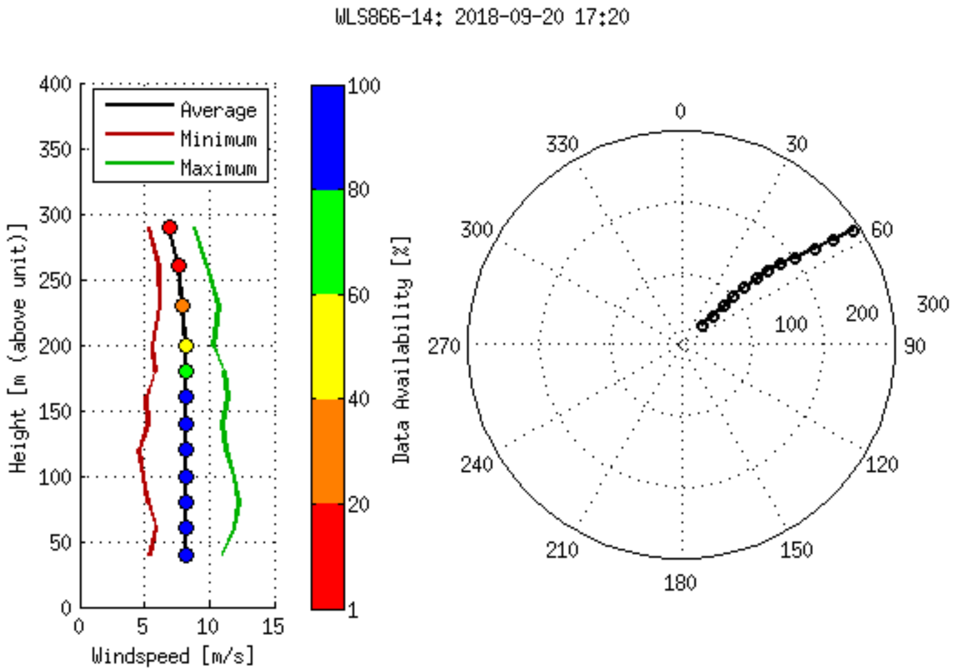


Figure 50. LIDAR profile of wind speed and direction. Colorbar represents data availability, an indication of data quality at a particular time and height.

3.5.10.2. HATPRO Microwave Radiometer

While the HATPRO dataset will require extensive processing and comparison to radiosonde data, to determine its accuracy, the duration and availability of the dataset is full and complete, running from midday 12 Sep until afternoon of 23 Sep.

3.5.11. Controlled Meteorological Balloons and Radiosondes

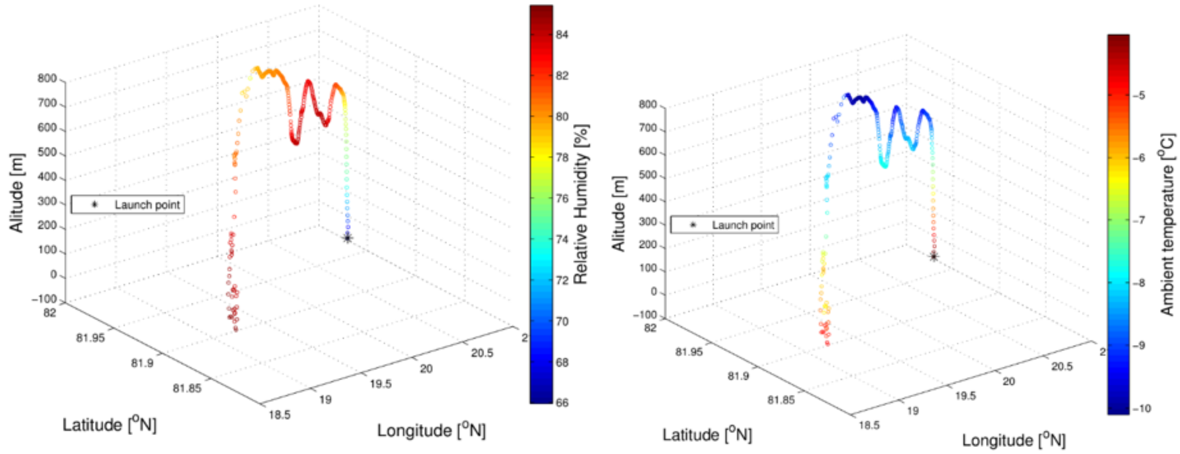


Figure 51. Measured data of relative humidity (RH) and ambient air temperature from Controlled Meteorological Balloon Olav, launched at 18 September at 13:27 UTC at 81.95N, 20.47E.

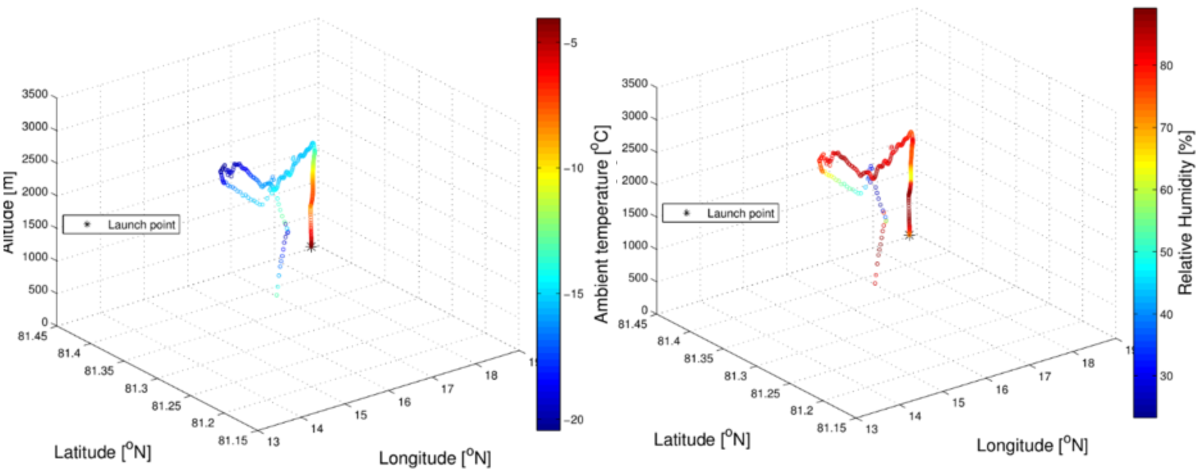


Figure 52. Measured data of relative humidity (RH) and ambient air temperature from Controlled Meteorological Balloon Martha, launched at 21 September at 16:41 UTC at 81.43 oN, 18.47 oE.

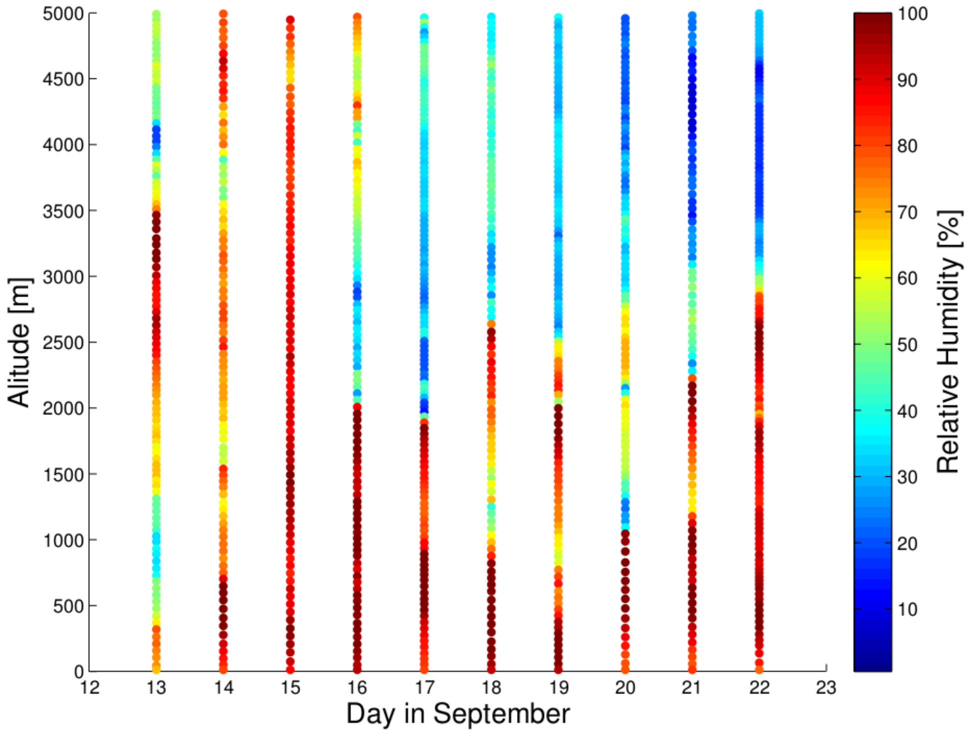


Figure 53. Radiosonde humidity measurements up to 5000 masl during the cruise

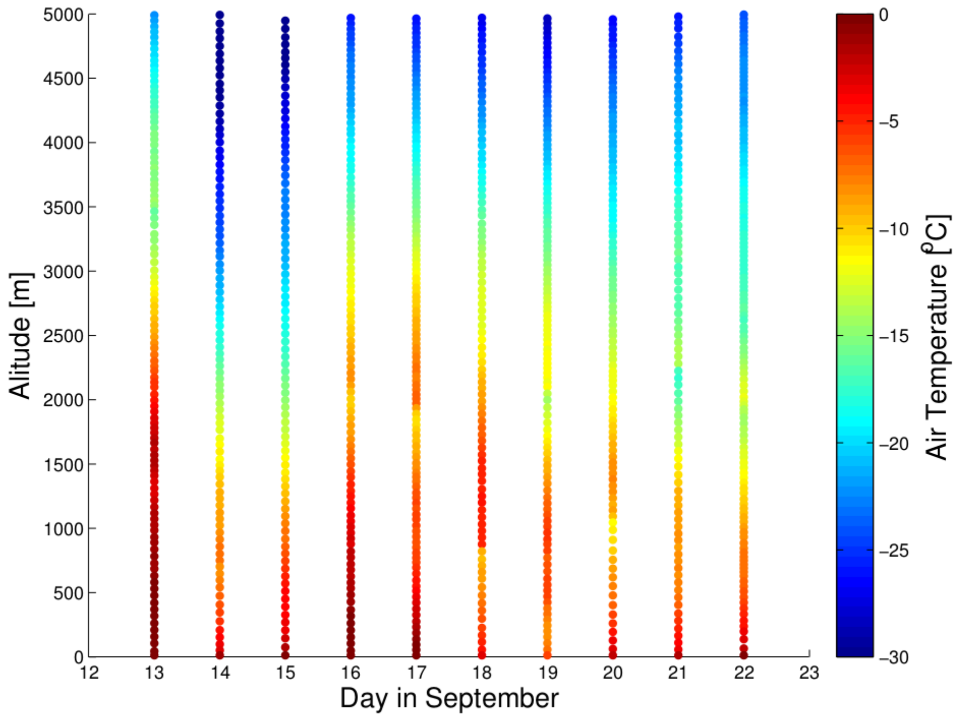


Figure 54. Radiosonde air temperature measurements up to 5000 masl during the cruise.

4. References

Fer, I., A. K. Peterson, and J. E. Ullgren (2014), Microstructure Measurements from an Underwater Glider in the Turbulent Faroe Bank Channel Overflow, *J. Atmos. Ocean. Technol.*, *31*. https://doi.org/10.1175/JTECH-D-13-00221.1

UNESCO (1988), The acquisition, calibration, and analysis of CTD data, Unesco technical papers in marine science, 54, A Report of SCOR Working Group 51.

Visbeck, M. (2002), Deep velocity profiling using lowered acoustic Doppler current profilers: Bottom track and inverse solutions, *J. Atmos. Ocean. Technol.*, *19*, 794-807. https://doi.org/10.1175/1520-0426(2002)019<0794:DVPULA>2.0.CO;2

Voss, P. B., L. R. Hole, E. F. Helbling, and T. J. Roberts (2013), Continuous In-Situ Soundings in the Arctic Boundary Layer: A New Atmospheric Measurement Technique Using Controlled Meteorological Balloons, *Journal of Intelligent and Robotic Systems*, *70*. https://doi.org/10.1007/s10846-012-9758-6

Appendix I: List of participants

Captain: Johnny P. Hansen. Chief Officer: Øyvind Nilsen. Instrument chief: Lage Drivenes.

	Name	Institute[1]	Responsibility[2]
Scientists	Ilker Fer Ilker.fer@uib.no	UIB	Cruise leader
	Frank Nilsen	UNIS	Cruise co-leader
	Anthony Bosse	UIB	Gliders, VMP
	Zoe Koenig	UIB	Gliders, VMP
	Eivind Kolås	UIB	VMP, SADCP
	Inga Breisnes Utkilen	UIB	LADCP, moorings
	Aleksander Dürr Libæk	UIB	LADCP, moorings
	Andrew Siedl	UIB	Atm. Boundary layer, SUMO
	Eva Falck	UNIS	LADCP, water sampling
	Ragnheid Skogseth	UNIS	LADCP, Moorings
	Marika Marnela	UNIS	LADCP
	Martin Ludvigsen	NTNU	AUV
	Petter Norgren	NTNU	AUV
	Trygve Fossum	NTNU	AUV
	Malte Muller	MET	Radiation, waves, drifters
	Jean Rabault	UiO/MET	Radiation and waves
	Lars R Hole	MET	Balloons and radiosonde
	Ben Lincoln	Bangor UK	Moorings, VMP
Technical Personnel	Helge Bryhni	UIB	VMP winch, moorings
	Algot Peterson	UIB	VMP winch, moorings
	Marcos Porcires	UNIS	VMP winch, Moorings
	Martin Mueller	UIB	SUMO piloting
	Jane Eert	Canada	LADCP
Outreach	Inger Lise Næss	UNIS	Outreach
	Rudi Caeyers	UiT	Photography
	Lena Gudd		Photography/art
	Silje Burgin-Borch		Alfred film tv
	Hege Holen Paulsrud		Illustrations/art

[1] UIB: University of Bergen; UNIS: University Centre in Svalbard; NTNU: Norwegian University of Science and Technology; MET: Norwegian Meteorological Institute; UiT: University of Tromsø
[2]The instruments and acronyms are described in the report.

CTD operation was conducted by the instrument personnel with no assistance from the scientists.

Cruise participants on RV Kronprins Haakon.

Appendix II: Cruise program

Cruise Timeline

11 September 2018, Tuesday

Approximately 15 participants arrived onboard RV Kronprins Haakon (KH hereafter) in the afternoon and 10 persons stayed the night of 11 Sept onboard. KB was positioned at Kullkaien.

While waiting, we installed and set up instruments and gear: HATPRO (microwave radiometer) and Windcube (LIDAR) installed on Deck 6, near automatic radiosonde container.

Mooring gear and the gliders arrived in containers from Bergen are loaded on board.

12 September 2018, Wednesday

Departure from Longyearbyen was scheduled in the afternoon.

Between 08-12, a combined ice security / survival suit course was organized at UNIS.

Throughout the day we installed and set up instruments and gear.

Instrument engineers swapped from rosette earlier used in the previous cruise (from GO SARS) to the KH rosette. LADCPs are installed. The master ADCP pointed downward (SN 24474) and the slave ADCP pointed upward (SN 24472).

We assembled the VMP profiler, configured and finalized setup files for various instruments.

We conducted a test station in the middle part of Isfjorden using CTD/LADCP (sta094)

Ship ADCP (SADCP), drop keel instruments started using the VmDAS software. Started logging 2130 UTC at 38 kHz, and 21:50 UTC at 150 kHz.

13 September 2018, Thursday

Mooring YP-1 recovered successfully at 1500 UTC

Mooring YP-2 recovered successfully at 1610 UTC

CTD at YP-C location before recovery. (sta096)

Started recovering YP-C around 2030 LT. During recovery, the line tangled around the drop keel (2050 LT). It was resolved by lifting the drop keel and the instruments were recovered in good health.

YP-3 delayed until end of cruise because of limited daylight.

We worked on preparing the instruments for the moorings. Programming and mounting the ADCP in the buoys.

Note: The SADCP logging was stopped around 1857 UTC, due to inspection after the mooring tangled around the drop keel. SADCP restarted at 1910 UTC.

Test station with VMP (cast001) at 1930 UTC

14 September 2018, Friday

Seaglider SG564 deployed smoothly in water 1130 UTC

Gnå deployed at 1220 UTC while steaming, 81N 31.148', 018E 24.10'.

Unfortunately, the ship was not steaming fast enough and Gnå approached the ship at the aft. There is no visual confirmation of any contact.

Collected CTD/LADCP stations: C13 to C12 (files 097 to 099) between 1500 and 2300 UTC

We finished preparing the instruments for the moorings. Programming and mounting the ADCP in the buoys.

SUMO communications checked from various spots on deck, and the position of the net landing system was decided upon. Turbulence on helipad tested with small quadcopter & windsock.

15 September 2018, Saturday

We finished the short section (a subset of Section C) at C10, 0050 UTC with CTD/LADCP station sta0100.

Deployed mooring W3, 0951 UTC, 81N 30.616', 018E 22.837', Echo depth: 1885 m

CTD/LADCP after deployment: sta0101

Deployed mooring W2, 1417 UTC, 81N 22.686', 018E 23.789', Echo depth: 727 m

CTD/LADCP after deployment: sta0102

Deployed mooring W1, 1820 UTC, 81N 10.979', 018E 29.052', Echo depth: 401 m

CTD/LADCP after deployment: sta0103

16 September 2018, Sunday

Transit to mooring array E.

En route to array E, we use the night to work a short CTD/LADCP section across the shelf, stations F1 to F5 (sta0104 to sta0108)

Deployed mooring E1, 0743 UTC, 81N 24.925', 024E 0', Echo depth: 300 m,

CTD/LADCP after deployment: sta0109

Deployed mooring E2, 1121 UTC, 81N 30.813', 023E 59.853', Echo depth: 706 m,

CTD/LADCP after deployment: sta0110

Deployed mooring E3, 1445 UTC, 81N 35.453', 023E 59.982', Echo depth: 1222 m,

CTD/LADCP after deployment: sta0111

Test flight of SUMO at 1830UTC. Test went well, though cut short due to issue with propeller.

17 September 2018, Monday

Changed VMP sh2 sensor from M546 to M1112, after cast vmp005. Corrected T2 calib coeff (offset 5K) on setup file.

After vmp008, changed mT2 to T809, and mC to C206.

Started logging EK80 frequencies 18, 70, 120, 200 and 333 kHz for the process station, 2300 UTC

18 September 2018, Tuesday

Worked a process station aim to study a front. A transect is made using thermosalinograph to detect a (surface) temperature front. The study is to facilitate AUV deployment and test of front-following navigation algorithm.

Front detected at 81N56.55, 21E at 3463 m depth. AUV deployed at 0430 UTC.

VMP repeat transect is made (5 repeat casts, 15-min break cycle, but interrupted frequently by work boat operation and other issues).

VMP hydraulic winch was not further allowed in the ship's hydraulic system. We set up the electric motor (1200 UTC)

AUV recovered after 3 hours of operation. AUV deployed later again in the afternoon. Moving closer to ice, we interrupted the mission and recovered.

VMP profiling across the front continued until 0200 UTC. Casts vmp017 to vmp049.

19 September 2018, Wednesday

After completing the process station, proceed toward sea ice edge.

Drop keep ADCPs stopped, and SADCPs in the Arctic window (flush) started: 00 UTC

0330: reached the open drift ice floes

04: security brief for ice party

0430: first wave sensor deployed on 76 cm thick ice floe (82N07.229', 020E43.372') using work boat

0730: second wave sensor deployed on 190-200 cm thick ice floe using work boat

0900: third sensor deployed in nearly 100% sea ice concentration (floes joined by refrozen leads) using work boat

1230: pack ice reached. Ice access using gangway from 3rd deck. 2 polar bears spotted in vicinity. Quickly deployed sensor #4.

On the way out to open water, 20-30 min stops every 4 nm to sample waves using the bow sensor. 6 stations in total. At station 2 and 6, SUMO flights.

2300: Started Section C from C14

20 September 2018, Thursday

08: the VMP winch broke.

Revisited W3 position where the mooring was deployed 700 m deeper than target depth. The upper buoy is not depth rated for such pressure (but there's enough other buoyancy in the mooring for recovery). Triangulated the position. Could not detect the buoy in the EK80 or sonar. Decided to recover / redeploy at correct depth.

W3 released 1330 UTC (81N 30.874', 018E22.607'). Recovered from the acoustic release side, aft of vessel, spooled into trawl winch.

Top flotation imploded. All instruments are OK. Borrow 170kg buoyancy McLane buoy from UNIS.

Re-deployment started 1645 UTC approx. 4 km maway from target deployment position.

Deployed: 1810 UTC, 81N27.356', 018E23.730, 1202 m depth

21 September 2018, Friday

1200: recovered Gnå in rough seas, using the net-recovery device, without any incidents.

MR059 connector to Gnå had a tiny hole which short-circuited. Pressure port is severely corroded. There is no sign of damage in electronics or in the nose cone.

Started a repeat CTD station at C9, 1450 UTC (sta0140). One profile every hour.

22 September 2018, Saturday

Completed the repeat station at C9 (sta152) 0330 UTC.

Transit to Section B

Stopped logging extra frequencies at EK80 on 1010 UTC

Started Section B from B14

23 September 2018, Sunday

Continue working Section B

CTD was terminated before sta158

Winds reaching 40 knots. Difficult conditions to deploy CTD from the side. During the night two profiles were taken from the moonpool (sta158 and 159). However, moonpool water is not suitable for CTD (oil slicks, grease etc.). Decided not to use.

After sta158, difficulty connecting to slave LADCP. Took a cast with master only (but not using the single adcp deployment! Sta158 LADCP is garbage). Troubleshoot the problem to a cable and replaced with a reserve.

Stopped operations 0830 UTC because of bad weather (wind > 40 knots, waves > 3 m). Last station was B7, sta0160.

1300 UTC: birthday celebration and exhibition event

We had to leave the last YP mooring. Too rough seas to recover.

Steaming toward Longyearbyen

24 September 2018, Monday

Took a CTD station in Isfjorden (sta161).

Arrival at Bykaien, and cruise ended early in the morning.

List of CTD stations

Table 6. List of CTD stations. Echo depth is from the ship's echo sounder (in situ). Last column indicates the cast number in file names for corresponding master/slave LADCP.

Cast	Station Name	Date	Time (UTC)	Lat decdeg	Lon decdeg	E. Depth (m)	LADCP
94	test	2018-09-12	19:15	78,257	15,527	70	M094_000.000
95	test I-N	2018-09-12	23:08	78,182	13,385	231	M095_000.000
96	YP-C	2018-09-13	17:36	80,135	8,530	512	M096_000.000
97	C13	2018-09-14	15:16	81,600	18,500	2780	M097_000.000
98	C12	2018-09-14	21:12	81,550	18,502	2077	M098_000.000
99	C11	2018-09-14	23:04	81,500	18,501	1790	M099_000.000
100	C10	2018-09-15	00:50	81,450	18,501	1090	M100_000.000
101	W3	2018-09-15	10:13	81,510	18,403	1873	M101_000.000
102	W2	2018-09-15	14:36	81,379	18,417	720	M102_000.000
103	W1	2018-09-15	18:57	81,181	18,492	399	M103_000.000
104	F1	2018-09-15	23:14	81,200	21,000	167	M104_000.000
105	F2	2018-09-15	23:42	81,217	21,001	237	M105_000.000
106	F3	2018-09-16	00:18	81,250	21,001	404	M106_000.000
107	F4	2018-09-16	01:24	81,283	21,001	493	M107_000.000
108	F5	2018-09-16	02:13	81,333	21,011	649	M108_000.000
109	E1	2018-09-16	08:00	81,418	24,009	316	M109_000.000
110	E2	2018-09-16	11:34	81,516	23,999	715	M110_000.000
111	E3	2018-09-16	17:26	81,588	24,011	1222	M111_000.002
112	D11	2018-09-16	19:30	81,669	23,906	2521	M112_000.000
113	D10	2018-09-16	23:31	81,643	23,899	2100	M113_000.000
114	D9	2018-09-17	02:47	81,614	23,905	1527	M114_000.000
115	D8	2018-09-17	05:39	81,578	23,898	983	M115_000.000
116	D7	2018-09-17	08:18	81,540	23,903	803	M116_000.000
117	D6	2018-09-17	11:38	81,503	23,894	650	M117_000.000
118	D5	2018-09-17	13:27	81,460	23,901	495	M118_000.000
119	D4	2018-09-17	14:53	81,431	23,913	410	M119_000.000
120	D3	2018-09-17	16:08	81,415	23,904	309	M120_000.000
121	D2	2018-09-17	17:20	81,390	23,901	201	M121_000.000
122	D1	2018-09-17	19:47	81,133	23,902	269	M122_000.000
123	P1	2018-09-18	06:27	81,928	20,877	3427	
124	P1	2018-09-18	07:17	81,942	20,877	3433	
125	P1	2018-09-18	08:14	81,955	20,880	3448	
126	C14	2018-09-19	23:08	81,676	18,529	2748	M126_000.000
127	C13	2018-09-20	03:05	81,629	18,503	2408	M127_000.000
128	C12	2018-09-20	07:04	81,537	18,497	2002	M128_000.000
129	C11	2018-09-20	09:25	81,476	18,501	1446	M129_000.000
130	C10	2018-09-20	18:59	81,466	18,502	1252	M130_000.000
131	C9	2018-09-20	20:45	81,429	18,501	997	M131_000.000

132	C8	2018-09-20	22:01	81,421	18,508	852	M132_000.000
133	C7	2018-09-20	23:10	81,402	18,502	752	M133_000.000
134	C6	2018-09-21	00:28	81,343	18,502	601	M134_000.000
135	C5	2018-09-21	01:54	81,278	18,503	518	M135_000.000
136	C4	2018-09-21	03:10	81,186	18,514	401	M136_000.000
137	C3	2018-09-21	04:19	81,094	18,504	303	M137_000.000
138	C2	2018-09-21	05:13	81,036	18,511	195	M138_000.000
139	C1	2018-09-21	06:36	80,939	18,504	149	M139_000.000
140	P2	2018-09-21	14:49	81,429	18,501	974	M140_000.000
141	P2	2018-09-21	16:37	81,429	18,501	975	M141_000.000
142	P2	2018-09-21	17:41	81,429	18,501	976	M142_000.000
143	P2	2018-09-21	18:35	81,429	18,501	994	M143_000.000
144	P2	2018-09-21	19:27	81,429	18,501	997	M144_000.000
145	P2	2018-09-21	20:23	81,429	18,501	997	M145_000.000
146	P2	2018-09-21	21:33	81,429	18,501	997	M146_000.000
147	P2	2018-09-21	22:33	81,429	18,501	997	M147_000.000
148	P2	2018-09-21	23:31	81,429	18,501	997	M148_000.000
149	P2	2018-09-22	00:30	81,429	18,501	997	M149_000.000
150	P2	2018-09-22	01:31	81,429	18,501	997	M150_000.000
151	P2	2018-09-22	02:33	81,429	18,501	997	M151_000.000
152	P2	2018-09-22	03:29	81,429	18,501	997	M152_000.000
153	B14	2018-09-22	10:30	81,200	12,000	2126	M153_000.000
154	B13	2018-09-22	12:46	81,084	12,004	2110	M154_000.000
155	B12	2018-09-22	15:20	80,913	12,011	1852	M155_000.000
156	B11	2018-09-22	17:26	80,791	12,006	1566	M156_000.000
157	B10	2018-09-22	20:03	80,667	12,007	1265	M157_000.000
158	B9	2018-09-23	02:11	80,543	12,008	914	M158_000.000
159	B8	2018-09-23	03:42	80,521	12,011	821	M159_000.000
160	B7	2018-09-23	07:45	80,491	12,011	698	M160_000.000
161	Isfjorden	2018-09-24	02:01	78,036	13,313	207	

List of VMP stations

Table 7. List of the VMP2000 deployments. Echo depth (ED) is from the ship's echo sounder. Start and end pressures mark the reading on the VMP data acquisition software when started and stopped logging. CTD file is the corresponding ship CTD cast taken before the VMP deployment.

Cast	Station Name	Date-UTC	Time (UTC)	LAT	LON	E. Depth (m)	Start (m)	End (m)	CTD File	Comments
1	test	2018-09-13	04:17	80N05.72	08E37.35	497	6	257		test station, sh1:M1109, sh2:M546, T1: T808; dummy on T2 and mC
2	D12	2018-09-16	13:36	81N40.20	23E54.03	2436	1	1944	112	added T2:T1001 and mC:C200
3	D11	2018-09-17	10:50	81N38.61	23E53.73	2090	1	1687	113	line jumped puller, slow fall rate for top 40m
4	D10	2018-09-17	05:24	81N36.83	23E54.28	1524	1	51	114	short cast ; not free fall
5	D10	2018-09-17	05:24	81N36.83	23E54.28	1524	1	1183	114	until this cast setup_VMP T1 calib coeff is off (5K). Corrected after this cast. Sh2 spectra look poor. Change sh2 to M1112 for the next cast
6	D9	2018-09-17	22:30	81N34.74	23E53.74	990	1	20	115	short cast aborted
7	D9	2018-09-17	22:30	81N34.74	23E53.74	990	1	897	1	mT2 off from about 450m depth
8	D8	2018-09-17	23:23	81N32.41	23E54.05	803	1	747	116	changed T2 to T809; changed mC to 206
9	D7	2018-09-17	22:54	81N30.25	23E53.70	654	1	612	117	0
10	D6	2018-09-17	22:39	81N27.63	23E53.73	519	1	447	118	short cast aborted
11	D5	2018-09-17	21:51	81N25.88	23E54.69	411	1	362	119	0
12	D4	2018-09-17	21:12	81N24.89	23E54.23	312	1	287	120	0
13	D3	2018-09-17	20:21	81N23.38	23E53.83	201	1	173	121	0
14	D1	2018-09-17	00:28	81N08.06	23E53.68	268	1	8	122	short cast aborted
15	D1	2018-09-17	00:23	81N08.06	23E53.68	263	1	233	122	0
16	P1	2018-09-18	13:04	81N55.19	20E54.93	3424	1	5		short cast aborted
17	P1	2018-09-18	14:04	81N55.19	20E54.93	3424	1	406		PROCESS STATION 1

18	P1	2018-09-18	20:04	81N55.73	20E59.05	3424	1	418		
19	P1	2018-09-18	20:04	81N55.92	20E57.28	3424	1	409		
20	P1	2018-09-18	21:17	81N56.17	20E55.57	3437	1	405		
21	P1	2018-09-18	21:04	81N56.44	20E54.25	3424	1	411		
22	P1	2018-09-18	21:15	81N56.63	20E52.52	3435	1	374		
23	P1	2018-09-18	22:06	81N56.73	20E50.52	3426	1	419		
24	P1	2018-09-18	23:04	81N55.73	20E56.23	3424	1	421		
25	P1	2018-09-18	23:04	81N55.90	20E54.87	3424	3	425		
26	P1	2018-09-18	00:04	81N52.26	20E52.10	3424	2	412		
27	P1	2018-09-18	00:04	81N56.07	20E50.87	3424	1	394		
28	P1	2018-09-18	00:04	81N56.17	20E49.01	3424	1	387		line jump out of the puller around 70m. Stopped the vmp
29	P1	2018-09-18	02:15	81N56.05	20E56.70	3435	1	433		0
30	P1	2018-09-18	04:20	81N55.59	21E05.63	3440	1	25		short cast aborted
31	P1	2018-09-18	04:20	81N55.59	21E05.63	3440	1	426		0
32	P1	2018-09-18	04:16	81N55.49	21E04.18	3436	1	415		cable pull out a bit too slow upper 100m
33	P1	2018-09-18	04:19	81N55.65	21E02.57	3439	1	416		0
34	P1	2018-09-18	05:24	81N55.81	21E01.19	3444	1	416		0
35	P1	2018-09-18	05:25	81N55.99	20E59.54	3445	1	405		0
36	P1	2018-09-18	06:25	81N56.14	21E05.43	3445	1	418		sh2 noisy below 250m (quality_check_VMP)
37	P1	2018-09-18	06:26	81N56.19	21E04.13	3446	1	405		
38	P1	2018-09-18	05:59	81N56.39	21E02.47	3419	1	395		
39	P1	2018-09-18	07:27	81N56.64	21E00.93	3447	1	416		
40	P1	2018-09-18	07:33	81N56.92	20E59.30	3453	1	419		
41	P1	2018-09-18	06:56	81N57.19	20E58.10	3416	1	408		
42	P1	2018-09-18	08:36	81N57.44	20E56.39	3456	1	410		
43	P1	2018-09-18	08:21	81N57.67	20E54.74	3441	1	410		
44	P1	2018-09-18	08:24	81N57.85	20E52.91	3444	1	10		ice on the line puller, we started over again
45	P1	2018-09-18	08:20	81N57.87	20E52.77	3440	1	412		
46	P1	2018-09-19	09:39	81N57.37	20E56.25	3459	1	440		

47	P1	2018-09-19	10:31	81N54.87	20E54.85	3451	1	413		
48	P1	2018-09-19	10:33	81N57.61	20E53.25	3453	1	409		0
49	P1	2018-09-19	10:31	81N57.75	20E51.41	3451	1	380		
50	C13	2018-09-20	21:41	81N40.50	18E31.40	2741	1	1605	126	0
51	C12	2018-09-20	19:54	81N37.73	18E30.07	2394	1	1491	127	0

LADCP Deployment Files

Table 8. Master LADCP deployment file

```
; Append command to the log file
$L C:\KH2018709\LADCP\Mladcp_log.txt
$P**************************************************
$P** LADCP Master. Looking down (firmware v16.3) ***
$P ***Master and Slave will ping at the same time **
$P *** staggered single-ping ensembles every 0.8/1.2 s *
$P *************************************************
; Send ADCP a BREAK
$B
; Wait for command prompt (sent after each command)
$W62
; Display real time clock setting
tt?
$W62
; Set to factory defaults
CR1
$W62
; use WM15 for firmware 16.3
; activates LADCP mode (BT from WT pings)
WM15
$W62
; Rename data file prior to new CTD station and use CTD station nr
RN M160_
; Flow control (Record data internally):
; - automatic ensemble cycling (next ens when ready)
; - automatic ping cycling (ping when ready)
; - binary data output
; - disable serial output
; - enable data recorder
CF11101
$W62
; coordinate transformation:
; - radial beam coordinates (2 bits)
; - use pitch/roll (not used for beam coords?)
; - no 3-beam solutions
; - no bin mapping
EX00100
$W62
```

```
; time per burst
TB 00:00:01.20
$W62
; time per ensemble
TE 00:00:00.80
$W62
; time between pings
TP 00:00.00
$W62
; - configure no. of bins, length, blank
; number of bins
WN015
$W62
; bin length [cm]
WS0800
$W62
; blank after transmit [cm]
WF0000
$W62
; ambiguity velocity [cm]
WV250
$W62
; amplitude and correlation thresholds for bottom detection
LZ30,220
$W62
; Set ADCP to narrow bandwidth and extend range by 10%
LW1
$W62
; SET AS MASTER ADCP
SM1
$W62
; TRANSMITS SYNCHRONIZING PULSE BEFORE EACH ENSEMBLE
SA011
$W62
; WAIT .55 s after sending sync pulse
SW05500
$W62
; SYNCHRONIZING PULSE SENT ON EVERY PING
SI0
$W62
```

```
; Sensor source:
; - manual speed of sound (EC)
; - manual depth of transducer (ED = 0 [dm])
; - measured heading (EH)
; - measured pitch (EP)
; - measured roll (ER)
; - manual salinity (ES = 35 [psu])
; - measured temperature (ET)
EZ0011101
$W62
;
; - configure staggered ping-cycle
; ensembles per burst
TC2
$W62
; pings per ensemble
WP1
$W62
; keep params as user defaults (across power failures)
CK
$W62
; echo configuration
T?
$W62
W?
$W62
; start Pinging
CS
; Delay 3 seconds
$D3
$p *****************************************
$P Please disconnect the ADCP from the computer.
$p *****************************************
; Close the log file
$L
```

Table 9. Slave LADCP deployment file

; Append command to the log file $L C:\KH2018709\LADCP\Sladcp_log.txt $P *** $P ***** LADCP SLAVE. Looking UP (firmware v16.30) ** $P *** Master and Slave will ping at the same time ****** $P ** staggered single-ping ensembles every 0.8/1.2 s **** $P ** ; Send ADCP a BREAK $B % Wait for the command prompt; BBTalk needs this before each command $W62 ; Display real time clock setting tt? $W62 ; Set to factory defaults CR1 $W62 ; use WM15 for firmware 16.3 ; activates LADCP mode (BT from WT pings) WM15 $W62 ; Rename data file prior to new CTD station and use CTD station nr RN S160_ $W62 ; Flow control (Record data internally): ; - automatic ensemble cycling (next ens when ready) ; - automatic ping cycling (ping when ready) ; - binary data output ; - disable serial output ; - enable data recorder CF11101 $W62 ; coordinate transformation: ; - radial beam coordinates (2 bits) ; - use pitch/roll (not used for beam coords?) ; - no 3-beam solutions ; - no bin mapping EX00100 $W62	; time per burst TB 00:00:01.20 $W62 ; time per ensemble TE 00:00:00.80 $W62 ; time between pings TP 00:00.00 $W62 ; - configure no. of bins, length, blank ; number of bins WN015 $W62 ; bin length [cm] WS0800 $W62 ; blank after transmit [cm] WF0000 $W62 ; ambiguity velocity [cm] WV250 $W62 ; amplitude and correlation thresholds for bottom detection LZ30,220 $W62 ; Set ADCP to narrow bandwidth and extend range by 10% LW1 $W62 ; ; SET AS SLAVE ADCP SM2 $W62 ; TRANSMITS SYNCHRONIZING PULSE BEFORE EACH ENSEMBLE SA011 $W62 ; don't sleep SS0 $W62 ; WAIT UP TO 300 SECONDS FOR SYNCHRONIZING PULSE ST0300 $W62

; Sensor source: ; - manual speed of sound (EC) ; - manual depth of transducer (ED = 0 [dm]) ; - measured heading (EH) ; - measured pitch (EP) ; - measured roll (ER) ; - manual salinity (ES = 35 [psu]) ; - measured temperature (ET) EZ0011101 $W62 ; - configure staggered ping-cycle ; ensembles per burst TC2 $W62 ; pings per ensemble WP1 $W62	; keep params as user defaults (across power failures) CK $W62 ; echo configuration T? $W62 W? $W62; start Pinging CS ; Delay 3 seconds $D3 $p *** $P Please disconnect the ADCP from the computer. $P *** ; Close the log file $L

SADCP Deployment Files

Table 6. Drop Keel instruments: 38 kHz and 150 kHz RDI Ocean Surveyors

;--- ; ADCP Command File for use with VmDas software. ; ; ADCP type: 38 Khz Ocean Surveyor ; Setup name: default ; Setup type: Low resolution, long range profile (narrowband) ; ; NOTE: Any line beginning with a semicolon in the first ; column is treated as a comment and is ignored by ; the VmDas software. ; ; NOTE: This file is best viewed with a fixed-point font (e.g. courier). ; Modified Last: 24 July 2018 for KPH oceanography test cruise, AHHR ; 12 September 2018, KPH LEGACY process cruise, Ilker Fer ;--/ ; Restore factory default settings in the ADCP cr1 ; set the data collection baud rate to 38400 bps, ; no parity, one stop bit, 8 data bits ; VmDas sends baud rate change command after all other commands in ; this file, so that it is not made permanent by a CK command. cb611 ; Set for narrowband single-ping profile mode (NP), sixty-five (NN) 24 meter bins (NS), ; 16 meter blanking distance (NF) WP00000 NP00001 NN065 NS2400 NF1600 ; Disable single-ping bottom track (BP),	;--- ; ADCP Command File for use with VmDas software. ; ; ADCP type: 150 Khz Ocean Surveyor ; Setup name: default ; Setup type: Low resolution, long range profile (narrowband) ; ; NOTE: Any line beginning with a semicolon in the first ; column is treated as a comment and is ignored by ; the VmDas software. ; ; NOTE: This file is best viewed with a fixed-point font (e.g. courier). ; Modified Last: 24 July 2018 for KPH oceanography test cruise, AHHR ; 12 September 2018, KPH LEGACY process cruise, Ilker Fer ;--/ ; Restore factory default settings in the ADCP cr1 ; set the data collection baud rate to 38400 bps, ; no parity, one stop bit, 8 data bits ; VmDas sends baud rate change command after all other commands in ; this file, so that it is not made permanent by a CK command. cb611 ; Set for narrowband single-ping profile mode (NP), sixty-five (NN) 8 meter bins (NS), ; 6 meter blanking distance (NF) WP00000 NP00001 NN065 NS0800 NF0600 ; Disable single-ping bottom track (BP),

; Set maximum bottom search depth to 1700 meters (BX) BP000 BX17000 ; output velocity, correlation, echo intensity, percent good ND111100000 ; 3 seconds between bottom and water pings TP000300 ; Three seconds between ensembles ; Since VmDas uses manual pinging, TE is ignored by the ADCP. ; You must set the time between ensemble in the VmDas Communication options TE00000300 ; Set to calculate speed-of-sound, no depth sensor, external synchro heading ; sensor, no pitch or roll being used, no salinity sensor, use internal transducer ; temperature sensor EZ1020001 ; Output beam data (rotations are done in software) EX00000 ; Set transducer misalignment (hundredths of degrees) EA004556 ; Set physical pitch alignment error (hundreths of degrees) EJ108 ; Set physical roll alignment error (hundreth of degrees) EI038 ; Set transducer depth (decimeters) ED00118 ; Set Salinity (ppt) ES35	; Set maximum bottom search depth to 800 meters (BX) BP000 BX08000 ; output velocity, correlation, echo intensity, percent good ND111100000 ; 1 seconds between bottom and water pings TP000100 ; Two seconds between ensembles ; Since VmDas uses manual pinging, TE is ignored by the ADCP. ; You must set the time between ensemble in the VmDas Communication options TE00000200 ; Set to calculate speed-of-sound, no depth sensor, external synchro heading ; sensor, no pitch or roll being used, no salinity sensor, use internal transducer ; temperature sensor EZ1020001 ; Output beam data (rotations are done in software) EX00000 ; Set transducer misalignment (hundredths of degrees) EA04467 ; Set physical pitch alignment error (hundreths of degrees) EJ0136 ; Set physical roll alignment error (hundreths of degrees) EI-018 ; Set transducer depth (decimeters) ED00118 ; Set Salinity (ppt) ES35

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

Table 8. Flush-mounted instruments: 38 kHz and 150 kHz RDI Ocean Surveyors

;--- ; ADCP Command File for use with VmDas software. ; ; ADCP type: 38 Khz Ocean Surveyor ; Setup name: default ; Setup type: Low resolution, long range profile (narrowband) ; ; NOTE: Any line beginning with a semicolon in the first ; column is treated as a comment and is ignored by ; the VmDas software. ; ; NOTE: This file is best viewed with a fixed-point font (e.g. courier). ; Modified Last: 24 July 2018 for KPH oceanography test cruise, AHHR ; 12 September 2018, KPH LEGACY process cruise, Ilker Fer ;--/ ; Restore factory default settings in the ADCP cr1 ; set the data collection baud rate to 38400 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. cb611 ; Set for narrowband single-ping profile mode (NP), sixty-five (NN) 24 meter bins (NS), ; 16 meter blanking distance (NF) WP00000 NP00001 NN065 NS2400 NF1600	-- ; ADCP Command File for use with VmDas software. ; ; ADCP type: 150 Khz Ocean Surveyor ; Setup name: default ; Setup type: Low resolution, long range profile (narrowband) ; ; NOTE: Any line beginning with a semicolon in the first ; column is treated as a comment and is ignored by ; the VmDas software. ; ; NOTE: This file is best viewed with a fixed-point font (e.g. courier). ; Modified Last: 24 July 2018 for KPH oceanography test cruise, AHHR ; 12 September 2018, KPH LEGACY process cruise, Ilker Fer ;--/ ; Restore factory default settings in the ADCP cr1 ; set the data collection baud rate to 38400 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. cb611 ; Set for narrowband single-ping profile mode (NP), sixty-five (NN) 8 meter bins (NS), ; 6 meter blanking distance (NF) WP00000 NP00001 NN065 NS0800 NF0600

; Disable single-ping bottom track (BP), ; Set maximum bottom search depth to 1700 meters (BX) BP000 BX17000 ; output velocity, correlation, echo intensity, percent good ND111100000 ; 3 seconds between bottom and water pings TP000300 ; Three seconds between ensembles ; Since VmDas uses manual pinging, TE is ignored by the ADCP. ; You must set the time between ensemble in the VmDas Communication options TE00000300 ; Set to calculate speed-of-sound, no depth sensor, external synchro heading ; sensor, no pitch or roll being used, no salinity sensor, use internal transducer ; temperature sensor EZ1020001 ; Output beam data (rotations are done in software) EX00000 ; Set transducer misalignment (hundredths of degrees) EA004688 ; Set physical pitch alignment error (hundreths of degrees) EJ-009 ; Set physical roll alignment error (hundreth of degrees) EI001 ; Set transducer depth (decimeters) ED00084 ; Set Salinity (ppt)	; Disable single-ping bottom track (BP), ; Set maximum bottom search depth to 800 meters (BX) BP000 BX08000 ; output velocity, correlation, echo intensity, percent good ND111100000 ; 1 seconds between bottom and water pings TP000100 ; Two seconds between ensembles ; Since VmDas uses manual pinging, TE is ignored by the ADCP. ; You must set the time between ensemble in the VmDas Communication options TE00000200 ; Set to calculate speed-of-sound, no depth sensor, external synchro heading ; sensor, no pitch or roll being used, no salinity sensor, use internal transducer ; temperature sensor EZ1020001 ; Output beam data (rotations are done in software) EX00000 ; Set transducer misalignment (hundredths of degrees) EA04642 ; Set physical pitch alignment error (hundreths of degrees) EJ008 ; Set physical roll alignment error (hundreths of degrees) EI-017 ; Set transducer depth (decimeters) ED00084 ; Set Salinity (ppt)

ES35 **; save this setup to non-volatile memory in the ADCP** **CK**	**ES35** **; save this setup to non-volatile memory in the ADCP** **CK**

Appendix III: Outreach and invited artists

For this cruise, the Nansen Legacy project had invited two artists to participate as well as a TV producer from Alfred Film doing research for a possible new television series. In addition, a photographer from UiT the Arctic University of Norway and a communications adviser from the University Centre in Svalbard (UNIS) took part in the cruise. In this initial phase of the project it is a priority to involve several of the partner institutions in the outreach efforts as well as finding new audiences and channels.

The communications adviser from UNIS had a coordinating role as well as the responsibility to produce blog texts to Forskning.no (published during the cruise) and text/photos/films to social media (to be published after the cruise due to lack of internet connection). The photographer from UiT took pictures for the sen Legacy project in addition to on-demand documentation for the scientists.

On the last day of the cruise, the outreach team hosted an «Artists' preview» for cruise participants and cruise where the process and work was presented as well as plans for future. It was a very nice session which included birthday cake for three of the cruise participants, including the cruise leader.

Hege Holen Paulsrud worked with an iPad on board, creating several prints and comic-like images of situations from the ship. After the cruise she plans to work with larger formats using acrylic and spray paint on canvas.

Lena Gudd works with analogue photography and merges anthropology and philosophy into her art. She would also like to use some of the scientific graphs and illustrations in collages together with her photos.

Silje Burgin-Borch from Alfred Film has done a lot of research and test filming on board. If all goes to plan, the idea for the TV series would be pitched for TV channels in January–May and production might start in September 2019. The overall idea is to make a 6-episode series on climate change, following scientists in the front line of the research area.

Rudi Caeyers from UiT has taken more than 4500 photos during the cruise and showed a selection of them. They are available on the common server area and high resolution pictures are available upon request.

Inger Lise Næss from UNIS has taken photos, GoPro films and done research for blogs, portraits and shorter input for the sen legacy's social media channels.

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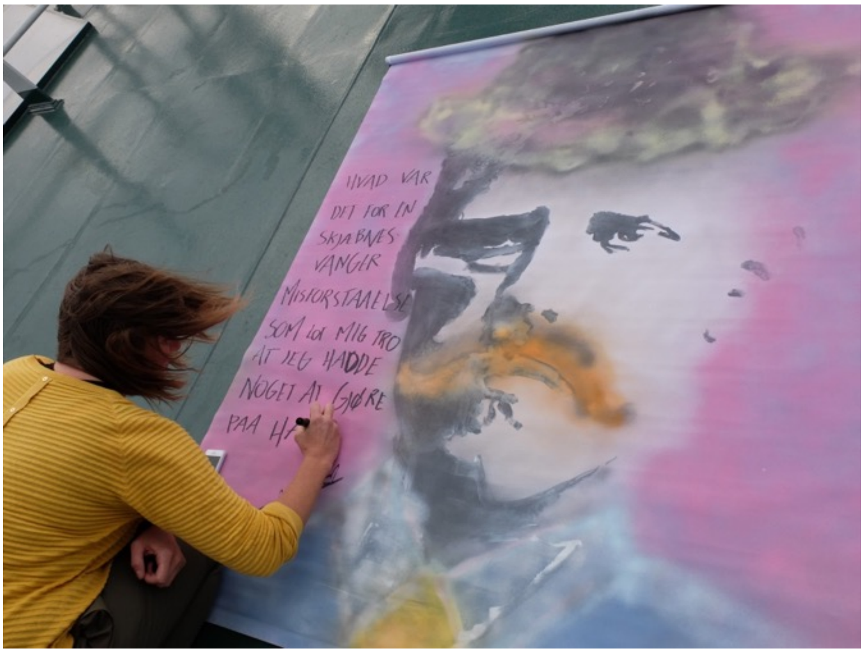

Hege Holen Paulsrud working on a portrait of Fridtjof Nansen in acrylic and spray paint.
Photo: Inger Lise Næss

Collage notes from Blåmann (2018) – Lena Gudd


Rudi Caeyers and Silje Burgin-Borch documenting the research activities on board.
Photo: Inger Lise Næss

The Nansen Legacy in numbers

6 years

The Nansen Legacy is a six-year project, running from 2018 to 2023.

1 400 000 km² of sea

The Nansen Legacy investigates the physical and biological environment of the northern Barents Sea and adjacent Arctic Ocean.

250 people

There are about 210 researchers working with the Nansen Legacy, of which 50 are early career scientists. In addition, 40 persons are involved as technicians, project coordinators, communication advisers and board members.

10 institutions

The Nansen Legacy unites the complimentary scientific expertise of ten Norwegian institutions dedicated to Arctic research.

>10 fields

The Nansen Legacy includes scientists from the fields of biology, chemistry, climate research, ecosystem modelling, ecotoxicology, geology, ice physics, meteorology, observational technology, and physical oceanography.

>350 days at sea

The Nansen Legacy will conduct 15 scientific cruises and spend more than 350 days in the northern Barents Sea and adjacent Arctic Ocean between 2018 and 2022. Most of these cruises are conducted on the new Norwegian research icebreaker RV *Kronprins Haakon*.

50/50 financing

The Nansen Legacy has a total budget of 740 million NOK. Half the budget comes from the consortiums' own funding, while the other half is provided by the Research Council of Norway and the Ministry of Education and Research.

Norwegian Ministry of Education and Research

With funding from The Research Council of Norway

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