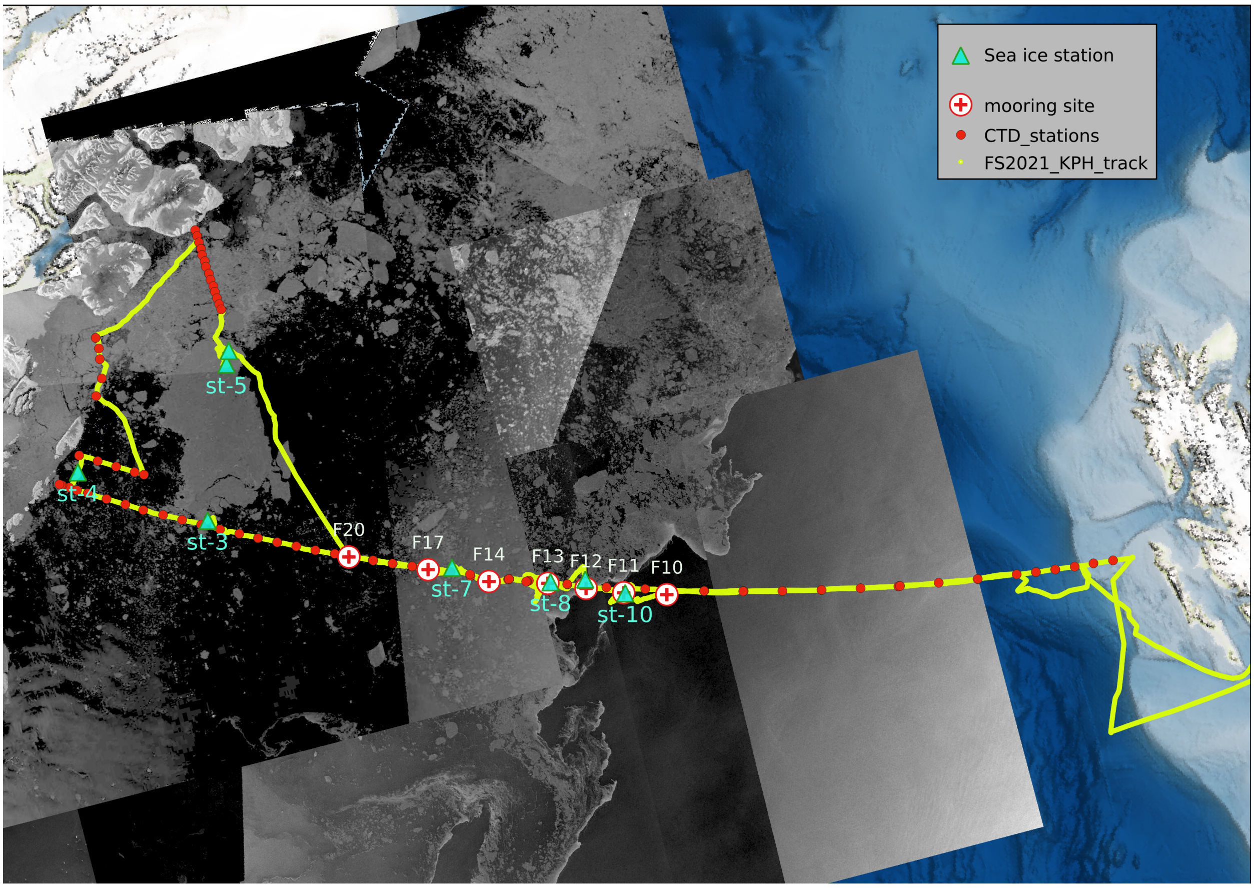
Fram Strait Cruise Report

31 July – 20 August 2021

Cruise no. 2021709



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1. Cruise Overview

The objective of the annual cruise of the Norwegian Polar Institute to Fram Strait is to service the Arctic Outflow Observatory in the western Fram Strait. The purpose of this observing system is to monitor the properties of the Arctic freshwater, sea ice, and returning Atlantic water, as well as the state of ocean acidification, CDOM and nutrients in the East Greenland Current.

The main priority was to recover and redeploy seven NPI moorings across the East Greenland Current at 78°50' N, and to carry out the CTD/LADCP section including extensive water sampling for various tracers across the whole Fram Strait along the 78°50'N line. The main section could be continued all the way to the coast of Greenland after which we turned northward toward 79N where some stations were taken, followed by the Westwind section.

Sea ice physics work was carried out across the East Greenland Current and shelf. This included in-situ work on some selected sea ice floes as well as on some land-fast ice which was just prior to it breaking up days after. It was challenging to find sufficient size of floes from which to work on. The land-fast ice region on Belgica bank was again very small.

This year, the ARICE team (EU funded) could join the Fram Strait cruise. A total of 9 participants including students/postdocs joint from DTU Aqua (Denmark), IOPAN (Poland), and SYSE (Finland). The project title was 'Novel Tracers of Arctic Carbon and water exchange in the Fram Strait (NoTAC) with dr. R Gonçalves-Araujo as lead-PI. NoTAC is an international collaboration focused on developing dissolved organic matter (DOM) as a tracer for Arctic water entering the Atlantic and exploring links between water mass origin and phytoplankton community composition. The project combines established tracer measurements with state-of-the art in situ sensor-based monitoring techniques to expand on existing techniques for tracing water mass origin in a major Arctic gateway, the Fram Strait.

On the cruise we also deployed one endurance Slocum glider in the eastern Fram Strait as part of NorEMSO (NFR infrastructure project) with a target mission of 12 months, taking sections across the Fram Strait (at ±78°50'N to 79°N) avoiding ice covered regions. A Seaglider as part of SIOS was deployed for Dr. I. Fer (UiB) in the middle of the strait at 78°50'N due to some initial communication failures, after which it was send down to 77°20'N.

Similar to 2018-2020, there was a whale research programme deploying satellite transmitters on large whales (bowhead whales, blue whales and narwhals) and in addition collect biopsies for genetic studies from the same species, and tracking their movements in the following year, as well as collecting skin biopsies for genetic analyses. These tasks were conducted from a helicopter (Ecureuil 350) based on KPH.

Prioritization and timing of mooring operations, CTDs and flights were guided by sea ice images (Sentinel) send to the ship by the data management group at NPI.

The cruise was challenged by COVID-19 pandemic and required home quarantine for 10 days for NPI participants prior to the cruise, or in a 3-day quarantine after entering Norway for external participants, or a 10-day hotel quarantine for one unvaccinated participant. All participants had to take a quick COVID test as well as a PCR test prior to boarding the vessel, unless they were already in Svalbard prior to the cruise (and fully vaccinated).

2. Participants

Organisation
1. Laura de Steur (Cruise leader NPI, mooring coordination)
2. Paul A. Dodd (Cruise deputy NPI, CTD coordination)

Sea ice
3. Hiroshi Sumata (sea ice lead, NPI)
4. Yannick Kern (NPI)

CTD/tracer/water sampling (ARICE):
5. Rafael Gonçalves-Araujo (DTU)
6. Colin Stedmon (DTU)
7. Anders Dalhoff Bruhn Jensen (DTU)
8. Gang Lin (DTU)
9. Lumi Haraguchi (SYKE)
10. Stine Zander Hagen (KU)

Optics (ARICE):
11. Piotr Kowalczuk (IOPAN)
12. Alexandra Cherkasheva (IOPAN)
13. Monika Zabłocka (IOPAN)

Whale research:
14. Christian Lydersen (NPI)
15. Kit Kovacs (NPI)
16. Harald Dag Jølle (NPI)

Technical Support:
17. Kristen Fossan (moorings, NPI)
18. Jan Are Jacobsen (moorings & sea ice, NPI)
19. Thodoris Karpouzoglou (moorings & sea ice, NPI)

Airlift helicopter crew:
20. Øyvind Myhre - Helicopter pilot Airlift
21. Gustav Svanstrøm - Helicopter technician Airlift

3. Sailing log

Saturday 31.07.21	Checking in at 9 am. Loading and installing on vessel. All day, loading and unpacking. Departure at 20:00 local time. Steam to Seaglider deployment position 78°N, 8°50'E. Preparation of Seaglider (for I. Fer, UiB).
Sunday 01.08.21	Attempts to deploy Seaglider failed due to bad or weak Iridium communication. Cancelled at 10 am, depart to start of CTD section. Potentially new attempt later on the main section. Arrival at first CTD station at 10°E at 15:15 local. CTD, optical profile, radio-meter measurements. Continue westward & prep Slocum glider (NorEMSO) Evening: Slocum glider on deck ready to be tested by pilot (Fiona Elliot, UiB)
Monday 02.08.21	Arrival at 7°E at ~ 5:15 am local time. Slocum glider test went well last night , clearance to go but then glider just went to sleep. Postponed to after the 7E CTD. At 07:15 (local) Slocum glider deployed at 78° 49.851'N, 07° 01.957'E Continue with CTDs 6°E and westward all night.
Tuesday 03.08.21	CTDs at 0°W, prep and Sea launch of Seaglider on deck. Ill communication at first, but improved after repositioning on deck. Green light from pilot (Algot Peterson, UiB) to deploy ~ 9:30 local time 78° 50'N, 0°E. At 11 am call with Pilot, confirmed all OK, 2 dives shallow performed and communication good after 2nd dive. CTDs at 1°W. Steam to Mooring F10 and recovery at 19:12. CTDs overnight
Wed 04.08.21	Recovery of F11 at 10:13. CTDs. Recovery of F12 at 20:00. CTDs overnight
Thur 05.08.21	All day: recovery F13. Got released at the CTD location, not the exact mooring site which was 0.5 nm off. Mooring got up under ice, 10 hrs to get it back. Drifting SSW with the sea ice at 0.6 to 0.8 knots, quite heavy ice, lots of floes. Tracing mooring release with deck unit. Finally, at 17:15 visual on the floats, still UNDER ICE! (Luckily it was spotted right next to port side while breaking a small floe). On deck in the evening, no instruments lost or damaged. Planned for 2 hr sea ice station at 20:30 but too much fog, so cancelled.
Fri 06.08.21	Look for ice floe for sea ice work starting at 8am. Too bad visibility, wait an hour to improve. When ready to go on ice at 10 am, station cancelled due to fog. Head to F14. Recovery F14. CTD at F14. Sea ice station in afternoon (2hr, coring only) on an isolated floe, with relatively good, sometimes poor visibility. CTDs overnight.
Sat 07.08.21	Recovery F17 after breakfast, continue to CTD 9W and 9.5W. Recovery F20 at 16:00. All good except IceCAT lost! Very foggy all day so no flights and no sea ice work. CTDs westward until ~ 13°W to start look for sea ice floe (from land fast ice) early next morning.
Sun 08.08.21	6-7 am: check weather and ice floe near 13°W. Too foggy and very rotten ice. CTD first at 13.5°W then look for floe(s) again just north of the section. Here, 2 ice stations, one in morning, one in afternoon. Foggy/flat light but just ok with visibility and with at least 2 polar bear guards on bridge. Continue with CTDs at 14°W and westward
Mon 09.08.21	Extremely foggy. Reach 17.5W for CTD (575 m deep) and wait for permission to enter the 3 nm zone from GL. Short heli flight for reconnaissance at 11:10, failure of GPS system underway and a lot of fog. Heli found ship back at

	11:40. Clearing up but still too bad to fly. Colin S. calling GL for the 3 nm allowance, waiting for that in order to proceed the main section up to 17°50'W. Wait for clearance which is obtained at 14:35 local time. Continue west to take 3 more CTDs: 500m, 350m, and 200m isobaths until 17°45.5'W. Weather improving to sunny and no clouds. Flight is finally undertaken, 15:10 to 16:35. A second flight in the eve. Very good weather conditions by now. Look for a small sea ice floe after dinner while steaming gradually north along GL coast in Norske Trough 79.5N. Ice station at 20:45 until 23:00 on a very small floe with 3pax. Needed to discontinue due to polar bear coming. Evening: steam across from W-E to take 5 short CTDs at 79N as a repeat from 2020 to compare how the northward transport there relates to that at 78°50'N.
Tues 10/08/21	Steaming to 79°20'N and 17°33'W until 9 am. Excellent weather again. Flight after breakfast. Plan for 5 CTDs from south to north at 17°33'W during the day including 3 for water sampling and optics. Flight after lunch. Excellent weather. Finish S-N CTDs near 79N. 2 more flights during the afternoon/eve. Finish around 9 pm and start steaming to Westwind section, northern end.
Wed 11/08/21	Start Westwind CTD section in the north. Good weather, cloudy but good visibility. Ice conditions OK, large floes but soft to break through, and large patches open water. Flight after lunch and after dinner. Finish WW section around 18:00. Continue south-southeast to look for suitable ice to work on next day. Find ok area with both FYI and MYI and stay there overnight.
Thurs 12/08/21	Polar bear with 2 cubs passing by ice area where we want to work on, passes on and we move ship away. Find suitable ice with several types of ice, plan for 4 activities, but just prior to deploying small boat another bear is seen, we stop and move the ship SSW before trying again. One more attempts for sea ice work, again stopped due to polar bear. Move SSE and find a very good (drifting!) floe for ACDP calibrations (3x), works very well, until 18:00. Excellent floe also for sea ice work, so decided to do about 4 hours of work here in the evening until 22:30. Pack up and steam to main CTD section to deploy F20 the next morning.
Fri 13/08/21	Deployment of F20 after lunch and F17 after dinner. CTDs after and in between and toward F14 overnight.
Sat 14/08/21	Sea ice station near 7°20'W in the morning, very good floe already found evening before and efficient team on ice. Steam to F14, deploy close to 14:00 local time. CTD near F14 and at 6·W. Steam to F13. Attempt to flight but return after 20 mins. Deploy F13 at 20:00. Sea ice station after 20:30 on small floe near vessel, small boat operation as before until 22:20 local time. CTDs at 5°W 5.5°W and 4.5°W overnight. Then steam to an area ~ 5-7 nm north of F12.
Sun 15/08/12	Sea ice work planned for morning, ~ 5 nm north of F12. Gettting ready with small boat (NPIs polarsirkel) but bear shows up so postpone. Steam south and look for suitable floes. Sea ice station at 10:45 to 14:30 with a lunch break, coring and EM31. No weather for flying. Continue to deploy F12. First attempt failed due to to much sea ice, too fast drift and a too short approach so that the depth was too shallow. Take it up again, and try again after dinner. Took out 15m kevlar and finally deployed at 21:43 local time. CTDs at 4W and 3.5W. Steam toward F11 overnight.
Mon 16/08/21	Get up early too look for sea ice options but it is too foggy to start it. Polar bear

	near boat at 10am. CTD at F11. Still too much fog to fly or do sea ice work. Deploy F11 in afternoon with very strong drift speed, anchor about 0.3 nm north of the drop, see notes in table moorings deployed. No sea ice work still in evening due to heavy fog. Drift southward but reposition in the night to stay in sea ice near F11 for the next morning.
Tues 17/08/21	Foggy but getting better visibility at 9am. Sea ice station for coring, getting better weather and work is done by 11:30. Steam to F10 site which is just in the MIZ. Drift is large to south, reposition 1.5 nm north just outside the MIZ and drift to the mooring while building it. First attempt (bottom depth test with marked kevlar) shows the mooring is too tall. Take out 40 m and shorten the IceCAT wire and retest, then ok and deploy at 16:02. CTD afterwards and continue to 0W for optical profiles for IOPAN at 0, 2E, 4E and 6E.
Wed 18/8/21	Finalize 6E optical profile at 10:30 am, steam toward the shelf break for whale research looking for blue whale rest of the day while steaming south for Longyearbyen. All hands on deck for packing and getting all pallets ready for Thurs morning 8 am.
Thurs 19/8/21	6am at the dock. Offloading between 8:00 and 15:00. We only get limited time to offload since the dock occupied later in the day and all of Friday (despite reserving a long time ago for Friday). Cleaning! Stay on vessel overnight still while it relocates in the fjord.
Fri 20/8/21	Checking out cabins at 8:30 and wait for flights in the afternoon.

4. Mooring operations during FS2021

The core Fram Strait Arctic Outflow Observatory moorings F11, F12, F13, F14, and F17 were recovered in good shape and were all deployed at the same positions. The pilot mooring F20 at ~10.1°W was also recovered and showed valuable information on the flow on the shelf, which is up to now, a big unknown in the transport and freshwater flux from the Arctic Ocean. It was also redeployed. The moorings F20, F17 and F10 are equipped with IceCATs to obtain salinity and temperature data as close as possible to the surface, with a target depth of ~25m. F10 is funded through the NorEMSO project, an NFR infrastructure project. Due to delayed delivery times related with COVID-19 in 2020, we could finally equip the mooring with pH and pCO2 sensors in 2021.

4.1 Moorings recovered during FS2021

Mooring	Position	Depth (m)	Date and time (UTC)	Instrument	Serial #	Instrument depth (m)	Actual depth
F10-16	N 78° 49.624' W 01° 57.041'	2666 m	Deployed: 10 Sept 2020, 12:32 UTC Recovered: 3 Aug 2021, 17:12 UTC **TOP WAS TOO DEEP!**	**SBE37-IM weak link**	**22258**	**30**	**48**
				ADCP	16831	57	
				AQD*	665	58	
				RBR +ODO	**205002**	**59**	**95**
				SBE37	**20789**	**254**	**258**
				AQD*	666	257	
				SBE37	**22261**	**2645**	**2648**
				AQD*	667	2650	
				AR861	2879	2653	
F11-22	N 78° 49.121' W 03° 03.065'	2474 m (instru-ments at 60 / 270m likely deeper..)	Deployed: 9 Sept 2020, 06:35 UTC Recovered: 4 Aug 2021, 08:13 UTC **TOP WAS TOO DEEP!**	**IPS5**	**51062**	**55**	
				SBE37	**3490**	**58**	**87**
				ADCP	24830	60	
				SBE37	**4702**	**270**	**280**
				RCM9	1324	273	
				SBE37	**3552**	**1496**	**1539**
				RCM11	494	1500	
				SBE37	**8227**	**2452**	**2457**
				RCM8	10071	2455	
				AR861	287	2460	
F12-22	N 78°49.116' W 04° 01.294'	1848 m (EK80 depth about 17 m too much?)	Deployed: 9 Sept 2020, 08:22 UTC Recovered: 4 Aug 2021, 18:00 UTC **TOP WAS A LITTLE TOO DEEP!**	**IPS5**	**51167**	**52**	
				SBE37	**3489**	**54**	**64**
				ADCP	16876	65	
				SBE37	**14100**	**114**	**130**
				SBE37	**4837**	**264**	**280**
				RCM Seagard	884	267	
				SBE37	**3554**	**1471**	**1489**
				RCM11	556	1474	
				SBE37	**8822**	**1814**	**1832**
				RCM11	228	1817	
				AR861	182	1820	
F13-22	N 78° 50.346' W 04° 59.959'	1026 m	Deployed: 8 Sept 2020; 18:22 UTC Recovered:	**IPS**	**51140**	**50**	
				SBE37	**7056**	**52**	**47**
				ADCP	18151	56	
				AURAL	n/a	81	

			5 Aug 2021, 08:25 UTC	**SBE37** **SBE37** **SBE37** RCM9 **SBE37** RCM11 AR861	**12234** **12232** **3993** 1327 **3551** 561 053	**104** **154** **255** 258 **1008** 1012 101 5	**102** **151** **256** **1010**
F14-22	N 78° 48.848' W 06° 30.130'	270	Deployed: 8 Sept 2020, 07:49 UTC Recovered: 6 Aug 2021, 09:25 UTC	**IPS** **SBE37** ADCP Nortek AQD **SBE37** **SBE56** **SBE56** **SBE37** RCM9 AR861	**51138** **14097** 24518 42839- 930 **13253** **10330** **10331** **3992** 1046 409	**50** **54** 58 60 **99** **203** **228** **253** 257 265	 **55** **105** **260**
F17-17	N 78° 50.185' W 08° 4.845'	224	Deployed: 7 Sept 2020, 20:45 UTC Recovered: 7 Aug 2021, 06:37 UTC	**SBE37-IM** **weak link** **RBR CDOM** **SBE37 SMP** ADCP **RBR CDOM** **SBE56** **SBE56** **SBE37 SMP** RCM7 AR661	**22260** **204799** **9651** 24385 **204800** **3942** **3943** **9650** 12733 1424	**25** **56** **96** 107 **109** **170** **196** **216** 218 219	**22** **59** **No P sensor** **115** **No P sensor**
F20-1	N 78° 50.100' W 10° 08.814'	326	Deployed: 7 Sept 2020, 12:47 UTC Recovered: 7 Aug 2021, 14:00 UTC	**SBE37-IM** **weak link** **SBE37** ADCP **SBE37** RCM7 AR661	**21029** **(lost)** **12233** 727 **10295** 7718 291	**25** **(lost)** **51** 102 **106** 314 316	**23** **51** **106**

Table 4.1: *Moorings recovered during FS2021*
AQD - Nortek Aquadopp*

Recovery notes:

IceCATS: for 2022: 2 IM SBE37 available after recovery, should be calibrated in 2022.

- ! Two IceCATS recovered on F10 and F17 (but dangling along the ADCP float, not near surface anymore). These two will be send to Seabird for service and calibration.
- ! Note: IceCATS at 22/23 m is a bit too shallow, lost too quickly: aim for 27-30m
- ! IceCAT lost at F20.

Microcat issues:

- ! Bottom SBE37 at F10 stopped working in April '21.
- ! Bottom SBE37 at F11 and F12 clear drift in S. To post-correct.
- ! SBE37 SN 7056 at F13 gave problems with downloading data. Theo managed with Seaterm (old version) but with wrong time stamp, needs checking. (Also failure of reading data in 2019). Redo/correct the time stamp in processing.
- ! 55m SBE37 of F17 P sensor did not work; constant at 45 ?!

RBR issues:

1. ODO sensor on F10 worked well, need to be checked against CTD / post calibrated
2. Both **CDOM** sensors (F17) did **not** work: we contact RBR why after the cruise. They found the electronics board for external sensors did not work properly, likely because of a thin crack in it. The instruments still fell under warranty and we will get them back fixed and calibrated in May/June '22.

ADCP issues:

- ADCP on F14 (SN24518) **stopped** prematurely in April '21. Likely battery issues
- All were programmed to go for 2 years in case cruise got delayed or cancelled.

Depths for 2022/2023 need to be carefully checked. There are two sets of Kevlar. So, changes in one year should not be carried out automatically on the kevlar set for the next year. Check every other year what the target depths and actual depths were for that specific set of Kevlar.

- IceCAT and RBR+ODO at F10 about 30 m too deep.
  In 2023: add 30m kevlar below RBR?
- 55m and 250m SBE37 at F11 about 30 m too deep.
  In 2023: add 30m kevlar below 260m?

Funding:

- ! F10-16 financed by NorEMSO infrastructure funding. New instruments (SBE37, ACDP, and Aquadopps) as well as RBR CTD+ ODO and IceCAT
- ! Two IceCATs on F20-1 and F17-17 funded by FreshARC.
- ! Two RBR CTD+ CDOM financed by the Polar Ocean Program, NPI.

Note: looks like overall there was a very fresh outflow event in April+May 2021.

4.2 Moorings deployed during FS2021

Mooring	Position	Depth (m)	Date and time (UTC)	Instrument	Serial #	Instrument depth (m)
F10-17	N 78° 49.637' W 01° 57.080'	2665 m	Deployed: 17 Aug 2021 16:03 UTC **Note: had to take out 40m kelvar and use 23m of icecat wire**	**SBE37-IM weak link** ADCP Data logger AQD **SAMI pH+pCO_2*** **RBR CTD+ODO** AQD **RBR CTD+** **SBE37** AQD AR861	**23250** 24899 NPI005 15910 (665) **227 / 261** **207317** 15888 (666) **207318** **23266** 15877 (667) 506	**25** 48 50 **51** **52** **54** 221 **223** **2634** 2639 2641
F11-23	Drop of top: N 78° 49.109' W 03° 03.087' **Note:** 1.2kt drift upon deploying! **Anchor position likely further north,** 250m group on EK80 seen at 78° 49.350'N 03° 02.840'W (±0.3 nm north?)	2474 m	Deployed: 16 Aug 2021 12:42 UTC **16/8/21 changed out 50 m kevlar with 40m to get top lower than in 2020**	**IPS5** **SBE37** ADCP **SBE37** **SBE37** RCM9 **SBE37** RCM11 **SBE37** RCM Seaguard AR861	**51062** **3492** 17462 **10294** **3996** 1049 **7061** 538 **8821** 834 499	**44** **46** 50 **150** **273** 276 **1526** 1529 **2439** 2442 2444
F12-23	N 78°49.968' W 04° 00.730'	1848 m (EK80 depth about 17 m too much?)	Deployed: 15 Aug 2021 19:43 UTC	**IPS5** **SBE37** ADCP **SBE37** **SBE37** RCM9 **SBE37** RCM11 **SBE37** RCM Seaguard AR861	**51167** **14099** 20021 **13252** **3994** 836 **13505** 556 **8226** 345 500	**52** **54** 65 **150** **275** 279 **1476** 1480 **1817** 1820 1822
F13-23	N 78° 50.333' W 04° 59.927'	1018 m	Deployed: 14 Aug 2021 20:01 UTC	**IPS** ADCP **SBE16** AURAL **SBE37** **SBE37** RCM9 **SBE37** RCM Seaguard AR861	**51140** 18070 **7253** N/A **7060** **3995** 1326 **13504** 883 743	**50** 56 **58** 72 **147** **245** 248 **996** 1000 1002
F14-23	N 78° 48.848' W 06° 30.127'	270	Deployed: 14 Aug 2021 14:05 UTC	**IPS** **SBE37** ADCP **SBE37 ?**	**51138** **7058** 17461 **7054 ?**	**48** **56** 60 **112 ?**

				SBE37	**9853**	**150**
				SBE56	**10330**	**203**
				SBE56	**10331**	**228**
				SBE37	**7057**	**257**
				Nortek AQD	16603	260
				AR861	568	267
F17-18	N 78° 50.139' W 08° 06.233'	230	Deployed: 13 Aug 2021 21:00 UTC	**SBE37-IM weak link**	**23259**	**30**
				Data logger	NPI004	52
				SBE16	**7212**	**54**
				ADCP ext. battery	24385	107
				SBE16	**7339**	**108**
				SBE56	**3942**	**170**
				SBE56	**3943**	**196**
				SBE37	**14098**	**216**
				RCM9	1325	218
				AR661	501	220
F20-2	N 78° 50.100' W 10° 08.813'	326	Deployed: 13 Aug 2021 14:09 UTC	**SBE37-IM weak link**	**20128**	**30**
				Data logger	NPI003	54
				SBE37	**9852**	**56**
				ADCP ext. battery	727	106
				SBE37	**7059**	**109**
				SBE37	**7055**	**313**
				RCM7	9694	316
				AR661	**410**	318

Table 4.2: *Moorings deployed during FS2021.*
*** SAMI** *pH/pCO2: P0261/S2CA01*

Moored instrument related preparations:

- Five ACDP calibrations were carried out in May in Tromsø. Two ADCPs recovered on F20 and F17 on the cruise received an external battery pack, however, still a calibration on ice was needed for these two with the external battery. See section 4.3.

- NOTE: One large ADCPs (SN 18070) was not disconnected after calibration and showed very low voltage on ship: Kristen changed to new batteries and so this one needed to be recalibrated on land-fast ice again.

4.3 ADCP calibrations FS2021

5 ADCPs calibrated in Tromsø (12, 19 and 20 May 2021):

- SN 17461, 18070, 20021 (calibrated at Holt, Tromsø. All errors < 2.5°)

- SN 17462 did not go through any calibration, several attempts with internal and external battery, none of them went through the whole 360°. Each time stuck in one quadrant. Compass broken? Kristen will contact RDI. (Note, this ADCP has worked well during the 2019-2020 season and calibration in June 2019 gave an error of 2.4°. Applied AR (reset) and AX commands (validate compass), then AF == > OK. New attempt 19 May (Holt): final error 0.9°

- New SN 24899 did not get an error less than 15° after 3 different attempts with different battery or with different orientation. Kristen will make a new battery from demagnetized cells and we try again on 19.5. New attempts 19+20 May (Holt and Fram Centre after discusion with Loic@ RDI): final error 4.1°

- External battery cases (F20 and F17): the ADCPs needed one time calibration on land fast ice. This went well on an ice floe during the cruise in August.

Deployment plan

F20 @ 100m	**F17** @ 100m	**F14**	**F13**	**F12**	**F11**	**F10**
External battery case On ice (12/8)	External battery case On ice (12/08)	Calibrated in Tromsø (12/5)	Calibrated in Tromsø (12/5)-flat! Redone on ice (12/08)	Calibrated in Tromsø (12/5)	Calibrated in Tromsø (19/5)	Calibrated at Fram Centre (20/5)
Error 3.4°	Error 4.7°	Error after cal: 1.5°	Error 3.3°	Error after cal: 1.3°	Error after cal: 0.9°	Error after cal: 4.1°
Alkaline	Lithium	Lithium	Alkaline	Lithium	Lithium	Lithium
N/A	ICE track	BTM track	BTM track	BTM track	BTM track	BTM track
SN 727	SN 24385	SN 17461	SN 18070	SN 20021	SN 17462	SN 24899

5. CTD Measurements

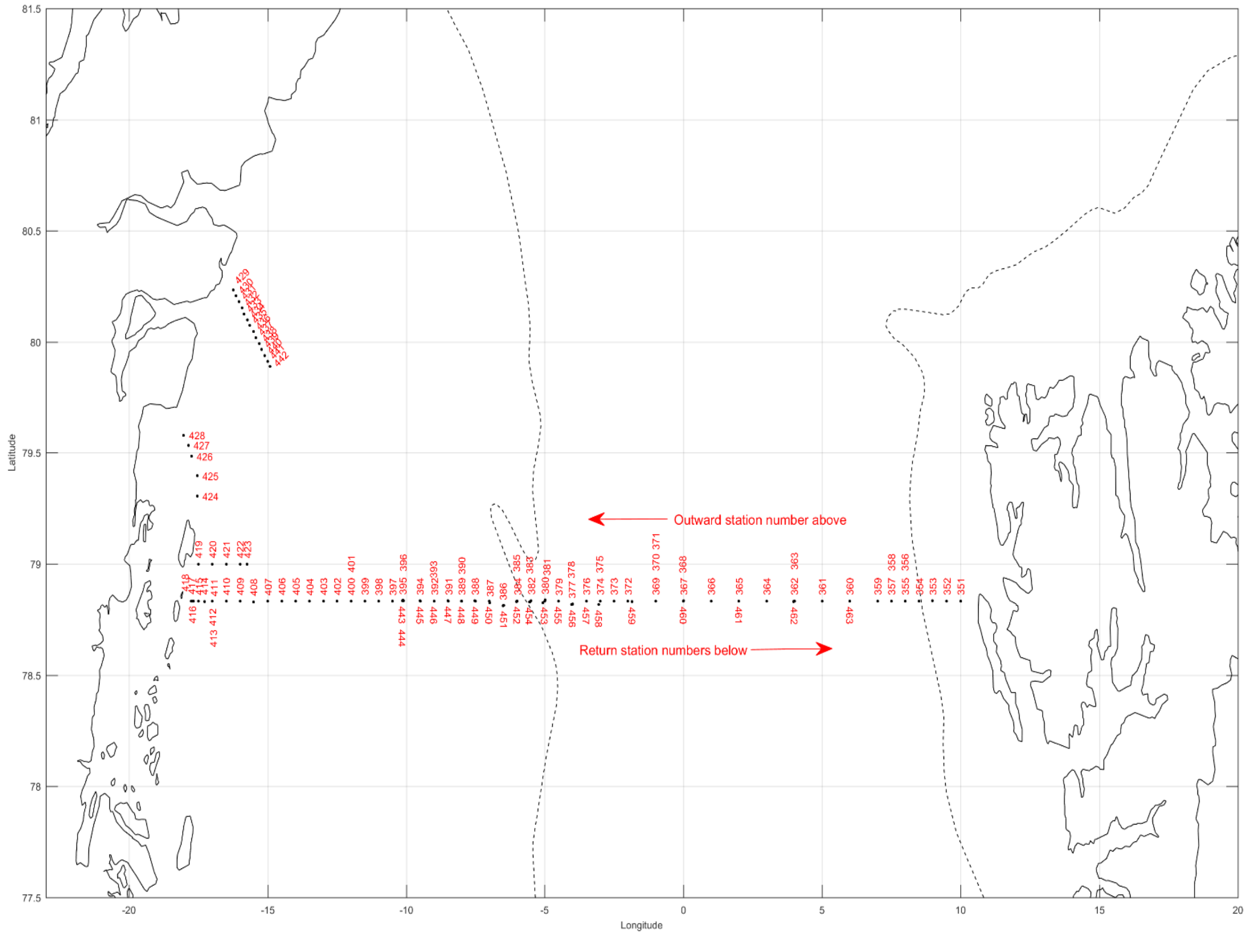


Figure 5.1. CTD stations completed during FS2021. Where two stations occur at the same location, the number of the second station is offset for readability.

5.1 General Approach

The CTD used was an SBE911+ unit. The T, S and O_2 ducts was flushed with Triton-X and freshwater between stations, which was blown out by mouth just before deployment, to avoid problems with icing. At the beginning of stations, the CTD was lowered to 10 dbar and allowed to soak until the pump started and sensors stabilised. The CTD was then brought to the surface and then lowered to within 10 m of seabed as determined using the altimeter. Data acquisition was generally initiated just before deployment with the CTD on deck and allowed to run until the CTD was back on deck at the end of the cast.

During FS2021 The CTD was always lowered over the side of the ship in the conventional way, the moon pool was not used. Niskin bottles were closed using the bottle fire command within the Sea-Bird acquisition software so that a .bl file was created for each cast when bottles were fired. NMEA time and position information was fed to the acquisition computer and added to each scan line of the data files. Cast positions and starting times were also automatically added to the header of all data files.

Note that the first station completed during Fram Strait 2021 has the number 351 and not 001. The vessel operators specify numbers assigned to CTD stations. The first cast each year has the number 1 and subsequent casts are numbered sequentially.

5.2 CTD Package Configuration

Channel	Sensor	Serial Number	Last Calibration
Frequency	Temperature 1	4535	20-Feb-2020
Frequency	Conductivity 1	4386	28-Jan-2020
Frequency	Pressure	141612	19-Dec-2017
Frequency	Temperature 2	4306	28-Jan-2020
Frequency	Conductivity 2	2799	28-Jan-2020
A/D Voltage 0	SBE43 Oxygen 1	3774	28-Feb-2020
A/D Voltage 1	Altimeter	73084	24-Dec-2017
A/D Voltage 2	SBE43 Oxygen 2*	0276 / 3635*	20-Jul-2019 / 27-Feb-20
A/D Voltage 3	(FREE)	N/A	25-Jul-2019
A/D Voltage 4	Transmissometer	CST-2003DR	01-Oct-2019
A/D Voltage 5	Chl. Flourometer	FLRTD-6506	18-Sep-2020
A/D Voltage 6	(PAR)	70736	29-Oct-2018
A/D Voltage 7	(CDOM Flourometer)	FLCDRTD-1930	25-Jul-2019

*Table 5.1: CTD package configuration during FS2021. * The secondary oxygen sensor 2799 became unstable, and was replaced with* 3635 *after station* ***361***. *The CDOM fluorometer FLRCTD1930 has an internal gain setting (AsV) which can be varied between 1, 2 and 4. AsV was set to 1 during FS2021 (maximum gain, smallest range). On Fram Strait cruises before 2019 the AsV was generally set to 2.*

5.3 CTD Sections

Two sections were completed during FS2021 as follows:

- The Main Section (Figure 5.2): An east-west section along the Fram Strait mooring array line at 78º 50 N, which is repeated annually. During Fram Strait 2021. Open drift ice conditions on the East Greenland Shelf allowed the vessel to extend the Main 78° 50' N section to the coast of Greenland and permitted a few stations in front of the 79N Glacier (Figure X.1). FS2021 occurred earlier in the year than previous Fram Strait cruises The Main Section shows much warmer temperatures in the upper 25m compared with sections collected in late summer.

- A Westwind Trough Section (Figure 5.3): A high-resolution section across the Westwind Trough on the Northeast Greenland continental shelf.

Station times and the types of samples collected at each station are summarized in Table 6.1.

5.4 Salinity Sensor Validation

Water samples for laboratory salinity measurement were collected along the Main Fram Strait section at standard depths where tracer samples were collected:1, 5, 15, 25, 50, 75, 100, 150, 200, 250 and 400 dbar, plus one sample from the bottom of the water column. Where time and rosette capacity allowed additional deep water samples were collected.

Salinity samples were analysed on broad using Guildline Portasal portable salinometer (serial number 70177), which was standardised after every 24 measurements using IAPSO P-series standard seawater. The salinometer performed well for the duration of the cruise.
Comparison of laboratory salinity measurements and CTD-salinity measurements revealed an offsets of 0.010 and 0.017 practical salinity units for the primary and secondary sensor groups respectively (Figure 5.4). The agreement between the primary and secondary sensor groups and the laboratory measurements was **an order of magnitude poorer** than in 2017, 2018 and 2019 and 2020. Moreover, the errors during 2021 were not normally distributed, featuring a long tail to the right-hand side of both histograms (Figure 5.4).

The sensors using during FS2021 had been used extensively since their last service and calibration in January 2021. It is unclear whether the extended service interval, routine flushing of sensors with freshwater and detergent (which potentially leads to icing) or another factor caused the poor performance, but from 2012-2017 when sensors were service and calibrated recently before cruises and the CTD was not flushed with freshwater or detergent between casts, precision was routinely of the order +/- 0.001 as opposed to +/- 0.01.

5.5 Dissolved Oxygen Sensor Validation

Water samples for laboratory oxygen measurement were collected at standard depths of 400, 1000 and 2000 dbar and at the bottom of the cast at stations along the main sections. Samples were collected in triplicate in volume-calibrated glass bottles, with an angled glass stopper. A silicon tube was attached to the spigots of the Niskin bottles and inserted to the bottom of the sampling bottles, which were filled slowly to minimise exposure to the atmosphere. Winkler re-agents 1 and 2 were added to the samples immediately after sampling and samples were then stored under water and allowed to reach room temperature before analyses to ensure volumetric consistency with reagents added.

Analysis followed standard Winkler protocol using a Metrohm Ti-Touch potentiometric titrator, with a 2 ml dosing unit filled with 0.1M thiosulphate. Samples were run in 6 batches of 24 samples (8 sets of 3 triplicates). Sets of 4 blanks were run before and after each batch of samples and 4 measurements of an internal iodate standard (0.01M, prepared at NPI in Tromsø in June 2021) were run before each batch of samples.

Comparison of laboratory oxygen measurements and CTD-oxygen measurements revealed an offset of -0.5 umolL-1 for the primary sensor and an offset of -2.6 umolL-1 for the replacement secondary sensor (s/n 3635) (Figure 5.4). These values are typical. Note that the secondary sensor used initially (s/n 0276) had a defective electrical connection and did not record useful measurements this was replaced after station 361.

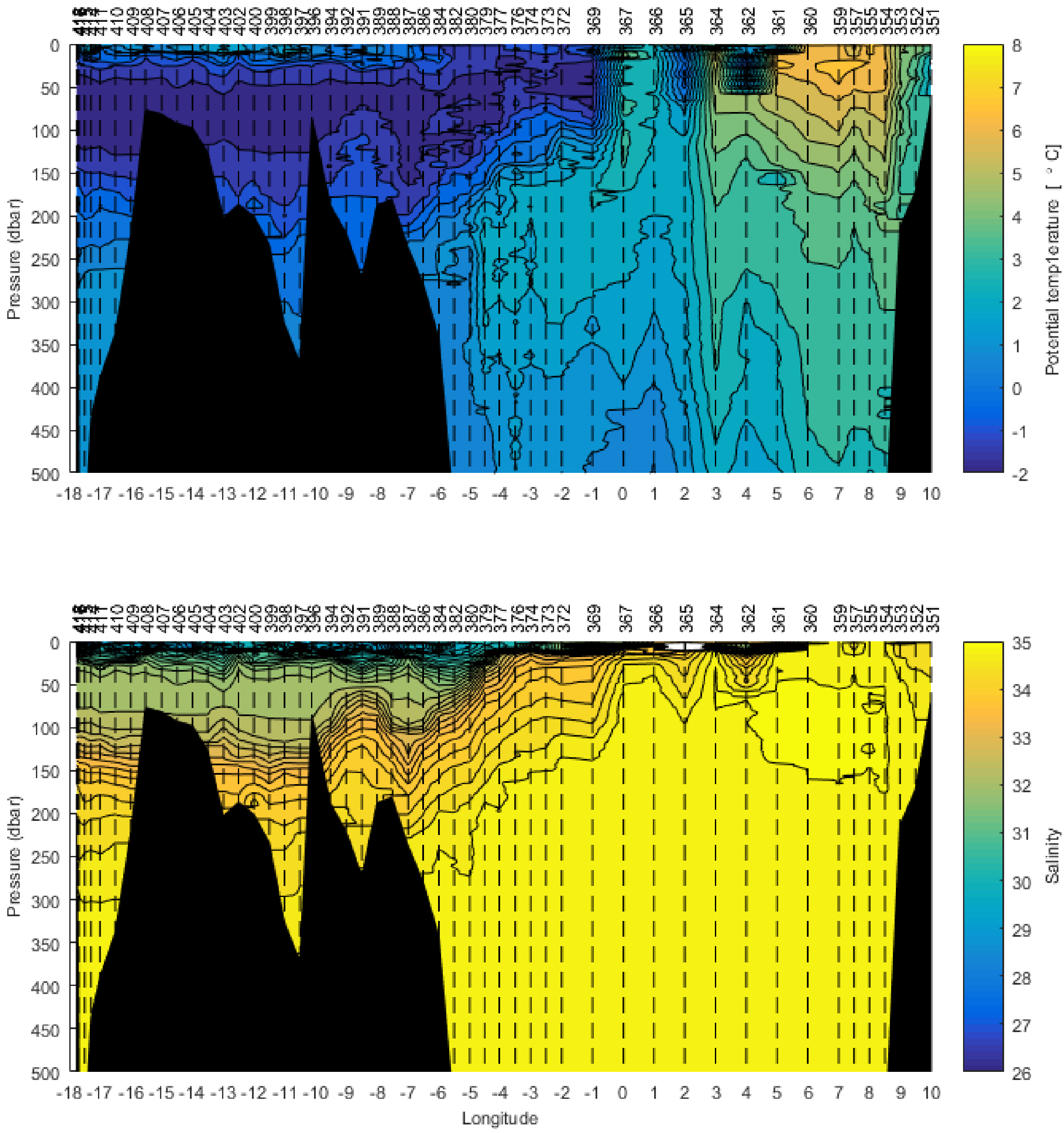


Figure 5.2: CTD measurements along the main Fram Strait section; Measurements are from the primary temperature (top panel) and primary salinity (bottom panel) sensors. Station numbers are indicated above the sections.

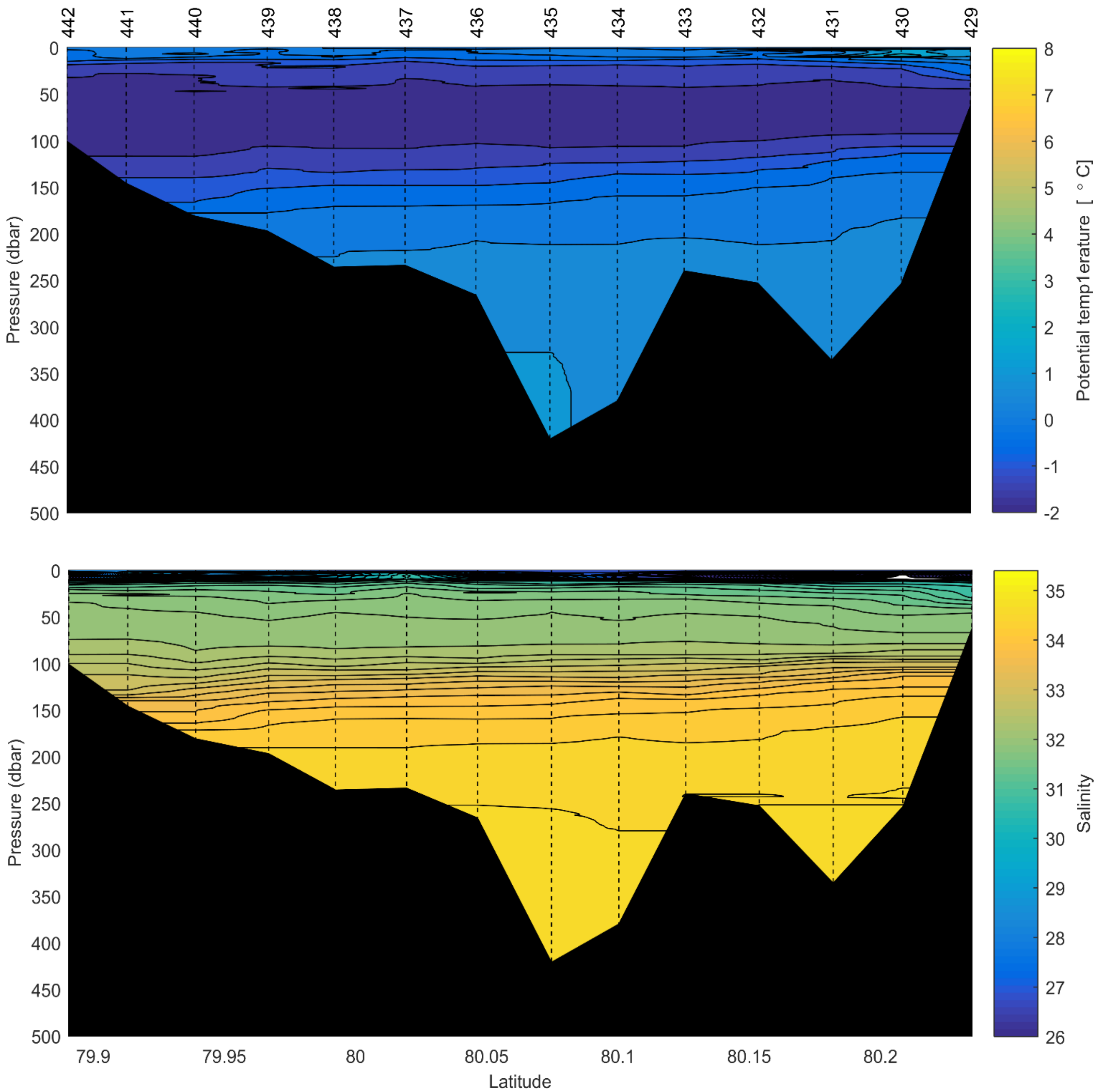


Figure 5.3: CTD measurements along the Westwind section. Measurements from the primary temperature (top panel) and primary salinity (bottom panel) sensors. Station numbers are indicated above the temperature section.

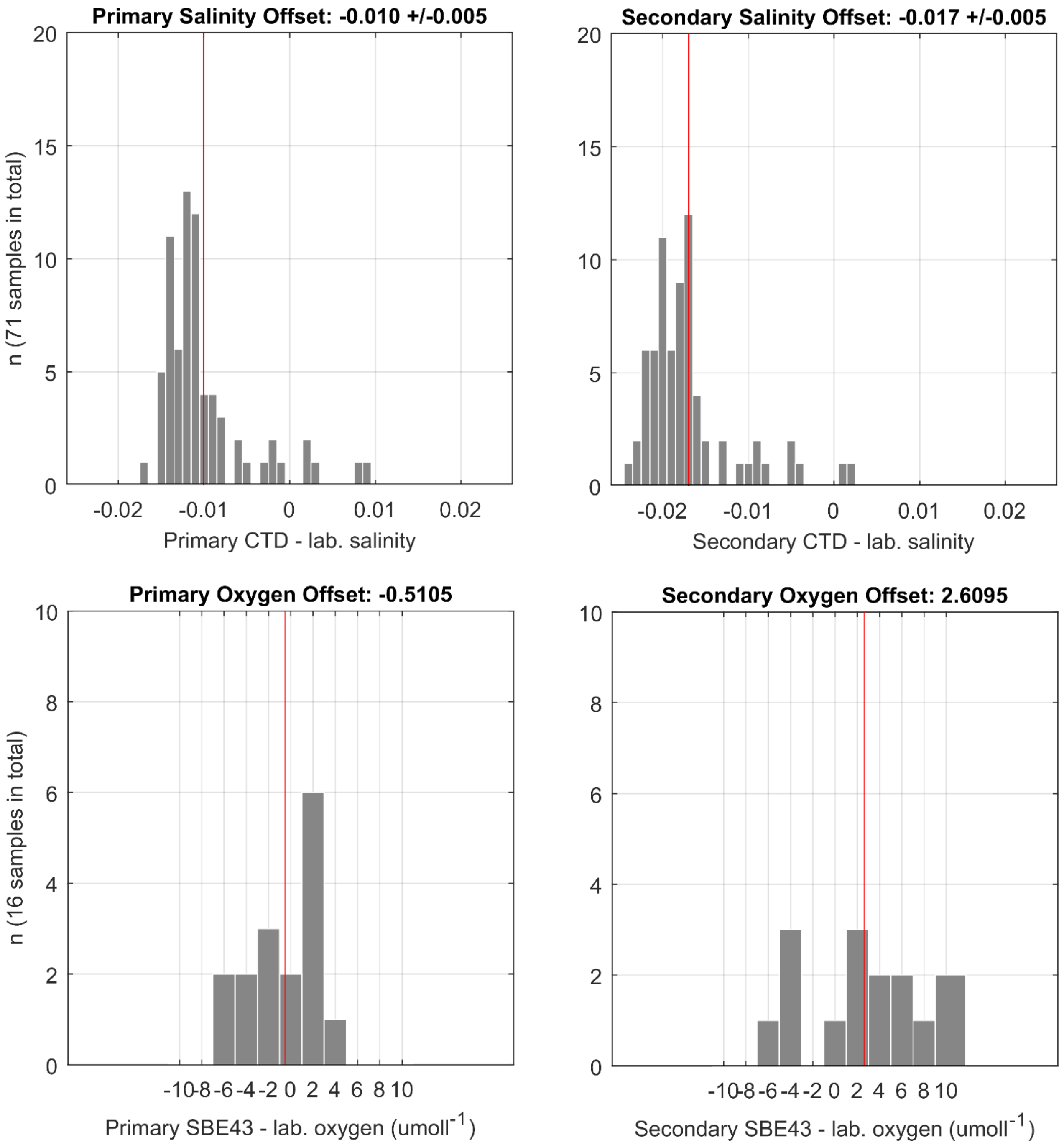


Figure 5.4: Histograms showing the difference between the primary (left hand panels) and secondary (right hand panels) sensor groups on the CTD and laboratory salinity and dissolved oxygen measurements. Only points deeper than 400 m are considered for salinity validation, due to step salinity gradients close to the surface.

For an overview of all biogeochemical parameters collected from the CTD water sampling stations, we refer to the next section on the ARICE project NoTAC, see Table 6.1.

6. NoTAC: Novel Tracers of Arctic Carbon and water exchange in the Fram Strait (EU-ARICE PROJECT)

6.1 Research objectives

The NoTAC project addresses four specific research objectives:
1. Assess the variability of DOM composition and concentration within the water masses and develop an empirical model for retrieving water fractions from the optical properties of DOM to be validated with environmental radioisotope analysis;
2. Link changes in microbial community (e.g., phyto- and microzooplankton) with different water mass origins;
3. Calibrate and validate the use of bio-optical sensor-based data for water mass tracing;
4. Determine the relative importance of photochemical- and microbial degradation on mineralization of Arctic organic carbon.

6.2 Water sampling

Water sampling was performed in 34 occupied stations along the transect across the Fram Strait Samples were taken with Niskin bottles attached to the Rosette system at selected sampling depths. The number of samples per profile ranged between 8 and 17, depending on the local bathymetry. The NoTAC team was sampling for several distinct parameters which were sampled with a distinct range of depths (e.g., some parameters were more focused on the surface layer, whereas other focused on the entire water column). In the framework of the NoTAC project, water samples were subject to the following analysis:

- Dissolved nutrients (NO2, NO3, SiO2 and PO4)
The samples were immediately frozen after sampling and were sent to DTU after the cruise for posterior analysis of nutrient concentrations. The samples have already been analyzed and the data is being currently quality-controlled and processed. Dissolved nutrients data will be further used for performing the water fractionation, which is our reference for water mass tracers in the project. The data will also support the incubation experiments and ecology-related studies.

-Dissolved Organic Carbon (DOC) concentration
Samples were filtered through 0.22µm filters and acidified to pH=2 immediately after sampling and stored in 4°C. The samples will be shipped to the North Carolina State University, where Dr. Christopher Osburn's group will perform the analysis of DOC concentration and 13C-DOC. Those analyses will provide a quantification of bulk dissolved organic carbon concentrations and ages, which will be further used for studies concerning biogeochemistry and also in the incubation experiments.

- Dissolved Organic Matter (DOM)
Samples for DOM analysis were filtered through 0.22µm filters immediately after sampling and stored in 4°C until analysis. The samples were analyzed onboard during the cruise with the instrumentation provided by the NoTAC team. CDOM measurements were performed with a Shimadzu spectrophotometer using a 10cm quartz cuvette. CDOM measurements are expressed as absorption spectra which can be further used to be converted into DOC concentrations (Gonçalves-Araujo et al., 2020). FDOM measurements were performed simultaneously with an HORIBA Aqualog fluorescence spectrophotometer. Those data are presented as excitation-emission matrices, which can be decomposed into individual fluorescent components that reflect different components of the DOM. Data is currently being processed and quality-controlled.

- Radioisotopes (233U, 236U)

Samples for the analyses of radioisotopes were collect and kept in room temperature until being shipped to DTU, where they will be analyzed by Dr. Jixin Qiao's group. In the lab, those samples will be filtered and a co-precipitated with a FeCl3 solution. The number of atoms of 233U and 236U will be determined using an accelerator mass spectrometry. This data will be used to investigate the pathways of Atlantic water entering the Arctic Ocean and exiting through the Fram Strait.

- Lignin Phenols and DOM molecular composition

Samples (5-10 L) for the analyses of dissolved lignin phenols were collected at 5-8 depths at selected stations. The samples were filtered through 0.22 µm filters and acidified to pH=2. The organic matter in seawater was then isolated by solid phase extraction (SPE) on board the research vessel. The SPE cartridges were shipped to DTU for further processing. Briefly, this process includes cupric oxidation under heat and pressure to release lignin phenols, followed by analytical measurements using High-Pressure-Liquid-Chromatography combined with absorbance and fluorescence spectroscopy. Lignin measurements will be assessed as a tracer for freshwater and terrestrial organic matter through the Fram Strait. The samples for analysis of DOM molecular composition were taken at the same locations as lignin samples. The samples contained in the SPE cartridges used for lignin analysis will be also used for the molecular analysis. This will be performed by Ass. Prof. Juliana D'Andrilli (LUMCON) using the Fourier-transform ion cyclotron resonance mass spectrometry (FT ICR-MS) methodology. This will give us a more refined idea of the DOM composition, by allowing us to track thousands of molecule-forms presented in the samples which cannot be differentiated by employing bulk spectroscopic methods (e.g., CDOM and FDOM).

- Nitrogen Isotope

Samples for the analysis of natural nitrogen (15N) isotope abundances were taken over the entire profile at selected stations and filtered through 0.22 µm filters and stored in freezer. The samples were shipped to Denmark together with the equipment from the DTU team and will be further shipped to South Africa, where Dr. Sarah Fawcett's group will perform the analyses and data processing. These results will be used to test their applicability as a water mass tracer in the Arctic Ocean.

- Phytoplankton and microbial composition

During the Fram Strait cruise 2021, sampling for phytoplankton community and bacterial abundances were conducted at 34 stations (in each station, 3-5 depths were sampled in the euphotic zone). Live phytoplankton community samples were characterized on board the ship, using pulse-shape recording flow cytometry. This technique can fast enumerate cells ranging from 0.5-1000 µm (covering most of sizes found among phytoplankton) and by storing the scatter and fluorescence information on each particle as an optical profile that reflects the particle characteristics (size, morphology, pigments, etc.) it allows to classify the particles in different populations. Bacterial abundances samples were fixed and will be analyzed in the Marine Research Laboratory (Finnish Environment Institute, SYKE). This dataset will be used to understand changes in microbial community related to different water masses and when combined with nutrients and DOM information, will provide an ecological perspective to the Fram Strait microbial community distribution. Additionally, we will further investigate the suitability of biological indicators as potential water masses tracer, due to the high spatial resolution of the data set.

- Particulate absorption

Samples for particulate absorption analyses were taken from three depths at selected stations (5, 15 and 25 m) and filtered onto 0.7 μm GF/F filters. The filters were stored in freezer and shipped to Poland, where they will be analyzed by Prof. Piotr Kowalczuk's group at IOPAN. Filter papers with deposited particles will be will be measured with use Lambda 850, (Perkin Elmer, USA) in the spectral range 300 - 850 nm with 1 nm resolution, equipped with the integration sphere. The transmission-reflection method described by (Tassan, 2002; Tassan & Ferrari, 1995). This technique allows to measure the optical densities, ODs(λ), of the suspended material collected on the filter.

ODs(λ)=log (1/(1-A(λ))

where: A(λ) is the total absorbance obtained from measurements in transmission and reflectance modes. Blank samples will be measured for every batch of samples to estimate correction factors for filter pad light scattering and absorption. The clean filters pads used for blank reference measurements will be rinsed with 30 ml filtered (0.2 μm pore size membrane filters) seawater.

The path length amplification correction will be applied for calculation of particulate absorption coefficients from measured OD**s**(λ) spectra. The light scattering by the layer of suspended matter collected on the filter caucused elongation of the optical path length of photons passing through the filters. A correction will be applied using the dimensionless path length amplification, the beta-factor, that converts the optical density of particles collected on the filter (ODs(λ)) into the optical density of particles in solution ($OD_{sus}(\lambda)$). The data set was corrected with the beta-factor proposed by (Stramski et al., 2015) for T-R method:

$OD_{sus}(\lambda)$ = 0.496·ὒ ἶ s ($)^2 + 0.388\cdot$ ODs(λ).

The absorption coefficient of particles was calculated using the formula: ὒ$_p(\lambda)$ = [ln(10).$OD_{sus}(\lambda)$]/l
where: l [m] – the hypothetical optical path in solution, determined as the ratio of the volume of filtered water to the effective diameter of the filter; which was the diameter of the colored area on the filter measured individually for each sample.

The absorption coefficient by non-algal pigments, named also detrital absorption, $a_{NAP}(\lambda)$, determined after bleaching of the algal pigments for 20 minutes with a 2% solution of calcium hypochlorite Ca(ClO)2 (Koblentz-Mishke et al., 1995). Filters were rinsed with artificial sea water (64 g NaCl in 1L of ultra-pure water). The phytoplankton pigment absorption coefficient, $a_{ph}(\lambda)$ was determined as the difference between $a_p(\lambda)$ and $a_{NAP}(\lambda)$, using the value of $a_{ph}(\lambda)$ at wavelength 750 nm as the null-point correction (Stramska et al., 2003, 2006). These results will provide us with data on the amount of light absorbed by particles distributed in the surface layer, which is essential for calibration and validation of bio-optical sensors and ocean color algorithms as well as its biogeochemical implications.

- Chlorophyll a concentration

Pigments contained in the suspended particles retained on filter pads will be extracted in 96% ethanol at room temperature for 24 hours (Wintermans & De Mots, 1965). Chla was determined by a spectrophotometric method (LORENZEN, 1967) using a Perkin Elmer Lambda 650 spectro-photometers. The optical density OD(λ) of the pigment extract in ethanol was measured in a 2 cm cuvette. The raw OD readings at 665 nm were corrected for the background signal in the near infrared region (750 nm): ΔOD = OD(665nm) - OD(750nm); and resulting OD was converted to Chla using an equation involving the volumes of filtered water (V_w) [dm^3] and ethanol extract (V_{EtOH}) [cm^3], path length (l) [cm] , and the specific absorption coefficient of chlorophyll a in 96% ethanol [dm^3 $(g\ cm)^{-1}$] (at 665 nm) (Stramska et al., 2003; Strickland & Parsons, 1972):

$$Chla = (10^3.\Delta OD.V_{EtOH})/(83.V_w.l)^{-1}.$$

The total of number of 126 samples for determination of chlorophyll a concentration and particulate absorption has been collected. Samples are analysed in the laboratory.

- Bacterial composition

Bacterial composition with special focus on diazotrophs will be analyzed based on the collection of nucleic acids (DNA and RNA) for amplicon sequencing targeting the nifH gene. For that, water samples were collected from 4 depths at selected stations and filtered onto 0.3 µm filters. Filters were stored in freezer and shipped to Denmark, where they will be analyzed at the University of Copenhagen (KU) at Prof. Lasse Riemann's group. These results will allow our team to map the species present in the region as well as to assess their ecological functioning with respect to the nitrogen cycle.

Table 6.1 lists the core water samples collected at each CTD station. During the cruise a paper log sheet was completed at each CTD station listing the depths at which bottles were fired and the samples taken from each bottle. Times, depths and positions manually recorded on log sheets are indented as a backup in the case of a problem with the data acquisition, not a replacement for electronically logged time and position data. There were no problems with time or position data during the cruise.

Station	Salinity	Winkler	$\delta^{18}O$	Nutrients	ATCT	129I	236U
351	6		6	6	5		
352	8		8	8			
353	9		9	9	9		
354	12		12	12			
355	14		14	14	12	6	15
356						4	6
357	12		12	12			
358							
359	12		12	12	12		
360	12	2	12	12	12		
361	16	3	12	12			
362	10		11	11	11		3
363			1	1	1		19
364	12		12	12			
365	12		12	12	12	8	
366	12		12	12	12	8	
367	4	2	1	1	1		18
368	11		11	11	11	7	6
369	1		1	1	1		16
370	11		11	11	11	8	9
371							
372	15	2	12	12	12	8	
373	12		12	12			
374	15		12	12	12	11	20
375							19
376	12		12	12			
377	15	4	12	12	12	11	19
378							21
379	12		12	12			
380	12	3	12	12	12	8	20
381							18
382	12		12	12			
383							

384	11		11	11	11	7	15
385							15
386	10		10	10			
387	10		10	10	10	7	
388							
389	9		9	9	9	6	11
390							11
391							
Station	**Salinity**	**Winkler**	**$\delta^{18}O$**	**Nutrients**	**ATCT**	**129I**	**236U**
392	10		10	10	10	7	
393							
394							
395	5		10	10	10	7	13
396							12
397							
398	10		10	10	10		
399							
400	8		9	9	9		7
401							6
402							
403	8		9	9			
404							
405	5		7	7			
406							
407	7		7	7	7		7
408							
409	10		10	10			
410							
411	10		10	10		6	6
412	1		1	1			13
413							3
414							
415	11		11	11	5		
416							
417							
418							
419							
420							
421							
422							
423							
424							
425							
426							12
427							
428							
429							
430	10		10	10			

431							
432							
433							
434							
435	8		8	8			16
436							
437							
438							
439							
Station	**Salinity**	**Winkler**	**$\delta^{18}O$**	**Nutrients**	**ATCT**	**129I**	**236U**
440							
441							
442							
443							
444							
445							
446							
447							
448							
449							
450							
451							
452							
453							
454							
455							
456		4		12			
457							
458	11	4					
459	9	6					
460							
461							
462							
463							

Table 6.1 Number of each type of water sample collected at each CTD station.

6.3 Bio-optical measurements

Two different bio-optical deployments were performed at selected stations during the cruise, which were coordinated by the NoTAC team. First, there was the deployment of the bio-optical sensors using a package and deployed with the facilitation of a winch (Figure 4).

Vertical profiles of inherent optical properties, fluorescent dissolved organic matter (FDOM) together with conductivity, temperature, and pressure were measured at all stations from the surface down to 200 m depth using an integrated instrument package consisting of an ac-9 plus attenuation and absorption meter (WET Labs Inc., USA), a WETStar CDOM fluorometer (WET Labs Inc., USA), and a Sea-Bird SBE 49 FastCAT CTD probe (Sea-Bird Electronics, USA). Spectral light absorption, a( ) and beam attenuation, c( ), coefficients were measured at nine wavelengths (412, 440, 488, 510, 532, 555, 650, 676, and 715 nm). The ac–9 plus calibrations were performed regularly. After cleaning with ultra-pure water, stability instrument readings were inspected with in-air measurements. The required correction of absorption signal for scattering was performed with the so-called proportional method by which zero absorption is estimated at 715 nm (Zaneveld et al., 1994). Subtraction of absorption coefficients from attenuation coefficients determined volume scattering coefficient, b( ).

FDOM was measured using a three-channel WET Labs WETStar fluorometer equipped with two laser LEDs that excited the water sample inside the flow-through quartz cell at 280 and 310 nm, and two detectors to measure emission intensity at 350 and 450 nm. Such construction allowed for combinations of three channels with distinct excitation–emission features in specific peak areas as given in (Coble, 1996): Channel 1 (CH1), ex.D310 nm and em.D450 nm, represents marine ultraviolet humic-like peak C and marine humic-like peak M; Channel 2 (CH2), ex.D280 nm and em.D450 nm, represents UVC terrestrial humic-like peak A; and Channel 3 (CH3), ex.D280 nm and em.D350 nm, represents the protein-like tryptophane peak T. **I**CHn is the fluorescence intensity at a particular channel, where n denotes the channel number from 1 to 3. Recorded raw **I**CHn values could be transformed in to so called Raman Units duirng post cruise calibration. An average value of the fluorescence intesity in the same excitaion and emission range for respective channel in the in situ FDOM fluorometer will calculated from measured excitation emission matrices (EEMs) of water samples measured with use of bench top spectro-fluorometer. Derived values of Raman calibrated EEMs will enable to develop calibration curves for each channel. During the use of the in situ WETStar fluorometer, a noticeable but small drift was reported in fluorescence intensities in raw counts (RC), which was corrected for. This offset will be determined as the difference in any **I**CHn, between measurements in a given year in the depth range 100–150 m, at salinity >34.9, and temperature T >0 and measurements repeated in the same salinity and temperature range during the field campaign in other years. The salinity and temperature characteristics at the chosen depth range were typical for the core of AW inflow, which is characterized with stable values of spectral absorption (measured with an ac–9 plus attenuation and absorption meter), negligible chlorophyll a, and very low background CDOM absorption levels (Kowalczuk et al., 2019).

The optical package described above was deployed on each measurement station at full degree longitude along the main transect, from 0 to depth of 200 m, or shallower depending on sea bottom topography at decent speed 0.4 m/s. After the third deployment, the instrument pump was broken. The package was provisionally fixed on board and the instrument package was used continuously during the cruise, however the decent speed was reduced 0.2 m/s, due to smaller flow rate of provisinal pump. Stations omitted during westbound transit were repeated during eastbound return passage. Data measured during the Fram Strait 2021 cruise, after processing and post cruise calibration and corrections will be added to Fram Strait Inherent Optical Data collections from 2014, 2015, 2016 and 2020 constituting a time series collection. The examples of IOP and FDOM data after initial calibration and processing were presented on Figure 7.

On selected stations during the day light (08:00 am – 18:00 pm) the set of radiometers was deployed (Figure 5). First we have deployed the floating TRIOS RAMSES (Trios Sensors, Gmbh., Germany) hyperspectral radiometer that measurered the upwelling radiance Lu(**l**), in the spectral range 320 – 820 nm, just below the water surface, see Figure 5. During deployments the simultaneous measurements of the incident vector solar irradiance, Es(**l**) were conducted with use of sky reference TRIOS RAMSES hyperspectral radiometer mounted on the ships top deck. After this measurements has been completed the IOPAN team conducted measurements of the distribution of solar irradiance in the water column with use of the multispectral C-OPS free-fall profiling radiometer (Bioshperical Inc., USA), that was hand deployed from the ship's side away from the ship shadow. Similarly to measurements conducted with use of TRIOS RAMSES radiometers, during C-OPS deployment the incident solar irradiance intensity was measured with use of reference sensor mounted on the ships top deck. The set of C-OPS radiometers have measured irradiance intesity in the following spectral band: 19 spectral channels (340, 380, 395, 412, 443, 465, 490, 510, 520, 532, 555, 565, 589, 625, 665, 683, 710, 765nm and PAR channel). Radiometric measurements were conducted during good meteorological conditions – wind speed less than 10 m/s and in the open waters or relatively loose ice pack.

6.4 Incubation experiments

To add a functional angle to the data set, rates of inorganic carbon and nitrogen (NO3 and NH4) uptake were conducted in short term incubations (4 hours) using stable isotope 13C and 15N. In total 9 experiments were conducted at selected stations across the transect (each one at 3 different depths). For the experiments, water was sampled and pre-filtered with a 200 µm mesh (to exclude larger grazers) and for each depth, two 1 L bottles were spiked with 15NO3 (0,2 µM final concentration) and the remaining two were spiked with 15NH4 (0,05 µM, final concentration) and H13CO3 (100 µM, final concentration), bottles were then incubated on deck with flowing surface sea water (to keep temperature close to the environment) and natural light. Bottles from deeper depths were wrapped in neutral optical film to simulate the appropriate light levels. After the incubations, all material was collected in 0.3 µm combusted glass fiber filters from which the amount of labelled dissolved inorganic carbon and nitrogen taken by the cells can be estimated. Results will be analyzed at Marine Biogeochemistry laboratory from University of Cape Town (South Africa), in collaboration with Dr. Sarah Fawcett. Such information can give insights on how different communities can influence nutrient flows in the water column and likely to vary with water masses.

Grazing on bacteria can impact the organic carbon cycling in the oceans and few datasets are available due to methodological constrains. Grazing on bacteria by small flagellates (< 20 µm) was estimated in 10 short term essays (2 hours at 4°C in the dark) over the cruise. Grazing by both heterotrophic and mixotrophic organisms was assessed by using the acidophilic stain LysoTracker Green, which binds to acid organelles (e.g., food vacuoles) and analyzed in the pulse-shape recording flow cytometer. Auto-, mixo- and heterotrophic organisms were identified based on the presence of red fluorescence only, presence of both red and green fluorescence or the presence of green fluorescence only. Number of cells in each class and the amount of green fluorescence in mixo- and heterotrophs was evaluated at the beginning and end of each incubation, and the difference is related to grazing activity by each community. Those results will be used to evaluate potential impact of grazing for bacteria in the Atlantic inflow and Arctic outflow and potential consequences for nutrients and DOM pool.

Microbial degradation and remineralization of the organic matter was evaluated in two big incubations, one from the Atlantic inflow core and a second from the Arctic outflow core. Those two contrasting water masses were chosen due to their contrasting properties: low DOC and higher autochthonous production in the Atlantic and high DOC and low autochthonous production in the Arctic. For each incubation, 15 glass bottles (4.6 L) were filled with water and incubated at 4ÅãC in the dark. At days 0, 2, 4 and 8 of each experiment, three bottles were sampled for inorganic nutrient concentration, DOC, CDOM, FDOM, POC+N, particle counts, bacterial abundances, and community composition. Three bottles from each experiment were shipped to Denmark and analyzed between 13-17 of September 2021 at DTU by Rafael Gonçalves-Araujo and Lumi Haraguchi, who had to travel to Denmark to conclude the experiments. Thus, degradation of the organic matter can be assessed after 42 days, providing information on the degradability of semi-refractory DOM of both water masses. In addition to the standard set of variables sampled, sampling for FT ICR-MS analysis of DOM were taken on day 0, 8 and 42 of each experiment to be performed at Louisiana Universities Marine Consortium (LUMCON) by Dr. Juliana D'Andrilli's research group.

Another experiment conducted on the ship aimed to determine the biological nitrogen fixation rates and primary production simultaneously. For that, water was collected at selected stations across the transect covering different water masses and were sampled at 4 depths (5, 50, 100 m and bottom). Samples were spiked with 15N2 gas and bicarbonate and then incubated for 24 hours. Then they were filtered onto 0.3 µm filters for posterior analysis at the University of Copenhagen.

Net Community Production was conducted through the incubation experiments. Bottles were overfilled with the seawater sample to prevent the formation of a headspace during closure of the glass stopper, and placed into containers with seawater under continuous illumination and mixing. The incubation temperature in the cold room was set to +4 C, which was representative of in situ conditions. Determination of the net community production by oxygen modification was carried out directly after sampling in 250 mL white glass bottles with optical oxygen sensor spots installed. Destruction was determined in foil-wrapped bottles of the same volume. The bottles were incubated in a thermo-stabilized luminostate at light levels representing surface, 15 m and 25 m Photosynthetic Available Radiation. The oxygen concentration dynamics was determined every 6 hours for 24, 48 or 72 hours depending on initial chlorophyll a concentration. Samples from the same Niskin bottles were filtered for chlorophyll a measurements in parallel to oxygen incubations. Optode sensors were calibrated for the bottles in use prior to the cruse using 0% and 100% dissolved oxygen standards of nitrogen-saturated water and oxygen saturated water, respectively.

7. VMADCP and LADCP measurements

During the cruise, both hull-mounted Vessel Mounted Acoustic Doppler Current Profilers (VMADCP) (38 kHz and 150 kHz) were used on the main transect across the Fram Strait to provide continuous measurements of ocean velocity. This meant it was turned when leaving Longyearbyen and stopped when reaching Isfjorden on Svalbard. It was decided to not use the drop-keel VMADCPs as the sampling would be interrupted too much when meeting sea ice implying that they would need to be stopped and lifted into the hull.

Lowered Acoustic Doppler Current Profiler (LADCP) data were collected at all CTD stations. The set up consisted of a double-head LADCP system (one downward looking (master) and one upward looking (slave) ADCP) with external battery case on the large, 24-bottle CTD rosette. The data were processed using the LDEO processing package (Version IX.7 – IX.10) and detided with the barotropic tidal model (TMD2.03/DATA/Model_tpxo6.2). The script files to program and start the LADCPs are given in Appendix C at the end of this report.

8. Sea ice work on the Fram Strait 2021 cruise

8.1 General overview

The sea ice work on Fram Strait 2021 cruise was conducted by Hiroshi Sumata, Paul A. Dodd, Yannick Kern and Thodoris Karpouzoglou with support from Jan Are Jakobsen, Laura de Steur, Colin Stedmon, Rafael Gonçalves-Aroujo, Anders Dalhoff Bruhn Jensen, Gang Lin, Lumi Haraguchi, Stine Zander Hagen, Piotr Kowalczuk, Alexandra Cherkasheva and Monika Zabłocka.

Different from the previous cruises, the 2021 cruise took place in August (31.07 – 20.08), which is about one month earlier than those of the previous years. At the time of this year, sea ice condition at the Fram Strait transect (N78.8°) and the north-east of Greenland shelf is characterized by a) main stream of sea ice outflow from the central Arctic Ocean that occurred from the eastern part of Greenland shelf to the shelf break (partly over the East Greenland Current), b) vast open water area between the main stream and fast ice over the Belgica Bank, c) fast ice over the Belgica Bank and its southward extension (Figure 8.1). The fast ice over the Belgica Bank was already unstable at the end of July 2021 (beginning of the cruise) and broken into pieces by the end of the cruise (Figure 8.2). The sea ice group successfully observed the in-situ sea ice conditions of the break-up event of the fast ice on site. Altogether, the sea ice group conducted 10 sea ice stations (Table 8.1) for ice core sampling including EM31 thickness survey at 5 stations in different ice provinces. Ship-based sea ice observations using ASSIST protocol as well as SAR image acquisition were made on daily basis during the cruise.

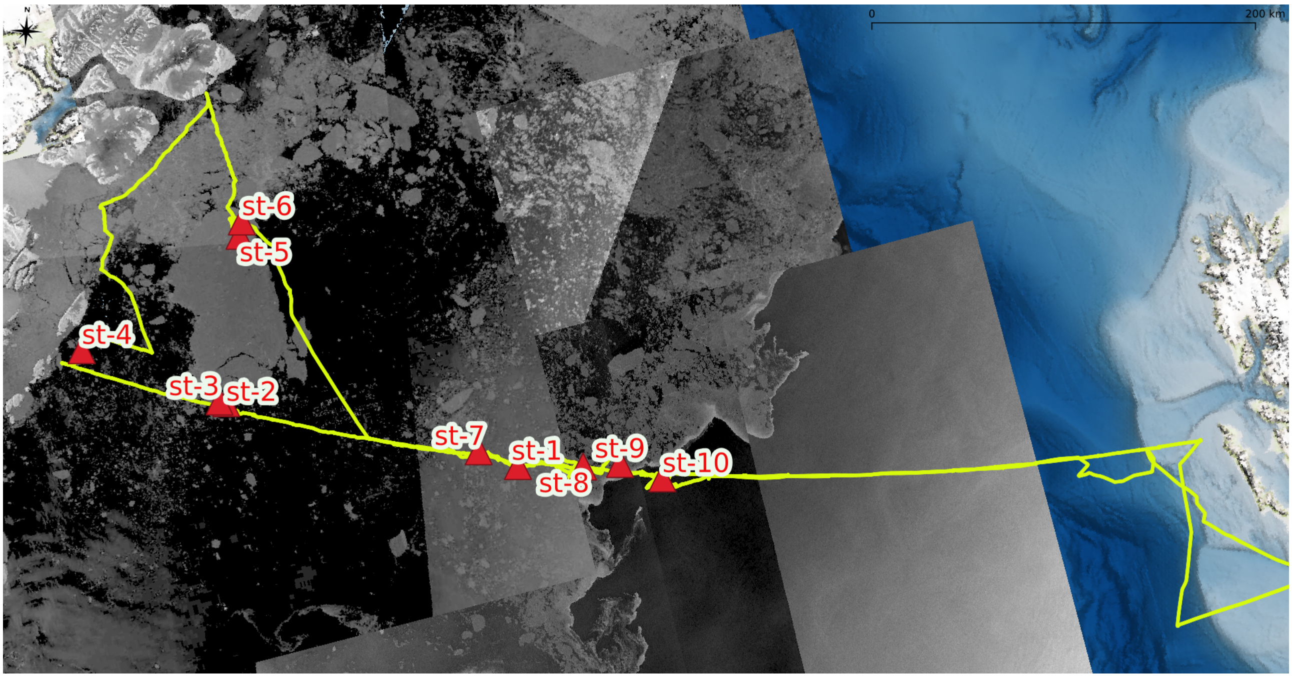


Figure 8.1: Location of ice stations (red triangle) together with cruise track (yellow) and sea ice image from Sentinel-1 SAR.

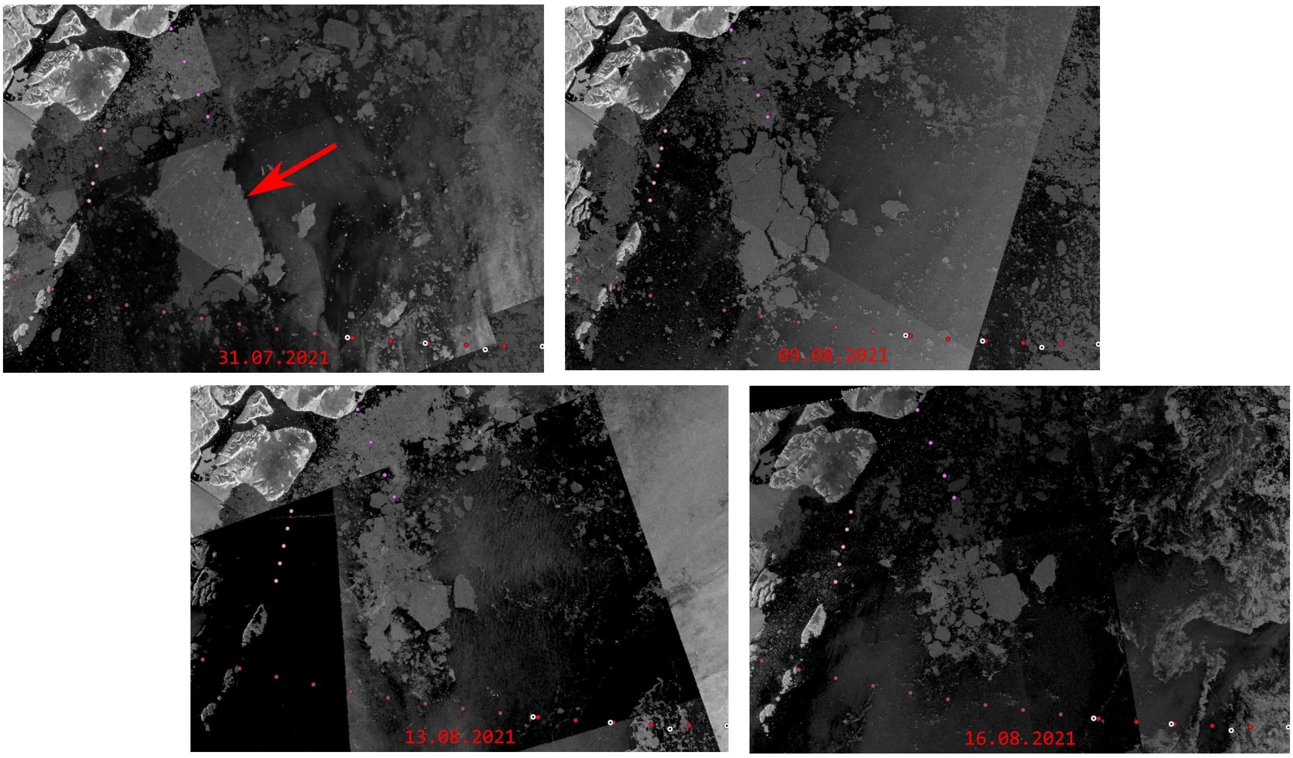


Figure 8.2: Sequence of Sentinel-1 SAR images capturing break-up of the fast ice over the Belgica Bank from the end of July to middle of August, 2021.

8.2 Sea ice stations

The sea ice team conducted ice stations in two different ice provinces in Fram Strait and northeast of Greenland shelf. The first ice province is approximately W 3° - W 8° over the Fram Strait transect, where the main stream of sea ice outflow from the central Arctic Ocean occurred during the cruise. The second ice province is the area between the main ice stream and the Greenland coast (W 8° - W 17°).

Sea ice conditions in the first province were characterized by strongly deformed multi-year thick ice with large fraction of ridges and rafting (Figure 8.3a). Ice thickness at the flat area of ice floes sometimes reaches 3 m, though variations in thickness were very large (1 – 3 m). Fraction of melt ponds was typically less than 30%. The surfaces of the ponds were refrozen and covered by few to several cm ice, except for bottom-open ponds. Zero to few (2 – 3 cm) snow could be seen on top of ice (flat area), while more thicker snow (> 15 cm) was observed around ridges. The typical floe size was 20 – 200 m, though sometimes large ice floes (> 1 km) can be observed. The large floes were characterized by a large fraction of bottom-open melt ponds (> 50%) and very weak lateral link.

The ice team conducted five ice stations in the first province (stn. 1, 7, 8, 9, and 10). The standard protocol for each ice station was to collect three ice cores for analysis of stratigraphy, temperature/chemistry and salinity and one additional core as archive/backup. Though, some cores were not taken due to time limitation and/or termination of the station work (fog or polar bear alarm). One EM31 thickness survey was conducted in this area (stn. 9). The EM31 transect crossed the minor axis of an ice floe (~ 50 m) and covered different types of ice surface from refrozen melt ponds to ridges exceeding 2 m. We carried out thickness drilling at 8 points covering different thickness ranges for EM31 calibration, which enabled us to calibrate EM31 measurements in a wide thickness range (Figure 8.4).

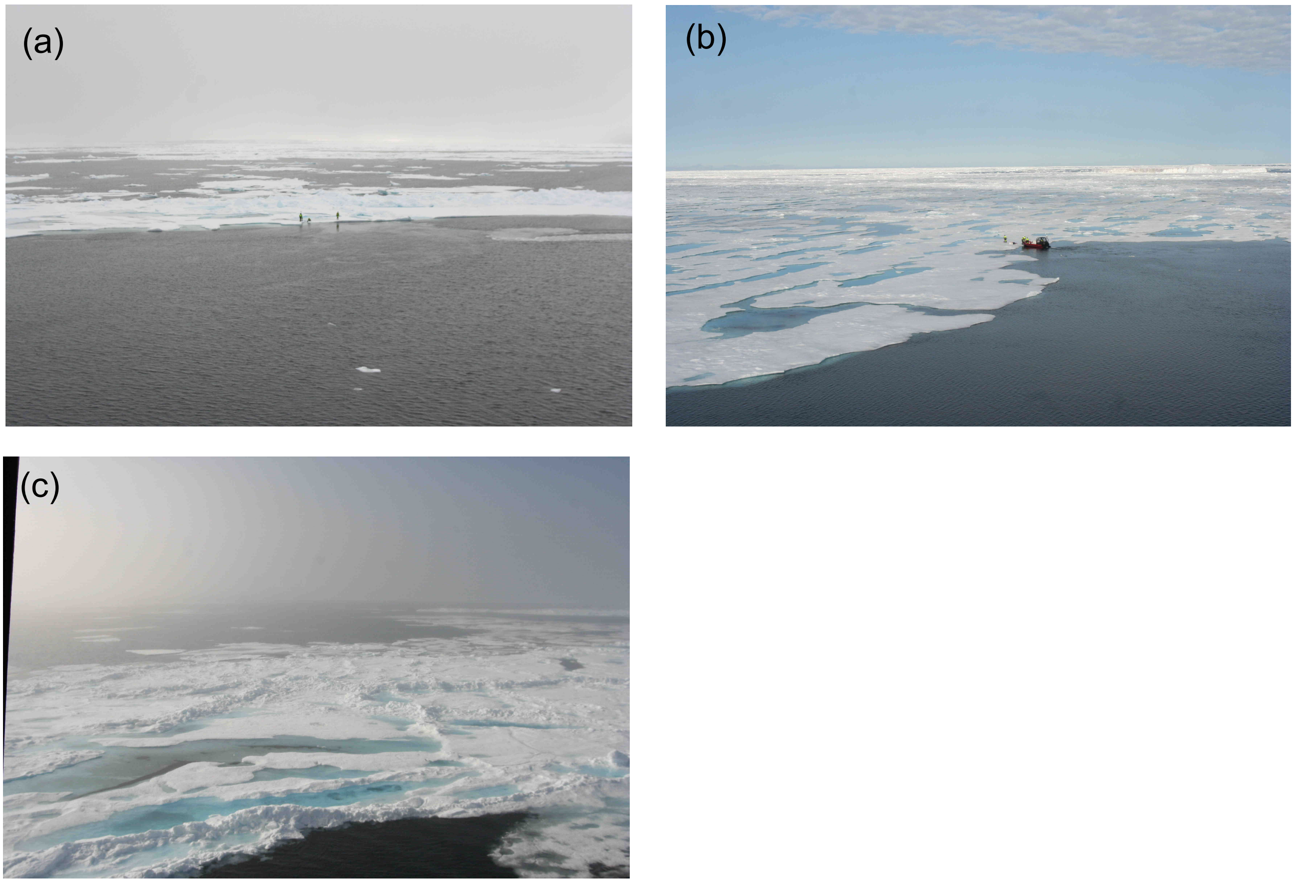


Figure 8.3: Overview of (a) stn. 9, (b) stn. 5, and (c) stn. 3, representing typical floes found in these areas.

In the second ice province, we also conducted five ice stations (stn. 2, 3, 4, 5 and 6) including four EM31 thickness survey (stn. 2, 3, 4 and 6). Ice floes in the second ice province are supposed to be formed over the Greenland shelf and experienced seasonal thickening/thinning in this area. Ice condition in this area can be clearly divided into two categories.

The first category is ice floes with flat surface and large fraction of bottom-open melt ponds (30 – 60%) observed over the Belgica Bank (Figure 8.3b). This is the main portion of the fast ice observed from the satellite SAR images (Figure 8.2). In this area, the ponds extended in one specific direction (Figure 8.3b). The fraction of ridges and rafting is very small (< 5%). The ice condition and ice surface properties do not change over tens of kilometers and the size of the floe is very large (> 10 km). The uniform property of ice is supposed to be developed by stagnant ice motion in this area. Before the break-up of fast ice during the cruise, the ice was supposed to be attached to grounded icebergs or even anchored to the sea floor on the shallow Belgica Bank. We conducted two ice stations in this area (stn. 5 and 6) including one EM31 transect across the major axis (~200 m) of a stable ice floe. Unfortunately we could not make an EM31 transect crossing the typical zebra pattern of ice and melt ponds in this area due to the bottom-open feature of the ponds. Next time use of EM31 on a plastic canoe can be considered to take a representative transect of ice in this time of this area.

The second category is ice floes found in the southern tip of the fast ice and in open water area between Belgica bank and the Greenland coast (Figure 8.3c). Ice floes in this area have a larger fraction of ridges (~ 15%) and experienced deformation/rafting over time. The surface type and thickness of ice floes changes considerably (less than 1 m to 2.5 m), the size of the floes also varies from several meters to several hundred meters. Since the ice floes are situated outside the shallow

Belgica Bank, they might have experienced strong deformation including ridging and rafting due to tide and wind forcing, which resulted in variational ice topography in this area. We corrected ice core samples in this area (stn. 2, 3, and 4) based on the standard protocol and carried out three EM31 short transects (stn. 2, 3, and 4).

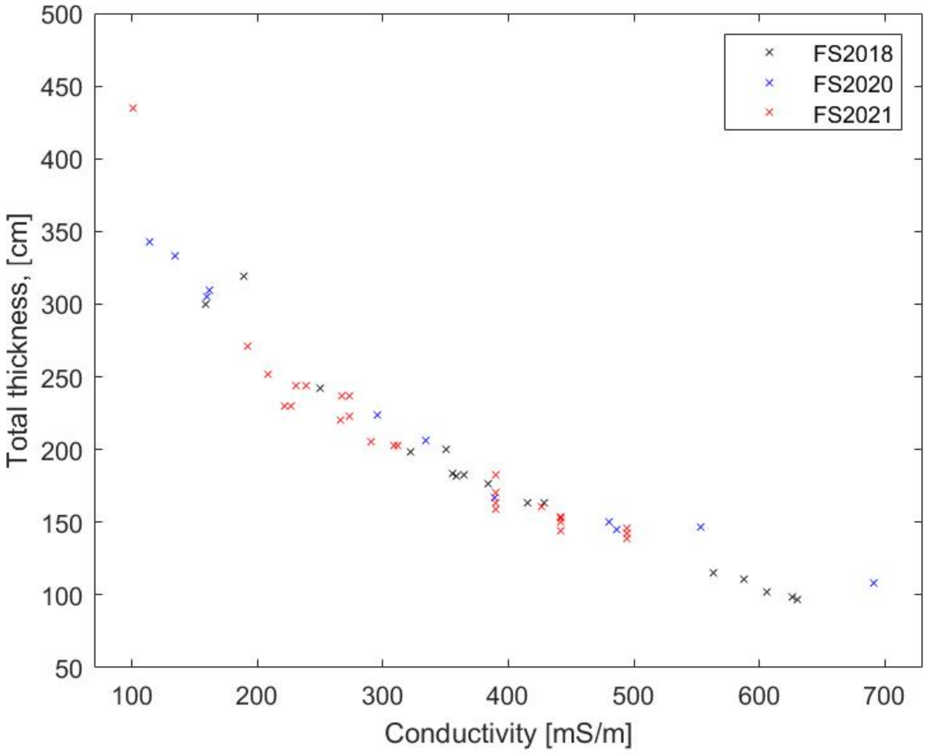


Figure 8.4: EM31 thickness - conductivity calibration curve obtained from FS2021

8.3 High-resolution SAR image acquisition

In order to relate remote sensing sea ice image with ice observations on site, we collected high-resolution SAR images over the Fram Strait and Greenland shelf during the cruise. The major goal of the activity is to acquire a combined data set with sea ice properties gained on sites (ice stations, ice camera equipped on board, and bridge based observations) and satellite observations. The activity successfully captured the break-up event of the fast ice over the Belgica Bank. The remote sensing images implied a vast and stagnant ice floe in this area before the break-up starts, whereas the on-site observations revealed that the ice had a very large fraction of bottom-open melt ponds (up to ~50%) which were weakly linked laterally. The data collected should be analyzed later together with ocean observations to investigate preconditioning for the break-up of fast ice in this area.

8.4 Ice service for the cruise

In order to support efficient implementation of the cruise plan in the ice covered area, the sea ice group had provided satellite-based sea ice charts on daily to sub-daily basis. High-resolution sea ice images were combined to make a composite image of ice cover on QGIS interface. The images were available via intranet during the cruise and saved in the cruise directory. The activity supported efficient allocation/combination of ship time for different activities, e.g., CTD casts, mooring recovery/deployment, ice stations and helicopter flight for whale research.

8.5 Ice observations from the bridge (ASSIST)

Sea ice conditions were observed based on the ASSIST protocol from the observation deck of RV KPH. The intervals of the observations have changed with ice conditions and ship activities. We carried out observations with relatively short time intervals (2 – 3 hours) when the ship crossed the sea ice edge and longer intervals when the ship stayed in/drifted with ice for CDT/mooring operation. Various sea ice parameters including ice type, floe size, snow cover, ridge and melt pond fraction were recorded together with meteorological data from on-board sensors (air temperature, water temperature at 4 m depth, wind speed and direction, surface air pressure and humidity). Digital photos were taken with each observations (3 photos, looking out towards port side, bow and starboard). In total 44 observations were made during the cruise while RV KPH was in or in proximity to ice covered area.

8.6 Observations available from ship-board sensors

In addition to the observation activities by the sea ice group, RV KPH constantly monitored and recorded ice condition from monkey-top camera. The images are available with 1 minute interval during the cruise. Water temperature near the sea surface (4 m and 8.5 m depth at water intake of RV KPH) had been recorded as well. These data, together with atmospheric data gained from ship-board sensors (air temperature, surface atmospheric pressure, humidity, wind), can be used to investigate atmosphere – ice – ocean interaction in Fram Strait and Greenland shelf.

8.7 Daily activities during the cruise

Table 8.1: summary of the daily activities related to sea ice work during FS2021.

Date	Day	Stn. #	Time (UTC)	lat.	lon.	Task/activities
31.07.2021	1					Cargo work, departure Longyearbyen 18:00, SAR image acquisition
01.08.2021	2					Sea ice lab. Set up, Ice gear check (1), instrument maintenance, SAR image acquisition
02.08.2021	3					Ice gear check (2), EM31 protocol, sea ice team meeting, ASSIST obs. start
03.08.2021	4					Ice gear check (3), ASSIST obs., SAR image update,
04.08.2021	5					Ice gear check (4), ASSIST obs., SAR image update, Ice station cancelled due to fog.
05.08.2021	6					ASSIST obs., SAR image update, Ice station cancelled due to fog.
06.08.2021	7	1	13:14	N 78.8°	W 6.5°	Station 1 on drifting ice, meeting, ice core repacking, SAR image update, ASSIST obs.
07.08.2021	8					Station log sheet, salinity measurements, SAR image update, ASSIST obs.
08.08.2021	9	2 3	08:26 12:37	N 78.9° N 78.9°	W 13.7° W 13.9°	Station 2 and 3 on drifting ice, SAR image update, ASSIST obs.
09.08.2021	10	4	18:50	N 78.9°	W 17.4°	Station 4 on drifting ice, station log sheet, SAR image update, ASSIST obs
10.08.2021	11					ASSIST obs., SAR image update, station log sheet, sea ice work planning
11.08.2021	12					SAR image update, ASSIST obs., station log sheet, ice station cancelled due to polar bear
12.08.2021	13	5	11:51	N 79.6°	W 14.4°	Station 5 and 6 on drifting ice, ASSIST obs., SAR

		6	17:09	N 79.7°	W 14.4°	image update, ice core repacking, salinity measurements
13.08.2021	14					Station log sheets, SAR image update, ASSIST obs., Ice station planning
14.08.2021	15	7 8	06:37 18:50	N 78.9° N 78.8°	W 7.5° W 4.9°	Station 7 and 8 on drifting ice, SAR image update, ice core repacking
15.08.2021	16	9	08:52	N 78.8°	W 4.1°	Station 9 on drifting ice, SAR image update, log sheets
16.08.2021	17					Station log sheets, logistic meeting, ice station planning,
17.08.2021	18	10	07:29	N 78.8°	W 3.0°	Station 10 on drifting ice, station log sheets, EM31SH data complication, ASSIST obs.
18.08.2021	19					Station log sheets, ice core sample list, ice core label check and repacking, processing cruise track data for QGIS, ice gear packing
19.08.2021	20					Freezer lab cleaning, ice lab cleaning, script for cruise track conversion, station log sheets, cruise data backup
20.08.2021	21					Ice core sample inventory, arrival to Longyearbyen

Table 8.2: FS2021 ice core box inventories:

box	ice station	cores	# of piece
A	1	temperature/chemistry	4
	1	stratigraphy	3
	2	temperature/chemistry	2
B	2	stratigraphy	2
	3	stratigraphy	4
	3	archive/backup	3
C	3	temperature/chemistry	4
	4	archive/backup	3
D	4	temperature/chemistry	3
	5	archive/backup	3
	6	temperature/chemistry	2
E	6	stratigraphy	2
	6	archive/backup	2
	7	temperature/chemistry (B)	3
F	7	temperature/chemistry (A)	5
	8	stratigraphy	4
G	8	archive/backup	3
	9	archive/backup	3
H	9	temperature/chemistry	2
	9	stratigraphy	2
I	10	archive/backup	4
	10	stratigraphy	4

Pointer to the data collection

A description of sea ice station activities with overview, logs and photos is available at Ice_stations directory in the cruise data collection. Cruise track, remote sensing ice chart during the cruise, GPS tracks, EM31 data, ASSIST observation logs can also be found in the collection. See Sea_ice directory in the cruise collection. Ice core box inventories are shown in Table 8.2.

Support from other groups - The sea ice group could manage the station works by the substantial effort of bear watching activity by other groups, for which we express our appreciation.

8.8 Biogeochemical samples collected from melted sea ice cores

Sea ice cores for biogeochemical analysis for NPI were collected from sea ice at the locations shown in Figure 8.5. Whole cores were melted onboard in a single container and meltwater samples were collected for the following analyses:

- Laboratory salinity
- Stable oxygen isotope ratio ($\delta^{18}O$)
- Nitrate, nitrite, phosphate & silicate
- Coloured dissolved organic matter (CDOM)
- Total alkalinity (A_T)

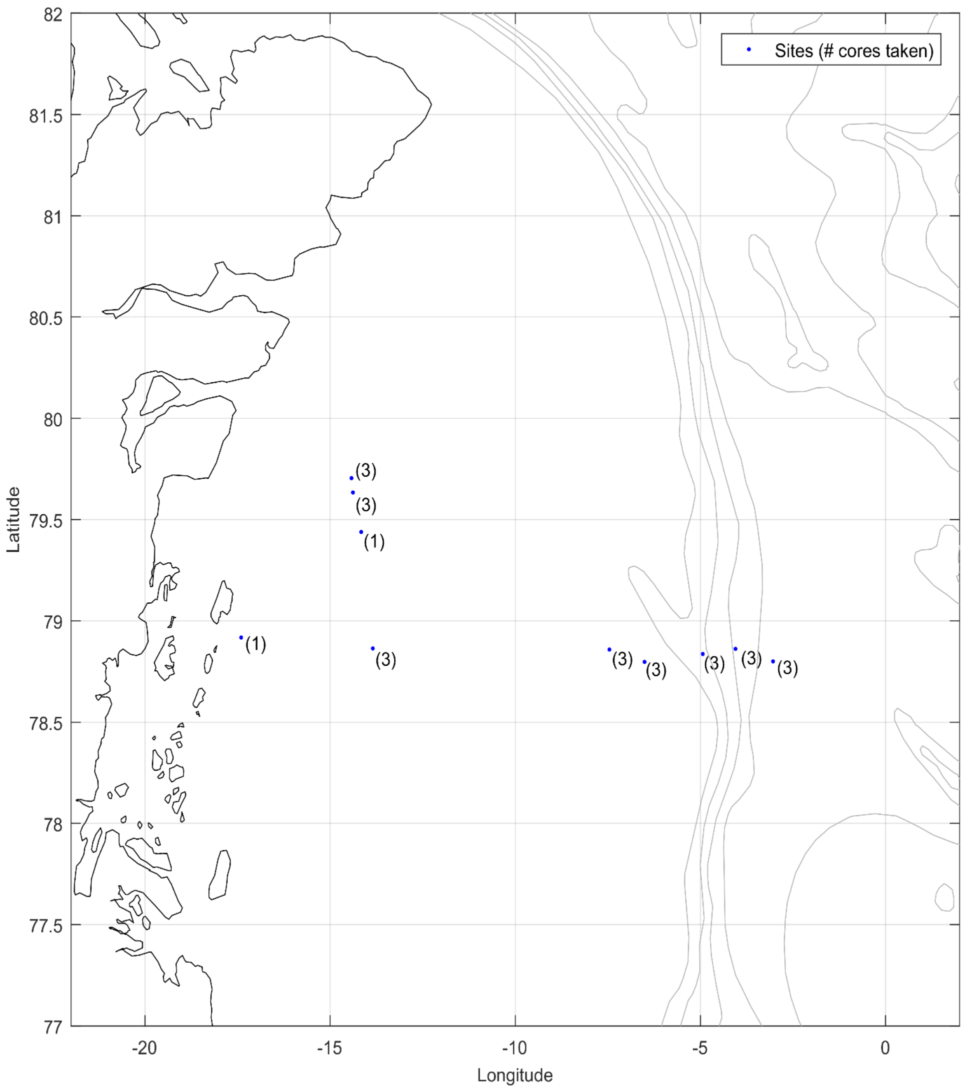


Figure 8.5 Locations where sea ice cores were collected for biogeochemical measurements.

9. Whale program

Christian Lydersen, Kit Kovacs, Harald Dag Jølle (NPI)

The purpose of this fieldwork was to attempt to deploy satellite transmitters on whales (bowhead whales, blue whales and narwhals) and in addition if possible collect biopsies for genetic studies from the same species. We only encountered bowhead whales and narwhals inside Greenlandic waters. We observed bowhead whales only 1 day, 10 tags were deployed, and biopsies were collected from all these 10 animals. In this general area (see Figure 1) there were more animals, likely around 20 and several were mother – calf pairs. We observed over 180 narwhals in an area close to the Greenland coast between 79˚ and 80˚ N (see Figure 9.1). They often occurred in small, loosely connected groups, many of which contained females with calves. A total of 12 biopsies were collected, 8 from adult males and 4 from females. In addition, 4 attempts were performed to attach satellite tags (limpet tags); 2 of these attempts were successful. All the tagging and the biopsy- sampling were conducted from a helicopter.

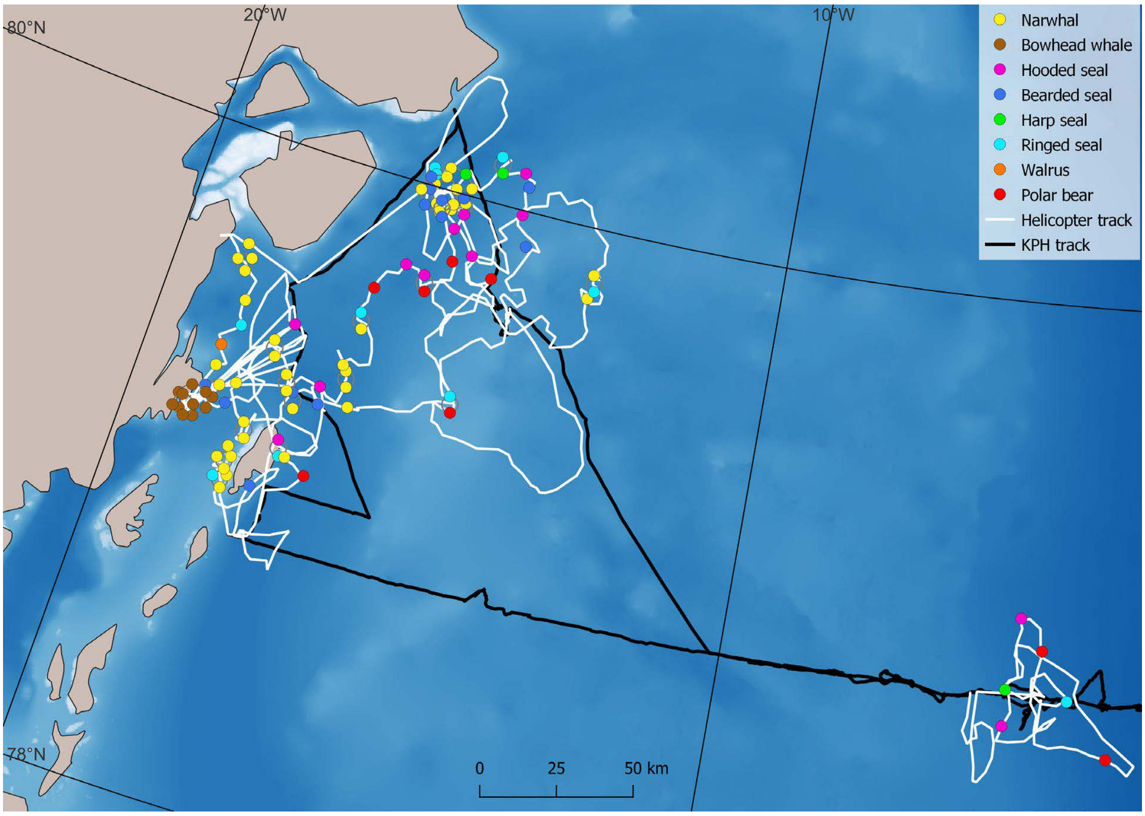


Figure 9.1: Observations of marine mammals during the expedition, Black line is the track for the research vessel (RV Kronprins Haakon) and the white line represents the helicopter tracks. During the cruise from west towards the Greenlandic coast and during return eastward more or less continuous foggy conditions prevented and observations.

Figure 9.2 on the following page show how the tag sits on a bowhead whale and the movements of the tagged animal until mid-November. These tags also collect dive data, that are not yet analyzed. However, these will give us new insight into the behavior of these large whales and also make us able to develop corrections factors for use in aerial surveys to correct for whales that are submerged (and thus not counted) at any given time. It was specifically asked from the Ministry for Agriculture, Self-Sufficiency, Energy and Environment for observed effects of the tagging on these animals. It is hard to see any specific response on the bowhead whales except that they dive when we get close with the helicopter (whether we tag them or not).

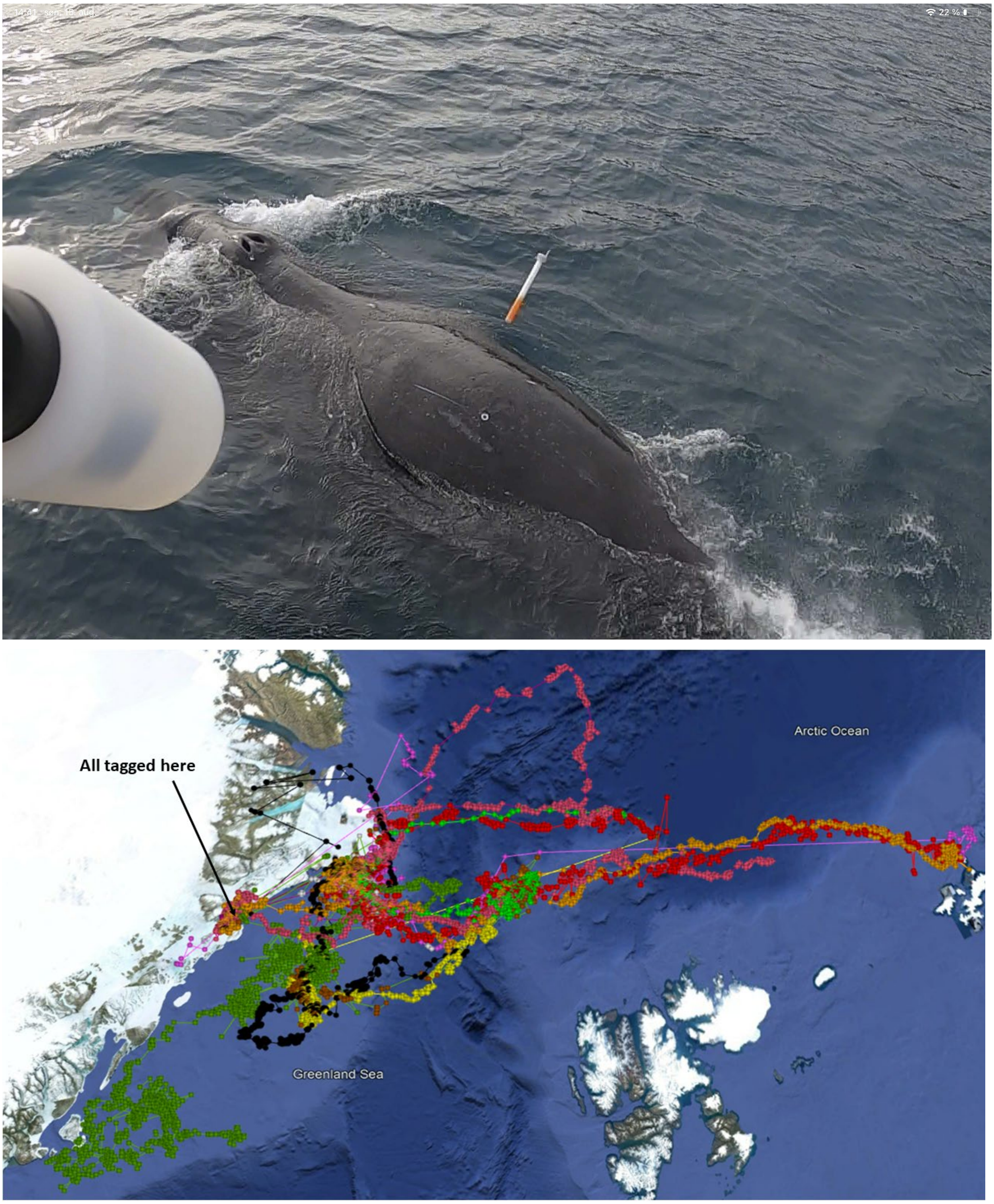
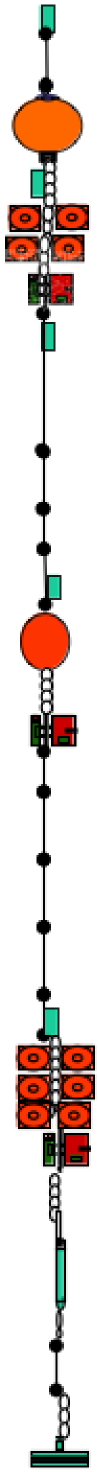


Figure 9.2: Upper panel shows a bowhead whale that just has been tagged. The small metal circle on the body of the whale is the tag and the carrying device that contains the biopsy tool is bouncing off and is picked up with a hoop net from the helicopter. Lower panel shows the movements of the whales until mid-November 2021

Appendix A: Diagrams of moorings recovered

Rigg F10-16 78 49,624N
Satt ut 10 Sep 2020, kl 12:32 001 57,048W

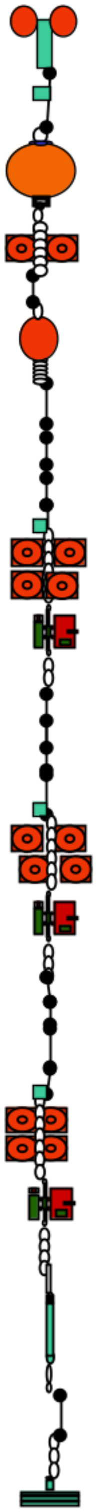


		Dyp:	Fra bunn:	Ned i vann:
SBE37IM	SNR. 22258	25	2602	11:37
30 m Vaier				
ADCP 300	SNR: 16831	56	2571	11:37
DATALOGGER	SNR.	58	2569	11:37
4 glasskuler 3 m Kjetting Galv.				
AQUADOPP	SNR. 665	61	2566	11:37
RBR ODO	SNR. 205002	63	2564	11:37
100 (102) m Kevlar				
40 m Kevlar				
20 (17)m Kevlar				
10 m Kevlar				
SBE37	SNR. 20789	230	2397	11:25
Plastkule 40'' Oransje Svivel 1 m Kjetting Galv.				
AQUADOPP	SNR. 666	234	2393	11:25
0,5 m Kjetting Galv. Med svivel.				
4 x 500 (497,498,498,498) m Kevlar				
208 m Kevlar				
100 m Kevlar				
40 m Kevlar				
40 m Kevlar				
SBE37	SNR. 22261	2612	15	10:54
6 Glasskuler 3 m Kjetting Galv.				
AQUADOPP	SNR. 667	2616	11	10:54
Svivel				
AR861	SNR. 2879			
5 m Kevlar				
2 m Kjetting				
ANKER	1000/(850) kg	2627(Ekko 2667)	0	

Rigg F11-22

Satt ut 10 SEP 2020 kl 06:35

78 49,121N
003 03,294W

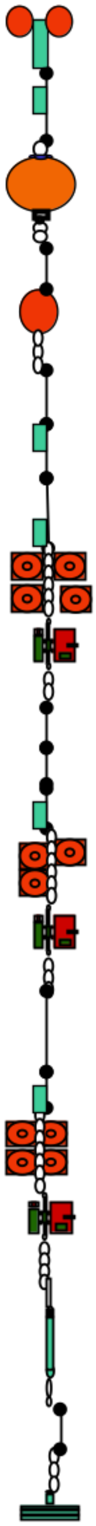


		Dyp:	Fra bunn:	Ut:
IPS	SNR. 51062	54	2369	06:27
SBE37	SNR. 3490	56	2367	06:27
5 m Kevlar				
ADCP300	SNR: 24830	60	2363	06:27
2 Glasskuler				
1 m Kjetting galvanisert				
5 m Kevlar				
Stålkule 37 McLane		69	2354	
0,5 m Kjetting galvanisert				
100 m Kevlar				
50 m Kevlar				
20 m Kevlar				
5 m Kevlar				
SBE37	SNR. 4702	244	2179	05:51
4 Glasskuler (gule)				
2 m Kjetting galvanisert				
RCM9	SNR.1324	247	2176	05:51
0,5 m Kjetting galv				
200(208) m Kevlar				
500(498) m Kevlar				
500(502) m Kevlar				
40 (41) m Kevlar				
SBE37	SNR. 3552	1496	927	05:10
4 Glasskuler				
2 m Kjetting galvanisert				
RCM11	SNR.494	1499	924	05:10
0,5 m Kjetting galv				
500 m Kevlar				
200 (201)m Kevlar				
200 (209)m Kevlar				
SBE37	SNR. 8227	2409	14	04:39
4 Glasskuler (gule)				
2 m Kjetting galvanisert				
RCM8	SNR.10071	2413	10	04:39
0,5 m Kjetting rustfri				
Svivel				
AR861	SNR. 287			
5 m Kevlar				
2 m Kjetting galvanisert				
ANKER	1220/(980) kg	2423(Ekko 2474)	0	

Rigg F12-22

Settes ut 9 SEP 2020 kl 08:22

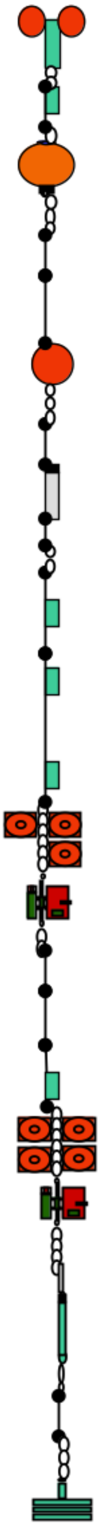
78 49,116N
004 01.294W



		Dyp:	Fra bunn:	Ut:
IPS	SNR. 51167	50	1778	08:20
SBE37	SNR.3489	52	1776	08:20
5 m Kevlar				
ADCP300	SNR: 16876	56	1772	08:20
0,5m Kjetting galvanisert				
5 m Kevlar				
Stålkule 37 Gul		62	1766	
0,5 m Kjetting galvanisert				
SBE37	SNR. 14100	114	1714	07:54
200 m Kevlar				
SBE37	SNR.4837	264	1564	07:49
4 Glasskuler				
2 m Kjetting galvanisert				
SEAGUARD	SNR. 884	267	1561	07:49
0,5 m Kjetting galv				
498 m Kevlar				
501 m Kevlar				
200m Kevlar				
SBE37	SNR.3554	1471	357	07:13
3 Glasskuler				
2 m Kjetting galvanisert				
RCM11	SNR.235	1474	354	07:13
0,5 m Kjetting galv				
199 m Kevlar				
99 m Kevlar				
40 m Kevlar				
SBE37	SNR. 8822	1814	14	07:05
4 Glasskuler				
2 m Kjetting galvanisert				
RCM11	SNR.228	1817	11	07:05
0,5 m Kjetting rustfri				
Svivel				
AR861	SNR. 182			
3 m Kevlar				
3 m Kjetting galvanisert				
ANKER	1120/(940) kg	1828 (Ekko1848)	0	

Rigg F13-22 78 50.346N

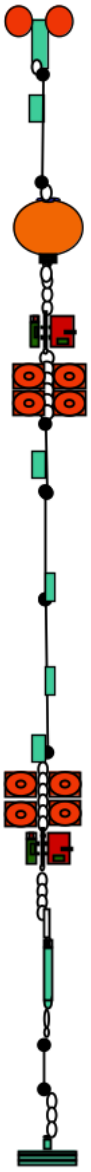
Settes ut 8 SEP 2020 , kl 18:22 004 59.959W



		Dyp:	Fra bunn:	Ned i vann:
IPS5	SNR. 51064	50	971	18:18
SBE37	SNR: 7056	52	969	18:18
5 m Kevlar				
ADCP300	SNR: 18151	56	965	18:18
1,5 m Kjetting galv				
5 m Kevlar				
10 m Kevlar				
Plastkule 37 Oransje		73	948	
1,5 m Kjetting galv.				
2 m Kevlar				
Hvallydopptaker M3	SNR. 304	78	943	18:11
2 m Kevlar				
0,5 m Kjetting galv.				
50 + 20 m Kevlar				
SBE37	SNR. 12234	102	919	17:56
SBE37	SNR. 12232	152	869	17:54
100 (103) m Kevlar				
SBE37	SNR.3993	253	768	17:48
3 Glasskuler				
2 m Kjetting galv.				
RCM9	SNR.1327	257	764	17:48
0,5 m Kjetting galv				
500 m Kevlar K				
200 m Kevlar				
50 m Kevlar				
SBE37	SNR.3551	1007	14	17:20
4 Glasskuler				
2 m Kjetting galv.				
RCM11	SNR. 561	1011	10	17:20
0,5 m Kjetting rustfri				
Svivel				
AR861	SNR. 053			
5 m Kevlar				
2 m Kjetting galvanisert				
ANKER 1110/(880) kg		1021 (Ekko 1026)	0	

Rigg F14-22
Satt ut 8 SEP 2020, kl 07:45

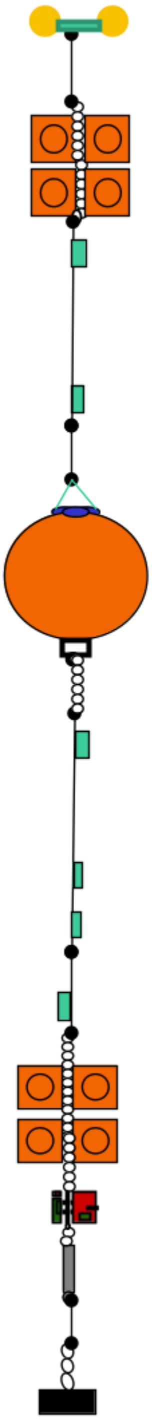
78 48,848N
006 30,130W



			Dyp:	Fra bunn:	Ned i vann:
IPS	SNR. 51138		50	217	08:31
SBE37	SNR: 14097		54	213	08:31
5 m Kevlar					
ADCP 300	SNR: 24518		58	209	08:30
0,5 m Kjetting Galv.					
AQUADOPP	SNR: 930		58	209	08:30
4 Glasskuler					
2 m Kjetting Galv.					
40 m Kevlar					
SBE37	SNR: 13253		99	168	08:21
100 (103) m Kevlar					
SBE56	SNR.10330	(25 m over 56)	203	64	08:16
SBE56	SNR.10331	(25 m over 37)	228	39	08:12
50 (51) m Kevlar					
SBE37	SNR.3992		253	14	08:03
4 Glasskuler					
2 m Kjetting Galv.					
RCM9	SNR. 1046		257	10	08:01
Svivel					
AR861	SNR. 1220				
3,5 m Kevlar					
2,5 m Kjetting					
ANKER	920/(740) kg		267 (Ekko 270)		0

Rigg F17-17
Satt ut 7 SEP 2020, kl 20:45 :

78 50. 185 N
008 04.845W



			Dyp:	Fra bunn:	Ut:
SBE37	SNR. 22260		32	196	14:02
23 m Kevlar Weak link o/u					
3 m Kjetting galv. 4 Glasskuler					
RBR CDOM	SNR.204799		56	172	14:02
0,5 m Kjetting galv.					
40 m Kevlar					
SBE37	SNR. 9651		96	132	13:52
10 m Kevlar					
ADCP	SNR.24385		107	121	13:48
1,5 m Kjetting galv.					
RBR CDOM	SNR.204800		109	119	13:48
0,5 m Kjetting galv.					
102 m Kevlar					
SBE56	SNR. 3942	(25 m over 56)	170	32	13:38
SBE56	SNR. 3943	(20 m over 37)	196	32	13:38
5 m Kevlar					
SBE37	SNR. 9650		216	12	13:34
2 m Kjetting galv.					
4 GLASSKULER			217	11	
RCM8	SNR. 12733		219	9	13:34
AR861Li	SNR. 1424				
3 m Kevlar. 2 m Kjetting galv.					
ANKER	815/(700)kg		228 (Ekko 225)	0	

Rigg F20-1 78 50.100 N
Satt ut 7 SEP 2020 , kl 12:47 010 08.814W

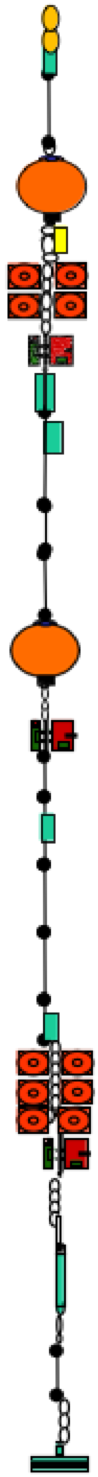
		Dyp:	Fra bunn:	Ut:
ICECat	SNR. 21029	28	298	12:46
25 m Wire Weak link				
3 m Kjetting galv. 4 Glasskuler				
ICECAT modem				
SBE37	SNR. 12233	56	270	12:42
51 m Kevlar				
ADCP	SNR.727	106	220	12:47
1 m Kjetting galv.				
SBE37	SNR. 10295	109	217	12:30
206 m Kevlar (Merke på ca 50 m ned)				
4 GLASSKULER		314	12	
2 m Kjetting galv.				
RCM7	SNR. 7718	316	10	12:15
AR661	SNR. 291			
5 m Kevlar.				
2 m Kjetting galv.				
ANKER	800/(620)kg	326(Ekko 326)	0	

Appendix B: Diagrams of moorings deployed

Rigg F10-17

Satt ut 17/8-21 , kl 16:03 UTC

78 49,637N
001 57,080W

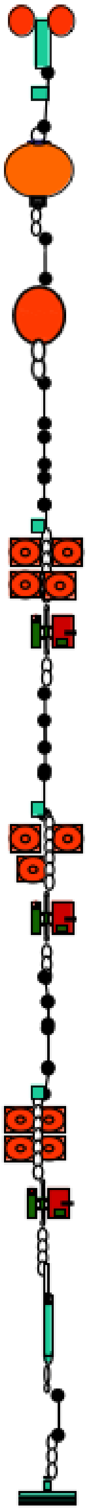


		Dyp:	Fra bunn:	Ned i vann:
SBE37IM	SNR. 23250	24	2626	18:02
ADCP 300	SNR: 24899	52	2598	18:00
Batteribeholder DL-NPI005		53	2597	18:00
AQUADOPP	SNR. 15910 (665)	56	2594	18:00
SAMI CO2/pH	SNR. 227/261	57	2593	18:00
RBR ODO	SNR. 207317	58	2592	18:00
100 (102) m Kevlar				
40 m Kevlar				
20 m Kevlar				
Plastkule 40'' Med svivel. 1 m Kjetting Galv.				
AQUADOPP	SNR. 15888 (666)	221	2419	15:10
0,5 m Kjetting Syrefast 0,5 m Kjetting Galv.				
RBR Concerto	SNR. 207318	223	2417	15:10
4 x 500 (538,40,21,198,198,516,506) m Kevlar				
200(204) m Kevlar 100 (101 m Kevlar 60 m Kevlar				
(totalt i midten 2322)				
SBE37	SNR. 23266	2634	16	14:17
6 Glasskuler 3 m Kjetting Galv.				
AQUADOPP	SNR. 15877 (667)	2639	11	14:17
Svivel				
AR861	SNR. 506			
5 m Kevlar				
3 m Kjetting				
ANKER 1200/(1000) kg		2650 (2665)	0	

Rigg F11-23

78 49,109N(*)
Satt ut 16/8-21 kl 12:42 UTC 003 03,087W

* NOTE: Anchor likely 250m further north: large drift!

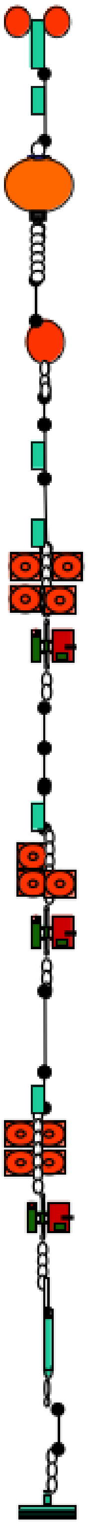


		Dyp:	Fra bunn:	Ut:
IPS	SNR. 51062	44	2409	12:45
SBE37	SNR. 3492	46	2407	12:45
5 m Kevlar				
ADCP300	SNR: 17462	50	2403	12:45
0,5 m Kjetting galvanisert				
10 m Kevlar				
Stålkule (gul)		72	2381	
Svivel				
1 m Kjetting galvanisert				
100 m Kevlar				
SBE37	SNR. 10294	150	2180	11:59
40 m Kevlar	11:597			
50 m Kevlar				
SBE37	SNR. 3996	273	2180	11:55
4 Glasskuler (2 gule og 2 oransje)				
2 m Kjetting galvanisert				
RCM9	SNR.1049	276	2177	11:55
0,5 m Kjetting galv				
200(199) m Kevlar				
500(519) m Kevlar				
500(511) m Kevlar				
20 m Kevlar				
10 m Kevlar	Kanskje bort			
SBE37	SNR. 7061	1526	927	11:30
3 Glasskuler (gule)				
2 m Kjetting galvanisert				
RCM11	SNR.538	1529	924	11:30
0,5 m Kjetting galv				
500(511) m Kevlar				
200 m Kevlar				
200 m Kevlar				
SBE37	SNR. 8821	2439	14	11:07
4 Glasskuler (gule)				
2 m Kjetting galvanisert				
RCM Seaguard	SNR.834	2442	11	11:07
0,5 m Kjetting rustfri				
Svivel				
AR861	SNR. 499			
5 m Kevlar				
3 m Kjetting galvanisert				
ANKER	1230/(980) kg	2453(2474)	0	

Rigg F12-23

Satt ut 15/8-21 kl 19:43UTC

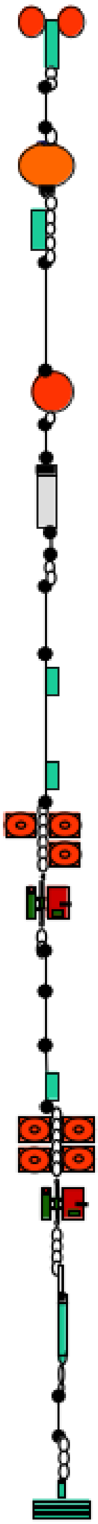
78 49,968N
004 00,730W



		Dyp:	Fra bunn:	Ut:
IPS	SNR. 51167	55	1775	17:22
SBE37	SNR.14099	57	1773	17:22
5 m Kevlar				
ADCP300	SNR: 20021	61	1769	17:22
0,5 m Kjetting galvanisert				
0,5 m Kjetting galv				
10 m Kevlar				
Skumkule 37	Oransje	74	1756	
0,5 m Kjetting galvanisert				
0,5 m Kjetting galv				
SBE37	SNR.13252	150	1680	17:10
200(199) m Kevlar				
SBE37	SNR.3994	275	1554	17:10
3 Glasskuler				
2 m Kjetting galvanisert				
RCM9	SNR. 836	279	1551	17:10
0,5 m Kjetting galv				
500(498) m Kevlar				
500(497) m Kevlar				
200(205) m Kevlar				
SBE37	SNR.13505	1476	354	16:53
3 Glasskuler				
2 m Kjetting galvanisert				
RCM11	SNR.556	1480	350	16:53
0,5 m Kjetting galv				
200(207) m Kevlar				
100(101) m Kevlar				
20 m Kevlar				
SBE37	SNR. 8226	1817	13	16:42
4 Glasskuler				
2 m Kjetting galvanisert				
Seaguard	SNR.345	1820	10	16:42
0,5 m Kjetting rustfri				
Svivel				
AR861	SNR. 500			
5 m Kevlar				
2 m Kjetting galvanisert				
ANKER	1190/(960) kg	1830 (1848)	0	

Rigg F13-21

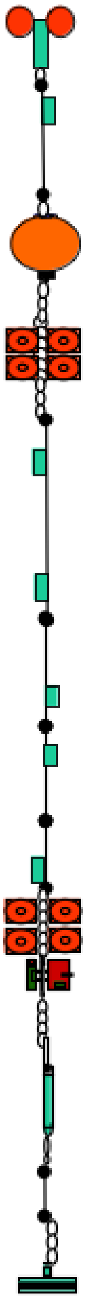
Satt ut 14/8-21 Kl 20:01 UTC — 78° 50.333N, 04° 59.927W



		Dyp:	Fra bunn:	Ned i vann:
IPS5	SNR. 51140	50	960	18:00
5 m Kevlar				
ADCP300	SNR: 18070	56	954	18:00
1,5 m Kjetting galv				
SEACAT SBE16	SNR. 7253	59	951	18:00
0,5 m Kjetting galv.				
10 m Kevlar				
Stålkule 37		69	941	
2 m Kevlar				
Hvallydopptaker	SNR. 304	72	938	
2 m Kevlar				
0,5 m Kjetting galv.				
20 m Kevlar				
Merke for instrument		95		
50 m Kevlar				
SBE37	SNR. 7060	147	863	17:41
100 m Kevlar				
SBE37	SNR. 3995	245	765	17:36
3 Glasskuler				
2 m Kjetting galv.				
RCM9	SNR.1326	248	762	17:36
0,5 m Kjetting galv				
500(499) m Kevlar				
100 m Kevlar				
100 m Kevlar				
50 m Kevlar				
SBE37	SNR. 13504	996	14	17:07
4 Glasskuler				
2 m Kjetting galv.				
SEAGUARD	SNR. 883	1000	10	17:07
0,5 m Kjetting rustfri				
Svivel				
AR861	SNR. 743			
5 m Kevlar				
2 m Kjetting galvanisert				
ANKER	1100/(880) kg	1010(1018)	0	

Rigg F14-23 78° 48,848N

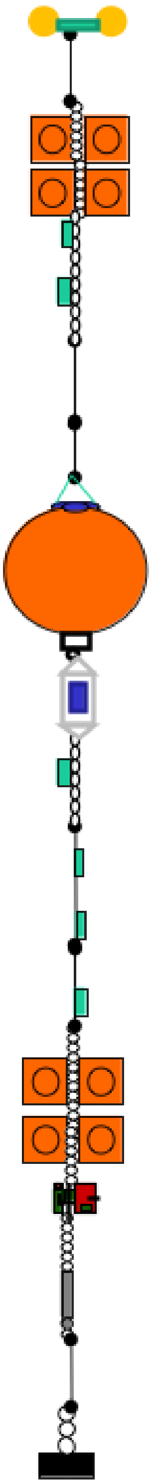
Satt ut 14/8-21 kl 14:05 UTC 06° 30,127W



		Dyp:	Fra bunn:	Ned i vann:
IPS	SNR. 51138	48	222	12:05
SBE37	SNR: 7058	60	210	12:05
5 m Kevlar				
ADCP 300	SNR: 17461	65	205	11:53
1 m Kjetting Galv. 4 Glasskuler 2 m Kjetting galv.				
0,5 m Kjetting Galv.				
SBE37	SNR. 7054	112	158	11:49
100 m Kevlar				
SBE37	SNR. 9853	150	120	11:45
50 m Kevlar				
SBE56	SNR: 10330	203	67	
SBE56	SNR: 10331	228	42	
40 m Kevlar				
SBE37	SNR.7057	257	13	10:53
4 Glasskuler 2 m Kjetting Galv.				
Aquadopp	SNR. 16603	260	10	10:53
Svivel				
AR861	SNR. 568			
3,5 m Kevlar				
2,5 m Kjetting				
ANKER	900/(740) kg	270 (270)	0	

Rigg F17-18 78° 50. 139 N

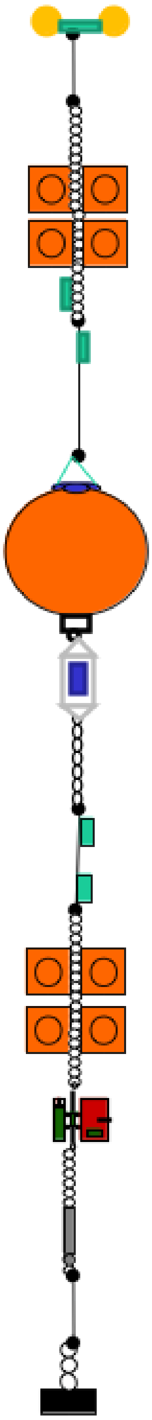
Satt ut 13/8-21 kl 21:00UTC 08° 06.233W



		Dyp:	Fra bunn:	Ut:
ICECAT	SNR.23259	25	205	18:57
3 m Kjetting galv.		52	178	
4 Glasskuler				
Datalogger	DL-NPI004			
SBE16	SNR.7212	54	176	18:57
0,5 m Kjetting				
51 m Kevlar				
ADCP	SNR.24385	105	125	18:07
Ekstern batteribeholder		106	124	
2 m Kjetting galv.				
SBE16	SNR.7339	108	122	18:07
0,5 m Kjetting				
SBE56	SNR.3942	170	40	17:58
99 m Kevlar				
SBE56	SNR.3943	196	34	17:53
5 m Kevlar				
SBE37	SNR.14098	217	13	17:51
4 GLASSKULER		218	12	
2 m Kjetting galv.				
RCM9	SNR.1325	220	10	17:51
AR861CS	SNR. 501			
5 m Kevlar.				
2 m Kjetting galv.				
ANKER	800/(700)kg	230	0	

Rigg F20-2
Satt ut 13/8-21 kl 14:09 UTC

78° 50.100 N
10° 08.813W



		Dyp:	Fra bunn:	Ut:
ICECat	SNR. 21029	30	296	12:05
22 m Wire				
Weak link				
3 m Kjetting galv.				
4 Glasskuler Gule				
ICECAT modem DL-NPI003				
SBE37	SNR. 9852	56	270	12:00
52 m Kevlar				
ADCP	SNR.727	106	220	11:50
Ekstern batteribeholder				
1 m Kjetting galv.				
SBE37	SNR. 7059	109	217	12:30
206 m Kevlar				
SBE37	SNR. 7055	313	217	11:37
4 GLASSKULER Gule		314	12	
2 m Kjetting galv.				
RCM7	SNR. 9464	316	10	11:35
AR661	SNR. 410			
5 m Kevlar.				
2 m Kjetting galv.				
ANKER	800/(620)kg	326(Ekko 326)	0	

Appendix C: Script files for Master and Slave LADCP programming and starting:

```
; Append command to the log file
$LC:\KH2020709\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 M047_
; 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
; 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
; 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
; 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
```

```
; Append command to the log file
$LC:\KH2020709\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 S047_
$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
; 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
; 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
; 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
```