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Cruise Report

RV Sanna, Cruise GLICE

10.08.2022 – 24.10.2022, Ilulissat (Greenland) – Ilulissat (Greenland)

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1 Summary

GLICE embarked a team of scientists to study the effect of icebergs on pelagic processes in Disko Bay in August 2022, anticipated to be close to the peak of the annual melt season. A combination of underway measurements, profiles and opportunistic sampling around icebergs were used to increase understanding of how ice melt affects marine biogeochemistry. In addition to sensor-based salinity, temperature, chlorophyll and turbidity measurements, our team focused on carbonate chemistry (direct measurements of pCO_2, pH and total alkalinity, TA), macronutrients (nitrate, phosphate, silicic acid – with a subset of samples analysed for silicic acid at sea) and acoustic Doppler current profiler (ADCP) data acquisition. Our sampling focused mainly on the upper 100 m where the strongest gradients in parameters that may respond directly to ice melt were expected and we mainly employed a statistical approach to dataset collection, focusing the majority of the cruise on sampling pre-defined transects in a grid across the Bay area intercepting areas with high and low ice/melt water distributions. This can be combined with satellite based observations to understand iceberg dynamics. Process studies were also conducted, tracking 3 large icebergs with concentric data collection within their vicinities to investigate the possibility of small scale responses to iceberg passage, incubating ambient seawater with additions of iceberg melt and/or sediment, and using repeat sampling of 'line F' in front of the Ilulissat Icefjord entrance to constrain short-term (diel) dynamics.

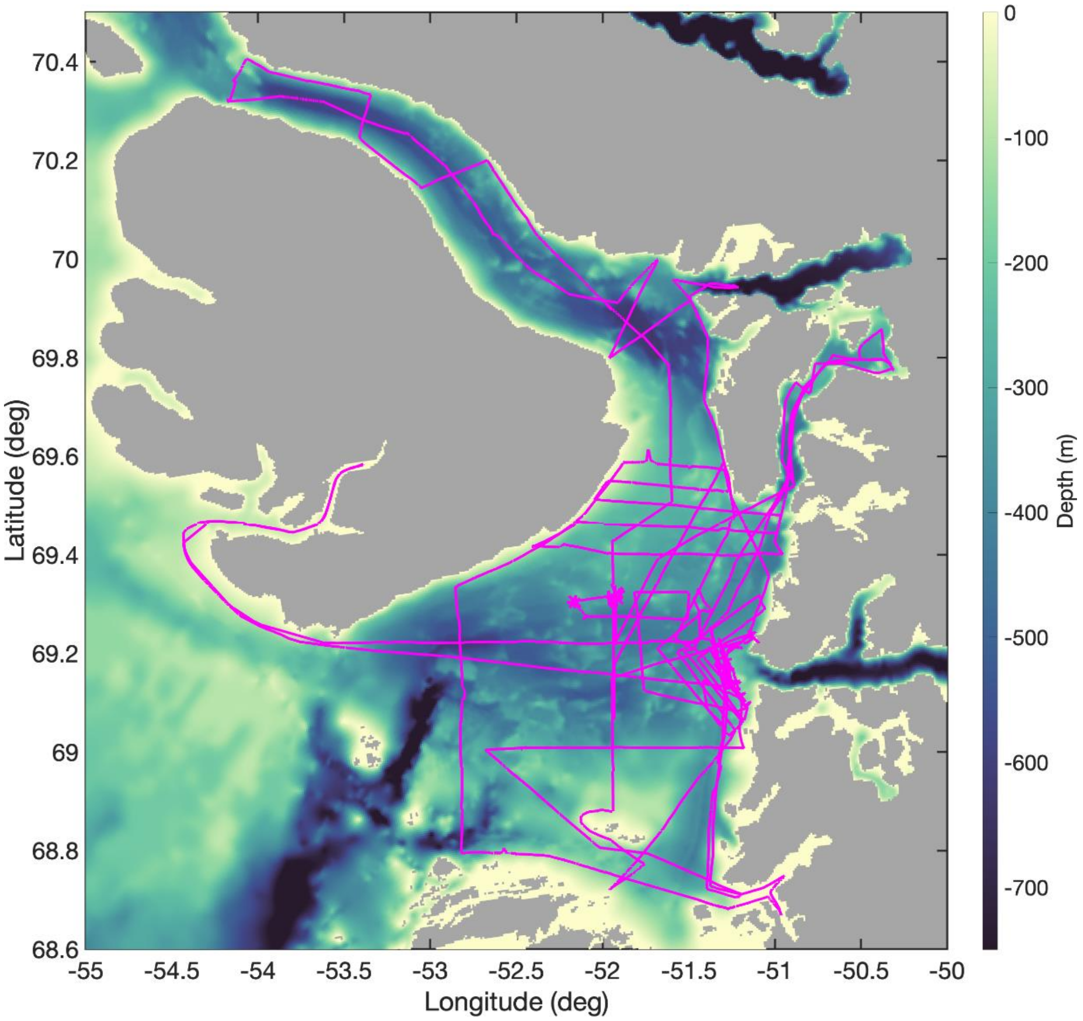

Fig. 1. Cruise track from GPS position logged at second intervals for the cruise duration. 140 CTD stations were distributed along 9 transects in a regular grid, with additional stations during intensive near-iceberg

studies, with sampling for biogeochemical parameters at 1/3 of stations. Deep stations sampled the full depth of the water column, other stations more intensively sampled the upper 100 m.

2 Research Programme/Objectives

Icebergs have long been speculated to act as a source of micronutrients to the ocean and thus affect marine primary production (Duprat et al., 2016; Schwarz & Schodlok, 2009). However, quantifying the links between icebergs, marine primary production and the carbon cycle has proven difficult due to the multiple mechanisms potentially affecting marine primary production at the iceberg ocean interface (Hopwood et al., 2019; Smith Jr. et al., 2007; Vernet et al., 2011). Whilst iceberg-fertilization, especially in the Southern Ocean, is generally inferred to mean Fe-fertilization (Shaw, Raiswell, et al., 2011), there are other potential mechanisms via which icebergs could affect primary production. Other micronutrients, for example manganese (Mn), which is also deficient with respect to phytoplankton demand across parts of the Southern Ocean (Browning et al., 2021; Latour et al., 2021), may be enriched following iceberg passage. Furthermore icebergs may also, depending on their depth relative to the surface mixed layer, contribute to enhanced vertical mixing of nutrients within the water column (Helly et al., 2011). The confounding effects of simultaneous mixing and nutrient addition from freshwater make it challenging to distinguish these two phenomena in close proximity to icebergs, particularly since the nutrient content of ice is not well defined. Whilst it is widely accepted that icebergs almost invariably increase Fe availability as they melt (Lin et al., 2011; Raiswell, 2011; Shaw, Raiswell, et al., 2011), there is little data concerning other (micro)nutrients or other aspects of iceberg-derived particle dynamics. Some studies have hinted at considerable silicic acid (up to 10 µM) or fixed nitrogen concentrations (up to 5 µM) within ice (Meire et al., 2016; Parker et al., 1978; Vernet et al., 2011). Furthermore, glacier-derived particles facilitate numerous effects besides acting as a nutrient source. In surface waters they reduce light availability, they release particles which may be detrimental to filter-feeding organisms, and the same particles may also suppress viral loads due to a poorly characterized surface absorption effect (Fuentes et al., 2016; Maat et al., 2019; Sommaruga, 2015).

Whilst poorly characterized, iceberg melt is expected to behave similarly to glacial runoff with respect to low alkalinity compared to most other freshwater sources (Cantoni et al., 2020). Diluting alkalinity drives coastal seawater towards corrosivity with negative implications for organisms with calcite shells (Evans et al., 2014). Mixing driven by the release of meltwater at depth however can drive high primary production which reduces pCO_2 in the water column and thereby increases pH. Furthermore, the non-linear effect of salinity on the carbonate system leads to substantial pCO_2 undersaturation even when both fresh and saline endmembers are in equilibrium with atmospheric pCO_2 (Meire et al., 2015; Rysgaard et al., 2012). This inorganic CO_2 sink is relatively large on annual timescales compared with weathering related fluxes that were classically thought to dominate the effect of ice sheet dynamics on the carbon cycle (Hopwood et al., 2020). Yet the effect of ice melt on the carbonate system in the ocean is poorly explored, partially due to the deficiency of data close to glacier outflows (Meire et al., 2015).

There are also fundamental uncertainties concerning the properties of ice. Whilst glacier ice is known to contain particles relatively rich in labile forms of the micronutrient Fe, estimates of iceberg sediment load vary widely (Dowdeswell & Dowdeswell, 1989; Shaw, Smith, et al., 2011), as do the few estimates of ice macronutrient content (Meire et al., 2016; Vernet et al., 2011). This is partially because the vast majority of particles, and therefore the associated micronutrients, are found in sediment-rich layers which account for only a few percent of the total ice calved from Greenland and Antarctica. The fate of these layers therefore determines the dispersion of associated nutrients (e.g. Fe and silicic acid) in the ocean and a large fraction of basal ice is thought to be lost relatively quickly after calving (Mugford & Dowdeswell, 2010) – although thin layers of sediment can to some extent also be 'replenished' in coastal areas by icebergs grounding in shallow sediments. In any case, these changes in the composition of ice with time after calving are un-quantified to date. The unknown fractional importance of sediment-rich ice also creates a major difficulty in constraining how much of the associated nutrients are ultimately injected into the surface mixed layer, and how much enter the sub-surface ocean. The scouring of shallow sediments creates similar uncertainties for both pelagic and benthic biogeochemistry (Barnes, 2017). The interaction of basal layers with marine biogeochemistry is therefore a key topic for future research. Iceberg-borne particles from sediment-rich layers are of interest both as potential sources of the nutrients Fe and silicic acid, and potential sinks for organic carbon due to the ballasting effect that lithogenic particles can have in the ocean (Lin et al., 2011; Seifert et al., 2019).

The temporal and spatial scale over which ice melt occurs is a key consideration in determining the relative importance for marine biogeochemistry. In moderately productive fjord environments, the summertime release of lithogenic particles may act as ballast for sinking organic carbon and thus enhance the carbon sink these environments provide. Conversely, in less productive offshore waters the main effect may be fertilisation from release of ice-derived Fe and upwelling of other nutrients (NO_3, PO_4, Si) around large icebergs. A goal of this project will be to investigate the spatial scale over which these processes operate; both laterally with distance from an iceberg source, and concerning the depth of melt release in the water column. The specific novelty of this project will be its sensor-based approach. Numerous on-going projects are gathering physical, chemical and biological data in glacier/iceberg affected regions of Antarctica and Greenland, yet data deficiency is still problematic considering the short length of time research vessels can spend in the vicinity of icebergs and glacier termini. We will overcome difficulties associated with the logistics of studying these fieldsites by deploying state-of-the-art sensors to constrain the perturbations induced by ice melt. In addition to core oceanographic data (salinity, temperature, turbidity), we will focus on carbonate chemistry and nutrient concentrations. Sensors will be rigged to underway systems to maximize data output during field campaigns.

The cruise objectives of GLICE were to:

1. Understand how iceberg melt affects the structure of the water column.

2. Determine how iceberg age affects the chemical composition of ice, for example from the rapid loss of basal/sediment-rich ice and on-going photochemical processes.

3. Assess the effect of iceberg melt on primary producers.

To complete these objectives, we employed the following 7 tasks:

1. Collection of CTD profiles across Disko Bay, including regions with strong and weak iceberg melt influence.
2. Continuous underway measurements of salinity, temperature, chlorophyll, turbidity, pCO_2 and TA across Disko Bay. As this work required minimum person-hours and assistance from deck crew, transects with stations were conducted during daytime hours and overnight work was routed to conduct mainly sensor based work.
3. Collection of iceberg samples and iceberg-affected water column samples across Disko Bay, to determine changes in the composition of ice driven by erosion. During the first 10 days of the cruise, we completed a survey along regular transects in order to use statistical approaches to assess the effect(s) of icebergs on the water column.

4. Incubation experiments to test the response of primary producers to iceberg melt, sediment and the potential release/adsorption of nutrients from/onto particle surfaces.
5. A process study where the ship tracked large icebergs (3 in total) collecting high resolution data around them, upstream/downstream and upwind/downwind of the iceberg track. Drone deployments were undertaken to quantify iceberg topography above the water line and radar measurements were used to track iceberg's relative and absolute positions during sampling.
6. Collection of samples for external colleagues interested in specific/specialist aspects of the above scientific questions (the following discrete samples were collected for colleagues external to the GLICE proposal: mercury, methyl-mercury, suspended particles, copper ligands, and dissolved trace metals).
7. Deployment of an autonomous profiler for the NASA Jet Propulsion Laboratory which will provide deep profiles across the Bay for a sustained time period (up to two years).

The cruise plan was modified slightly from those stated in the pre-cruise plan, this related to constructive comments from two reviewers and also some logistical changes necessitated due to the long (3 years) timeframe since the cruise was funded. Scientifically, the main query raised in review was whether a statistical or process approach would be better deployed to assess the effects of icebergs on biogeochemistry. A process study may more directly address research questions, i.e. by tracking individual icebergs and logging upstream/downstream data task 5), but such an approach has not worked well in prior work - mainly in the Southern Ocean. Because the iceberg melt/mixing 'signal' is small compared to unrelated water column heterogeneity, large datasets are required to see any iceberg related effects and distinguish them from background field changes as anomalies that can unambiguously be attributed to iceberg movement or melt. In Disko Bay, surface waters can be relatively warm (up to 9°C during our survey) thus iceberg melt signals are larger than in the Southern Ocean, but there was still a fair chance that an intensive process-based study may not yield any significant results. Whilst such an approach would seem more direct, it also faces the problem that any data collected will be of limited use to other studies. A statistical approach, sampling broader areas in a pre-defined way, i.e. with transects, and then investigating how iceberg 'intensity' affects observations is potentially more useful (tasks 1 and 2), both in terms of data re-use and modelling. Accordingly, the GLICE cruise track mainly focused on a statistical approach, running transects through pre-defined regions which span the main routes of iceberg passage and surveying the state of the Bay with cross-sections. In the last 4 days of the cruise, we complimented this with a more process based approach, opportunistically tracking the largest 3 icebergs in the NE sector of the Bay and investigating water column properties in their vicinities.

Logistically, the budget and cruise plan were prepared in 2019, the cruise was initially scheduled in 2021. However, based on institutional advice, the PI informed EUROFLEETS in February 2021 (a realistic deadline for committing to a Greenlandic cruise in summer 2021 as flights/hotels for the summer season are usually fully booked by March) that the cruise could not be run as planned due to COVID restrictions resulting in a high likelihood that cruise participants, particularly those based outside the EU, would be stranded en-route or unable to meet vaccine/test requirements to arrive at the ship. In hindsight this was probably a wise decision as none of the participants would have been vaccinated for the original cruise departure date. EUROFLEETS kindly offered to re-schedule the cruise in summer 2022, which we are exceptionally grateful for. This however meant that 2 of the original cruise participants were no longer available to attend having being blessed with newly arrived children, and some equipment (particle traps) were no longer available having been booked for cruise work in the Pacific. Communication with the ship coordinator also revealed some discrepancies with the information available when the cruise application was submitted, most importantly that, contrary to the EUROFLEETS listing, the ship does not come equipped with a CTD or bottle rosette system for users and that only 6 scientific berths are normally available on the ship, not 7 as advertised. In planning the cruise for 2022, large cost increases in travel and shipments also had to be dealt with (over +50% in both cases compared to 2019 quotes) and the PI is extremely grateful for an increased cost allocation to partially deal with this. The remaining costs above the cruise budget were met by using equipment/consumables which had been prepared for the canceled Swiss Polar Institute GLACE expedition, and by a grant from the NSFC (China) awarded to M. Hopwood.

A general problem in ice-ocean interaction studies is that offshore and near-shore dynamics are rarely studied in parallel. This means that processes which occur in near-shore environments, for example in the intense particle plumes associated with glacial outflows, can be more challenging to study than if these campaigns were closely tied together. Concerning the Ilulissat Icefjord these issues are compounded by the lack of access to the main fjord due to ice cover and the additional issues associated with sampling within the World Heritage Zone. There has been very limited historical data collection within the fjord. In order to lessen the inherent limitations of not being able to study processes within the fjord on the GLICE cruise, a team of 4 scientists was deployed in the week before the cruise for a land/coastal based campaign (Ice Disko) funded by the NSFC. Data from this campaign is beyond the scope of the EUROFLEETs proposal but will be made available in parallel (hence profile numbers on the cruise begin at number 14). Ice Disko work immediately prior to the cruise obtained surface transects, ice samples, freshwater samples, and inshore profiles in the mouth of the Ilulissat Icefjord, at the junction between the icefjord and the open water fjord branch to the south. The value of this additional data is that it covers a low salinity range (0-20) in inshore waters which were sparsely sampled on the cruise.

3 Narrative of the Cruise

The cruise arrived and departed from Ilulissat harbor. The following table denotes cruise activities in chronological order.

Date	time (UTC)	Event
2022-07-10	15:00	DC and MH visit RV Sanna in harbor. Ship ready to depart anytime tomorrow, boxes will be loaded 08:00-10:00, estimated departure time 18:00 tomorrow (local). One box due to arrive from JPL has not yet arrived, non-essential equipment (a deep profiler we offered to deploy), delivery status is in Copenhagen, we have left them with contact details for a reliable contact in town. Last 2 of scientific party are due to arrive late tonight but delayed.
2022-08-10	10:00	All shipped equipment loaded in Ilulissat harbor, 4/6 scientists onboard, awaiting 2 arrivals delayed due to fog and canceled flights. Latest information suggests arrival this evening, we will delay departure if possible for them to join the ship tonight, if not arrange a boat transfer tomorrow as the ship will be operating within line of site of the city for at least 24 hours.
2022-08-10	19:00	Last 2 scientists onboard, equipment on deck to deploy a clean and standard pumped water line from a towfish, ready to deploy once underway
2022-08-10	22:25	Underway from Ilulissat harbor
2022-08-10	22:45	Deploy towfish underway and test pump systems

2022-08-10	23:30	Clean pump and standard pump systems operational. All sensors intercalibrated in flow through system in wet lab entrance which outflows into the ship's drain and is fed by the pump. One pump line feeds into an insulated flow through box and a flow-through TA system, the other through a laminar flow hood that can be directly sampled from when desired (all in the wet lab entrance area). Ship slowly cruising (6 knots) south along the coast, returning in a loop to the Icefjord entrance in the morning to commence ADCP and CTD work
2022-08-11	9:30	Safety brief with the captain, fire MOB evacuation and work on deck protocols. Ship located in front of Icefjord entrance
2022-08-11	10:36	CTD(14) from A frame to 100 m
2022-08-11	11:00	Commence ADCP operations towing ADCP unit on rope to port out of the ship bubble stream, underway at 2 knots to calibrate settings, a linear section 'down ice' from the fjord mouth, accelerating to 4 knots once data stream established, repeating a section at 300 m depth along entrance to the Icefjord within ca. 1 km of the edge of the ice field/ice debris. CTDs repeated at end points and mid point of the section throughout the day. We refer to this as 'Line F',
2022-08-11	15:00	CTD(15) from A frame to 100 m
2022-08-11	15:30	CTD(16) from A frame to 100 m
2022-08-11	16:30	CTD(17) from A frame to 100 m
2022-08-11	19:28	CTD(18) from A frame to 100 m
2022-08-11	19:52	CTD(19) from A frame to 100 m
2022-08-11	20:55	CTD(20) from A frame to 100 m
2022-08-11	21:43	CTD(21) from A frame to 100 m
2022-08-11	22:19	CTD(22) from A frame to 100 m
2022-08-11	23:26	CTD(23) from A frame to 100 m
2022-08-12	0:25	CTD(24) from A frame to 100 m
2022-08-12	1:01	CTD(25) from A frame to 100 m
2022-08-12	1:40	CTD(26) from A frame to 100 m
2022-08-12	2:47	CTD(27) from A frame to 100 m
2022-08-12	3:46	CTD(28) from A frame to 100 m
2022-08-12	4:28	CTD(29) from A frame to 100 m
2022-08-12	5:16	CTD(30) from A frame to 100 m
2022-08-12	6:22	CTD(31) from A frame to 100 m
2022-08-12	7:22	CTD(32) from A frame to 100 m
2022-08-12	7:59	CTD(33) from A frame to 100 m
2022-08-12	8:43	CTD(34) from A frame to 100 m
2022-08-12	9:55	CTD(35) from A frame to 100 m, end of underway dedicated ADCP operations along the specified line. Now proceeding to a short transect of the main fjord entrance.
2022-08-12	11:13	CTD(36) from A frame to 100 m with biogeochemistry, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-12	12:37	CTD(37) from A frame to 100 m
2022-08-12	12:47	CTD(38) from A frame to 100 m with biogeochemistry, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-12	13:52	CTD(39) from A frame to 100 m
2022-08-12	14:38	CTD(40) from A frame to 100 m with biogeochemistry, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.

2022-08-12	15:30	Sanna proceeding west to make the longest offshore transects tomorrow, taking advantage of good weather conditions in the Bay. Underway sensor measurements continuing as well as clean pump from towfish, entering Disko Fjord overnight.
2022-08-13	4:00	Exiting Disko Fjord, underway transect of main plume on way out of system, underway TA disabled as the plume here is too fresh for the automated setup to produce reliable data (designed for S>28)
2022-08-13	9:38	Choppy seas due to a SW wind, towfish cannot be used at speed so removed for maintenance.
2022-08-13	12:11	CTD(41) from A frame to 100 m. Towfish redeployed.
2022-08-13	12:47	CTD(42) from A frame to 100 m with biogeochemistry, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-13	14:10	CTD(43) from A frame to 100 m
2022-08-13	14:52	CTD(44) from A frame to 100 m with biogeochemistry, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-13	16:15	CTD(45) from A frame to 100 m
2022-08-13	16:58	CTD(46) from A frame to 100 m with biogeochemistry, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-13	18:25	CTD(47) from A frame to 100 m
2022-08-13	19:08	CTD(48) from A frame to 100 m with biogeochemistry, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-13	20:33	CTD(49) from A frame to 100 m
2022-08-13	20:30	Underway measurements up to and along Eqip Sermia fjord system overnight
2022-08-14	0:44	Trial drone deployment while underway for iceberg imagery
2022-08-14	9:13	CTD(50) from A frame to 100 m
2022-08-14	9:56	CTD(51) from A frame to 100 m with biogeochemistry, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-14	10:00	Drone photo operations around ship
2022-08-14	11:11	CTD(52) from A frame to 100 m
2022-08-14	12:01	CTD(53) from A frame to 100 m with biogeochemistry, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-14	13:20	CTD(54) from A frame to 100 m
2022-08-14	14:28	CTD(55) from A frame to 100 m with biogeochemistry, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-14	15:01	CTD(56) from A frame to 100 m
2022-08-14	15:30	Cross-sections of NE exit of Disko Bay, 'boxing in' the major freshwater/ice plume with underway measurements at 6.5 knots, 5 cross-sections total
2022-08-15	10:00	CTD(57) from A frame to 100 m with biogeochemistry, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-15	11:31	CTD(58) from A frame to 100 m
2022-08-15	12:28	CTD(59) from A frame to 100 m

2022-08-15	13:34	CTD(60) from A frame to 100 m with biogeochemistry, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-15	14:53	CTD(61) from A frame to 100 m
2022-08-15	15:44	CTD(62) from A frame to 100 m with biogeochemistry, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-15	17:14	CTD(63) from A frame to 100 m
2022-08-15	17:30	Incubation experiment testing responses of plankton to iceberg melt set up on deck with ship's seawater supply pumped through a large (c 2m2) open container on deck with overflow.
2022-08-15	18:00	Underway measurements up to and along SE fjord branch system overnight
2022-08-16	8:56	CTD(64) from A frame to 100 m
2022-08-16	11:12	CTD(65) from A frame to 100 m with biogeochemistry, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-16	9:36	CTD(66) from A frame to 100 m
2022-08-16	12:35	CTD(67) from A frame to 100 m with biogeochemistry, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-16	13:53	CTD(68) from A frame to 100 m
2022-08-16	14:52	CTD(69) from A frame to 100 m with biogeochemistry, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-16	16:17	CTD(70) from A frame to 100 m
2022-08-16	17:51	CTD(71) from A frame to 100 m
2022-08-16	17:51	Photo ops from drone whilst ship stationary for CTD
2022-08-16	18:24	CTD(72) from A frame to 100 m, one bottle of water collected for incubation experiments (at 10 m depth) which are continuing on deck
2022-08-16	19:06	CTD(73) from A frame to 100 m
2022-08-16	19:20	Underway measurements in a grid at the Ilulissat ice fjord capturing the main area of ice and freshwater outflow
2022-08-17	10:05	CTD(74) from A frame to 100 m
2022-08-17	11:04	CTD(75) from A frame to 100 m
2022-08-17	12:25	CTD(76) from A frame to 100 m, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-17	14:08	CTD(77) from A frame to 100 m
2022-08-17	15:20	CTD(78) from A frame to 100 m, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-17	16:40	CTD(79) from A frame to 100 m
2022-08-17	17:21	CTD(80) from A frame to 100 m
2022-08-17	17:00	The crew informed the PI that due to a family emergency the ship is returning to Ilulissat immediately, pumps are removed from the water and the ship turned full speed for Ilulissat. Science suspended, operations will re-commence exiting Ilulissat harbor after the drop off
2022-08-17	18:25	After two crew disembark and a late delivery is taken onboard from JPL (profiler), we depart from Ilulissat harbor. Profiler prepared for deployment, confirmed successful from correspondence with JPL.

2022-08-17	19:00	Towfish redeployed and pumps restarted for underway measurements, ship heading NE along coastline for underway data towards a final fjord transect overnight
2022-08-18	3:36	Towfish snagged an iceberg damaging the inflow line, brought aboard for repairs, redeployed at 04:16 and pumps flushed
2022-08-18	11:16	CTD(81) from A frame to 100 m
2022-08-18	12:30	CTD(82) from A frame to 100 m, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-18	13:59	CTD(83) from A frame to 100 m
2022-08-18	14:42	CTD(84) from A frame to 100 m, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-18	15:55	CTD(85) from A frame to 100 m
2022-08-18	16:49	CTD(86) from A frame to 100 m
2022-08-18	17:59	CTD(87) from A frame to 100 m, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-18	19:16	CTD(88) from A frame to 100 m
2022-08-18	20:17	CTD(89) from A frame to 100 m
2022-08-18	21:09	CTD(90) from A frame to 100 m
2022-08-18	22:40	CTD(91) from A frame to 100 m, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-18	23:00	Transect along channel north of Disko Island complete, towfish removed from water and serviced, snagged kelp removed, underway measurements commence on return leg towards main Bay area
2022-08-19	8:26	CTD(92) from A frame to 100 m
2022-08-19	9:25	CTD(93) from A frame to 100 m, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-19	12:46	CTD(94) from A frame to 100 m
2022-08-19	13:57	CTD(95) from A frame to 100 m, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-19	14:05	Drone op to test ability to measure heights above sea level.
2022-08-19	15:18	CTD(96) from A frame to 100 m
2022-08-19	16:51	CTD(97) from A frame to 100 m
2022-08-19	17:53	CTD(98) from A frame to 100 m, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-19	18:26	Iceberg suitable for a process study cited within tonight's box and close to tomorrow's deployment site. Tracked on radar to verify moving. Rate of change over 3 hours confirms a steady movement, however deteriorating weather (sea state 1 to sea state 3 in a few hours) means unlikely operations close to the iceberg will reveal a clear plume. No attempt made to commence close operations, will evaluate possibility of near-iceberg measurements with a weather report tomorrow morning, presently no internet or phone signal so impossible to get a reliable forecast except by radio.
2022-08-19	19:20	CTD(99) from A frame to 100 m

2022-08-19	20:14	CTD(100) from A frame to 100 m, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-19	21:37	CTD(101) from A frame to 100 m
2022-08-19	21:50	Underway measurements 'boxing in' the NE sector of the Bay area overlapping with the prior gridwork infront of the icefjord mouth and Equip Sermia entrance.
2022-08-20	7:00	Weather report obtained, best weather opportunity for iceberg operations is from 0600 21/08/2022, today choppy seas ok for transects and stations but not for ice face work. Re-directed today's efforts towards a deep profile at the entrance to Equip Sermia and operations within the fjord where conditions are more favorable, track plotted to have us on station for favorable wind in the central Bay area tomorrow morning
2022-08-20	11:50	CTD(102) from A frame to 100 m, bottle samples at 1 and 5 m only
2022-08-20	12:42	CTD(103) from A frame to 100 m, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles. We attempted further casts to conduct deeper profiles, but a strong down-fjord wind resulted in a wire angle of 50 degrees even with additional weight (+20 kg) on the line, attempts to conduct deeper work were thus abandoned.
2022-08-20	14:25	CTD(104) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-20	15:08	CTD(105) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-20	15:15	We spotted some waste plastic floating near the station and practiced our bergy bit sampling (nylon net) technique recovering a fisherman's glove.
2022-08-20	15:54	CTD(106) from A frame to 100 m, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-20	17:12	CTD(107) from A frame to 100 m, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles.
2022-08-20	18:14	CTD(108) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-20	19:11	CTD(109) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-20	20:06	CTD(110) from A frame to 100 m, bottle samples at 1 and 5 m only
2022-08-20	20:15	Heavy ice (melange) encountered near ice front. Towfish removed after heavy collisions. We took advantage of having to proceed slowly (3 knots) to 'fish' for icebergs with nylon nets over the side of the boat, recovering about 50 samples for analysis.
2022-08-20	21:00	Small boat deployed with one niskin bottle, salinity/temperature probe, and some 1 L bottles for freshwater samples, Sampling conducted in region of freshwater outflow. After sampling a near-surface niskin for water, the S/T probe used to determine the actual condition of the bottle (in addition to a short S/T profile cast)
2022-08-20	22:08	CTD(111) from A frame to 100 m, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles. During operation, the winch line became unspooled and created a mess. The line had to be detached, unspooled and re-spooled delaying operations.
2022-08-20	22:15	Small boat operations over, small boat recovered, Sanna underway to exist Equip Sermia fjord and return to central bay area for iceberg operations, underway measurements at 6.5 knots.
2022-08-20	22:30	Towfish redeployed

2022-08-21	7:45	CTD(112) from A frame to 100 m at desired profiler deployment site. Unfortunately weather is not favorable for small boat or profiler deployment so we postpone this event. Weather charts indicate a finer weather window tomorrow evening.
2022-08-21	8:00	On station at desired profiler deployment site, however swell is too great to allow small boat deployment. Forecast suggests a weather window later today, Captain concurs this evening would likely be a good deployment time. As we are in the vicinity of several large icebergs, we opt to remain in the central Bay area conducting underway surveys to assess local iceberg influence
2022-08-21	8:30	Iceberg "Muskox" sited and tracked, moving Eastwards, a 'flower' pattern arranged around the iceberg to survey it for a four hour period. This includes a regular survey at 45 degree intervals proceeding away from the ice, then back to the ice, placing a CTD at the tip of the flower 'petal' away from the ice. Upon completion of the flower, we circle the ice putting 3 CTDs as close to the iceface as the captain feels safe. Based on observed windspeeds an upwind/downwind comparison is made and a 'wiggle' transecting the upwind-downwind line (wind from 070 degrees). Throughout, nutrients are sampled underway at 5 minute intervals from the pumped seawater supply.
2022-08-21	10:00	CTD(113) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-21	10:40	CTD(114) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-21	11:16	CTD(115) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-21	11:39	CTD(116) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-21	12:16	CTD(117) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-21	12:52	CTD(118) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-21	13:24	CTD(119) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-21	13:57	CTD(120) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-21	15:39	CTD(121) from A frame to 100 m, bottle samples at 1 and 5 m only. Station close to ice face of "Muskox"
2022-08-21	15:53	CTD(122) from A frame to 100 m, bottle samples at 1 and 5 m only. Station close to ice face of "Muskox"
2022-08-21	16:06	CTD(123) from A frame to 100 m, bottle samples at 1 and 5 m only. Station close to ice face of "Muskox"
2022-08-21	16:14	Iceberg "Muskox" survey complete, proceeding underway to next survey using radar to select and track large iceberg candidates in the northern Bay area.
2022-08-21	16:52	Arrived 1 nm from Iceberg "Narwhale", sited, largest sited berg within northern Bay. Same 'flower' pattern repeated around iceberg as was undertaken previously around "Muskox", an underway line proceeds at every 045 degrees away from the iceberg for 1 nm, stopping for a CTD at the tip of the petal and then returning to the proximity of the iceberg, before moving away at another +045 degrees. In this case there is practically no wind (light airs) so cannot complete an upwind/downwind section. Speed less than 5 knots throughout, slowing to 2 close to the ice and when proceeding through the ice field to limit damage to the towfish.
2022-08-21	16:53	CTD(124) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-21	17:29	CTD(125) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-21	17:51	CTD(126) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-21	18:20	CTD(127) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-21	19:00	CTD(128) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-21	19:10	Ice chunks are calving actively from "Narwhale" creating 'ice rings' of debri. DC able to sample underway for fragments of Narwhale present in an icefield skewed to the SW of the iceberg using nylon nets over the side of the ship.

2022-08-21	19:42	Towfish out of water to load small boat on crane
2022-08-21	19:45	Small boat in water, DC and CC deployed on profiler deployment mission, proceeding SE of the iceberg position to deploy a profiler away from the ship
2022-08-21	19:46	CTD(129) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-21	19:49	Towfish returned to water
2022-08-21	20:26	CTD(130) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-21	20:35	DC contacts boat with some queries concerning the profiler deployment. Instructions were followed to activate and push the float underwater, upon which it should activate and conduct a profile. The float however failed to descend, then upon a second try descended for only a few minutes before resurfacing. Via the ship's satellite phone, FB contacted the profiling team and relaying instructions to check profiler hardware, all of which appeared to be in order and no technical issues could be found. Final instructions were to leave the profiler assuming it is attempting to activate and conduct it's first profile.
2022-08-21	21:01	CTD(131) from A frame to 100 m, bottle samples at 1 and 5 m only.
2022-08-21	21:19	Profiling float sank correctly after a redeployment and wait
2022-08-21	21:45	Towfish detached to recover small boat. Small boat recovered.
2022-08-21	21:55	Towfish reattached and pumps re-engaged.
2022-08-21	23:08	CTD(132) from A frame to 100 m, bottle samples at 1 and 5 m only. Ice proximal station at "Narwhale", bottles at 1 and 5 m only.
2022-08-21	23:10	drone ops to survey iceberg "Narwhale"
2022-08-21	23:19	CTD(133) from A frame to 100 m, bottle samples at 1 and 5 m only. Ice proximal station at "Narwhale", bottles were due to be collected at 1 and 5 m, but a bottle was dropped hard on the deck by mistake smashing the handle and spigot. Both parts recovered, will attempt repairs tomorrow. No samples collected at station.
2022-08-21	23:27	Drone ops over, drone recovered
2022-08-21	23:31	CTD(134) from A frame to 100 m, bottle samples at 1 and 5 m only. Ice proximal station at "Narwhale", bottles at 1 and 5 m only.
2022-08-21	23:42	Iceberg operations around "Narwhale" complete, moving to deep Profiler station to complete a deep profile. Manual underway 5 minute resolution sampling stopped.
22-08-2022	0:05	CTD(135) Deep CTD at Profiler station. Full biogeochemistry with 1, 5, 10, 15, 20, 40, 60, 95, 150, 200, 250, 300 m. Go-Flo bottles mounted two at a time on the A frame, niskin used for shallow work (down to 40) over the side.
22-08-2022	0:28	Underway section across bay back towards the Icefjord 'filling in' the largest remaining gap for underway data in the NE sector of the bay.
22-08-2022	9:15	Repeat underway measurements of Line F across the main fjord mouth (a repeat section where ADCP was collected and will be collected again later today).
22-08-2022	12:00	Ship slowly approaching ice front of Icefjord to re-cover areas we know show strong pCO2 gradients, slowly approaching ice front then returning to Line F.
22-08-2022	14:30	Ship passing through ice slicks which are opportunistically sampled for ice samples with nylon nets over the side of the ship.
22-08-2022	14:05	Towfish snagged on ice, removed from water, tubes re-connected and pumps reengaged
22-08-2022	14:20	Towfish underway pumps working normally again
22-08-2022	15:29	CTD(136) from A frame to 100 m
22-08-2022	16:13	CTD(137) from A frame to 100 m

22-08-2022	16:59	CTD(138) from A frame to 100 m, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, and an extra depth at 150 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles. Salinity/temperature of deep bottles checked with EXO1.
22-08-2022	18:30	CTD(139) from A frame to 100 m
22-08-2022	19:27	CTD(140) from A frame to 100 m, 2 Go-Flo bottles deployed on A frame with CTD, standard depths of 60 m and 95 m, deep depths of 150 m , 200 m, 250 m and 320 m, remaining depths (1, 5, 10, 15, 20, 40 m) deployed using horizontal niskin 5 L bottles. Salinity/temperature of deep bottles checked with EXO1.
22-08-2022	21:00	Exit fjord vicinity, large iceberg sited NE, steamed at 6.5 knots for a final iceberg study, physical only. "Beluga"
22-08-2022	21:40	Arrive at "Beluga" actually a large berg almost or just about to split in two. Weather is calm but there is a swell preventing us from going slower than about 3 knots if we wish to maintain desired course. Rings of bergy bits extend out to the W, N and E.
22-08-2022	21:55	Visual inspection shows "Beluga" is still a single berg, connection between 'halves' is below the water line, commencing an iceberg flower maneuver as per yesterday but only for physical underway measurements.
22-08-2022	22:08	Preliminary radar data suggests this is definitely not a grounded iceberg, proceeding northwards at quite some rate.
22-08-2022	22:31	Based on the rapid northward trajectory of the iceberg, a flower route design would be meaningless compared to when deployed around a stationary iceberg, instead we opt for a circle design, tracking around the iceberg slowly as it transits northwards, with an occasional lateral movement of the ship west / east out of the iceberg's trajectory.
22-08-2022	23:35	Drone ops to observe iceberg "Beluga". Launched and recovered from aft deck.
22-08-2022	23:47	Drone recovered underway
23-08-2022	1:01	Last circling pass of iceberg "Beluga". Note the iceberg is close to (within visual range) of the ribbon of ice fragments which follow the NE coastline which may complicate data interpretation.
23-08-2022	1:15	Opportunistic sampling of ice fragments from the "Beluga" ice vicinity over the side of the ship with nylon nets.
23-08-2022	1:24	Proceeding to Line F (slightly extended to the S) to complete a second ADCP survey in the same area as the first survey. Quite a heavy load of bergy bits and growlers observed, speed generally reduced to 4 knots to avoid damage to the underway towfish system (usually cruise at 6.5 as the optimum speed for transiting with a towfish in the water)
23-08-2022	1:45	Heavy ice impeding passage to north end of line F. Given potential to lose the towfish and inability to fully crew the ship overnight (we are still 2 crew short and science party are exhausted after 2 days of limited sleep), decided to abandon attempts to deploy ADCP until better lighting in the morning. Proceeding slowly SW to open water out of the ice mélange.
23-08-2022	8:00	Ship spent the night W of the ice fjord entrance, now proceeding inshore to the S end of line F
23-08-2022	9:15	On station at S end of Line F. ADCP deployment commenced in water along line F
23-08-2022	11:50	ADCP transect abandoned after the unit was damaged twice in an hour, the sea state and ice cover are making a transect challenging. Ice cover is too intense to leave ADCP unattended and choppy seas are a threat to the power connection to the ship which is fragile and not designed for this sea state. We will instead complete a final series of underway measurements to the SW of the fjord

		mouth, filling in the largest remaining gaps in data coverage close to the ice fjord.
23-08-2022	18:13	Sensors switched off
23-08-2022	18:20	Towfish removed from water, ship makes for port.
23-08-2022	19:00	Alongside in harbor, equipment stripped and prepare for shipments
24-08-2022	14:00	Truck to remove boxes from ship arrives, frozen goods and samples for urgent analysis remain on ship to be transported back with scientists' flights tomorrow
25-08-2022	9:00	Frozen goods removed from freezer, sealed in cryobox and taken off ship. Scientists leave ship.

4 Preliminary Results

4.1 Underway salinity, temperature, turbidity, O_2, pCO_2 and chlorophyll (M. Hopwood, A. Körtzinger and D. Carroll)

Underway salinity, temperature and chlorophyll data were obtained from 2 parallel sets of sensors which will be compared to assess data quality. Sensors were mounted in a flow through box system with a pumped water supply from a 60 kg steel towfish which was mounted at approximately 1 m depth from the starboard winch for most of the cruise duration. Uncontaminated seawater was pumped through an insulated bath (water volume approx. 100 L) at a flow rate of approx. 8 L/min. Submerged in this bath were sensors for temperature (T), salinity (S), chlorophyll a fluorescence (chl a), dissolved oxygen (O_2) and CO_2 partial pressure (pCO_2). The O_2 and pCO_2 sensors were operated in pumped mode by connecting them via tubing to a Sea-Bird 5T pump (Sea-Bird Scientific Inc, Bellevue/WA, USA) also submerged in the bath. The following sensors were in use throughout the cruise: Sea-Bird SBE 37 MicroCAT (T, S), Wetlabs ECO FLNTU fluorometer (chl a), Sea-Bird SBE 63 optode (O_2) (all Sea-Bird Scientific Inc, Bellevue/WA, USA), CONTROS HydroC CO_2 sensor (-4H-JENA engineering GmbH, Jena, Germany) configured to carry out daily automatic zero gas measurements, and an EXO1 (YSI) equipped with salinity/temperature/turbidity/chl a sensor options. Data were logged at 30-120 s intervals. The pCO_2 sensor received a multi-point pre- and post-cruise calibration from the manufacturer. The O_2 sensor has a multi-point calibration polynomial from the manufacturer which was adjusted by measurement of 0% and 100% air-saturated freshwater right after the cruise.

From prior experience, the towfish is known to perform best at around 6 knots, at faster speeds the fish is prone to 'bouncing' in anything other than calm weather conditions, and the intake of air increases. A standard cruising speed of 6 knots was thereby adopted for most of the cruise. The fish mounted on a steel chain can cope with fragments of ice but becomes snagged and can result in damage to the tubes feeding pumps on the ship when ice fragments of >0.5 m are encountered. Under these ice conditions, the ship was either made to reduce speed to 1-2 knots with a crew member or scientist assigned to fending off large ice chunks, or the towfish was removed from the water column. These conditions were only encountered for a few hours at a time and so for >95% of the cruise track there is continuous coverage of the above sensor parameters.

Surface (1 m towfish depth) data demonstrated a wide range of salinity, temperature and conditions, with surface waters ranging from -0.7 to 9°C, and salinity 20 to 32. A particularly interesting recurrent feature was the presence of a distinct coastal low salinity belt in the NE sector of the Bay which was where the largest concentration of iceberg fragments were observed, many of them grounded at the coastline. The highest chlorophyll concentrations (again, uncalibrated at this point) were seen in the entrance to Equip Sermia fjord, and high turbidity was unsurprisingly associated with glacier outflows, particularly in Disko Fjord.

4.2 Underway and discrete total alkalinity (A. Körtzinger)

In addition, semi-continuous measurements of total alkalinity (TA) were performed on a separate water flow teed-off from the main pumping line. The particle-free and bubble-free sample flow for the TA system (flow rate approx. 200 mL/min) was separated via a cross-flow filter and a debubbler (water volume approx. 200 mL). We used a CONTROS HydroFIA TA system (-4H-JENA engineering GmbH, Jena, Germany). Discrete samples were drawn automatically from the pumped seawater flow and measured at intervals varied between 10-15 min depending on the situation. The TA system was referenced against daily measurements of certified reference material for the marine CO_2 system (procured from Dickson Laboratory, UCSD, La Jolla/CA, USA). A total of about 1000 underway surface TA measurements were performed. Discrete samples will be compared to manual titrations on a selection of profiles.

4.3 Manual O_2, dissolved silicic acid and pH measurements at sea (C. Cantoni, S. Cozzi and M. Hopwood)

O_2 and pH measurements were made on all biogeochemical profiles (on average, 3 per day) totaling 272 measurements for O_2 and 283 measurements for pH over the cruise duration. DO samples were analysed by Winkler method, within one day of the sampling, using an automated potentiometric titration system Metrohm 798 MPT Titrino (CV = 0.17 % at 210 µmol O_2 l^{-1}). Apparent Oxygen Utilization (AOU; µmol O_2 l^{-1}), the difference between the oxygen saturation concentration and the measured DO concentration, was calculated using CTD data of temperature and salinity.

pH was determined spectrophotometrically at sea, within 12 hours from sampling, using m-cresol purple as pH indicator, at 20 ± 0.05 °C. 50 samples were analyzed in duplicates and certified reference material for the marine CO_2 system (procured from Dickson Laboratory, UCSD, La Jolla/CA, USA) were measured regularly . Samples were duplicated for sensor-based TA then obtained on the same water (see 4.2) and 50 additional water samples were preserved and retained for manual TA measurements in Trieste. This will ensure that the sensor and manual carbonate chemistry measurements are properly intercalibrated. The combination of TA,, pH and pCO_2 data will allow full characterization of the carbonate system including accurate quantification of uncertainties.

Dissolved silicic acid was determined on a subset of 100 samples using the absorbance of molybdate blue at sea. Samples were stored refrigerated in the dark with both filtered and unfiltered replicates. Within 48 hours of collection, dSi was determined spectrophotometrically. Samples with intense blue coloration were diluted with acidified de-ionized water.

4.4 CTD Measurements (D. Carroll and F. Barcena)

CTD data were obtained at around 10 stations per day, 126 profiles in total (140 including prior Ice Disko work), focused mainly on 8 different transects which covered the Bay area in a regular grid and resulted in a mean distance of ~10 km between profiles. A lense of fresh Polar Water is clearly identifiable across the Bay area. A large number of CTDs were conducted during the first 2 iceberg studies which collected a high resolution of data within the vicinity of two icebergs in the NE sector of the Bay area (see s4.6).

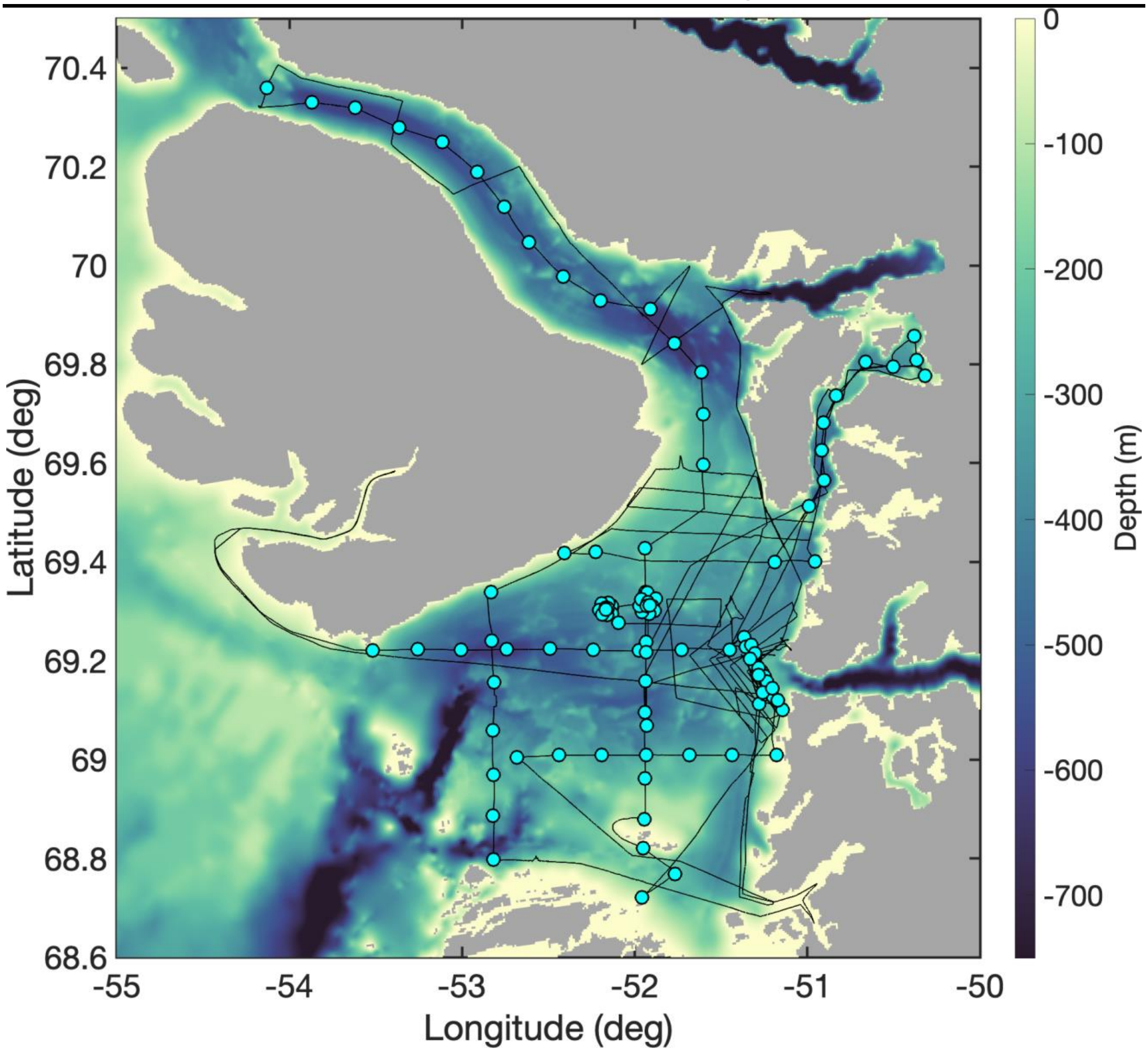

Fig. 2. All CTD casts on the cruise overlain on the cruise track. 1/3 of stations were sampled for biogeochemical parameters (pH, TA, macronutrients and O_2).

4.5 ADCP data (F. Barcena)

'Line F' was selected as the closest continuous line that could be made across the main icefjord mouth without encountering heavy ice cover and a repeat section of this line was made throughout the cruise (x times in total). A 24 hour study across line F was conducted with continuous ADCP measurements made from a towed boat which was mounted on the port side of the vessel with a rope pulley system that reduced the tendency of the ADCP unit to bang against the side of the ship and stabilised it's relative position. CTDs were conducted at both the endpoints and midpoint of Line F and a total of x passess of line F were made during the diel study.

4.6 Drone and iceberg process operations

Whilst the main approach to study icebergs herein will be statistical via analysis of cruise data in the context of mean iceberg intensity in different areas of the Bay as established by satellite imagery, 3 process studies were conducted where individual icebergs were subject to intensive measurements with the ship in close proximity to the ice face (within 1 km and up to 100 m from the ice edge). During these deployments a drone was used to circle the icebergs producing high resolution imagery, and to establish the height of the iceberg above sea level. Radar was used to help the ship obtain a regular course around the iceberg and to track the iceberg's movement.

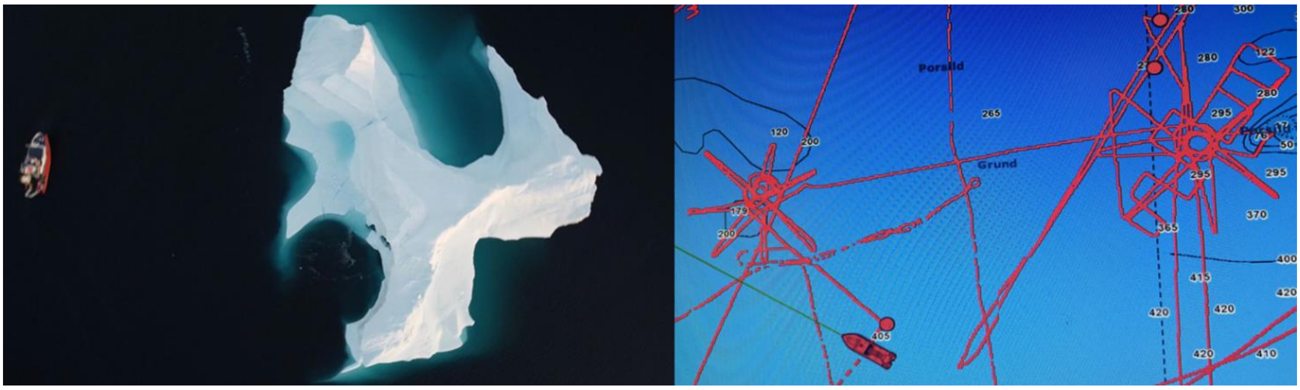

Fig. 3. Iceberg operations at "Muskox" and "Narwhale". Drone footage was used to constrain the dimensions of the icebergs (left) whilst radar was used to conduct a regular survey of the iceberg periphery (right).

Our first attempt at this maneuver for a large iceberg named "Polar Bear" was abandoned due to deteriorating weather conditions which meant it would not have been possible for the ship to safely navigate within a few hundred meters of the iceberg. Our 2nd, 3rd and 4th attempts were all more successful. Icebergs "Muskox" and "Narwhale" were tracked and studied for approximately 4 hours each, with the ship moving upstream/downstream, upwind/downwind and circumnavigating each iceberg several times. The ship's speed was reduced to 2-4 knots considering the response time of the sensors used for underway data and the flushing time of the pump systems used to obtain an underway water feed. Radar data showed that "Muskox" became grounded as we were tracking it, whereas conversely "Narwhale" was grounded when we began observations but began moving during our observations. In our work around the Bay it become apparent that most large icebergs observed were grounded and generally observed close to shallow seamounts. A third process study followed the iceberg "Beluga" which was notable for a fast NE trajectory.

4.7 Autonomous profiler deployment

In collaboration with the Oceans Melting Greenland team at JPL/NASA, we deployed an autonomous profiler in the centre of Disko Bay followed by a deep CTD station at the same location. Following the profiler deployment, we received verification that CTD depth profiles were being successfully collected, this datastream is independent of the cruise proposal but will be freely available to complement interpretation of cruise data. The profiler can collect measurements for up to two years and we look forward to tracking its progress (every time the profiler surfaces it tramsits its last profile data).

5 Data and Sample Storage / Availability

CTD and underway data logged during the cruise have been formatted into a preliminary dataset (CSV) which is now stored on a google drive accessible to all cruise participants. A bottle and underway way point file is also available to add discrete measurements to as chemical measurements are completed in coming months. Upon completion of chemical analysis (DOC/N, macronutrients, particle digests, Hg, Hg-Me, Cu-L and dTMs) the complete cruise dataset will be uploaded to PANGAEA.

6 Participants

No.	Name	Early career (Y/N)	Gender	Affiliation	On-board tasks
1	Mark Hopwood	Y	M	GEOMAR*/ SUSTech	PI, incubation experiments, underway sampling, iceberg tracking ops, dSi measurement
2	Dustin Carroll	N	M	San Jose University	CTD operation, data processing, profiling float deployment
3	Maria Fernanda Gastelu Barcena	Y	F	University of Florida	CTD operation, ADCP, drone ops
4	Arne Körtzinger	N	M	GEOMAR	Underway sensors, TA measurement, pCO_2 measurement, underway sampling
5	Carolina Cantoni	N	F	CNR-ISMAR	pH measurement, bottle sampling
6	Stephano Cozzi	N	M	CNR-ISMAR	O_2 measurement, bottle sampling, data logging, underway sampling

All participants funded by EUROFLEETS. *Due to the change of cruise year, the main PI changed affiliations from GEOMAR, where the EUROFLEETS grant was awarded, to SUSTech, an institution not formally party to the original cruise agreement. To minimize disruption to cruise planning, GEOMAR kindly agreed to continue to act as the host institution and data owner. Thus, formally the cruise is GEOMAR led. No objections were raised to this arrangement by other partners.

GEOMAR GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany

CNR-ISMAR Consiglio Nazionale delle Ricerche, Istituto delle Scienze Marine, Trieste, Italy

7 Station List

Station	*Type*	*Date (UTC)*	*Start time UTC*	*End time UTC*	*Lat °N*	*Long °E*	*Bottom Depth m*	*Sampling depth (/ bottle depths)*
14	CTD	11/08/2022	10:36	10:47	69.1143	51.2807	276.9	105 m
15	CTD	11/08/2022	15:05	15:11	69.2481	51.3666	387.0	95 m
16	CTD	11/08/2022	15:34	15:49	69.2282	51.3567	364.0	95 m
17	CTD	11/08/2022	17:36	17:57	69.1382	51.2503	204.7	95 m
18	CTD	11/08/2022	19:28	19:36	69.2000	51.3090	315.0	95 m
19	CTD	11/08/2022	19:52	20:04	69.1837	51.2839	295.2	95 m
20	CTD	11/08/2022	20:55	21:03	69.2313	51.3245	358.0	95 m
21	CTD	11/08/2022	21:43	19:49	69.2042	51.3031	313.5	95 m
22	CTD	11/08/2022	22:19	22:26	69.1858	51.2867	308.0	95 m

23	CTD	11/08/2022	23:26	23:35	69.1332	51.2473	216.5	95 m
24	CTD	12/08/2022	0:25	0:34	69.1837	51.2878	307.0	95 m
25	CTD	12/08/2022	1:01	1:07	69.2091	51.3061	323.0	95 m
26	CTD	12/08/2022	1:40	1:48	69.1853	51.2862	309.0	95 m
27	CTD	12/08/2022	2:47	2:56	69.1348	51.2529	219.8	95 m
28	CTD	12/08/2022	3:46	3:57	69.1826	51.2892	307.0	95 m
29	CTD	12/08/2022	4:28	5:16	69.2128	51.3030	324.0	95 m
30	CTD	12/08/2022	5:16	5:23	69.1838	51.2832	283.0	95 m
31	CTD	12/08/2022	6:22	6:31	69.1343	51.2480	214.0	95 m
32	CTD	12/08/2022	7:22	7:31	69.1843	51.2842	296.0	95 m
33	CTD	12/08/2022	7:59	8:10	69.2082	51.3092	322.0	95 m
34	CTD	12/08/2022	8:43	8:49	69.1843	51.2836	295.0	95 m
35	CTD	12/08/2022	9:55	10:00	69.1336	51.2497	216.5	95 m
36	CTD+ Bottles	12/08/2022	11:13	11:20	69.1855	51.2946	216.5	1-95 m
37	CTD	12/08/2022	12:37	12:44	69.1772	51.2623	247.0	95 m
38	CTD+ Bottles	12/08/2022	12:47	12:57	69.1688	51.2464	191.8	1-95 m
39	CTD	12/08/2022	13:52	14:12	69.1567	51.2351	168.1	95 m
40	CTD+ Bottles	12/08/2022	14:38	14:50	69.1273	51.2006	171.3	1-95 m
41	CTD	13/08/2022	12:11	12:15	69.2211	53.5184	162.0	95 m
42	CTD+ Bottles	13/08/2022	12:47	13:20	69.2230	53.2562	428.0	1-95 m
43	CTD	13/08/2022	14:10	14:20	69.2221	53.0071	548.0	95 m
44	CTD+ Bottles	13/08/2022	14:52	15:30	69.2235	52.7418	348.0	1-95 m
45	CTD	13/08/2022	16:15	16:20	69.2241	52.4905	512.0	95 m
46	CTD+ Bottles	13/08/2022	16:58	17:30	69.2224	52.2408	307.0	1-95 m
47	CTD	13/08/2022	18:25	18:31	69.2210	51.9762	422.0	95 m
48	CTD+ Bottles	13/08/2022	19:08	19:21	69.2228	51.7298	431.0	1-95 m
49	CTD	13/08/2022	20:33	20:41	69.2222	51.4521	515.0	95 m
50	CTD	14/08/2022	9:13	9:18	69.4014	50.9551	342.0	95 m
51	CTD+ Bottles	14/08/2022	9:54	10:13	69.4007	51.1896	343.0	1-95 m
52	CTD	14/08/2022	11:11	11:16	69.4012	51.4548	228.0	95 m
53	CTD+ Bottles	14/08/2022	12:00	12:30	69.4003	51.7195	306.0	1-95 m
54	CTD	14/08/2022	13:20	13:27	69.4030	51.9662	217.6	95 m
55	CTD+ Bottles	14/08/2022	14:27	14:55	69.4212	52.2247	240.0	1-95 m
56	CTD	14/08/2022	15:01	15:13	69.4174	52.4097	70.0	60 m
57	CTD+ Bottles	15/08/2022	10:00	10:12	69.3396	52.8274	273.0	1-95 m
58	CTD	15/08/2022	11:31	11:37	69.2409	52.8305	567.0	95 m
59	CTD	15/08/2022	12:28	12:33	69.1569	52.8157	265.0	95 m

60	CTD+ Bottles	15/08/2022	13:35	13:50	69.0599	52.8234	310.3	1-95 m
61	CTD	15/08/2022	14:53	14:57	68.9691	52.7359	196.0	95 m
62	CTD+ Bottles	15/08/2022	15:45	16:05	68.8872	52.8211	248.0	1-95 m
63	CTD	15/08/2022	17:14	17:22	68.7980	52.8203	332.7	95 m
64	CTD	16/08/2022	8:56	9:09	69.0044	52.6813	331.0	95 m
65	CTD+ Bottles	16/08/2022	11:12	11:40	69.0094	52.4408	254.3	1-95 m
66	CTD	16/08/2022	9:36	9:42	69.0089	52.1930	341.0	95 m
67	CTD+ Bottles	16/08/2022	12:36	12:58	69.0089	51.9351	328.0	1-95 m
68	CTD	16/08/2022	13:53	14:01	69.0089	51.6845	276.0	95 m
69	CTD+ Bottles	16/08/2022	14:55	15:05	69.0101	51.4325	287.9	1-95 m
70	CTD	16/08/2022	16:17	16:23	69.0087	51.1801	176.0	95 m
71	CTD+ Bottles	16/08/2022	17:51	18:00	69.1361	51.2577	217.0	10 m only
72	CTD	16/08/2022	18:24	18:40	69.1883	51.2849	309.0	95 m
73	CTD	16/08/2022	19:06	19:10	69.2142	51.3056	329.0	95 m
74	CTD	17/08/2022	10:05	10:14	68.7205	51.7205	105.0	95 m
75	CTD+ Bottles	17/08/2022	11:05	11:14	68.7687	51.7692	271.0	1-95 m
76	CTD	17/08/2022	12:25	12:32	68.8212	51.9510	323.0	95 m
77	CTD+ Bottles	17/08/2022	14:07	14:19	68.8796	51.9450	46.0	1-95 m
78	CTD	17/08/2022	15:20	15:27	68.9602	51.9417	206.0	95 m
79	CTD	17/08/2022	16:40	16:44	69.0956	51.9461	481.0	95 m
80	CTD+ Bottles	17/08/2022	17:25	17:34	69.1516	51.9466	414.0	1-95 m
81	CTD	18/08/2022	11:16	11:20	69.9115	51.9117	613.7	95 m
82	CTD+ Bottles	18/08/2022	12:30	12:41	69.9292	52.1991	737.0	1-95 m
83	CTD	18/08/2022	13:59	14:04	69.9774	52.4143	251.7	95 m
84	CTD+ Bottles	18/08/2022	14:42	14:51	70.0422	52.6100	505.1	1-95 m
85	CTD	18/08/2022	15:55	16:00	70.1192	52.7570	482.0	95 m
86	CTD	18/08/2022	16:49	16:54	70.1883	52.9116	531.0	95 m
87	CTD+ Bottles	18/08/2022	18:00	18:08	70.2496	53.1150	431.0	1-95 m
88	CTD	18/08/2022	19:16	19:21	70.2793	53.3658	575.0	95 m
89	CTD	18/08/2022	20:17	20:22	70.3180	53.6192	733.0	95 m
90	CTD	18/08/2022	21:09	21:15	70.3296	53.8680	567.2	95 m
91	CTD+ Bottles	18/08/2022	22:40	22:54	70.3597	54.1296	360.0	1-95 m
92	CTD	19/08/2022	10:26	10:31	69.8428	51.7714	624.0	95 m
93	CTD+ Bottles	19/08/2022	11:25	11:33	69.7839	51.6138	548.0	1-95 m
94	CTD	19/08/2022	12:46	12:52	69.6986	51.6033	410.0	95 m

95	CTD+ Bottles	19/08/2022	13:57	14:15	69.5965	51.6039	265.0	1-95 m
96	CTD	19/08/2022	15:18	15:22	69.5072	51.5965	255.0	95 m
97	CTD	19/08/2022	16:51	16:57	69.4283	51.9417	292.0	95 m
98	CTD+ Bottles	19/08/2022	17:52	18:01	69.3390	51.9323	307.0	1-95 m
99	CTD	19/08/2022	19:20	19:25	69.2381	107.1520	405.0	95 m
100	CTD+ Bottles	19/02/2022	20:15	20:25	69.1593	51.9371	388.0	1-95 m
101	CTD	19/08/2022	21:37	21:43	69.0685	51.9314	319.0	95 m
102	CTD+ Bottles	20/08/2022	11:50	11:55	69.5143	50.9879	448.0	1 & 5 m
103	CTD+ Bottles	20/08/2022	12:42	13:02	69.5663	50.9055	510.0	1-95 m
104	CTD+ Bottles	20/08/2022	14:25	14:30	69.6260	50.9180	495.0	1 & 5 m
105	CTD+ Bottles	20/08/2022	15:08	15:14	69.6822	50.6822	411.0	1 & 5 m
106	CTD+ Bottles	20/08/2022	15:55	16:01	69.7367	50.8364	160.0	1-95 m
107	CTD+ Bottles	20/08/2022	17.13	17:21	69.8044	50.6637	383.0	1-95 m
108	CTD+ Bottles	20/08/2022	18:14	18:24	69.7951	50.8352	374.0	1 & 5 m
109	CTD+ Bottles	20/08/2022	19:11	19:16	69.8577	50.3824	318.0	1 & 5 m
110	CTD+ Bottles	20/08/2022	20:06	20:11	69.8080	50.3681	328.0	1 & 5 m
111	CTD+ Bottles	20/08/2022	22:08	22:12	69.7753	50.3120	217.0	1-95 m
112	CTD	21/08/2022	8:08	8:12	69.2168	51.9343	362.0	95 m
113	CTD+ Bottles	21/08/2022	10:00	10:05	69.3375	51.9286	243.0	1 & 5 m
114	CTD+ Bottles	21/08/2022	10:40	10:45	69.2754	51.8787	250.0	1 & 5 m
115	CTD+ Bottles	21/08/2022	11:16	11:20	69.3100	51.8948	246.0	1 & 5 m
116	CTD+ Bottles	21/08/2022	11:39	11:44	69.3018	104.1230	362.0	1 & 5 m
117	CTD+ Bottles	21/08/2022	12:16	12:22	69.2954	51.9159	267.0	1 & 5 m
118	CTD+ Bottles	21/08/2022	12:52	12:58	69.2982	51.9594	364.0	1 & 5 m
119	CTD+ Bottles	21/08/2022	13:24	13:31	69.3116	51.9708	312.0	1 & 5 m
120	CTD+ Bottles	21/08/2022	13:57	14:02	69.3247	51.9620	390.0	1 & 5 m
121	CTD+ Bottles	21/08/2022	15:39	15:45	69.3179	51.9233	228.0	1 & 5 m
122	CTD+ Bottles	21/08/2022	15:53	15:58	69.3109	51.9308	259.0	1 & 5 m
123	CTD+ Bottles	21/08/2022	16:06	16:11	69.3119	51.9140	237.0	1 & 5 m

124	CTD+ Bottles	21/08/2022	16:53	17:02	69.3077	52.1328	348.0	1 & 5 m
125	CTD+ Bottles	21/08/2022	17:29	17:33	69.3111	52.1327	512.0	1 & 5 m
126	CTD+ Bottles	21/08/2022	17:51	17:56	69.3173	52.1546	162.0	1 & 5 m
127	CTD+ Bottles	21/08/2022	18:20	18:24	69.3163	63.6050	250.0	1 & 5 m
128	CTD+ Bottles	21/08/2022	19:00	19:05	69.3030	52.2052	347.0	1 & 5 m
129	CTD+ Bottles	21/08/2022	19:46	19:52	69.2951	52.1332	315.0	1 & 5 m
130	CTD+ Bottles	21/08/2022	20:26	20:34	69.2926	52.1601	340.0	1 & 5 m
131	CTD+ Bottles	21/08/2022	21:01	21:08	69.2937	52.1884	317.0	1 & 5 m
132	CTD+ Bottles	21/08/2022	23:08	23:13	69.3079	52.1690	303.0	1 & 5 m
133	CTD	21/08/2022	23:19	23:25	69.3065	52.1589	345.0	95 m
134	CTD+ Bottles	21/08/2022	23:31	23:39	69.3043	52.1670	353.0	1 & 5 m
135	CTD+ Bottles	22/08/2022	0:05	0:28	69.2769	52.0951	402.0	1-300 m
136	CTD	22/08/2022	15:29	15:36	69.1013	51.1415	114.0	95 m
137	CTD	22/08/2022	16:13	16:19	69.1198	51.1718	112.0	95 m
138	CTD+ Bottles	22/08/2022	16:59	17:10	69.1444	51.2033	150.0	1-160 m
139	CTD	22/08/2022	18:30	18:35	69.1708	51.2816	286.0	95 m
140	CTD+ Bottles	22/08/2022	19:27	19:36	69.2036	51.3306	331.0	1-300 m

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