Canadian Arctic Through-flow

2012 Cruise to Nares Strait

CCGS Henry Larsen

August 2-17, 2012

Institute of Ocean Sciences Cruise 2012-20

Humfrey Melling – Chief Scientist

Fisheries & Oceans Canada

Collaborating Institutions:
Institute of Ocean Sciences, University of Delaware,
Oxford University, Danish Technical University, Scottish Association for Marine Science

Cover photo, courtesy of Jason Box:

View looking south across the Petermann ice shelf towards Joe Island, Kennedy Channel and Ellesmere Island at the horizon.

Note the small ice-shelf fragments in the foreground and cracks within the protruding lobe of the ice .

The photograph taken in 2009, before the large ice islands calved from the shelf in August 2010 and again in July 2012.

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Overview

The Canadian Arctic Through-flow (CAT) study embodies ten years' effort within Canada and the international community to measure flows of seawater and ice through the Canadian Archipelago, between the Arctic and the Atlantic Oceans.

CATs is the outgrowth of a pilot effort, the Arctic Canada Watch, established in 1997. Moorings enabling year-round measurements were first placed in western Lancaster Sound and Cardigan Strait in 1998. These carried instruments to measure current, temperature and salinity and utilized innovations to address the unique challenges of observing: 1) current direction near the geomagnetic pole; 2) salinity within the hazardous 30-m zone beneath drifting ice pack. These early installations have been maintained and augmented since 1998.

In 2003, a large array of instruments was installed across the third principal path for Canadian Arctic through-flow, Nares Strait. The study was initiated with the support of the US National Science Foundation and USA collaborators – Dr Andreas Münchow of the University of Delaware and Drs Kelly Falkner and Roger Samelson of Oregon State University. At this time the Canadian Arctic Through-flow study came of age as an important component of the international Arctic Sub-Arctic Ocean Fluxes project (ASOF). Most of the instruments placed in Nares Strait in 2003 were retrieved using CCGS Henry Larsen in 2006.

The CAT study has scientific objectives with both short (1-3 year) and long-term perspectives. In the short term, the study is exploring the seasonal and inter-annual ocean variability within the Canadian Archipelago, using recently proven technology. One long term goal is an understanding of the forcing and control of CAT, so that it may be represented more realistically in the computer models used to predict climate change. A second is the development of effective affordable approaches to monitoring ocean climate – sustained observations of seawater and ice movements through the Canadian Archipelago.

The principal goal of the first CATs expedition for the International Polar Year (IPY) on CCGS Henry Larsen in 2007 was to re-establish observational arrays in Nares Strait and in Cardigan Strait for the two-years of the IPY. The IPY CAT project also supported at the same time the maintenance of the existing array in Lancaster Sound using CCGS des Groseilliers, and the first-ever installation of an oceanographic mooring in Bellot Strait from CCGS Louis S St Laurent. With the capabilities so installed, the CAT study strove to measure the flows of seawater, salt and heat through all important straits of the Canadian Archipelago.

The second IPY CATs expedition was completed in 2009. Its goal was recovery of the sub-sea observational arrays in Nares and Cardigan Straits (with the data recorded during 2007-09) and the deployment of smaller replacement arrays (with instruments to measure current, ocean temperature, salinity, ice drift, ice thickness) to continue observations for another three years: an line of 7 moorings across Nares Strait at Franklin island and another of 3 moorings across Cardigan Strait. Other supporting installations included a sea-level gauge in Alexandra Fjord and automatic weather stations along the strait at Cape Baird, Hans Island and Brevoort Island.

There were two CATs expeditions in the summer of 2012: one on CCGS des Groseilliers to Cardigan Strait and one on CCGS Henry Larsen to Nares Strait.

The goal of the 2012 expedition to Nares Strait on Henry Larsen was to recover the arrays of measuring instruments and the data recorded by them since 2009. It also allowed a brief sortie into Petermann Fjord to collect preliminary information on water properties and bathymetry to aid in planning a future study of the floating shelf of glacial ice in Petermann Fjord.

Planned Components of the CATs Scientific Programme

Moorings in Nares Strait

Eight oceanographic moorings supporting internally recording instruments variously measuring current, ice drift, ice thickness, tide, temperature and salinity were to be recovered from Nares Strait.

Seven of these moorings were in deep (400 m) water in Kennedy Channel west of Franklin Island.

One mooring was in shallow (18 m) water in Alexandra Fjord just west of Skraeling Island. If time and ice conditions allowed, we planned to attempt retrieval of a second shallow mooring in Discovery Harbour, which has not been accessible by ship since its installation in 2003.

There was no plan to re-deploy recovered instruments and mooring components.

Seawater Surveys by CTD

Seawater properties were to be mapped via profiling CTD on five cross-sections of Nares Strait and two of Petermann Fjord.

Profiles were to be acquired from surface to seabed at stations approximately 2.5 km apart.

Sections were to be repeated if time permitted, so as to document short-term change in the properties of seawater flowing through the strait.

Sampling Seawater for Trace Chemical Analysis

Samples of seawater were to be collected using a profiling CTD-rosette system on three sections across Nares Strait and one in Petermann Fjord.

Samples were to be acquired at stations approximately 5 km apart and at as many as 12 levels.

Samples were to be stored (cool or frozen) for later analysis of salt, dissolved nutrient, oxygen-isotope and barium concentrations.

Petermann Ice Shelf

Seawater temperature and salinity were to be measured to 1000-m depth across the full width of Petermann Fjord using a profiling CTD, with water samples collection at some stations using a CTD-rosette system. These samples could reveal changes in trace composition reflecting the melting of the floating ice shelf by warm intruding seawater.

Soundings by CCGS Henry Larsen were to be recorded to delineate the sill of the fjord (shallow seafloor topography at its mouth) and the depth of the basin behind it. Approximately 30 km of the fjord was opened to ship access for the first time following the calving of large ice islands the summers of 2010 and 2012.

Automatic weather stations

Automatic weather stations have been operating at four locations along Nares Strait since 2009: Littleton and Brevoort Islands on Smith Sound, Hans Island in mid Kennedy Channel and Cape Baird on Hall Basin. The station at Littleton Island was serviced in August 2011, but the others have been operating without maintenance.

The stations at Littleton, Brevoort and Hans Islands were to be serviced and left to operate for another 2-3 years. The station at Cape Baird was to be dismantled and moved to Joe Island on the other side of Hall Basin.

Equipment Cache at Resolute

Equipment and supplies used on CCGS Henry Larsen were to be moved to the PCSP base in Resolute Bay at the time the science team disembarked in mid August. This equipment will support a linked scientific activity in Byam Martin Channel, to be accomplished from the ice surface via ski-equipped aircraft in April 2013.

Operating Area

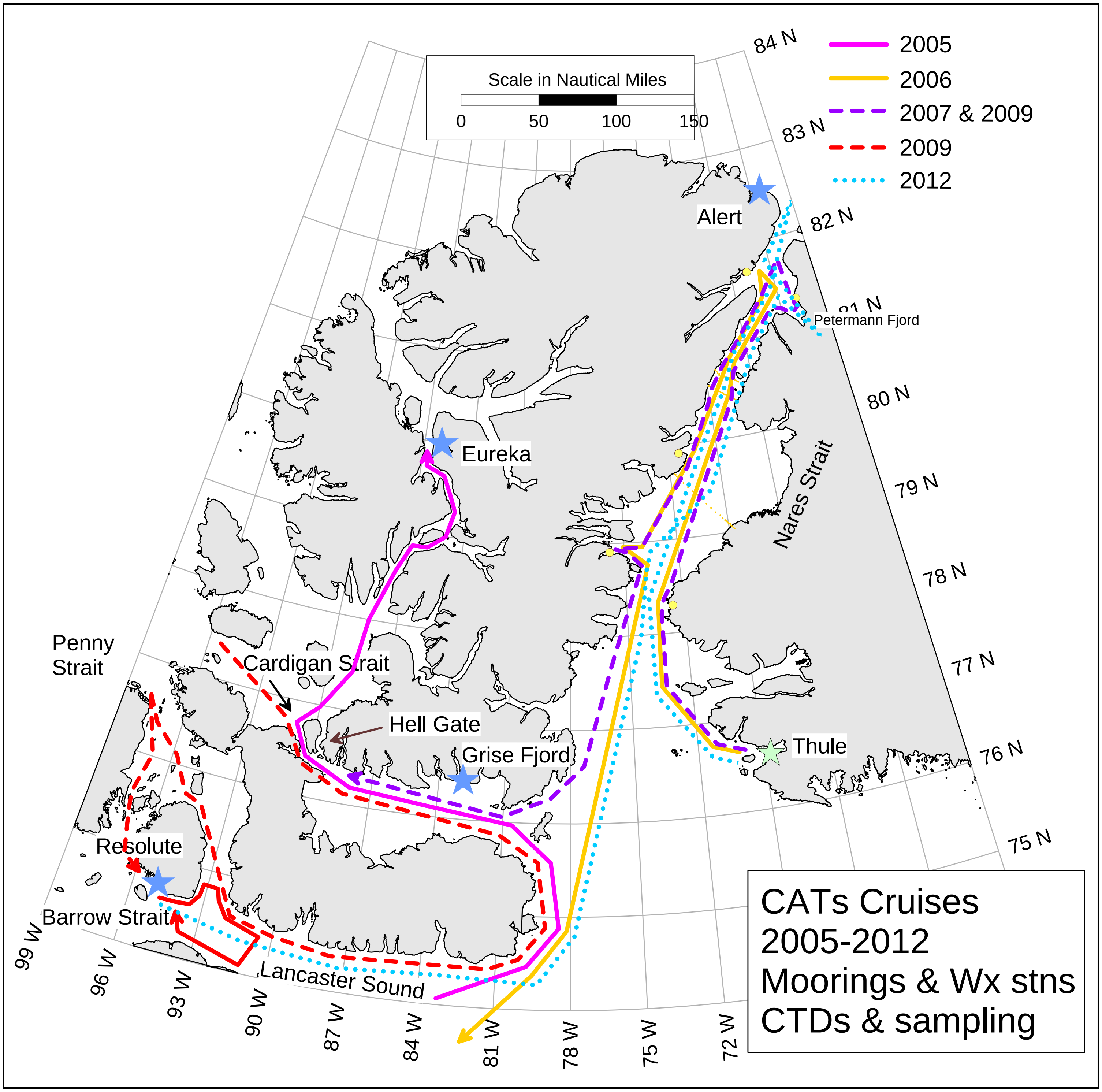


Figure 1. Simplified ship tracks for CATs field expeditions, prior to, during and following the International Polar Year.

Detailed Sub-Area Maps

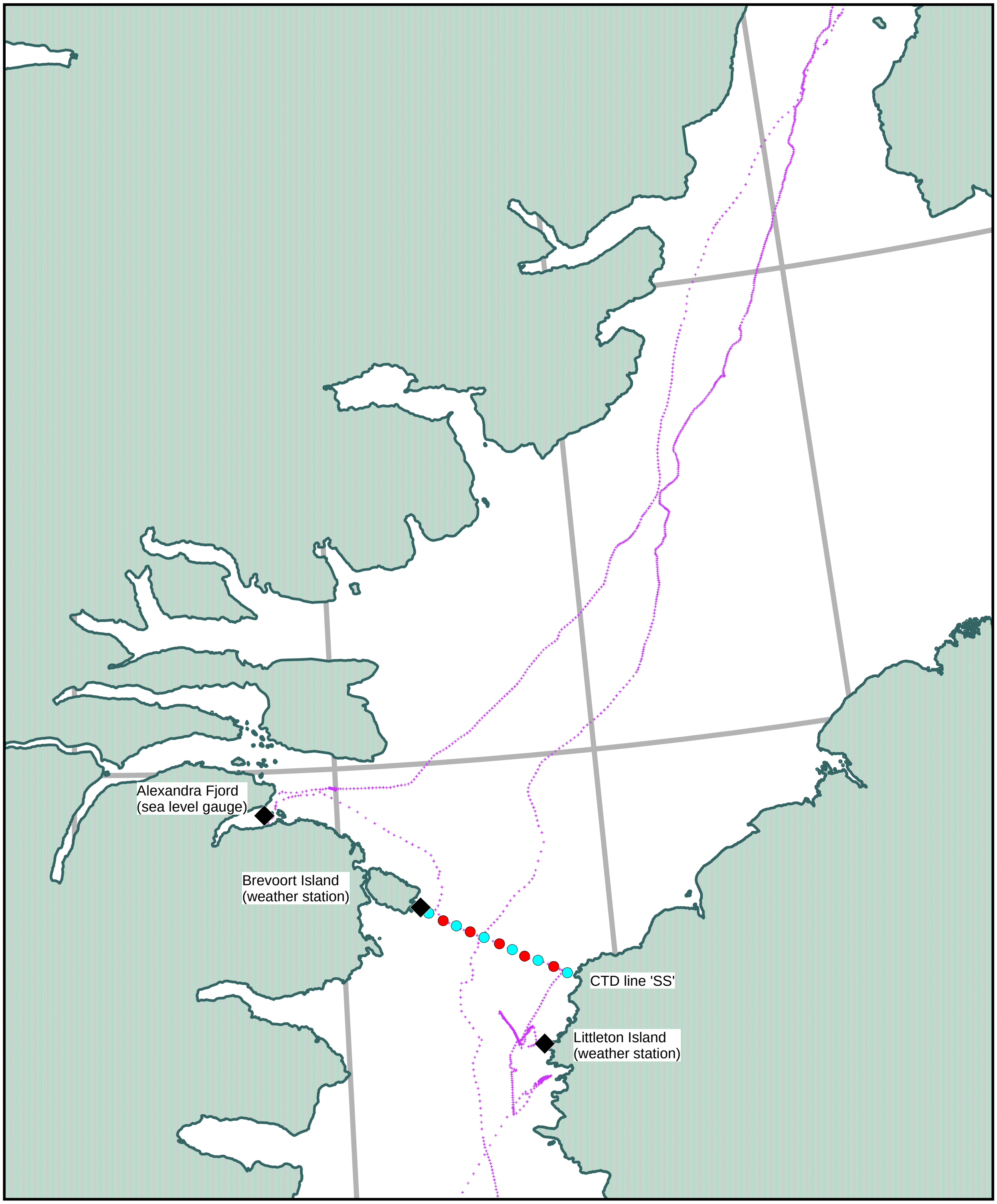


Figure 2. Locations in Smith Sound & Kane Basin. Ship track (dotted), CTD stations in cyan, rosette stations in red, moorings and weather stations in black.

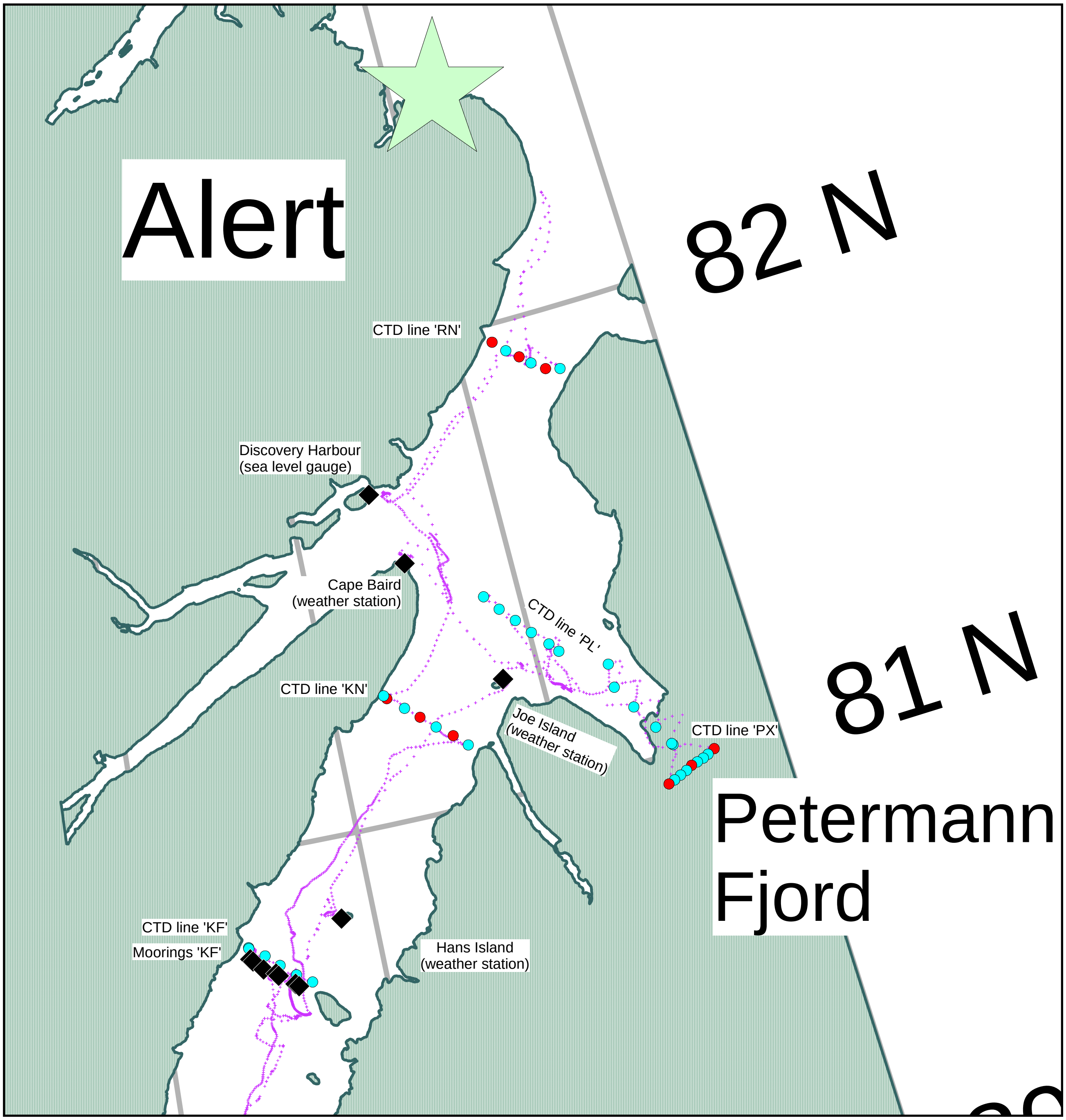


Figure 3. Locations in Kennedy Channel, Hall Basin and Robeson Channel. Ship track (dotted), CTD stations in cyan, rosette stations in red, moorings and weather stations in black..

Time Line (30 July to 20 August 2012)

Cruise scientists arrived in St John's on Monday July 30 or before noon the next day. Our arrivals were well in advance of the scheduled departure (06:00 Wednesday August 1) of the charter flight carrying us to CCGS Henry Larsen at Thule Greenland. Early arrival was a precaution against the possibility of loss in transit of personal baggage during travel form distant places. Such an occurrence delayed the timely departure of the charter flight to Thule in 2006.

However, it was an equipment failure on First Air's Boeing 737 charter plane that kept us waiting at the airport for most of Wednesday. Ultimately, the flight was re-scheduled for the next day. Ultimately, the flight north on August 2 via Iqaluit was uneventful, arriving at Thule Airbase about noon Newfoundland daylight time. Weather here was sunny and 7°C.

Henry Larsen left Thule in the early afternoon of the following day, on course for Nares Strait. The ship worked in Nares Strait from August 5 to August 13, with brief side trips into Petermann and Alexandra Fjords. The most northerly position was at the edge of the Lincoln Sea, 82º 14.75'N 061º 01.15'W, attained early on August 8 where old ice blocked passage further north. At this position, Henry Larsen was about 40 km by sea from Alert.

Henry Larsen left Smith Sound on August 14, bound for Resolute Bay via Nanisivik. She came alongside CCGS Terry Fox at Nanisivik early on August 16, in order to transfer fuel, and dropped anchor in Allen Bay west of Resolute early on August 17. All science personnel and equipment were on shore by midday.

Most of the science team left Resolute for Iqaluit at 3 pm on Saturday August 18. Two (Ron Lindsay, Jo Poole) remained behind awaiting a charter flight to Eureka and transfer to CCGS des Groseilliers at Eureka on Tuesday August 21. They subsequently travelled south on des Groseilliers to complete the recovery of oceanographic moorings from Cardigan Strait.

For those heading south on August 18, the planned overnight stay in Iqaluit expanded to two nights because First Air's Boeing 737 was unserviceable for the flight to Ottawa. Scientists resumed their journey at 13:45 on Monday August 20, and arrived home late the same day.

Distances and Transit Times (approximate)

Thule to Smith Sound	150 miles	0.6 days	Positioning
Slowdown for ice & fog		1.0 days	Smith Sound
Smith Sound to KF line	205 miles	0.7 days	Deep moorings near Franklin Is
KF line to Cape Baird	60 miles	0.3 days	Weather station
Cape Baird to farthest north	88 miles	0.3 days	Probe towards Alert, return
Cape Baird to Petermann	50 miles	0.2 days	Ice shelf study
Petermann to Hans Island	75 miles	0.3 days	Weather station
Hans Island to Smith Sound	165 miles	0.6 days	Weather stations & tide gauge
Smith Sound to Resolute Bay	655 miles	2.5 days	De-positioning

Transit times based on 12 knots or 280 miles per day (i.e. no ice or fog)

Ice Conditions

The ice cover of Nares Strait is most often land-fast in winter, stabilized behind an ice bridge across Smith Sound. Whereas the ice cover of Kennedy Channel begins to move with the tide in June or July, the transition from land-locked to drift ice along the full length of the strait usually occurs between mid July and mid August, following collapse of the southern ice bridge. Prevailing winds and currents then begin to flush ice southward into Baffin Bay, initiating a wave of clearing moving from south to north in Nares Strait.

Lighter ice conditions are short lived. After the northernmost ice bridge across Robeson Channel breaks, usually in mid August, multi-year pack from the Lincoln Sea invades the strait. By early September this ice makes navigation challenging as far south as Smith Sound. The sequence of break-up is revealed in the weekly series of maps displaying median ice concentration in Nares Strait, derived from 30 years of charting by the Canadian ice Service.

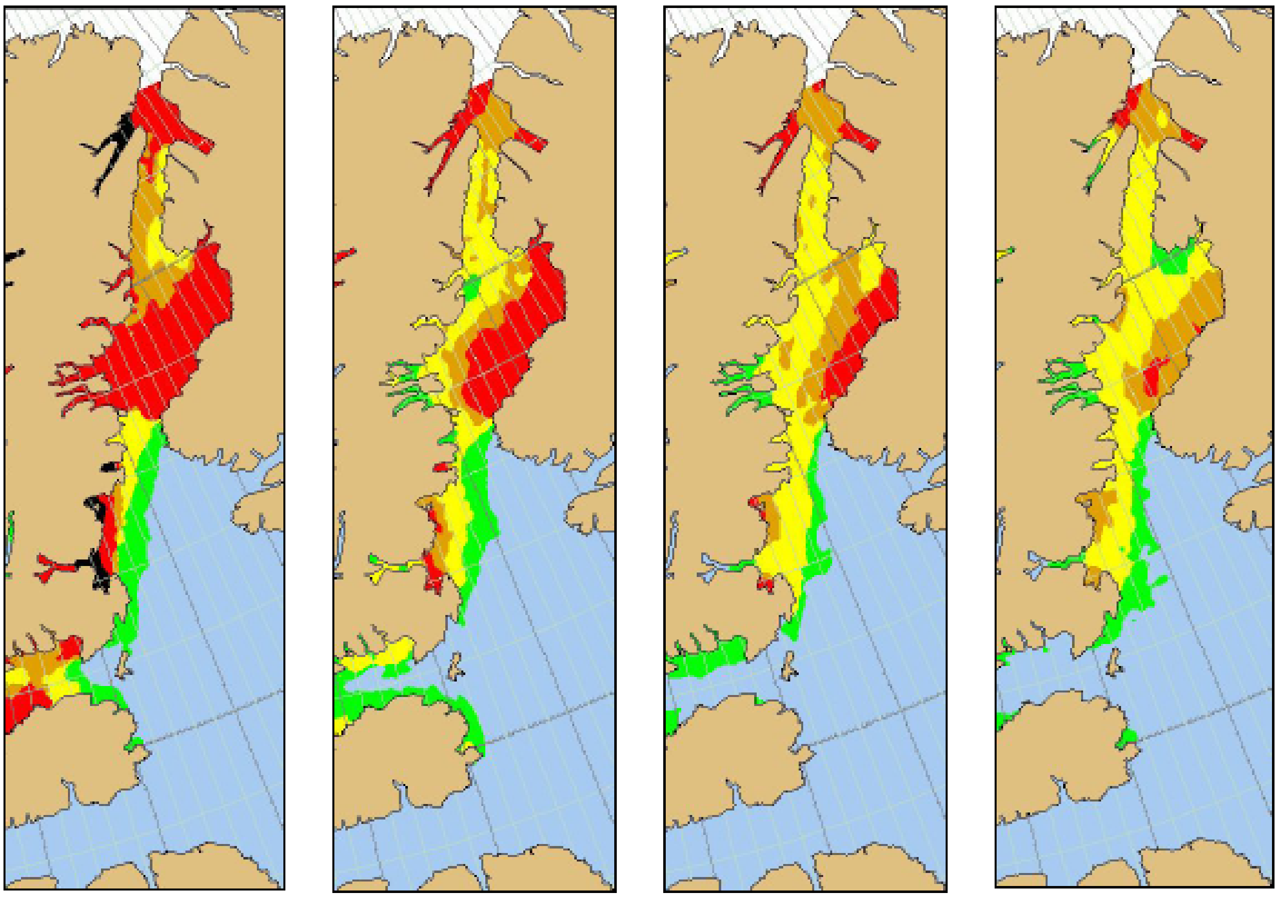


Figure 4. Median concentration of sea ice in Nares Strait at weekly intervals during August. . Dates are 6th, 13th, 20th and 27th (legend below). Charts from the Canadian Ice Service.

The preceding discussion neglects the significant distinction between seasonal and old sea ice in relation to navigation. Within Nares Strait in August, there is 4-10 tenths old ice in half to two-thirds of all years. Old ice is much more of an impediment to navigation than is seasonal ice in late summer.

Ice conditions during 2012 differed greatly from the median climatological state. The ice bridge across Smith Sound collapsed early this year and ice was moving south along the entire strait by July 8. The pattern of air pressure during August (Figure 6), with low values over the Canada Basin and highs over Greenland, maintained a south-westerly airflow in Nares Strait which opposed the entry of ice from the Lincoln Sea. This pattern maintained relatively light ice conditions in Nares Strait during August and permitted Henry Larsen to reach the edge of the Lincoln Sea. The atmospheric forcing and consequences for the ice cover were very similar to the conditions experienced by USCG Healy in this area in 2003.

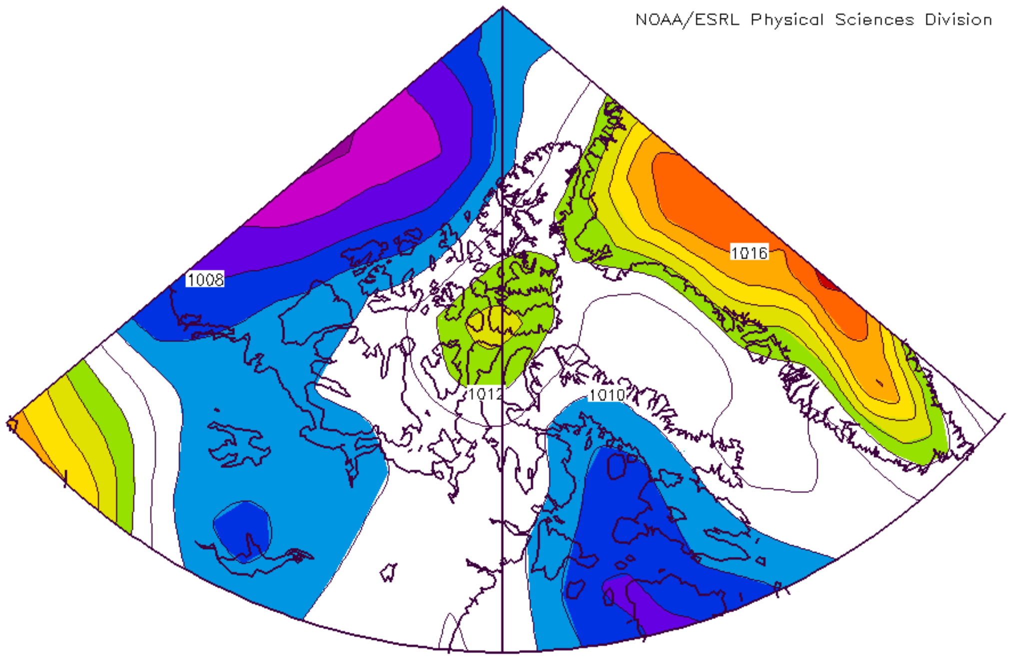


Figure 5: Average sea-level pressure (mb) in August 2012, showing persistent south-west wind over Nares Strait.

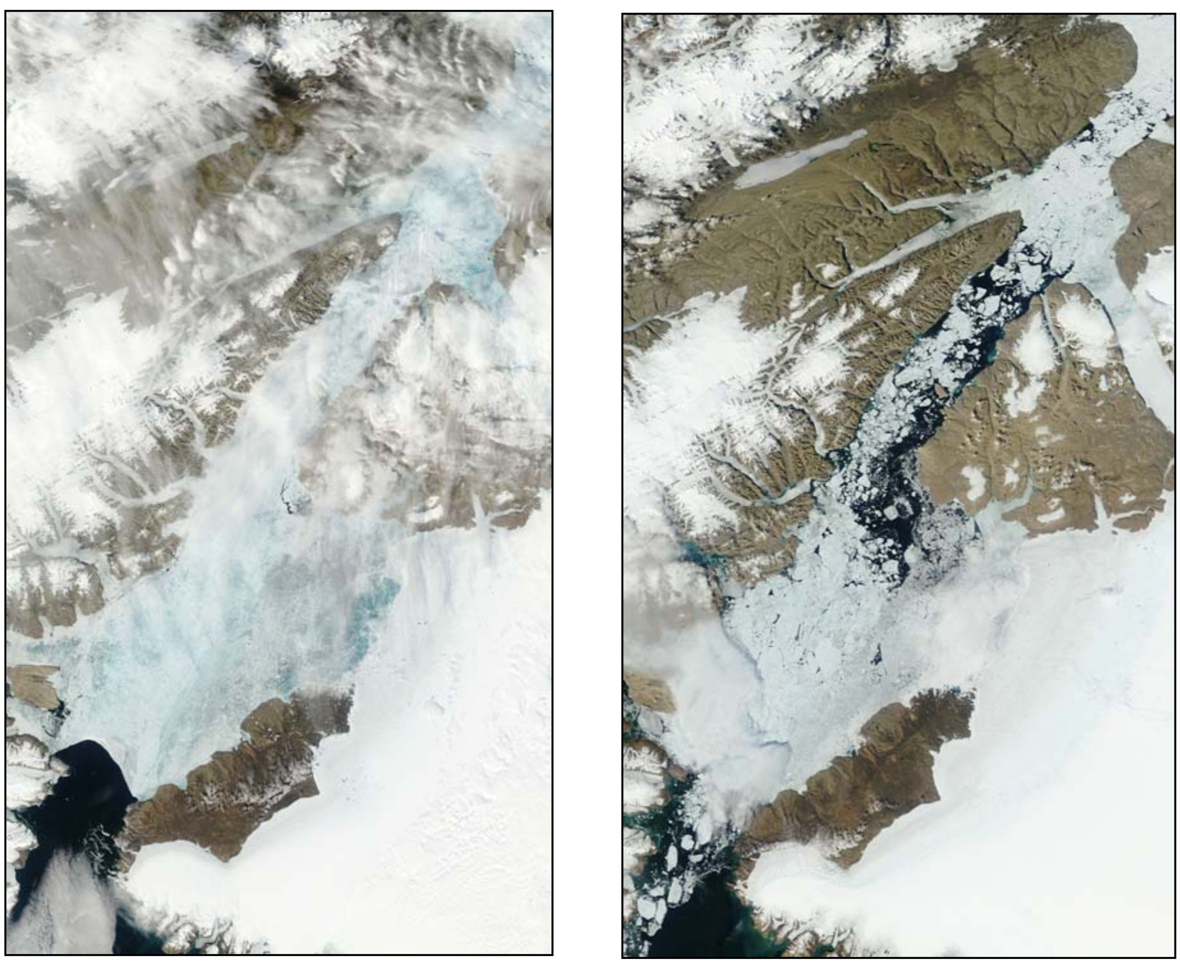


Figure 6. Collapse of the ice arch in 2012. - intact on 26 June (left) and shattered to Lincoln Sea on 8 July (right).

The satellite images (MODIS) on the preceding page show the initial stage of ice bridge collapse in early July 2012. The ice charts below display ice conditions at 6-day intervals between August 12 and August 30.

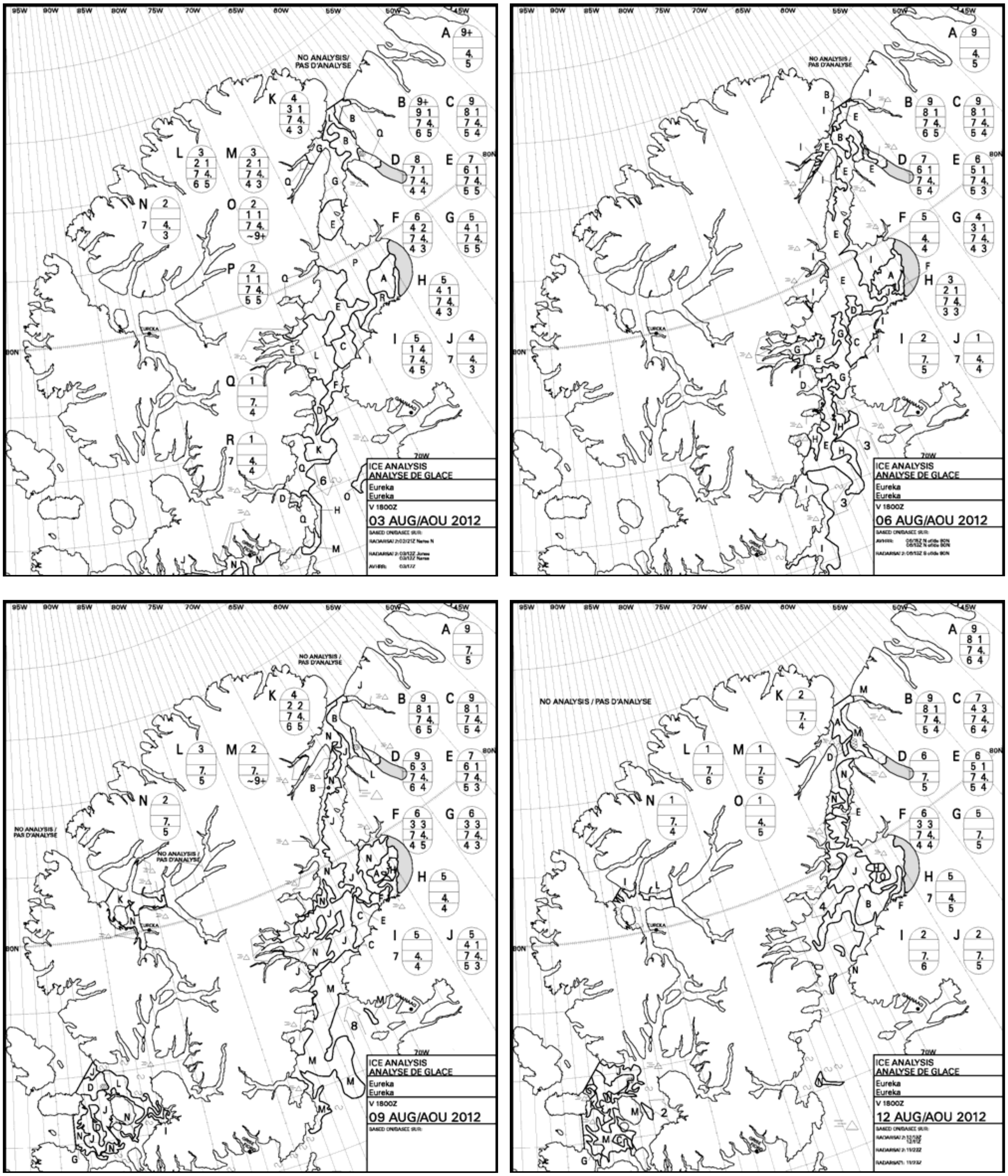


Figure 7. Charts displaying ice conditions in the Canadian High Arctic during the time that Henry Larsen was in Nares Strait. Note the unusually low concentrations of ice throughout.

A shelf of floating glacial ice ranging between 60 and 600 m in thickness fills much of Petermann Fjord. From time to time, ice islands calve at the shelf front as it moves towards Hall Basin at about 1.2 km per year. When USCG Healy supported the CAT project in 2003, there were a number of tabular bergs in Kennedy Channel that had calved recently from Petermann. Subsequently little ice broke free of the shelf until mid July 2008, when a ice island measuring 10 by 3.5 km broke off its south-western side. In 2010, the portion of the front remaining after the calving in 2008 was about 8.5 km further out than at the time of our first visit in 2003.

On 4 August 2010, an ice island covering about 300 square km broke off the shelf. The island quickly drifted out of the fjord and broke into many fragments; some had reached Newfoundland by the following summer.

On July 16 2012, a third ice island measuring about 130 square km broke free. By the time of our arrival there on August 10 of this year, this new island had drifted to Offley Island at the mouth of the fjord. The three recent calvings have uncovered a 30-km reach of the fjord which has never before been accessible by ship. Black lines in Figure 8 mark known positions of the ice front back to 1871.

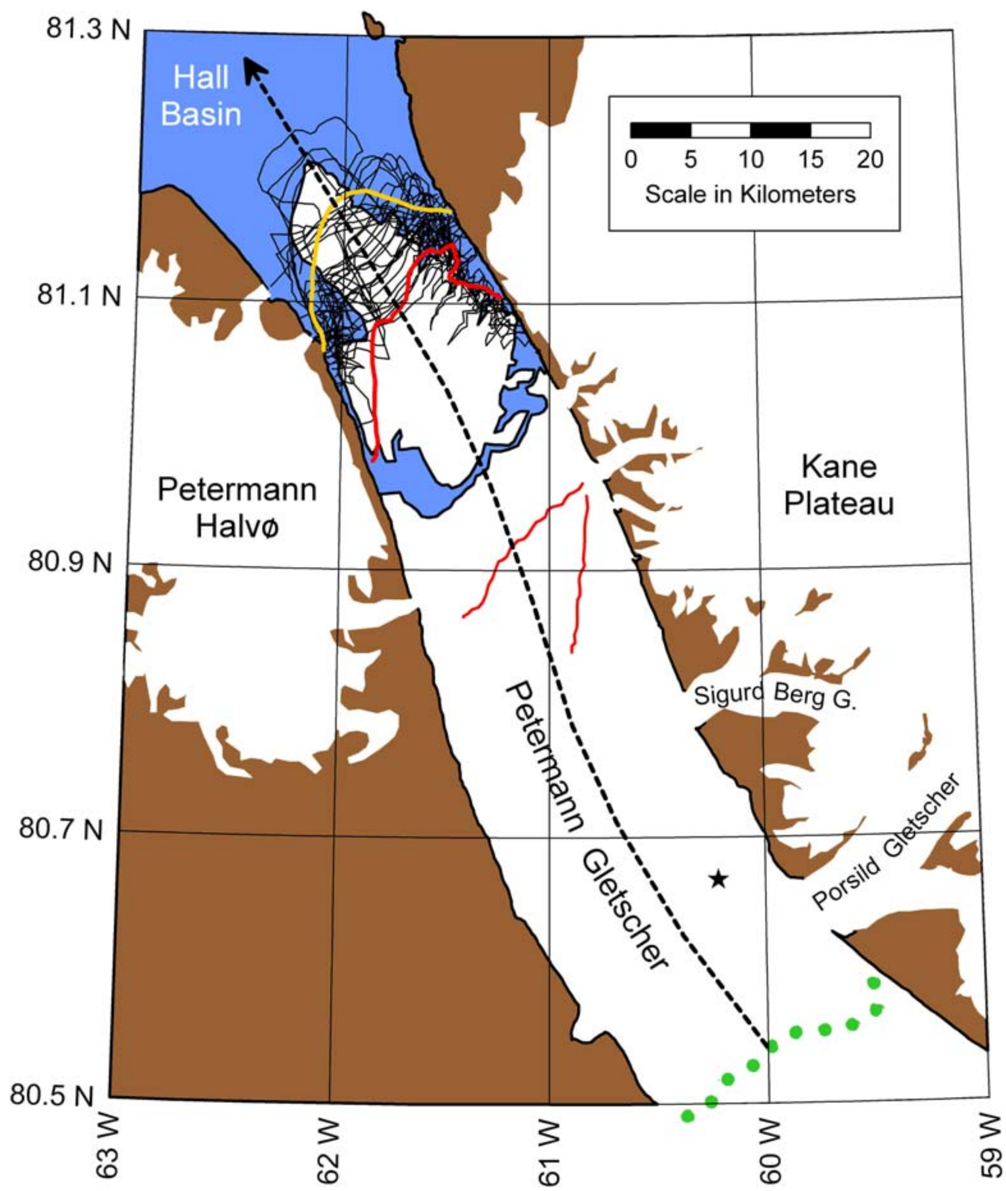


Figure 8. A large ice island calves from the Petermann ice shelf in August 2010. The 2012 island separated close to the more westerly of the two cracks marked near 80.9°N. Earlier positions of the shelf front are delineated in black.

Description of Activities

Recovery and Deployment of Moorings

In the absence of pack ice, the recovery of our oceanographic moorings can be completed in an hour.

In seaways where pack ice is plentiful, access to work sites may be blocked heavy ice. It is necessary in such situations to stand-by in the vicinity, waiting for accessible openings in the drifting pack into which moorings may be released from below. The need for this wait-go approach is derived from past experience with CCG icebreakers in these areas: in Smith Sound in August 1998, 1999 and 2001, in Cardigan Strait in September 2000, 2002, 2005, 2007 and 2009, and in Kennedy Channel in August 2006, 2007 and 2009.

Obviously, our need to access particular locations and to wait for suitable ice conditions for mooring recovery requires patience, tactical flexibility and luck. We were obliged to adopt an opportunistic approach to work in this ice environment.

Seawater Surveys by CTD

When working from the Coast Guard's operational vessels such as Henry Larsen, we use a small CTD (conductivity, temperature, depth) probe and winch system to measure basic physical properties of seawater. About 100 CTD stations were listed, grouped into cross-sectional surveys of the straits; 51 were completed. The nominal spacing of stations was 2.5 km. Such surveys will provide a detailed map of the water within the Nares Strait at the time of the expedition. They will also provide data for the calibration of similar sensors that have been recording data from the moorings since 2009.

Figure 9. Setup for operating the CTD probe on board CCGS Henry Larsen. CTD deck electronics and the computer for logging data were installed in a nearby shipping container. container seen at the edge of the picture.

We used an SBE25 CTD probe, modified into a streamlined package capable of rapid profiling at 1-2 m/s. Data were relayed to an SBE33 deck box and computer, located within the science container on the foredeck, for real-time inspection and recording. Sea-water pressure, temperature and conductivity were the variables logged.

The winch and rigging used for lowering the CTD from CCGS Henry Larsen is shown on the right. The light-weight winch with 2000 m of 0.125" wire was mounted on its (reinforced) packing box just ahead of the house-works. The winch is electrically powered (110 V). The total load on the winch with 1000 m of wire out (deepest cast planned) was about 180 lb. The boom to support the block (our supply, not shown) was ship's equipment originally used for landing personnel at canal locks.

Seawater Surveys by Sampling Rosette

We use a small 12-bottle rosette, equipped with a second SBE25 CTD probe, to collect samples of seawater at as many as 12 levels in the water column. These surveys provided information on the chemical composition of seawater, necessary to deduce its origin and its modification by mixing, ice formation and ice melting during its time in the Arctic Ocean.

We deploy the rosette from the foredeck on a conducting wire under control of a work winch placed on board by Laval University for a separate science project to be conducted from Henry Larsen during September-October. The winch lowered and raised the rosette from a block suspended outboard using the ship's crane. We therefore needed a crane operator from the ship's crew for rosette casts in addition to the winch operator, who was one of our science team.

Figure 10. Bottle rosette for sampling seawater. The pictured unit carries 12 8-litre bottles and an SBE25 CTD mounted in a cage beneath.

Sampling bottles were closed under operator control on the down cast without stopping the CTD; bottles were triggered close to standard pressure levels: 5, 15, 30, 50, 75, 100, 125, 150, 200, 250, 350, 450 db. A bottle was also closed at the bottom of the profile after the pressure reading had been constant for one minute. Because the flushing of the sampling bottles is relatively inefficient, the sampled water actually comes from levels a few metres shallower than nominal values.

Approximately 35 rosette stations were planned; 14 were completed. The nominal spacing of stations was 5 km. Casts using the independent CTD were interleaved with the sampling casts to allow time for drawing and storing samples between rosette stations.

Samples were drawn from the rosette on the open deck. Although we did not have to work the rosette in sub-zero temperature in 2012, with risk of freezing samples, the open-air setup had the potential at times to compromise the quality of samples via contamination with rain water.

Petermann Ice Shelf

Our study here was aimed at understanding the ocean's influence on the Greenland ice sheet via its exit glaciers. The ice shelf in Petermann Fjord tapers to as little as 50-m thickness at its terminus, 90% less than it value 60-70 km up the fjord where it floated off bedrock half a century earlier. Most of the thinning on route has occurred via melting to the ocean. This characteristic of Petermann Glacier is unusual in Greenland, where most glaciers lose ice mainly by calving, not melting.

Our first objective was to locate and measure the melt-water freshened outflow of seawater from beneath the ice shelf. Lines of CTD stations interleaved with rosette water-sampling stations accomplished this objective.

Our second objective was to map the depth of the fjord, particularly in the vicinity of the sill near Offley island. Restricted depths at the sill between the Petermann Fjord and Hall Basin, and those at possible additional sills further up the fjord, are important constraints on the access of warm ocean waters to the underside of the ice shelf. We believe that the outermost sill is located where the fjord widens abruptly into Hall Basin and that its deepest part is about 350 m. We measured a depth of 1050 m 17 km to the southeast at the location of the shelf front in 2003. Now after the calving of 2010, it will be possible to collect soundings another 18 km into the fjord.

We logged GPS position and soundings from CCGS Henry Larsen on track-lines along and across the fjord.

Automatic weather stations

Low-level winds in Nares Strait can be extremely strong (sustained at 30-40 m/s, 68-80 kt) because air flow between the Arctic Ocean and Baffin Bay is forced through the narrow gap provided by the strait between high terrain on both sides. Such strong winds are hazardous for humans and aircraft and important drivers of ice and water movement through the strait. At present, there is a self-recording automatic weather station on Brevoort Island on Smith Sound and Iridium reporting stations on Littleton Island, on Hans Island and at Cape Baird. These stations are a collaborative effort among scientists in Canada (DFO), Denmark (DTU) and Scotland (SAMS).

The stations on Littleton and Hans Islands were serviced and left to operate for another two years. The station on Brevoort Island was serviced and upgraded with an Iridium data link, again to operate for two years. The station at Cape Baird, on Ellesmere Island at the northern end of Kennedy Channel, was dismantled. A replacement was established on Joe Island on the Greenland side of Hall Basin, also for two years.

The ship's helicopter was used to move two or three persons and equipment to each site. On-site time for data recovery, maintenance, set-up, photo-documentation and operational checks was 2-4 hours.

The elevations and reference directions for wind at existing stations were confirmed on site through careful measurements of air pressure and via GPS. The wind vane at Brevoort Island was retrieved for a full calibration of its voltage output versus azimuth, in order remove a present ambiguity in recorded wind data. All stations were configured for conformity with the global GTS weather reporting protocol; data are accessible in real-time to users.

Figure 11. Automatic weather station at 170 m elevation on Hans Island. Ellesmere Island is in the background.

The Geological Survey of Denmark operates a geodetic GPS station on Joe Island. We installed our new AWS lower than the GPS antenna and more than 50 m from it, compromising to take advantage of site permission that was already granted.

Designs of Installations – Atmosphere & Ocean

Automatic Weather Stations (4 maintained)

Weather stations were built by mounting components on a 2-m steel tube. The wind sensor was on the main mast at approximately 2.5-m elevation. Other sensors (temperature & humidity in a radiation shield, incoming solar radiation, net long-wave radiation) were attached to arms at approximately 1.5 m height, with care taken to minimize shadowing by the structure. Pressure was measured near ground level by a sensor inside the control box.

Establishing the reference direction for the RM Young wind set is surprisingly challenging. We built a jig to attach to the wind set, fitted with a referencing arm and a 100-m inelastic line that could be walked out until taut and then lined up with the reference arm. The heading back to the tower was measured by GPS.

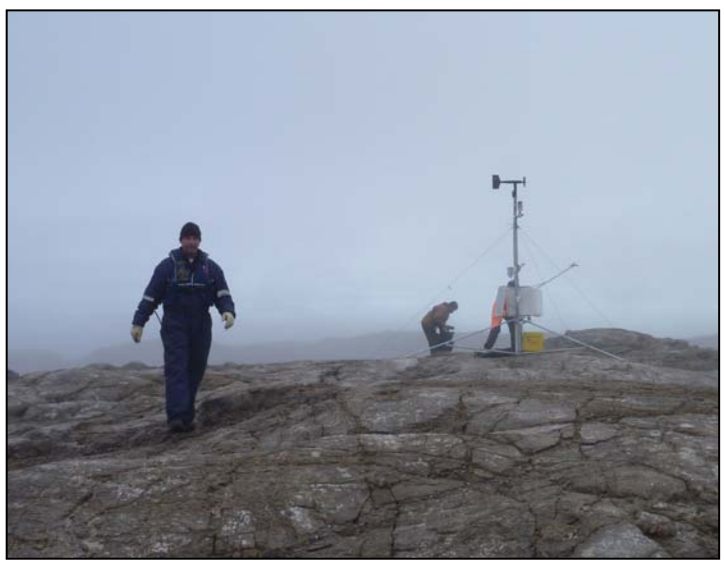


Figure 12. Automatic weather station established at 197 m elevation on Joe Island, 11 August 2012.

We set up all stations to operate on a WMO standard cycle: 10 minutes of operation twice per hour, sampling 3-second averages ending at the half hour and at the hour. Means and standard deviations were calculated over the 200 3-second samples and the gust was the largest 3-second speed in the group.

All stations (Joe Island, Hans Island, Brevoort Island) were equipped with an Iridium telephone, data modem and antenna for automatic relay of data. The cost of half-hourly messages is about $200 per month.

Pressure Mooring (1 deployed)

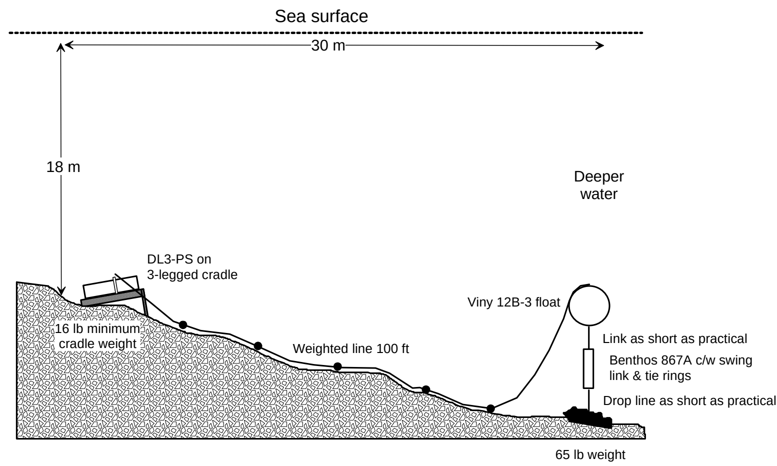


Figure 13. Mooring used in 2007, 2009 and 2012 to deploy recording pressure gauges in sheltered waters.

The mooring was designed to provide a stable foundation for the pressure gauge (vertical movement limited to millimetres) during a 2-3 year deployment. The instrument was placed as shallow as practical while clear of sea ice (18-20 m).

Vulnerability was reduced by deploying in shallow bays that are covered by fast (non-drifting) ice for much of the year and relatively sheltered from icebergs in summer. Discovery Harbour and Foulke Fjord were our best sites in this respect.

In 2003, the moorings were placed by divers from Healy upon metal stakes hammered into the seafloor. Pressure recorders deployed in 2007 and 2009 were secured on simpler moorings (see figure at right) for which divers were not required. Unlike normal oceanographic moorings that float to the surface after the acoustically activated release disconnects the mooring from its anchor, the release of this mooring only permits the surfacing of a tethered float. Recovery is achieved by pulling up on the tether to lift the non-buoyant mooring off the seabed.

Ocean Current Mooring (3 for recovery)

This is a torsionally rigid mooring used to support an Acoustic Doppler Current Profiler (ADCP) and a temperature-salinity recorder. The mooring holds the sonar at fixed heading and pointing upward within a few degrees, even in strong current. There are two acoustic transponder-releases to provide redundancy in case of failure.

SBE37 T-S recorders were not installed on the three moorings deployed in Nares Strait in 2009.

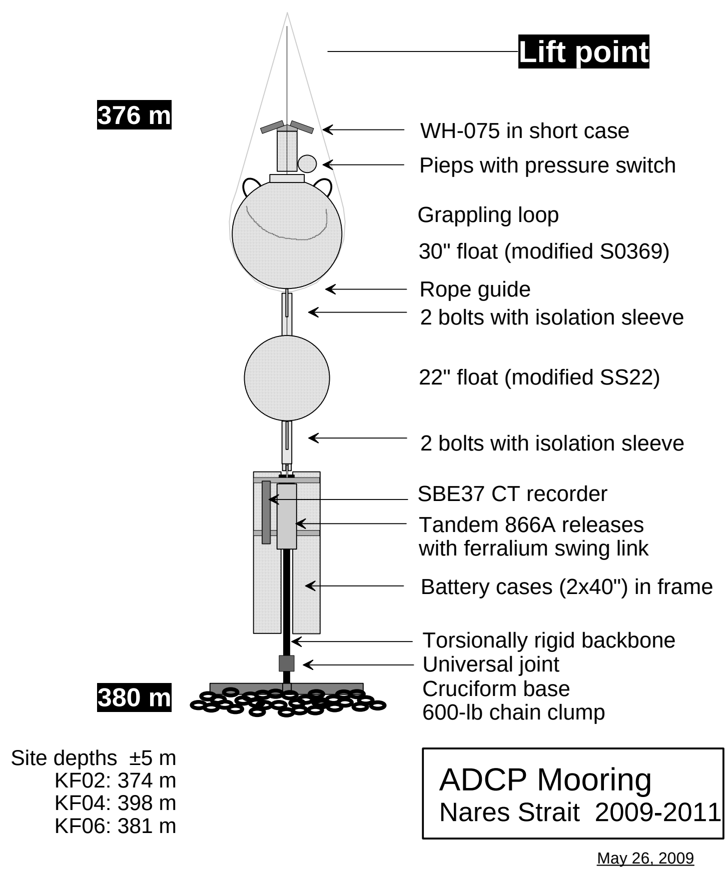
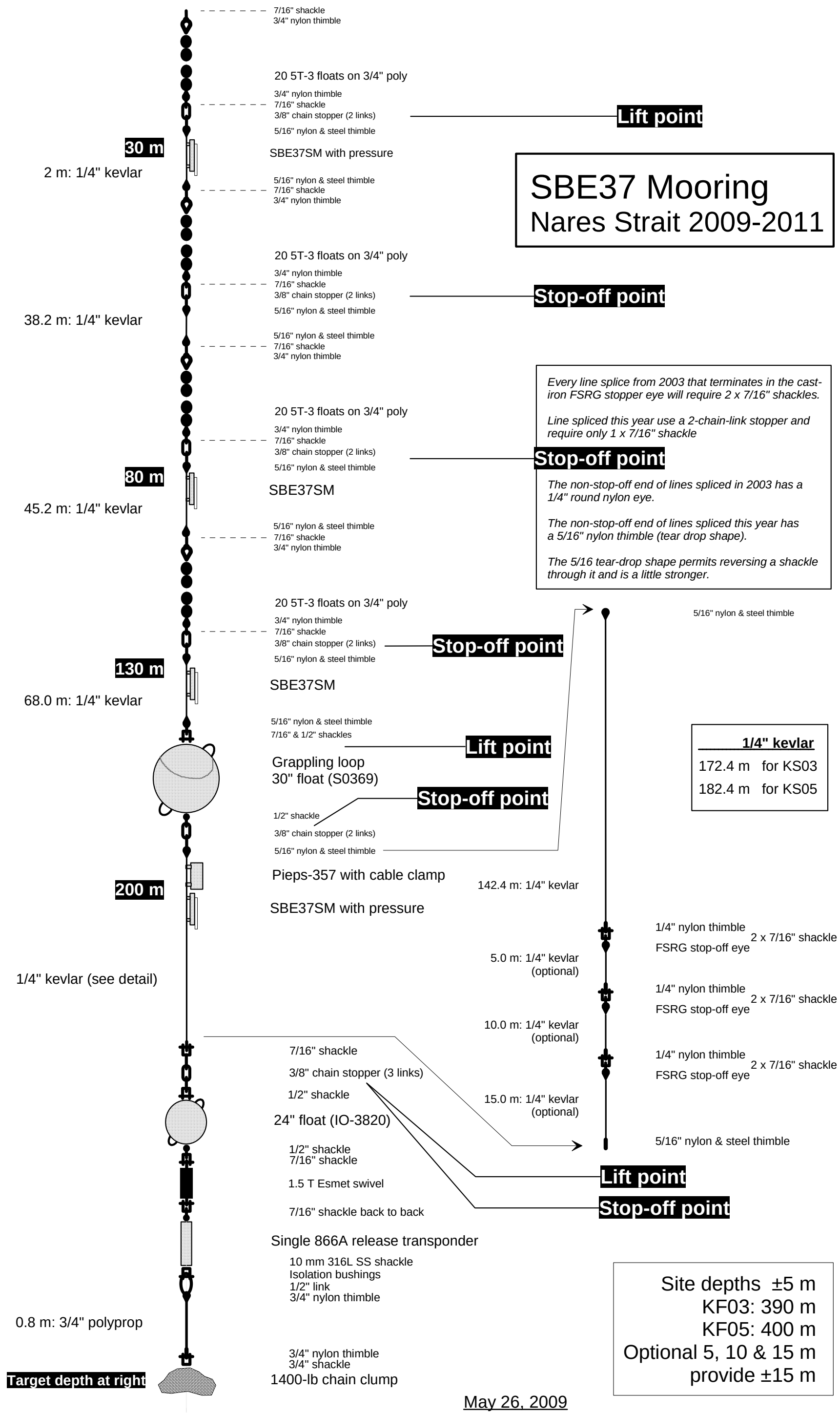


Figure 14. Schematic diagrams of the mooring used to position acoustic Doppler current profilers (ADCPs) near the seabed in areas where the geomagnetic field is not a reliable reference direction. These moorings can lean in strong current but do not twist. The ADCPs measure ice drift and ocean current at all depths in the water column.

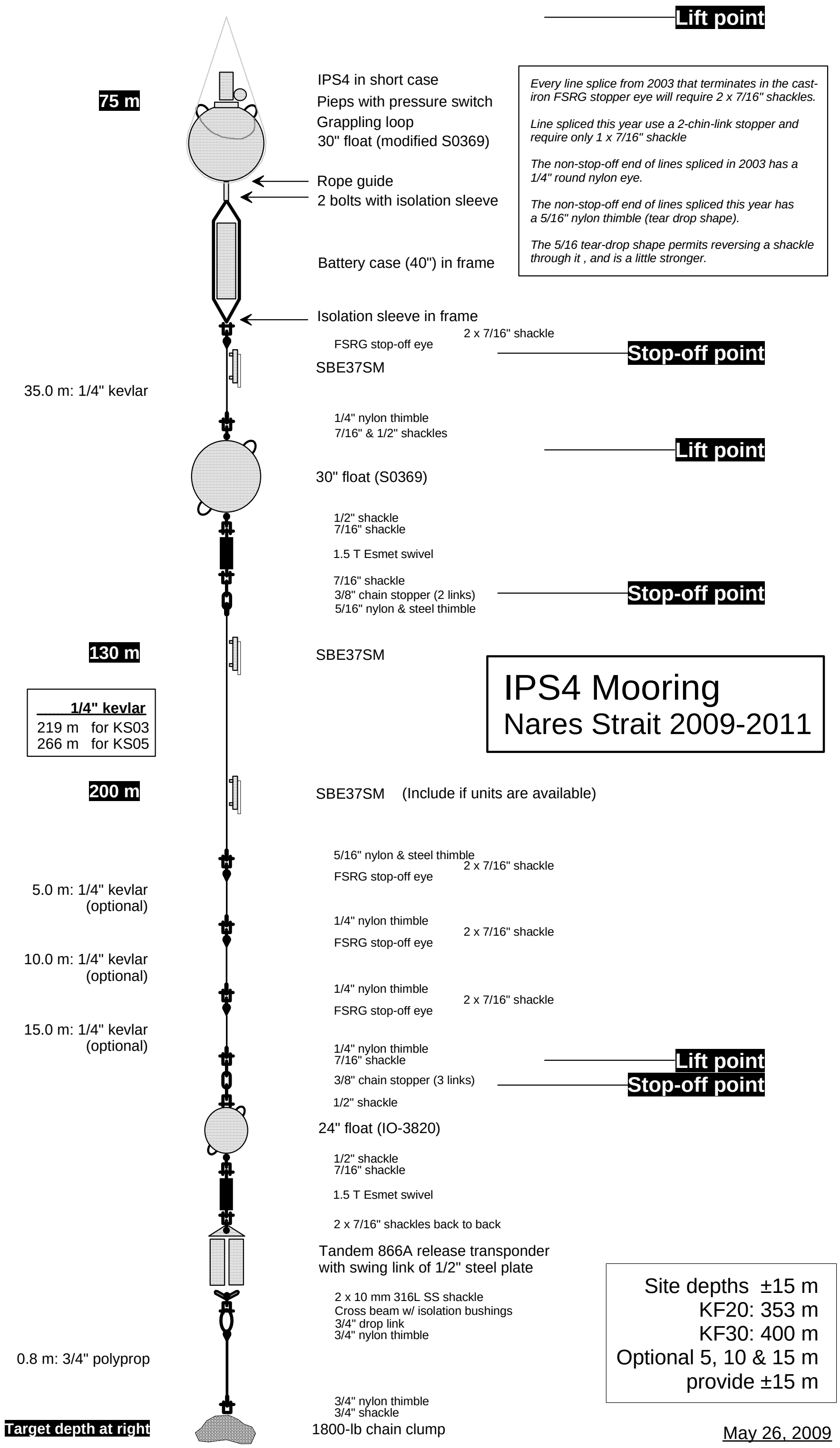
Temperature-Salinity Mooring (2 for recovery)

This is a taut-line mooring used to support temperature-salinity recorders at four levels between 30-m and 200-m depth, with a single acoustic transponder-release. The buoyancy above 200-m depth was small, so that the top of the mooring pulls down appreciably in strong current. This sensitivity was deliberate: since icebergs sweep larger volumes per unit time in strong current, pull-down in such conditions reduces the likelihood of strikes by icebergs. The mooring straightens at slack tide allowing observations closer to the surface. The mooring relies on strings of small plastic floats for buoyancy at upper levels, instead of conventional spherical floats, in order to reduce the likelihood of snagging on contact with drifting ice.



Ice-thickness Mooring (2 for recovery)

This was a taut-line mooring used to support ice-profiling sonar (IPS) at 75-m depth. There were two acoustic transponder-releases. Because measurements by the IPS are degraded by pull-down and tilt of the instrument, this mooring had appreciable buoyancy. A necessary consequence of buoyancy is a heavy anchor; at 1800 lb, this was the heaviest among the four mooring types. The IPS was placed at the shallowest depth consistent with safety in the occasional presence of icebergs. SBE37 temperature-salinity recorders were added to these moorings on their deployment in 2009.



Accomplishments

Recoveries of Sub-sea Moorings

The cross-sectional view below shows the arrangement of 7 instrumented moorings across Kennedy Channel between the western end of Franklin Island and the Ellesmere coast. This is a narrower crossing than that instrumented between 2003 and 2009. The narrower section was selected in 2009 to reduce the number of moorings needed. The greater depth of this new section does, however, challenge the operating range of the Doppler sonar, especially in the winter months when scatterers are scarce. The new section is about 30 km north-east of the original.

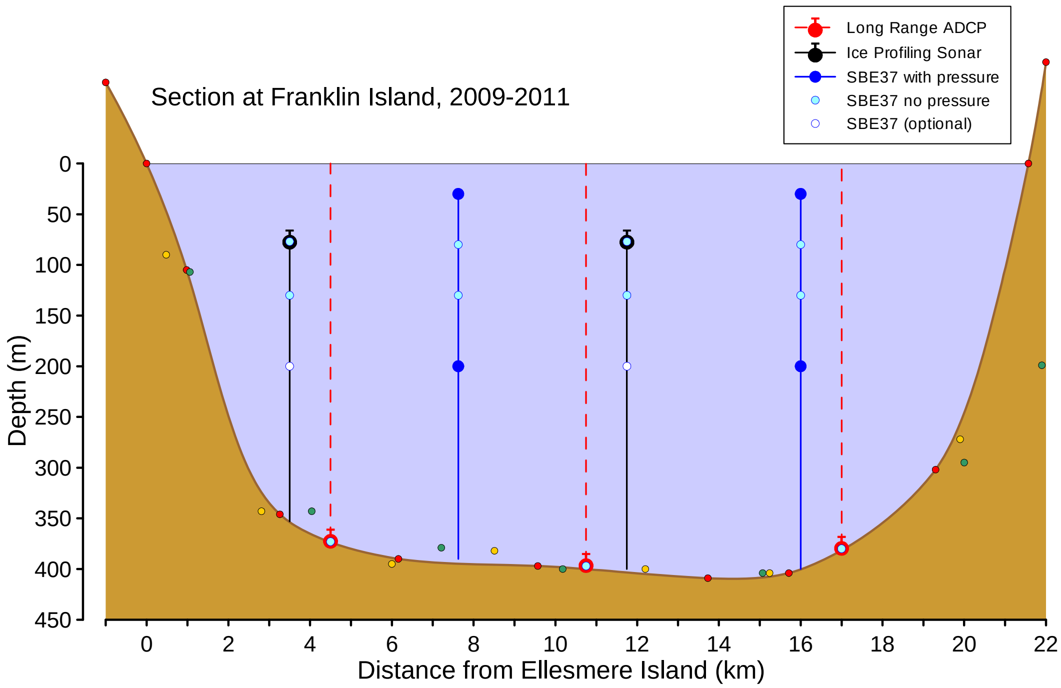


Figure 15. Arrangement of moorings deployed in August 2009 with instruments for recording ocean current, ocean temperature & salinity and ice thickness in Kennedy Channel at Franklin Island.

An eighth mooring was placed in shallow (18 m depth) water in Alexandra Fjord.

All but one of the moorings placed in 2009 were retrieved with ease. The recovered instruments included 2 Doppler current profilers (ADCPs, operating at 75-kHz), 2 ice-profiling sonar (IPS4), 14 conductivity-temperature recorders (SBE37, some also recording pressure). The pressure, conductivity and temperature recorder at Alexandra Fjord (model DL3-PS/SBE4) was also retrieved.

In contrast to circumstances in 2007, we had no difficulties waking and activating our Benthos 867A and 866A release-transponders on moorings. The modification of the firmware in 2007 to double the sleep-wake cycle from 3 minutes to 6, expanding the access interval from 1 minute to 2, seems to have been a successful solution to our difficulties. The sleep-wake cycle was a modification of original instrument firmware to allow these releases to function for deployments of three-year duration or longer.

One of the recovered Long Ranger ADCPs (at KF04) leaked immediately on immersion and returned no data. The leak occurred via the pressure port, caused by a manufacturing fault that was identified by T-RDI in 2010, too late unfortunately for remediation of our circumstance.

One SBE37 units leaked following breakage of the external electrical connector, which apparently occurred when the instrument package collided with a small ice floe at deployment (this was witnessed).

The mooring that was not recovered was placed at 350-m depth close to Franklin Island (KF06). These was no response from either Benthos release within an area of search that extended from 20 km north-east of

KF06 to 30 km south-west in a swath at least 8 km wide. This instrument was too deep to have been destroyed by ice. We presume that it dragged its anchor in strong current.

The surprise of the trip was the recovery of a pressure-gauge mooring placed in Discovery Harbour in 2003. Ice, which had subsequently prevented small-boat access in 2006, 2007 and 2009, was not an impediment in 2012. The site was actually visited by helicopter in 2007 and a release command transmitted from an ice floe in the bay, but nothing surfaced. By August 2012, the Benthos release was no longer operating, but the mooring was grappled from the ship's boat and draggged to the surface. The pressure recorder was still operating after 9 years.

Emboldened by this success, we also re-visited Foulke Fjord, where a pressure recorder placed in 2006 could not be recovered in 2007 or 2009. This initiative was not successful..

Recovery of Data from Sub-sea Instruments

<u>Data records from Teledyne RDI Long Ranger ADCPs</u>

KF02: ADCP recovered with 3-years of observations

Full-depth ocean current, acoustic scattering, ice velocity, bottom pressure & temperature

KF04: ADCP recovered with NO DATA

KF06: ADCP not recovered, NO DATA

<u>Data records from Sea Bird SBE37s T-S recorders</u>

KF03: 4 SBE37s recovered, all with 3-years of observations

Temperature & salinity at 30, 80, 130 & 200 m depth; pressure at 30 & 200 m depth

KF05: 4 SBE37s recovered, all with 3-years of observations

Temperature & salinity at 30, 80, 130 & 200 m depth; pressure at 30 & 200 m depth

KF20: 3 SBE37s recovered, all with 3-years of observations

Temperature & salinity at 80, 130 & 200 m depth; pressure at 80 & 200 m depth

KF30: 3 SBE37s recovered, 2 with 3-years of observations, 1 with NO DATA

Temperature & salinity at 130 & 200 m depth; pressure at 200 m depth

SBE37 at 80 m depth was flooded, following damage by impact with a small ice floe.

<u>Data records from DL3-PS pressure recorders</u>

Alexandra Fjord: DL3-PS/SBE4 recovered with 3 years of observations

Pressure, temperature & salinity at 18 m depth

Discovery Harbour: DL3-PS recovered with 9 years of observations

Pressure & temperature at 18 m depth

<u>Data records from IPS4 ice profiling sonar</u>

KF20: IPS4 recovered, with 13 months of observations

Ice draft, plus temperature & pressure at 75 m depth

Data record truncated by premature battery failure, linked to impact of ice island on 22 September 2010

KF30: IPS4 recovered, with 3 years of observations

Ice draft, plus temperature & pressure at 75 m depth

Hydrographic Sections by CTD & Water Sampling

6 hydrographic cross-sections were completed at locations, listed from north-east to south west:

Robeson Channel, Petermann Fjord (longitudinal & transverse), northern Kennedy Channel, Kennedy Channel at Franklin Island, Smith Sound.

Seawater samples were acquired on 4 of these cross-sections:

Robeson Channel, Petermann Fjord (transverse), northern Kennedy Channel, Smith Sound.

Nominally, the levels sampled were 5, 15, 30, 50, 75, 100, 125, 150, 200, 250, 350, 450 db, with a sample 5-10 m above the seabed replacing the shallowest level not reached.

Samples were drawn for analysis of salinity, dissolved nutrients (N, P, Si), barium and oxygen-isotope ratio and stored for later analysis; those for nutrient analysis were quickly frozen and stored at -18°C.

Stations were closely spaced, typically 2.5 km or less, in order to resolve features on the internal Rossby scale.

CATs initiated 51 hydrographic events. The locations are plotted on maps in Figures 2 and 3.

Seq #	Location	Code	CTD Stns	CTD w/ sampling	Total stations	Date
14-19	Robeson Channel	RN	3	3	6	8 Aug
20-25	Petermann (along)	PL	11		11	10-11 Aug
35-40						
26-34	Petermann (across)	PX	6	3	9	10 Aug
7-13	Kennedy North	KN	4	3	7	7 Aug
1-6	Franklin Island	KF	5		5	6 Aug
41-51	Smith Sound	SS	6	5	11	14 Aug

Automatic Weather Stations

The station at Cape Baird, set up in August 2009, was examined and then retrieved. The station had been damaged by animals (sensor connecting wires severed) and the location has proven not representative of regional winds because of local orographic effects. The strongest wind measured at this location was about 35 m/s from the south-west, and quite likely a down-slope phenomenon.

In pursuing the goal of measuring wind representative of that over Hall Basin, an automatic weather station was installed as a replacement on Joe Island, on the Greenland side just south-west of the mouth of Petermann Fjord. This is a bleak mound of rock well exposed to wind from all directions. The station was installed close to the top of the dome, 197 m above sea level, on August 11. It is equipped with an Iridium telephone and relays data hourly.

The existing station at Hans Island, installed in May 2008, was also serviced on August 11 – checking the physical integrity of the installation, collecting the data recorded on site, replacing the wind set and the batteries and cleaning the windows of the radiometers. A plastic tube was installed to link the pressure sensor, formerly sealed within the electronics housing, to the outside world via the wiring outlet. The replacement wind set had new bearings and the linearity of its vane potentiometer had been checked. Once installed, the bearing back to the station along the perpendicular to the vane's reference surface was measured as 47ºT, acceptably close to the original value of 46ºT.

On-site batteries were replaced with a pre-made battery kit – two 55 A-h AGM (advanced glass mat) batteries in a weather-proof wooden box, diode isolated with wiring and voltage regulator already connected. The small solar panel was replaced by a larger one with 30-W charging capacity. Exposed wiring was tightened against the mast to minimize possibility of small-animal damage. Once on site, it was discovered that the gel cell inside the data-logger housing had ruptured, causing a mess and a bit of damage inside; the supplementary external lead-acid battery installed in 2009 was returned to the ship.

The station on Brevoort Island was visited on August 13. Two bears were spotted from the air near the southern end of the island before landing at the summit. No mechanical damage was noted at the station. The RM Young wind set was replaced with a refurbished unit (new bearings, re-calibrated) and the temperature-humidity sensor was replaced with a new unit. A new pair of AGM batteries and voltage regulator was substituted. The entire Campbell Scientific data logger assembly, including logger, compact-flash memory module and pressure sensor was replaced, so that the wiring of the original could be thoroughly checked; an analysis of wind directions recorded here during 2009-11 has suggested that the direction sensor may not have been correctly wired. The new unit had the Iridium telephone hardware already mounted to provide communication capability at this site, which formerly had only on-site recording. The Iridium antenna was mounted on a new crossbar below the wind monitor. Exposed wires were tidied and secured tightly to the mast to minimize the possibility of damage by animals[1].

The station on Littleton Island was visited on August 14. Weather conditions were difficult with a cap of cloud on the island and very strong south-west wind. The station was inspected, on-site data were collected and the reference heading was verified. The station's batteries were not replaced because our AGM replacements were too large to fit within the weather-proof housing. Moreover, there was already 2x 39 A-h of battery capacity installed at the station; our potential replacements would have supplied only 25% more. It was too windy to complete a reliable verification of the North-alignment of the wind direction.

Deployments beyond 2012

1 mooring with pressure recorder for tide and sea level at Alexandra Fjord

4 weather stations (all Iridium reporting) at Joe Island, Hans Island, Brevoort Island and Littleton Island, in collaboration with the Danish Technical University and the Scottish Association for Marine Science.

Disappointments

Loss of Long Ranger ADCP (KF06)

We were unsuccessful in recovering one of the three torsionally rigid moorings supporting Long Ranger ADCPs in Kennedy Channel. We were unable to contact either Benthos transponder on this mooring at 350-m depth near Franklin Island (KF06). Subsequently we acoustically searched an area 8-km wide from 20 km up-channel of KF06 to 30 km down-channel, without success.

Because simultaneous failure of two transponders is very unlikely and the mooring was too deep to encounter ice, we presume that it dragged its anchor in strong current.

Leaks into instruments

Seawater leaked into the Long Ranger ADCP deployed at KF04 immediately after deployment, causing it to stop functioning and record no data.

The leak apparently occurred via the opening for the pressure sensor. This unit was subject to a recall from the manufacturer for this potential fault in the summer of 2010. This recall was unfortunately too late for remediation of this instrument which was purchased and already deployed in Nares Strait a year earlier.

Seawater leaked into the SBE37 temperature-salinity at the 75-m level on the mooring at KF30. The leak was the consequence of impact against an ice floe at the time of deployment. The impact broke the plastic signal connector on the end cap of the instrument, compromising the O-ring seal, and tore away the external protective shield around the conductivity cell.

[1] Despite precautions, the signals from the temperature-humidity sensor were lost within 24 hours of the visit to the station. Even more unfortunate has been the loss of Iridium contact with the station on 10 September 2012, less than 28 days after its upgrade for real-time weather reporting.

Ice island collision with Ice Profiling Sonar (KF20)

An ice island with area more than 300 km^2 separated from the Petermann ice shelf in August 2010. One piece of the island passed over the moorings near Franklin Island on 22 September 2010. The top levels of both moorings carrying ice-profiling sonar at 75-m depth (KF20 & KF30) and of one of those carrying SBE37 temperature-salinity recorders at 30 m depth were hit by one piece of this island and pushed down as the island passed. The IPS at KF20, near the Ellesmere side, stopped working at this time, apparently because the jostling of the instrument by the ice caused damage to the connecting wires for the battery. No data were recorded by this instrument during the last two years of its deployment.

Bathymetric survey of the Petermann sill

Improved bathymetric characterization of Petermann Fjord was an objective of this expedition. The position and limiting depth of the sill separation the fjord's basin from hall Basin was of particular interest. Unfortunately, the ice island that calved in July stayed over the sill during the time that Henry Larsen was in the area, and no sill survey was possible.

It was, however, possible to complete soundings lines in the previously unexplored area of the fjord exposed by the exit of the ice island.

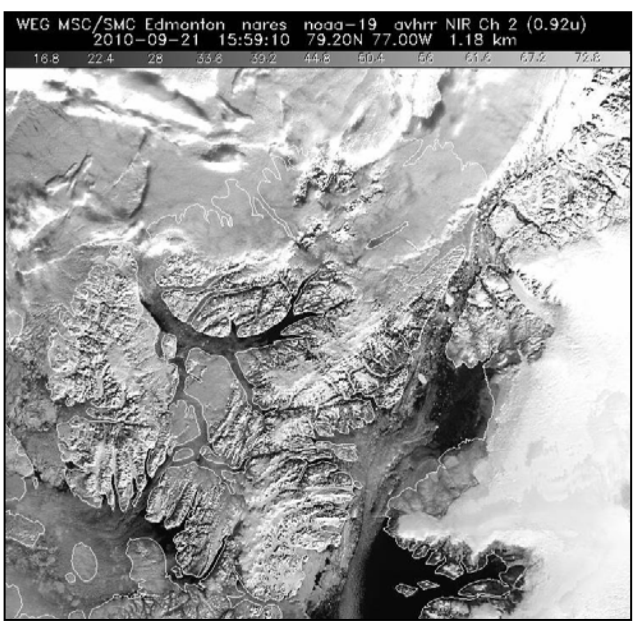
Malfunction of acoustic release

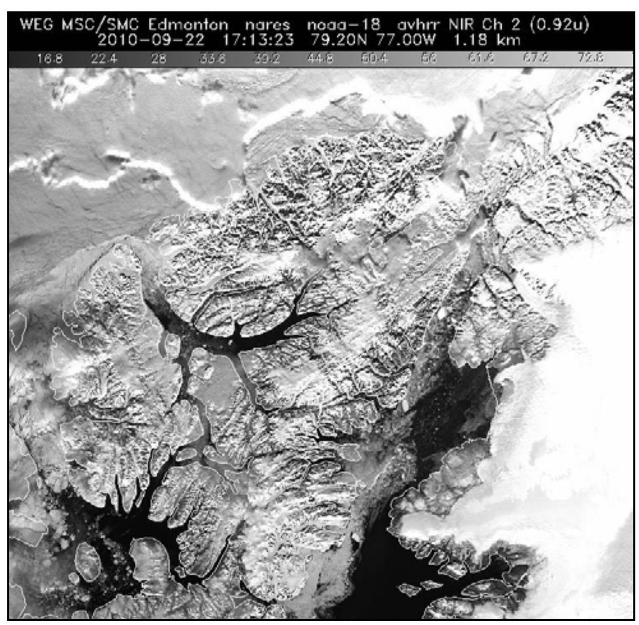
The Benthos Model 867A acoustic release transponder in Alexandra Fjord (s/n 107) communicated effectively but did not open. It's recovery was via dragging. However, when the release was retried on board ship, it did open. The cause of the malfunction is under investigation.

Early Findings of Interest

Petermann Ice Island passes over Moored Instruments

A part of the floating shelf of glacial ice in Petermann Fjord broke free on 5 August 2010 to form an ice island with an area of about 300 km^2. The island moved slowly out of the fjord and came to rest against Joe Island on 1 September. The island broke in two on 9 September. The smaller piece PII-A (the original "nose" of the ice shelf) continued to drift south-west. Satellite images below show it just north of the KF line at 12:10 utc on 11 September. It passed over the ADCP at KF02 at about 15:30 the same afternoon, in less than an hour moving at 0.8 m/s. The sonar measured draft was 40 m. The larger piece, PII-B, was hung up on Joe Island until late on 17 September, when it also started south. The satellite pictures below show PII-B just to the north of the KF line at 15:59 utc on 21 September and over the line at 17:13 utc on the next day.





Instruments on the moorings collected information on the ice-island draft in different ways.

At KF20, 3.5 km from Ellesmere Island, the top instrument (IPS) was pushed down to 111 m when it failed.

At KF02, 4.5 km from shore, the sonar-measured draft was typically 112 ±2 m.

At KF03, 7.6 km from shore, the top instrument (SBE37) was pushed down to 98 m.

At KF30, 11.8 km from shore, the top instrument (IPS) was pushed down to 90 m.

At KF05, 16.0 km from shore, there was no contact with the ice island.

In the echoes recorded by the ADCP, most of the ranges corresponded to 112-m draft, but there were two ridges with 120-m draft and 136-m draft at the trailing edge. Two channels in the underside, near the leading and trailing edges, have draft of only 48 m.

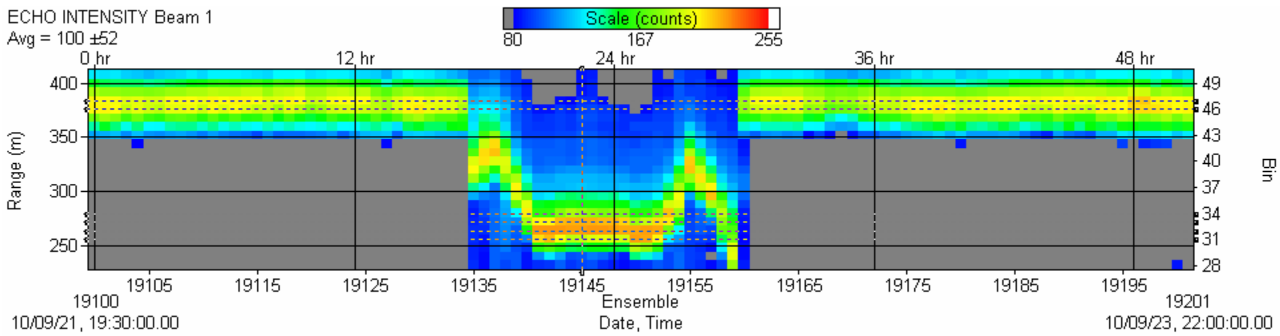
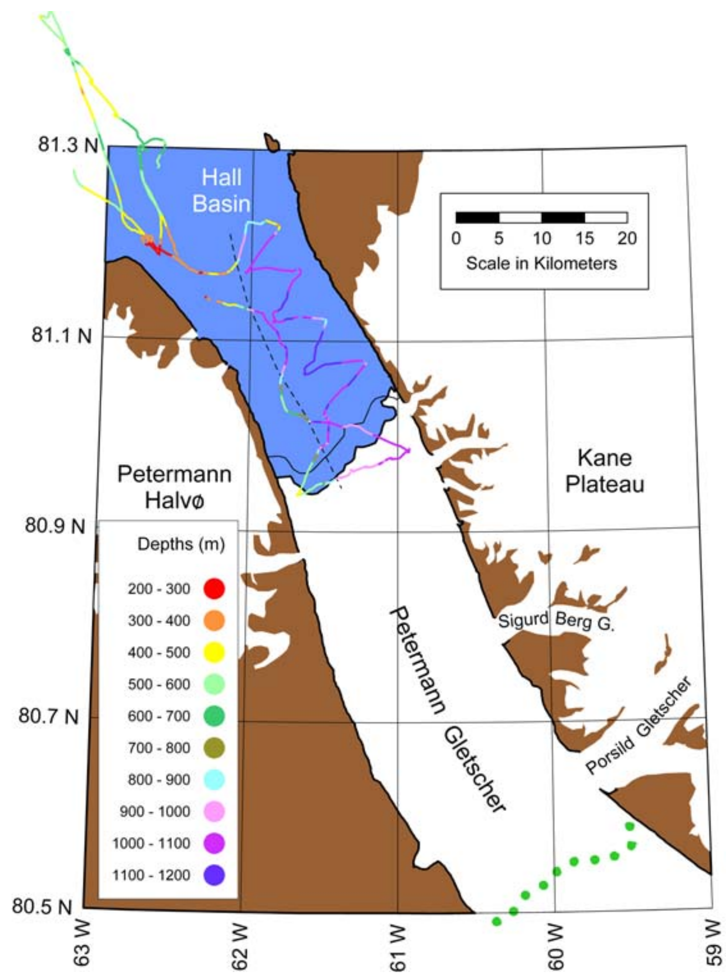


Figure 16. Echo from the underside of PII-B as it passed over moorings on the KF line on 22 September 2010.

Bathymetric Data: Petermann Fjord

Three recent calvings of ice islands from the floating ice shelf in Petermann Fjord have uncovered a 30-km reach that has never before been accessible by ship. For a few hours on 10-11 August, we had the opportunity to complete a reconnaissance survey of water depth in the basin between the position of the 2012 ice island over the sill south of Offley Island, and the edge of the ice shelf. On 10-11 August, the ice island occupied the position of the “Hall Basin” label on the adjacent map; the ship could not go there and no sounding was possible. The survey was also constrained by caution in approaching the rapidly shoaling side walls of the channel and in avoiding the many smaller ice islands drifting in the fjord.

The floor of the fjord is fairly flat at a depth of about 1100m. However, the fjord is unusual in having a shallower bench at a depth of 500-600 m that occupies roughly a third of its width on the western side. The depth of the basin is appreciably greater than that of the sill that separates the deep waters of the fjord from those of Hall Basin. The sill has yet to be surveyed in detail, but its maximum depth is estimated to be only 350-400 m.



Water Structure on Hydrographic Sections

The distribution of temperature and salinity of seawater was measured on four cross-sections of Nares Strait, across the mooring line at Franklin Island, across Kennedy and Robeson Channels further north and across Smith Sound at the southern opening to Baffin Bay. Observations from the northern and southern parts of the strait are displayed in Figure 17.

In the section across Kennedy Channel, shallow isohalines slope down towards Greenland, suggesting reduced southward flow of surface water or perhaps northward flow; this feature likely reflects the Ekman effect of the dominant south-west wind in August. Deeper isohalines rise towards Greenland, indicating southward current. Steeper slopes near Ellesmere reveal a narrow sub-surface jet of south-going current. Surface water is cold, below 0°C to about 250 m depth; temperature does not exceed 0.5°C anywhere.

The wider section across Smith Sound is relatively simple below 100-m depth: south-flowing current within 10 km of Ellesmere Island and northward flow in the eastern part of the section. The latter corresponds to a branch of the West Greenland Current that contributes water as warms as 1°C; water as warm as 0.5°C is present as shallow as 175 m on the Greenland side. Undulating isohalines in the upper 100 m suggest interleaved filaments of northward and southward current. The surface temperature is above 0°C.

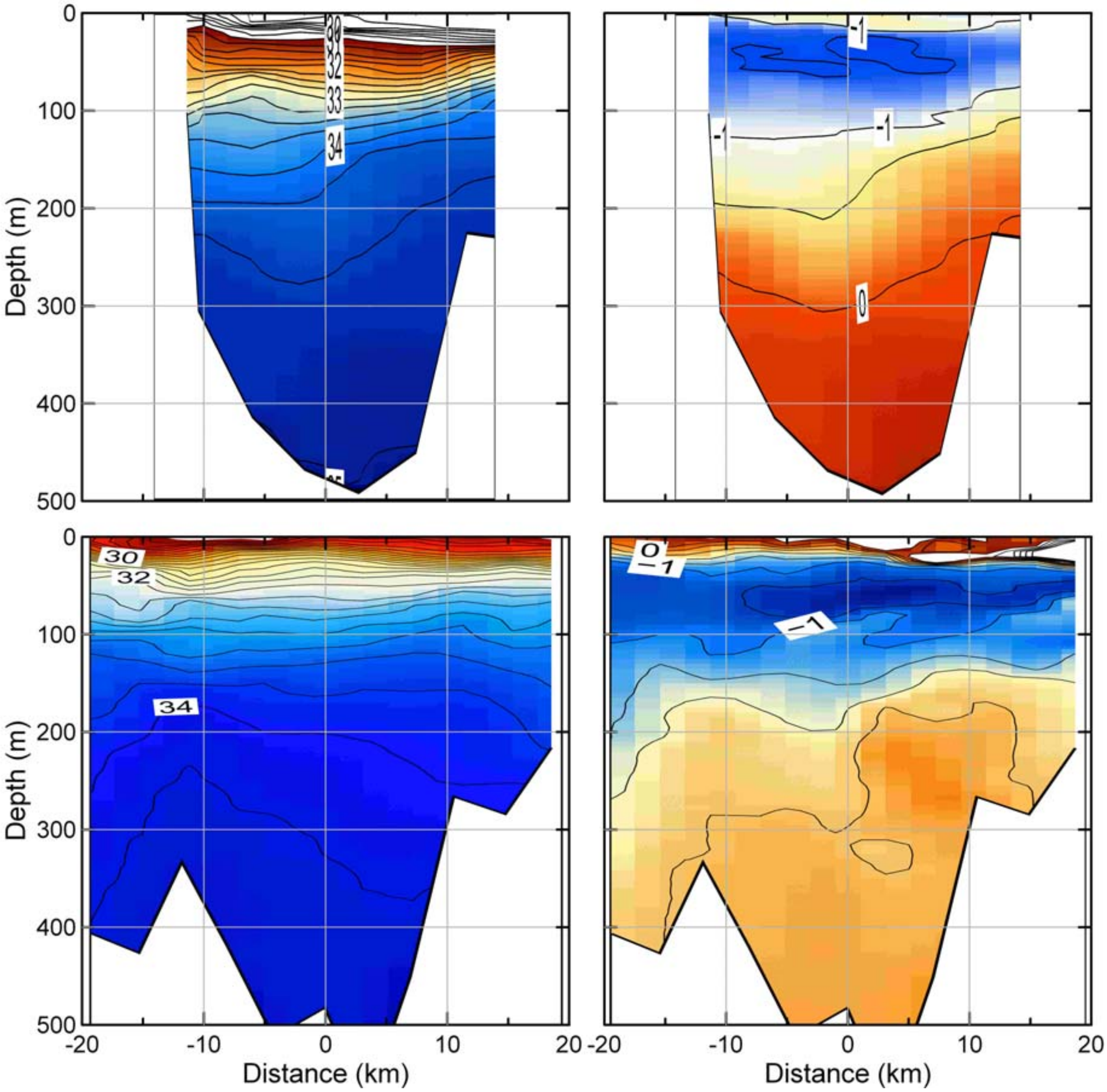


Figure 17. Salinity (left) and temperature (right) in cross-sections of Nares Strait in northern Kennedy Channel (top) and in Smith Sound (bottom). Ellesmere Island is on the right-hand side of the plots.

Moorings in Place 2012-14

Site	Date	Latitude	Longitude	Depth	Instruments	Transponding Release
Alexandra Fjord	13 Aug-12	78º 54.254' N	075º 49.818' W	19 m	DL3-PS s/n 006	1 x 867A, s/n 108

Weather Stations in Place 2012-14

Site	Date	Latitude	Longitude	Height	Power system
Joe Island	11 Aug-12	81º 15.080' N	063º 30.997' W	197 m	2x 55 A-h glass-mat batteries charged by 30 W solar panel
Hans Island	11 Aug-12	80º 49.432' N	066º 26.752' W	174 m	2x 55 A-h glass-mat batteries charged by 30 W solar panel
Brevoort Island	13 Aug-12	78º 41.068' N	074º 06.964' W	107 m	2x 55 A-h glass-mat battery charged by 30 W solar panel
Littleton island	14-Aug-12	78º 21.841' N	072º 51.855' W	117 m	2x 39 A-h gel cells, charges by a small solar panel

Site	Wind	Temperature & Humidity	Solar Radiation	Long-wave Radiation	Reference Heading	Iridium
Joe Island	2.9 m	1.5 m	1.5 m	1.5 m	057ºT	Yes
Hans Island	2.4 m	2.1 m	1.9 m	1.9 m	046ºT	Yes
Brevoort Island	3.1 m	1.5 m	Not installed	Not installed	000ºT	Yes
Littleton island	2.5 m	2.5 m	Not installed	Not installed	000°T	Yes

Moorings Now Judged Lost from 2003, 2005, 2006, 2007 & 2009 Deployments

Site	Date In	Latitude		Longitude		Depth (m)	Type	Explanation
KS04	Aug-03	80	32.124' N	068	42.840' W	357	ADCP	Did not release
KS06	Aug-03	80	30.162' N	068	27.240' W	363	ADCP	Did not release
KS08	Aug-03	80	28.286' N	068	11.433' W	350	ADCP	Did not release
KS11	Aug-03	80	25.650' N	067	47.833' W	288	CT	Lost to ice?
KS13	Aug-03	80	22.501' N	067	25.821' W	109	CT	Lost to ice?
Discovery Harbour	Aug-03	81	42.371' N	064	47.940' W	19	DL3-PS	Recovered Aug-12
Offley Island	Aug-03	81	18.408' N	061	48.824' W	20	DL3-PS	Lost to ice?
Scoresby Bay	Aug-03	79	54.654' N	071	21.388' W	21	DL3-PS	Lost to ice?
ACW05-1	Sep-05	76	32.045' N	090	28.346' W	130	ADCP	Moved by current?
KS09	Aug-06	80	27.167' N	068	03.936' W	320	CT	Lost to ice?
Foulke Fjord	Aug-06	78	17.830' N	072	34.080' W	20	DL3-PS	No more ship time
KF06	Aug-09	80	41.867' N	067	10.709' W	388	ADCP	Moved by current?
ACW09-1	Aug-09	76	32.016' N	090	28.403'W	129	ADCP	Moved by current?

Figure 18. Foulke Fjord Greenland, looking west towards Ellesmere Island, 14 August 2012.

Locations of CTD & Sampling Stations

Date EDT	Seq No	Name	Latitude		Longitude		Start EDT	Depth, m	s/n	Configuration
05-Aug	1	KF01	80	47.930	067	45.260	20:21	246	0307	Arctic w/ Twin-Otter winch
05-Aug	2	KF01	80	47.810	067	45.230	20:44	246	0307	Arctic w/ Twin-Otter winch
05-Aug	3	KF02	80	46.510	067	33.310	21:28	383	0307	Arctic w/ Twin-Otter winch
05-Aug	4	KF03	80	44.960	067	22.750	22:07	413	0307	Arctic w/ Twin-Otter winch
05-Aug	5	KF04	80	43.360	067	11.080	22:49	407	0307	Arctic w/ Twin-Otter winch
05-Aug	6	KF05	80	42.070	066	59.480	23:30	315	0307	Arctic w/ Twin-Otter winch
07-Aug	7	KN06	81	07.870	064	13.580	15:16	225	0307	Arctic w/ Twin-Otter winch
07-Aug	8	KN05	81	09.500	064	24.100	16:16	443	0293	SBE cage w/ 12-bottle rosette
07-Aug	9	KN04	81	11.100	064	36.500	17:31	483	0307	Arctic w/ Twin-Otter winch
07-Aug	10	KN03	81	12.800	064	47.900	18:01	460	0293	SBE cage w/ 12-bottle rosette
07-Aug	11	KN02	81	14.380	064	59.060	18:49	407	0307	Arctic w/ Twin-Otter winch
07-Aug	12	KN01	81	16.100	065	12.000	19:25	302	0293	SBE cage w/ 12-bottle rosette
07-Aug	13	KN00	81	16.540	065	14.190	20:01	106	0307	Arctic w/ Twin-Otter winch
08-Aug	14	RN06	81	52.000	061	31.440	08:47	474	0307	Arctic w/ Twin-Otter winch
08-Aug	15	RN05	81	52.500	061	44.200	09:32	744	0293	SBE cage w/ 12-bottle rosette
08-Aug	16	RN04	81	53.730	061	55.680	10:31	528	0307	Arctic w/ Twin-Otter winch
08-Aug	17	RN03	81	54.900	062	04.600	10:59	513	0293	SBE cage w/ 12-bottle rosette
08-Aug	18	RN02	81	56.130	062	14.960	12:42	701	0307	Arctic w/ Twin-Otter winch
08-Aug	19	RN01	81	57.660	062	25.140	13:20	685	0293	SBE cage w/ 12-bottle rosette
09-Aug	20	PL06	81	16.750	062	39.640	19:01	562	0307	Arctic w/ Twin-Otter winch
09-Aug	21	PL05	81	18.000	062	46.200	20:05	553	0307	Arctic w/ Twin-Otter winch
09-Aug	22	PL04	81	20.020	062	58.280	21:01	475	0307	Arctic w/ Twin-Otter winch
09-Aug	23	PL03	81	22.050	063	09.010	21:47	409	0307	Arctic w/ Twin-Otter winch
09-Aug	24	PL02	81	23.990	063	20.150	22:34	562	0307	Arctic w/ Twin-Otter winch
09-Aug	25	PL01	81	26.040	063	30.580	23:19	479	0307	Arctic w/ Twin-Otter winch
10-Aug	26	PX05	80	59.100	060	56.400	14:41	1033	0293	SBE cage w/ 12-bottle rosette
10-Aug	27	PX04A	80	58.640	061	02.630	15:33	1013	0307	Arctic w/ Twin-Otter winch
10-Aug	28	PX04	80	58.330	061	07.300	16:00	986	0307	Arctic w/ Twin-Otter winch
10-Aug	29	PX03A	80	58.080	061	12.860	16:53	953	0307	Arctic w/ Twin-Otter winch
10-Aug	30	PX03	80	57.860	061	18.190	17:19	960	0293	SBE cage w/ 12-bottle rosette
10-Aug	31	PX02A	80	57.410	061	23.400	18:10	904	0307	Arctic w/ Twin-Otter winch
10-Aug	32	PX02	80	57.040	061	29.190	18:33	777	0307	Arctic w/ Twin-Otter winch
10-Aug	33	PX01A	80	56.660	061	35.030	19:14	518	0307	Arctic w/ Twin-Otter winch
10-Aug	34	PX01	80	56.350	061	40.430	19:35	471	0293	SBE cage w/ 12-bottle rosette
11-Aug	35	PL11	81	01.110	061	28.110	21:00	1050	0307	Arctic w/ Twin-Otter winch
11-Aug	36	PL11	81	01.300	061	28.960	21:16	1050	0307	Arctic w/ Twin-Otter winch
11-Aug	37	PL10	81	03.900	061	37.950	22:48	1099	0307	Arctic w/ Twin-Otter winch
12-Aug	38	PL09	81	07.210	061	50.980	00:25	1042	0307	Arctic w/ Twin-Otter winch
12-Aug	39	PL08	81	10.350	062	02.300	02:41	969	0307	Arctic w/ Twin-Otter winch
12-Aug	40	PL07	81	13.440	062	01.920	04:05	836	0307	Arctic w/ Twin-Otter winch
13-Aug	41	SS01	78	40.240	074	01.790	19:03	400	0307	Arctic w/ Twin-Otter winch
13-Aug	42	SS02	78	39.110	073	52.490	19:32	419	0293	SBE cage w/ 12-bottle rosette
13-Aug	43	SS03	78	38.300	073	43.900	20:12	329	0307	Arctic w/ Twin-Otter winch
13-Aug	44	SS04	78	37.380	073	34.950	20:42	413	0293	SBE cage w/ 12-bottle rosette
13-Aug	45	SS05	78	36.500	073	26.000	21:22	502	0307	Arctic w/ Twin-Otter winch
13-Aug	46	SS06	78	35.500	073	16.100	21:50	433	0293	SBE cage w/ 12-bottle rosette
13-Aug	47	SS07	78	34.600	073	07.900	22:33	569	0307	Arctic w/ Twin-Otter winch
13-Aug	48	SS08	78	33.600	073	00.100	23:07	425	0293	SBE cage w/ 12-bottle rosette
13-Aug	49	SS09	78	32.900	072	51.400	23:50	264	0307	Arctic w/ Twin-Otter winch
14-Aug	50	SS10	78	31.900	072	41.400	00:25	282	0293	SBE cage w/ 12-bottle rosette
14-Aug	51	SS11	78	30.910	072	32.780	01:16	216	0307	Arctic w/ Twin-Otter winch

Water Samples for Geochemical Analysis

Seq No	Location	Station	No of Levels	Sample Numbers		
0008	Kennedy Channel North	KN05	12	1	to	13
0010	Kennedy Channel North	KN03	12	14	to	26
0012	Kennedy Channel North	KN01	11	27	to	38
0015	Robeson Channel	RN05	12	39	to	51
0017	Robeson Channel	RN03	12	52	to	64
0019	Robeson Channel	RN01	12	65	to	79
0026	Petermann Fjord	PX05	12	80	to	92
0030	Petermann Fjord	PX03	12	93	to	105
0034	Petermann Fjord	PX01	12	106	to	118
0042	Smith Sound	SS02	12	119	to	131
0044	Smith Sound	SS04	12	132	to	144
0046	Smith Sound	SS06	12	145	to	157
0048	Smith Sound	SS08	12	158	to	170
0050	Smith Sound	SS10	11	171	to	182

Personnel

1	Humfrey Melling	M	Institute of Ocean Sciences DFO	Chief scientist
2	Andreas Münchow	M	University of Delaware, USA	USA lead scientist
3	Renske Gelderloos	F	Oxford University, UK	Scientist: oceanography
4	David A. Riedel	M	True North Consulting	Scientist: support
5	Ron W. Lindsay	M	Institute of Ocean Sciences DFO	Technician: electronics
6	Jonathan Poole	M	Square Wave Marine Technology	Technician: mooring equipment
7	Patricia Ryan	F	University of Delaware, USA	PhD student: oceanography
8	Allison Einolf	F	University of Delaware, USA	BSc student: oceanography

Research Permits

Fisheries and Oceans Canada: Institute of Ocean Sciences Cruise No. 2012-20

Denmark Ministry of Foreign Affairs

Permission to work in Greenland waters was granted on 1 August 2012. JTF, File no.55.Dan.9-11.

Danish Polar Centre

We were informed in 2006 that a science permit is not required for marine research near Greenland. However, we did provide the Danish Polar Centre with the work plan for CCGS Henry Larsen in 2012.

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Nunavut Research Institute

Variation & forcing of fluxes through Nares Strait and Jones Sound – Nunavut Scientific Research Licence No. 0204406R-M received August 1, 2006 (valid until December 31, 2006)

Variation & forcing of fluxes through Nares Strait and Jones Sound – Nunavut Scientific Research Licence No. 0203207R-M received May 7, 2007 (replaces No. 0204406R-M, and valid until December 31, 2007)

Variation & forcing of fluxes through Nares Strait and Jones Sound – Nunavut Scientific Research Licence No. 0202409N-A received May 6, 2009 (replaces No. 0203207R-M, and valid until December 31, 2009)

Variation & forcing of fluxes through Nares Strait and Jones Sound – Nunavut Scientific Research Licence No. 0213011R-M received July 19, 2011 (replaces No. 0202409N-A, and valid until December 31, 2011)

Variation & forcing of fluxes through Nares Strait and Jones Sound – Nunavut Scientific Research Licence No. 0203312R-M received June 5, 2012 (replaces No. 0213011R-M, and valid until December 31, 2012)

Automatic weather stations: Under SRL held by Professor David Barber, Arctic Net.

Drs Humfrey Melling completed a consultation tour of the North Baffin Region in June 2007. The tour was coordinated by DFO's National Centre for Arctic Aquatic Research Excellence (N-CAARE) and visited Resolute Bay, Grise Fjord, Pond Inlet and Arctic Bay. Participants met with members of the local HTAs and discussed proposed and completed work at public meetings.

Canadian Environmental Assessment Act

Canadian Environmental Assessment Act: Screening document completed and signed off by Robin Brown DFO.

Deck Equipment and Scientific Workspace

CCGS Henry Larsen is not equipped for oceanographic work. Several significant items of deck equipment which were shipped by truck to St John's in June:

- Work Winch with built-in hydraulic power pack and several thousand metres of conducting cable, from Université Laval
- Workshop built within a 20-foot steel-clad cargo container, for use on the foredeck. Weight 6000 lb
- Instrument laboratory within a 20-foot aluminium-clad cargo container, for use on the boat deck. Weight 5000 lb
- Light-weight CTD winch (110-volt electric) & block, with 2000 m of 1/8" single-conductor wire. Weight 400 lb

These items were competently installed by the ship's deck and engineering departments. The work winch was mounted on a deck ring on the starboard side of the foredeck hatch, with a lead to a block suspended from the ship's crane at the starboard rail. The workshop was chained to the foredeck near the portside rail, doors opening aft, and supplied with power. The CTD winch was mounted on its reinforced wooden shipping box and secured against the house-works on the port side; the pulley block was suspended from a boom pivoted from the corner of the house-works. The instrument lab was secured via twist locks to the boat deck also on the port side, just aft of the Miranda davit, with doors opening aft.

Mooring operations were handled using the ship's crane. A foredeck mounted A-frame and associated hydraulics would have enabled the anchor-first deployment of moorings in close pack ice. Unfortunately, such equipment was not available at IOS and could not be procured elsewhere.

Water sampling operations with the rosette were also handled using the ship's crane, in conjunction with the large work winch. A foredeck mounted A-frame would have permitted this activity to be conducted more expeditiously and with fewer staff. Unfortunately, such equipment is not available at IOS and could not be procured elsewhere.

As the mooring work progressed, we used a significant fraction of the foredeck for storing floats, anchor weight and other mooring components. All remaining free space on the starboard side was used for staging moorings at times of recovery and deployment.

The large Special Navigation Chart Room behind the bridge was used for computer work and for the servicing and preparation of scientific instruments that could be carried conveniently to this level in the ship.

Boat and Helicopter

We made frequent use of the ship's Fast-Response Craft (FRC, a 7-m rigid hull inflatable) for retrieving and deploying moorings both in the vicinity of the ship and on sorties of several miles to coastal sites.

In addition to its role in tactical ice reconnaissance, the ship's helicopter was essential to the NRC project for the following tasks:

- Access to weather stations on land, for installation, recovery or maintenance.
- Ice reconnaissance

Acknowledgements

We are very appreciative of Captain Duffet's commitment to completing the scientific programme on *CCGS Henry Larsen.* The support of his officers and crew towards this objective has been professional, enthusiastic and of the highest quality. We were welcomed by all on board and came to feel comfortable and at home with the ship's company. Special assistance to the scientific programme by the ship's deck department (for weather station work) and by the engineering department (for use of the machine shop and supply of material) is gratefully acknowledged. Without this help, our team would have been much less effective. Funds from The Graduate College of Marine Studies, University of Delaware, towards vessel operations costs are gratefully acknowledged.

Appendix: Cruise Narrative

30 July, Monday

Scientists travelling to St John's: 4 from Victoria BC, 3 from Newark Delaware, 1 from Oxford UK.

31 July, Tuesday

Scientists on standby in St John's.

1 August, Wednesday

Up at 4:15 am NDT and at the Woodward Hanger, St John's airport at 5 am.

On standby at the airport for much of the day, while First Air explored whether their aircraft could be repaired in time to complete the charter.

Flight re-scheduled for tomorrow after a wait of about 7 hours.

2 August, Thursday

Up at 4:15 am NDT and at the Woodward Hanger, St John's airport at 5 am. Aircraft airborne at 06:00 am.

Stop in Iqaluit for fuel. All allowed to enter the terminal. Airborne at 10:00 am

Arrival at Thule at 12:00 pm NDT. Weather clear with partial high overcast, 7°C.

Henry Larsen remains at Thule overnight.

3 August, Friday

Science meeting at 8 am to discuss allocation of work space, deck layout, staff assignments and preparatory tasks [ship now working on Eastern Daylight Time: EDT = UTC - 4].

Ship safety briefing, immersion suits and walk-about at 12:30 pm. Helicopter safety briefing at 3 pm. Boat and fire drill at 7 pm.

Henry Larsen underway at 2:15 pm.

4 August, Saturday

At 78°N in scattered ice at 8 am. Slow overnight progress in fog.

At the ice edge in Smith Sound at 11:15 am, 78° 23' N.

Decide to press northward to Kane Basin through congested ice in Smith Sound.

9 pm: In lighter ice in Kane Basin, doing 5-8 kt.

5 August, Sunday

8:00 am: At 80° N. Ship making 4-5 kt in multi-year ice at 4 tenths.

8:30 am: Helicopter leaves for ice reconnaissance as far as Hans Island. Reports ice concentration of 6 tenths over the KF line of moorings, most as small floes.

1:00 pm: Task analysis meeting with Captain, First Officer, Bosun to discuss the recover of oceanographic moorings.

7:30 pm: Start the Kennedy Franklin (KF) CTD section at the western side, near Ellesmere Island, ranging also on the Benthos releases on moorings during stops for CTDs. CTD's completed at 11:30 pm.

6 August, Monday

8:00 am: Positioned to recover moorings along the KF line, starting at the western side. Ice drifting north-eastward on a flood tide.

8:40 am: Ice-profiler (IPS) mooring at KF20 recovered.

9:10 am: Doppler current profiler (ADCP) mooring at KF02 recovered.

10:23 am: Temperature-salinity (SBE37) mooring at KF03 recovered.

11:15 am: Doppler current profiler (ADCP) mooring at KF04 recovered.

1:15 pm: Ice-profiler (IPS) mooring at KF30 recovered.

2:00 pm: At site KF05 to recover the SBE37 mooring deployed there. Some interference from ice. No response from the Benthos release-transponder.

3:00 pm: At KF06 to recover the ADCP mooring deployed there. No response from either release-transponder.

4:00 pm: Back at KF05, after it was realized that the wrong enabling codes at been used during the earlier recovery attempt. Again some interference from ice, but mooring successfully released within 30 minutes and on board by 4:50 pm.

6:00 pm: Back at KF06, running through all possible Benthos frequencies and release codes (based on our inventory), just in case our record keeping in 2009 may have been flawed. No response from below for any combination.

6:50 pm: Considering a “blind release” command to the mooring, in case the releases were hearing but unable to transmit. However, there was too much ice to make this viable.

8:00 pm: Overnight plan for CTD work cancelled because of strong wind (SSW 20-25 kt)

7 August, Tuesday

7:00 am: Henry Larsen in heavy fog, so not practical to fly to the nearby weather station on Hans Island.

Proceed slowly north-east to the Kennedy North (KN) CTD line.

3:00 pm: Start the KN CTD-rosette section on the Greenland side, interleaving CTD and rosette drops across the width of the strait.

8:30 pm: KN section completed. Ice-free conditions along the Ellesmere side provide the opportunity for a “dash to Alert”.

Henry Larsen reached 82º 14.75’N 061º 01.15’W early on August 8, where concentrated old ice blocked passage into the Lincoln Sea.

8 August, Wednesday

8:40 am: Start the Robeson North (RN) CTD-rosette section on the Greenland side. Completed about 2 pm.

Proceed south-west (25 miles) to Discovery Harbour, exploiting our first opportunity to attempt retrieval of a pressure recorder placed there in 2003. Ice blocked access by Henry Larsen in 2006, 2007 and 2009.

5:40 pm: The rigid-hull inflatable (FRC) was sent into the bay with grappling gear. By 8:30 pm they had been successful in retrieving the installation, which had been 9 years at sea … and was still recording data even though the batteries of the acoustic release-transponder had failed.

Standby overnight on the other side of Lady Franklin Bay, in strong (0-40 kt) south-west wind.

9 August, Thursday

Too windy at Cape Baird to use the helicopter to recover the weather station there. We took the FRC ashore and walked up.

The weather station was in good condition except that wires to sensors have been gnawed through. Done by 12:30 pm, and heading east to install a replacement station on Joe Island.

2:30 pm: A cap of cloud on Joe Island precluded helicopter use there. Proceed east into Petermann Fjord.

3:00 pm: Ice reconnaissance via helicopter into Petermann Fjord. The new ice island is pushed up against Offley island, but the resulting gap between the ice island and the south-western side of the fjord is blocked by sea ice.

The western part of the planned longitudinal CTD section of Petermann Fjord was completed by midnight, extending from the western side of the ice island out into Hall Basin. Unfortunately the section could not be extended over the sill of the fjord, which lay beneath the ice island at this time.

10 August, Friday

8:30 am: Reconnaissance within Petermann Fjord by helicopter. Ice island has moved little overnight. Clear skies.

10:00 am: Henry Larsen breaking through ice south of the ice island to enter Petermann Fjord. Helicopter sent back at intervals to check for movement of the ice island.

2:45 pm: Starting a CTD-rosette section across Petermann Fjord near the near ice front: 5 casts to 1000 m, including 3 for water sampling, plus 6 interleaved casts to 300 m with the CTD alone.

9:00 pm: Resume the Petermann longitudinal section, working north-west from the ice front to the back side of the ice island. The path here was zig-zagged in order to complete a number of traverses across the deeper north-east side of the fjord.

11 August, Saturday

5:00 am: Complete the longitudinal section at PL07. Again, it was not possible to traverse the sill.

9:00 am: At Joe Island. Cap of cloud intermittent. Melling on first trip up by helicopter, to select the site for the weather station.

1:30 pm: Weather station installation complete. Proceed south in dense fog.

7:00 pm: Henry Larsen at Hans Island. Fog has cleared. Helicopter dispatched with weather-station maintenance crew.

9:30 pm: Task complete.

10:00 pm Begin acoustic sweep for possibly displaced ADCP mooring from KF06. Transmit the enable command for each release-transponders for 6 minutes. Each stop sweeping a disc about 8 km across; stops about 6 km apart from 20 km north of the deployment site to 30 km south.

Complete sweep at 4th site XPD-4 at 2 am. Standby until 7 am.

12 August, Sunday

Continue the acoustic sweep at XPD-5, continuing until 1 pm, when search pattern completed. No success.

Proceed south towards Alexandra Fjord: 3-4 tenths ice at 3-8 kt.

13 August, Monday

9:15 am: Henry Larsen in Alexandra Fjord. FRC launched to retrieve the pressure gauge west of Skraeling Island. Mooring recovered by dragging at about 10:15.

2:30 pm: Replacement mooring deployed from the FRC.

4:00 pm: Helicopter sent ahead to Brevoort Island to service the weather station there. Maintenance complete and helicopter back on board by 6:30 pm.

7:00 pm: Start the CTD-rosette section across Smith Sound, 11 station in total, complete about 2 am.

14 August, Tuesday

8:00 am: Standing off Littleton Island in strong (30 kt) south-west wind; marginal conditions for helicopter landing on rough terrain.

8:55 am: Successful helicopter landing on Littleton Island. Station in good condition, and mission completed by 10:15 am.

11:00 am: Helicopter reconnaissance of Foulke Fjord – not such rough conditions inshore.

12:50 pm: FRC heading in to look for the pressure recorder placed on a mooring there in 2006.

3:30 pm: FRC back on board, without success in finding the mooring. Proceed on route to Resolute Bay

15 August, Wednesday

8:00 am: Henry Larsen in Baffin Bay, south-west of Lady Ann Strait

8:30 pm: Screech-in ceremony for novices.

16 August, Thursday

8:30 am: Coming alongside Terry Fox at Nanisivik, in order to transfer fuel.

3:45 pm: Henry Larsen casts off on route for Resolute Bay.

17 August, Friday

Henry Larsen drops anchor in Allen Bay about 9 am. All personnel ashore via helicopter by 11:30 am.

Slinging of heavy supplies needed for the IPS aircraft-supported programme in April 2013, was completed by 1 pm, after a break for lunch.

Overnight stay at the PCSP base.

18 August, Saturday

3:30 pm: Scientists leave Resolute Bay for Iqaluit on First Air scheduled flight (except for Lindsay and Poole, who remain in Resolute awaiting transport to the des Groseilliers at Eureka).

Overnight stay in Iqaluit

19 August, Sunday

1;45 pm: Departure of First Air's connecting flight to Ottawa cancelled because of a mechanical fault. No options until tomorrow.

First Air pays for the overnight stay at the Discovery Lodge Hotel.

Lindsay and Poole reached Eureka via a PCSP Twin Otter flight about noon.

20 August, Monday

Others successful in leaving Iqaluit on the flight at 1:45 pm. West Coasters continue on to Victoria, arriving around midnight local time.