Canadian Arctic Through-Flow

2007 Cruise to Nares Strait

CCGS Henry Larsen

August 9 – September 1, 2007

Institute of Ocean Sciences Cruise 2007-52

Humfrey Melling – Chief Scientist

Fisheries & Oceans Canada

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Overview

The Canadian Arctic Through-flow (CAT) study during the International Polar Years is the culmination of ten years' effort within Canada and the international community to measure flows of seawater and ice through the Canadian Archipelago, from Arctic to Atlantic.

A pilot effort, the Arctic Canada Watch, was established in 1997. In 1998 the first moorings for year-round measurement were placed in western Lancaster Sound and in Cardigan Strait. These carried instruments to measure current, temperature and salinity and embodied innovations to address the challenges of measuring: 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 our US 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 goals of the present expedition in 2007 were to re-establish an observational array in Nares Strait for the IPY and to recover and re-deploy the long-standing installations in Cardigan Strait. The IPY CAT project has during 2007 also supported maintenance of the Lancaster Sound array from CCGS des Groseilliers and installation of an oceanographic mooring in Bellot Strait from CCGS Louis S St Laurent. Bellot Strait is the least of the four constrictions for Canadian Arctic through-flow. The CAT study is now observing the flows of seawater, salt and heat through all the pertinent straits within the Canadian Archipelago.

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 interannual 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 approach to monitoring for ocean climate – sustained observations of seawater and ice movements through the Canadian Archipelago.

Elements of the Scientific Programme

CAT Mooring Project – Nares Strait

Recover internally recording instruments on 12 oceanographic moorings; 8 are in deep water & 4 in shallow bays; dragging will be necessary at 3 sites.

Service recovered instruments and mooring components.

Re-deploy internally recording instruments on oceanographic moorings at 18 sites (perhaps more); 14 are in deep water & 4 in shallow bays.

Measure seawater properties via profiling CTD on cross-sections at 5 locations along the strait.

CAT Mooring Project – Cardigan Strait

Recover internally recording instruments on 2 oceanographic moorings in deep water.

Service recovered instruments and mooring components.

Re-deploy internally recording instruments on oceanographic moorings at 2 sites (perhaps 3); all are in deep water.

Measure seawater properties via profiling CTD on cross-sections in Cardigan Strait, Hell Gate, Fram Sound.

The CAT project is the responsibility of Fisheries and Oceans Canada, with funding from the Canadian Programme for the International Polar Year (IPY 2006-SR1-CC-135).

Multi-year Ice Properties – Arctic straits

Measure profiles of thickness across selected multi-year ice floes using surface-based electromagnetic induction radar and drill holes, coincident with imaging by Radarsat.

Measure the compressional strength sea ice in holes drilled into some of these multi-year floes.

Deploy satellite tracking beacons on one or two floes to facilitate their re-measurement at a later time.

Observations are to be carried out in Nares Strait, Norwegian Bay and western Jones Sound.

This activity is the responsibility of the Canadian National Research Council with project funding from industrial partners.

Arctic Transportation Project – Arctic straits

Measure the acceleration components of (viz. total force on) CCGS Henry Larsen when breaking ice, using an autonomous measurement and logging system (MOTAN).

Record scenes from a forward-looking video camera mounted at the bow. The images will be used to identify the ice features whose impacts are associated with high forces.

Photograph ice blocks from floes broken by the ship using a down-looking camera. The images will be used to determine the thickness of ice broken during the ship-ice interaction.

This work involves no requirement for dedicated ship's activity.

This activity is a collaborative effort of the Canadian National Research Council, the Canadian Ice Service and Fisheries and Oceans Canada. The work is supported via funding from the Climate Change Technology & Innovation Initiative (CCTII) of the federal programme on energy research and development (PERD) and the Canadian Programme for the International Polar Year (IPY 2006-SR1-CC-135)

Shoreline Pick-ups

We have received a number of requests from colleagues to retrieve ocean instruments now stranded within our working area in the Canadian Archipelago. All objects are small and readily carried by helicopter.

Meteorological Project

Two automatic weather stations were deployed in September 2006 near the eastern shore of Ellesmere Island, one on Pim Island and the other at Cape Isabella. We have been asked to visit these sites, to retrieve data recorded during the last year, to assess the continued viability of the installations and to refurbish or retrieve them.

Schedule

Scientific personnel left home on Tuesday August 7, spent the night in St John's and travelled north on Wednesday via the CCG crew-change flight to Thule. The CCGS Henry Larsen sailed from Thule on that evening and arrived at the southern end of the work area on the following morning.

We worked up the channel to the primary work area over the next five days. Immediately upon her arrival in Kennedy Channel on August 14, CCGS Henry Larsen was obliged to depart for Grise Fjord, 400 nautical miles to the south, to disembark a crew member on compassionate grounds. The ship arrived back in the work area on Saturday (August 18) after an absence of about four days.

The ship supported the CAT study in Kennedy Channel for the next nine days, working where ice allowed as far north as 81° 30'. Heavy pack ice was a serious obstacle for the oceanographic activities, but provided valuable opportunities for the ice-related components of the scientific programme. CCGS Henry Larsen turned south late on August 25 and reached the vicinity of Cardigan Strait two days later. The weather, which had been calm and sunny for most of our time in the north became overcast and foggy.

Team members reached Pond Inlet via Lady Ann Strait, Baffin Bay and Lancaster Sound on September 1st, flew south to Iqaluit on the September 4th and to Ottawa and beyond on the 5th.

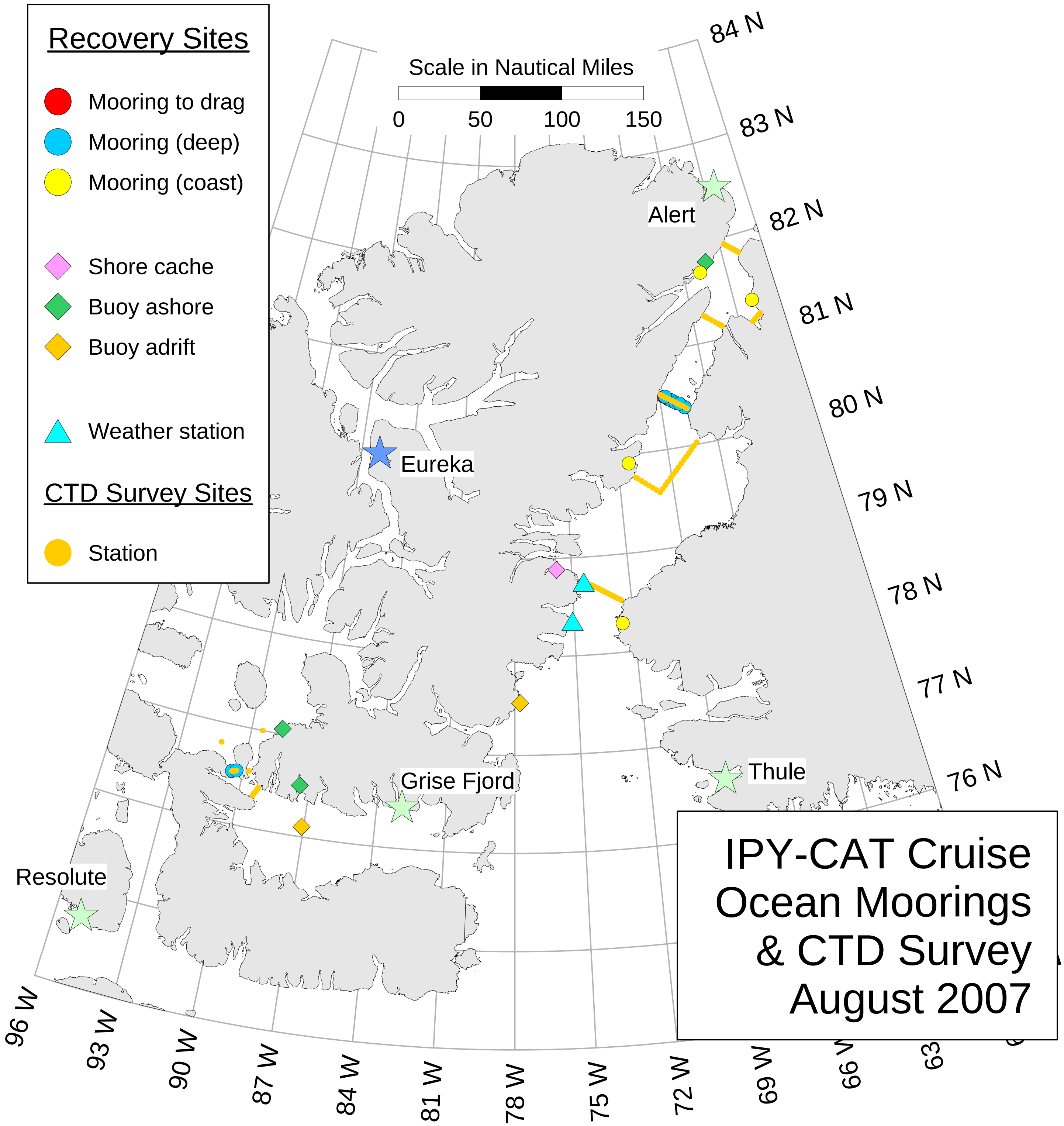


Figure 1. Sites of scientific activity to be conducted from CCGS Henry Larsen during August 2007. The principal centres of activity are in southern Kennedy Channel between Greenland and Ellesmere Island at 80.5°N and in Cardigan Strait between Ellesmere and Devon Islands at 091°W.

Ice Conditions

The transition from land-locked to drift ice in Nares Strait usually occurs between mid July and mid August. Although ice in Kennedy Channel begins to move with the tide in June or July, it is typically not until late July that the ice bridge across Smith Sound collapses. Prevailing winds and currents then begin to flush ice southward into Baffin Bay, initiating a wave of clearing that progresses from south to north in Nares Strait.

But lighter ice conditions are short lived. After the northernmost ice bridge across Robeson Channel breaks, usually in mid August, heavy multi-year pack from the Lincoln Sea invades the Strait. By early September navigation become 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.

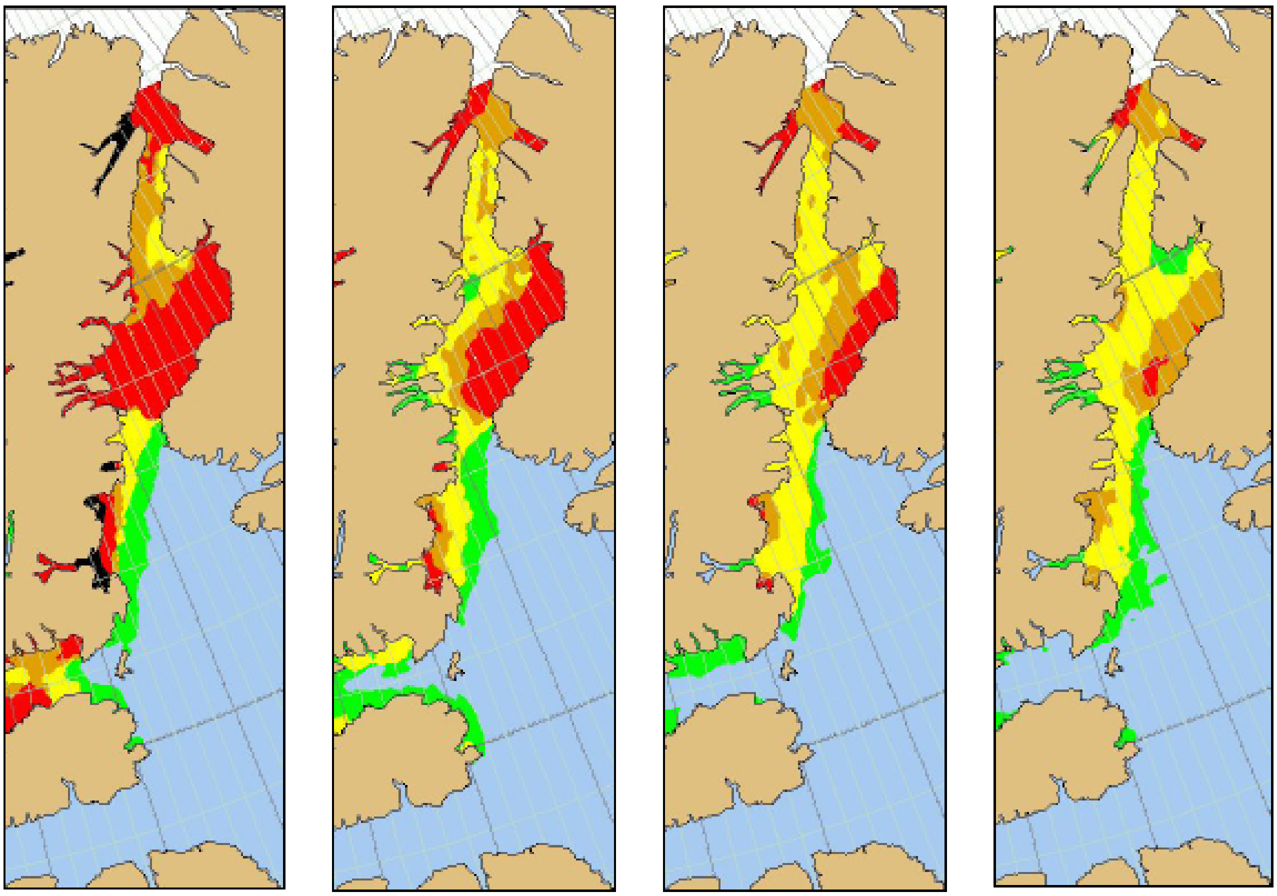
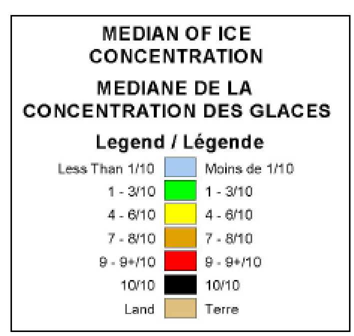


Figure 2. Median concentration of sea ice in Nares Strait at weekly intervals during August. . Dates are 6th, 13th, 20th and 27th (legend below). Charts from the Canadian Ice Service.



Median conditions are approximately static at 4-6 tenths concentration for the last two weeks of August, with the exception of continued ice decay in eastern Kane Basin. By September 3 the pack is compact in northern Kennedy Channel and a week later, ice concentration is 7-8 tenths throughout.

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.

Generally speaking, actual ice conditions in 2007 were close to the median climatological state, except that timing was advanced. This anomaly reflects the (relatively unusual) absence of ice bridges across Smith Sound and Robeson Channel during the preceding winter. The adjacent satellite image

(MODIS) reveals ice streaming south from Smith Sound and on the move throughout Nares Strait already on July 25, three weeks ahead of normal.

The ice charts on the following page display ice conditions at 5-day intervals between August 9 when we arrived in Smith Sound and August 24. They reveal the persistence of multi-year ice at more than five tenths concentration throughout August along the western side of Kane Basin, in the western half of Kennedy Channel and throughout Hall Basin and Robeson Channel. Much of this ice was in the form of giant floes as much as 10 km in extent. Drilling by the NRC group revealed these floes to be very thick, typically much more than 5 m even in level sections.

The chart for August 9 displays conditions encountered when working in Smith Sound and eastern Kane Basin during 10-12 August. The second chart (August 14) marks the time of our first arrival in Kennedy Channel, prior to the four-day diversion to Grise Fjord. The third chart (August 19) shows conditions at the time CCGS Henry Larsen travelled north to Hall Basin, taking advantage of light (3 tenths) ice along the Greenland side. The fourth (August 24) shows increased multi-year ice congestion in northern Kennedy Channel just before our departure for the south late on August 25.

We were rewarded for our patience during the night 24-25 August when strong south-westerly winds loosened up the pack along the western side enough to allow CCGS Henry Larsen to advance to within 6 km of the coast of Ellesmere Island for deployment of moorings.

Work in Cardigan Strait and Norwegian Bay was completed during 28-30 August and that in Lady Ann Strait on August 31. At these times conditions in these areas were similar to those shown on the chart for August 24.

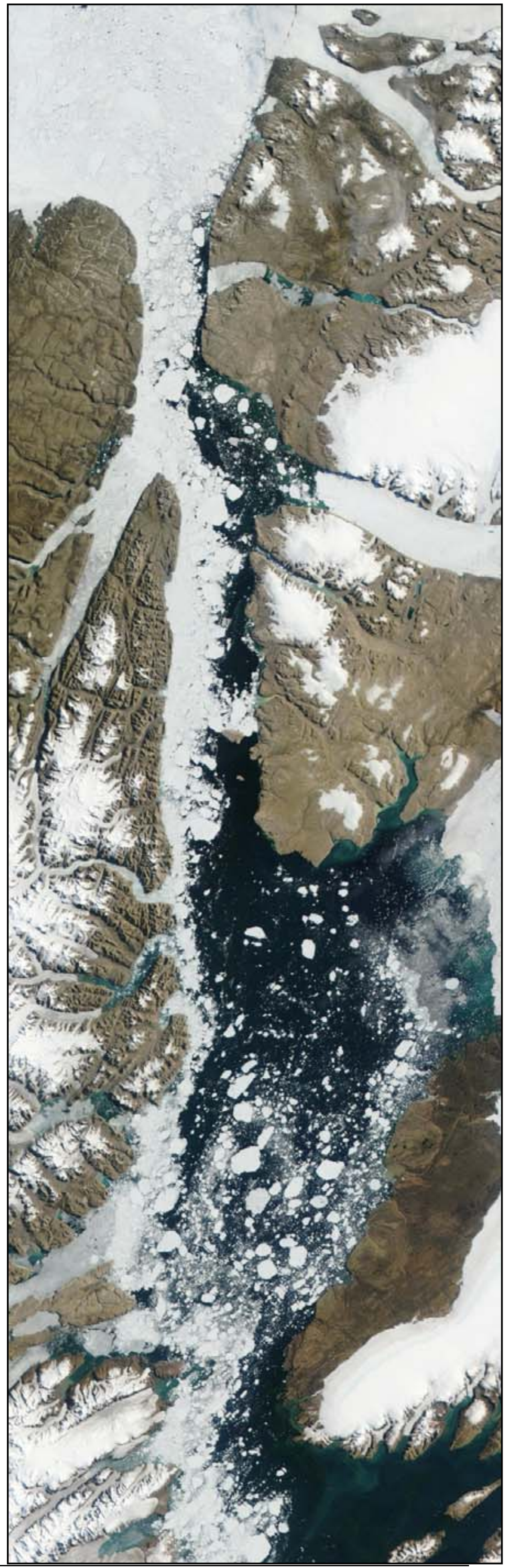


Figure 3. Ice in Nares Strait, 25 July 2007 (MODIS)

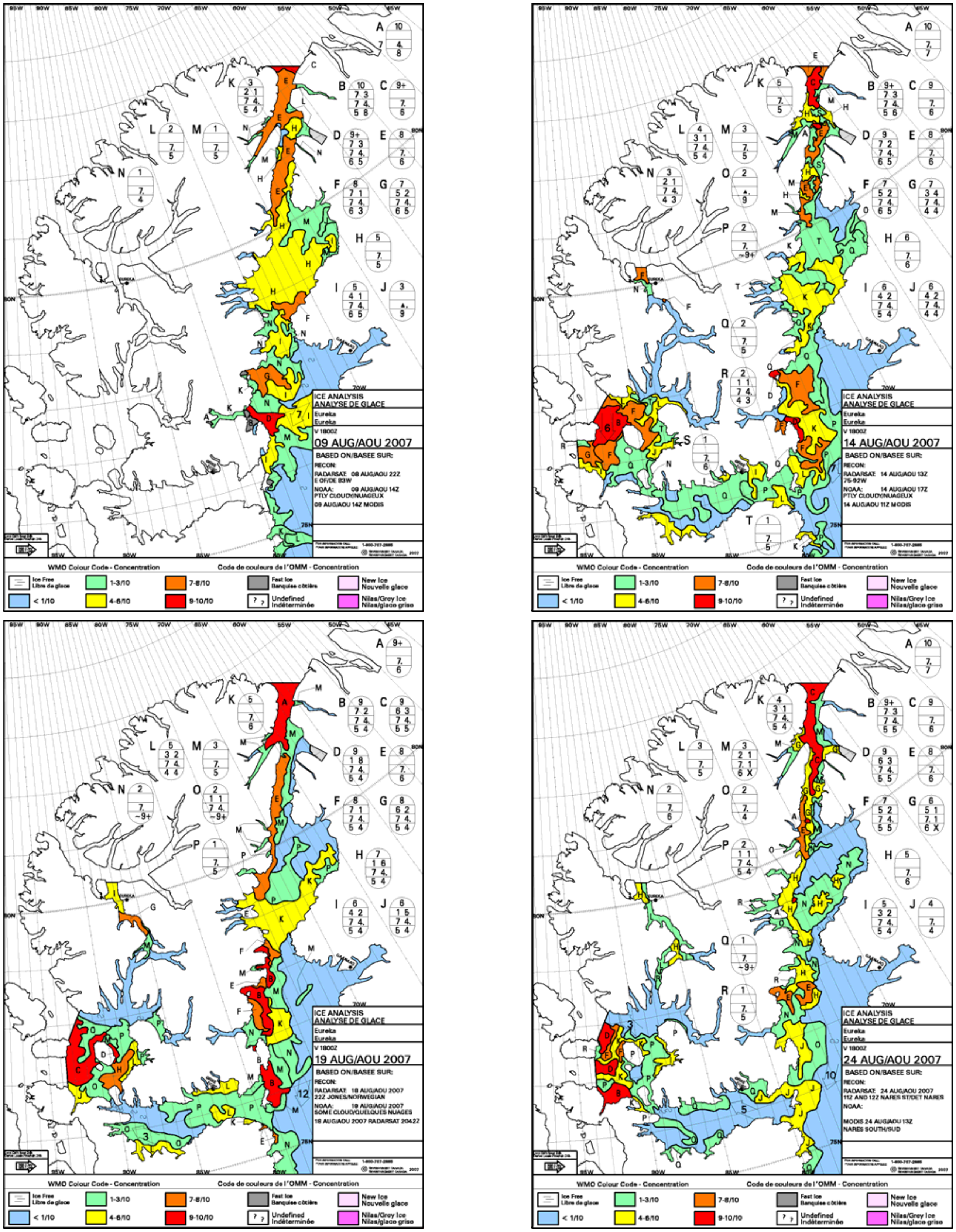


Figure 4. Charts displaying Ice conditions in Nares Strait while CCGS Henry Larsen was in the area. Note the persistence of multi-year ice at high concentration in the western half of Kennedy Channel.

Accomplishments

Recoveries of Sub-sea Moorings

Moorings deployed in 2006 with temperature-conductivity recorders were recovered at KS07 and KS13. There was no response from the transponder on the similar mooring deployed at KS09, despite prolonged attempts at different times to enable it. This mooring, with it topmost floatation at 30-m depth, is presumed lost to ice

One mooring deployed in 2006 with ice-profiling sonar was recovered at KS30. Several attempts were made to recover another with the same instrumentation at KS20, but all were thwarted by heavy ice.

One mooring deployed in 2005 with Doppler sonar was recovered from Cardigan Strait at ACW05-4. Several unsuccessful attempts were made to recover another deployed at ACW05-1. Because simultaneous failure of two transponders is very unlikely and because the mooring was too deep to have been hit by ice, we suspect that it drifted off on failure of some structural component in the mooring, perhaps because of corrosion.

Three moorings carrying Long Range ADCPs were identified as possible dragging targets for this expedition. Although both release units on each mooring had been activated in 2006, the moorings did not surface. Moreover, they were still at the seabed two weeks later when CCGS Henry Larsen left Nares Strait in late August. Our optimism that these moorings would remain until this summer was not rewarded. We received no response from any of the six transponders (sites KS04, KS06, KS08) despite prolonged attempts at several different times. These moorings are presumed to have shaken free of their anchors during the intervening months and to have drifted away.

Attempts were made to recover pressure recorders moored at Foulke Fjord, Scoresby Bay, Discovery Harbour and Offley Island. The first was deployed last year; the others in 2003. Those at Scoresby and Offley did not communicate and could not be dragged up; they are presumed lost to ice. Those at Foulke and Discovery did communicate but did not release pop-up buoys when so commanded. We surmise that their line spools are fouled by marine growth. Dragging was not possible at Discovery Harbour because the bay could not be reached from the ship in ice. Dragging was prematurely terminated by fog at Foulke Fjord. Both installations are in sheltered locations and likely still to be in place when next we return.

In summary, of the 11 moorings in the recovery plan, 4 were recovered, 3 remain in place for the future and 4 are presumed lost. The uncertain status of 3 other moorings on the list for dragging since last year has been altered to ‘lost’. Of the 7 losses, 3 are tentatively attributed to ice and 4 to failure of mooring components.

Dragging for Sub-sea Moorings

Moorings at four sites (Scoresby Bay, Foulke Fjord, Offley Island and KS15) would not release as expected from their anchors. In two instances (Scoresby and Offley) we were unable to communicate with the transponders on the moorings; we deployed grappling gear without knowing whether the transponder was simply inoperable or whether the mooring had been moved or destroyed by ice. The drag at KS15 was conducted with heavy gear from CCGS Henry Larsen. Those at the other three near-shore sites were carried out with lighter gear using the ship’s fast-response craft (FRC, a 7-m rigid hull inflatable). We did not recover moorings by dragging at any of the sites.

The mooring at KS15 was a ghost from the past. It was deployed in 2003 and judged lost to ice after repeated attempts to communicate with it in 2006. This year we detected a response from a transponder at 7.4-km range from the site of deployment. We traced it by triangulation to a position south of Cape Jefferson in about 75 m of water. The mooring was originally placed in 109 m of water and extended to 47-m depth (62 m long). The seabed where the mooring was found appeared rough and boulder strewn; it was difficult to sweep the dragline across the target site because of frequent snags; several grappling hooks were bent backwards; nothing was recovered.

Recovery of Data from Sub-sea Instruments

Full data records were obtained from all eleven of the instruments recovered: year-long observations from the eight temperature-conductivity recorders, year-long observations from the ice-profiling sonar and two-year records from the Doppler sonar and temperature-conductivity recorder in Cardigan Strait.

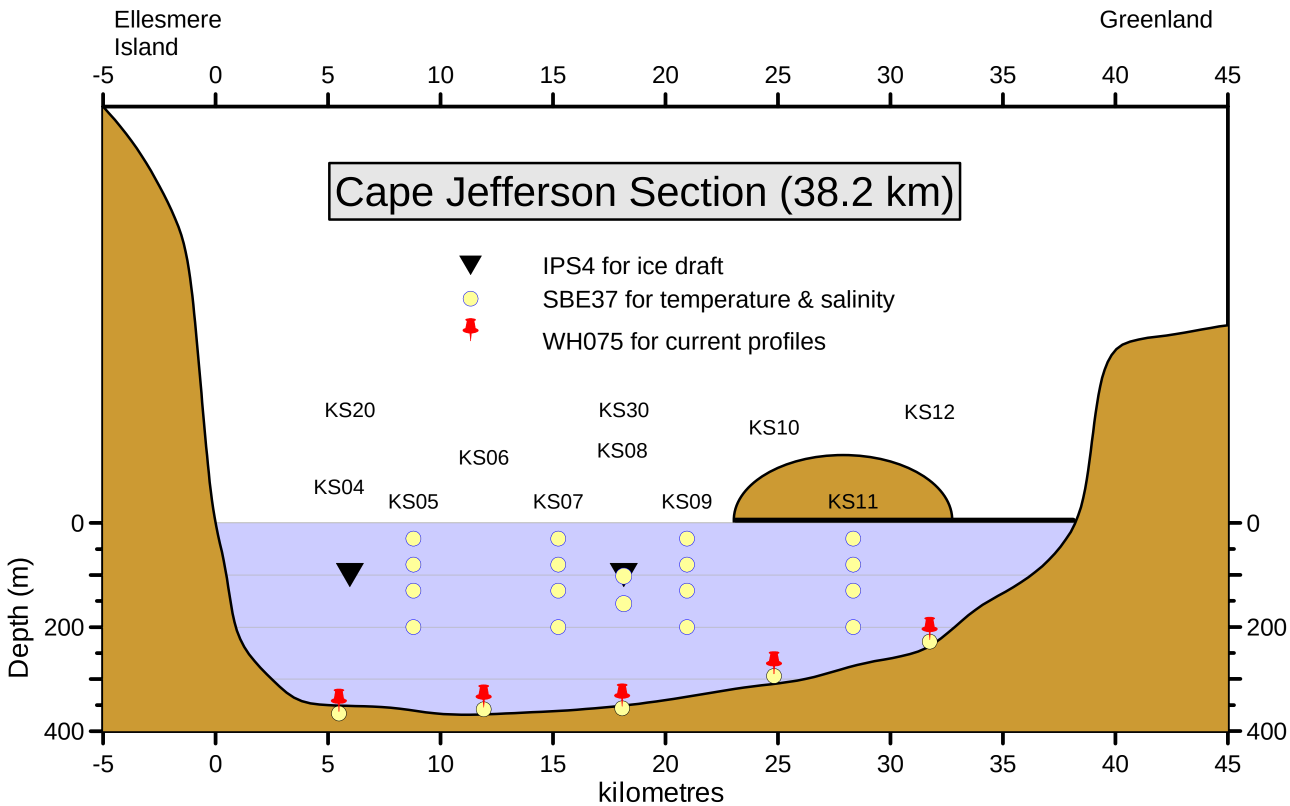


Figure 5. The array of recording instruments established in southern Kennedy Channel to measure Canadian Arctic through-flow via Nares Strait during the International Polar Year, 2007-09. Two more moorings close to Ellesmere Island could not be deployed because of heavy ice.

Deployment of Moorings for the IPY

Moorings supporting conductivity-temperature recorders at four levels were deployed at KS05, KS07, KS09 and KS11 in Nares Strait. Heavy ice prevented access to site KS03 on the Ellesmere side and the loss of the mooring at KS09 precluded its redeployment at KS13 on the Greenland side.

A refurbished mooring carrying ice-profiling sonar was deployed KS30. This mooring also supported temperature-conductivity recorders at two levels. The sonar deployed in 2006 to acquire ice-draft data at KS20 was not recovered this year because of obstruction by ice. It will continue to collect data here until 2009.

Long Ranger ADCPs were deployed at KS04, KS06, KS08, KS10 and KS12. A sixth instrument intended for use at KS02 near the Ellesmere coast was not deployed because of obstruction by ice. All Long Ranger moorings also carried a temperature conductivity recorder at 2-m elevation above the seabed.

One mooring supporting a pressure recorder was deployed near the southern end of Nares Strait at Alexandra Fjord. Another deployed in 2006 at Foulke Fjord on the Greenland side of Smith Sound was not recovered this year and should record data until 2009. A third, deployed in 2003, remains in place near the northern end at Discovery Harbour; it may record data for some of the present study.

In Cardigan Strait, a 300-kHz ADCP was deployed at ACW07-1 and a Long Ranger ADCP at ACW07-3. The placement of a second 300-kHz ADCP at ACW07-4 on the eastern side, which was contingent upon the recovery of the mooring at ACW05-1, was not possible. Both moorings also carried a temperature conductivity recorder at 2-m elevation above the seabed.

In summary, there are 16 moorings in place for the IPY CAT project in Nares Strait and Cardigan Strait, 7 for currents, 2 for ice thickness, 4 for temperature-salinity and 3 for pressure.

Observations by CTD

We used an SBE25 CTD probe, modified into a streamlined package capable of rapid profiling at 1-2 m/s. It was deployed on light-weight 1/8" conducting cable using a compact and fast electrically powered winch. Data were relayed to an SBE33 deck box and computer for real-time inspection and recording. We did have problems with this CTD and with the back-up SBE19 early in the expedition (see below). Subsequent to their diagnosis and repair their operation was trouble-free.

Seawater pressure, temperature and conductivity were routinely logged. A SBE43 dissolved-oxygen sensor was interfaced to the SBE25 but our preliminary inspection suggests that this sensor was not operating correctly. Water samples were not collected.

123 CTD stations were completed at close spacing, typically 2.5 or 5 km, in order to resolve features on the internal Rossby scale. Stations were organized into hydrographic cross-sections in the following locations, listed from north-east to south-west:

- Petermann Fjord
- Northern Kennedy Channel
- Southern Kennedy Channel (not fully completed to the Ellesmere side because of heavy ice)
- Sill in Kane Basin, with west-east and north-south legs
- North-south along the axis of flow through Kane Basin
- Smith Sound
- Fram Sound
- Hell Gate
- Cardigan Strait
- Norwegian Bay
- Lancaster Sound

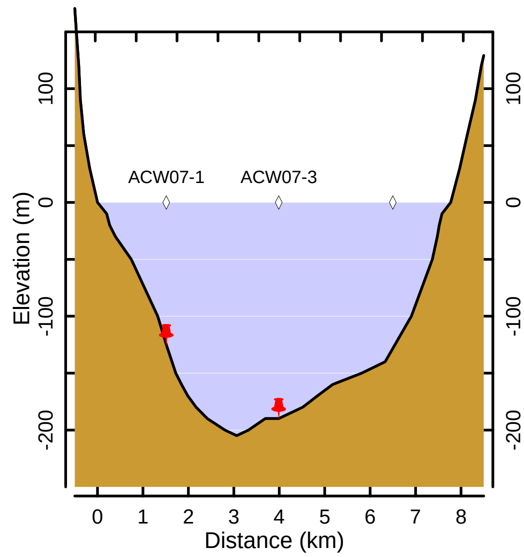


Figure 6. The array of recording instruments established to measure Canadian Arctic through-flow via Cardigan Strait during the International Polar Year, 2007-09.

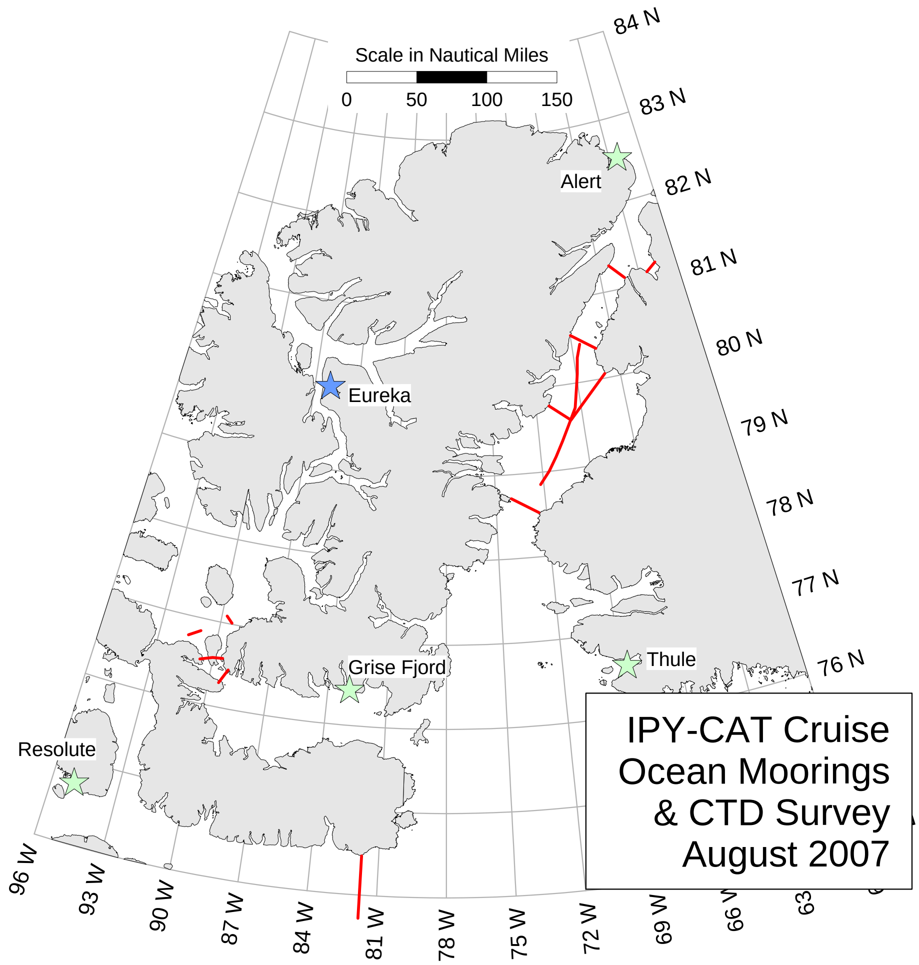


Figure 7. Locations of hydrographic sections completed during August 2007 from CCGS Henry Larsen

Multi-year Ice Properties

This was the second year of sampling multi-year ice in Nares Strait. In August 2006, we visited six floes and deployed satellite tracking beacons (provided by the Canadian Ice Service) on three. The beacons provided information on where and how fast the floes traveled and on how they decayed and broke up. The first tracked floe stuck in the fast ice off the coast of Ellesmere Island shortly after deployment; the second moved through Kane Basin to Baffin Bay, over to Greenland and then on to Labrador. The third moved from Kane Basin to meet the sealers off the Newfoundland in the spring of 2007 - 3000 km of travel in less than 9 months.

This year we were interested in measuring the thickness, strength, temperature and salinity of multi-year ice in the warm season. This work will contribute to a description of the ice most threatening to ships and offshore structures, its fate and rate of degradation.

We conducted surveys of thickness on 11 floes at locations from Hall Basin in the north, to Norwegian Bay and Lady Ann Strait in the south. The floes were drifting quite rapidly towards Baffin Bay as we sampled them. In nine hours N07 moved 4.4 miles and N08 moved 11.8 miles.

Our primary measurements of thickness came from holes drilled at 10-m intervals. The cumulative depth of all holes was almost 1500 m.

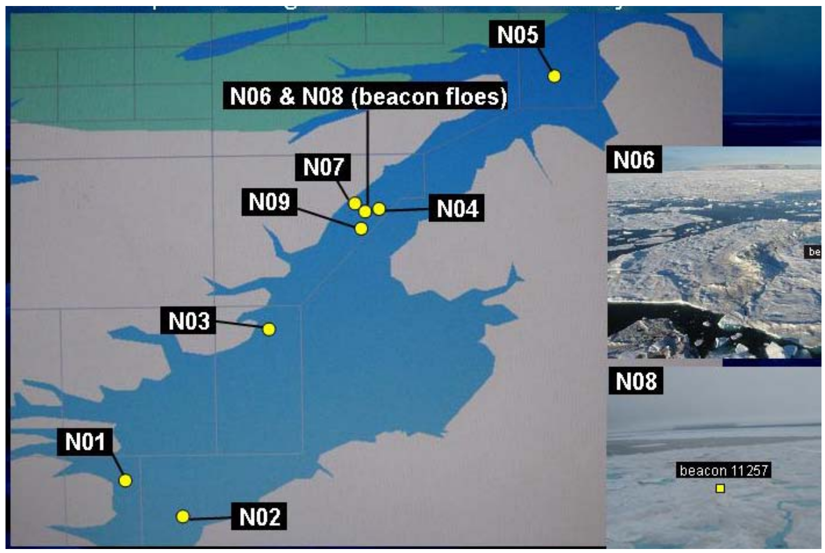


Figure 8. Locations of multi-year ice floes sampled in Nares Strait. Floes N10 and N11 were sampled in Norwegian Bay and Lady Ann Strait, respectively.

We also used electromagnetic induction radar to measure ice thickness remotely. The EM-34 has two coils separated by 10 m; one transmits electromagnetic energy that sets up a field in the seawater below the ice and the second measures the intensity of that field; the intensity is greater for thin ice than for thick. Ours was the first use of the EM-34 over sea ice. The EM-31 operates at higher frequency and has its coils fixed inside a 3.66-m long fibre glass tube.

We were striving to discern the limitations of the EM-31 and EM-34. If either instrument can measure the ice thickness remotely, then we do not need as many drill hole measurements (Richard sighs in relief). The EM-31 did not give good results for multi-year ice, since it is not capable of 'penetrating' ice that is more than about 5 m thick – lots of ice thicker than this in Nares Strait.

The hardest part of drilling on multi-year ice is, without a doubt, extracting ice cores. We need the cores to measure ice temperature and salinity. The temperature was measured by inserting a probe into small holes drilled at 20-cm intervals; the salinity was derived from measured electrical conductivity of melt water from discs cut from the cores. A bore-hole jack was deployed into the 6" core hole to measure the ice strength at 30 cm depth increments. This year we measured strength to 5.10-m depth, deeper than last year's 3.6 m.

We found homes for our two satellite tracking beacons, which are transmitting information as they move south.

MOTAN

The motion analysis (MOTAN) system was installed near the ship's centre of mass in the engineers' office on the upper deck. MOTAN is fully autonomous, and recorded data throughout the trip for later analysis of ship's acceleration during collisions with ice. A switch wired to the bridge allowed insertion of marks in the record to facilitate finding the data for notable impacts at a later date.

Cameras for Ice Documentation

Two slow-frame video cameras were mounted on the ship to provide photographic documentation of ice features associated with powerful impacts of the ship upon ice. One camera mounted at the bow viewed oncoming ice while the second was mounted down-looking at the position of the sea stairs on the port side. The latter was positioned to capture images of ice blocks broken by impact of the ship and turned on edge to the camera. Ice thickness can be determined via photogrammetric analysis of these images, recorded at three times per second.

An initial assessment indicates that the images from both cameras are perhaps of marginal quality for the purposes intended. Discrimination of ice ridges and other features in the forward looking images is difficult, and the 2-cm resolution of the down-looking camera at the height of installation makes for blurred views. We noted that few ice blocks were rotated on edge when the ship was working through multi-year pack ice, perhaps because the ice concentration was never high along the ship's immediate path and fragments of floes were simply pushed aside. More 'hits' were acquired when working in first-year ice at high concentration. In such conditions, the optimum position for the camera, to capture the most on-edge views, would have been 5-10 m behind the actual mounting position.

Figure 9. Cameras used to photograph the ice in the ship's path. That at the left is down-looking and provides images for measurement of ice thickness. That at the right photographs floes ahead of the ship before their impact.

Shoreline Pick-Ups

The collection of the equipment cache at Alexandra Fjord Fjord was straightforward and accomplished early in the expedition.

Satellite-tracked drifting buoys proved more elusive; all candidates for retrieval became mobile or went off the air (melted through the ice and sank?) about the time we were planning to retrieve them. A sortie was flown into Muskox Fjord on August 16, seeking an AWI drifting buoy that was deployed on a floe in the Lincoln Sea in May 2006; nothing was spotted.

The flotsam found by Parks Canada in June in St Patrick Bay was retrieved via helicopter on August 19. It is a Type 7200A COMPATT acoustic transponder manufactured by Sonardyne in the UK. An attached service tag dated 6/8/85 suggests that this instrument was not a recent arrival on the shore here.

Weather Stations on Smith Sound

Automatic weather stations installed by the University of Manitoba in September 2006 at Pim Island and at Cape Isabella were visited by helicopter on August 10 to retrieve data and to assess the condition of the installations and their need for repair. Both installations were operating and in fair-to-good condition. The data loggers were disconnected and carried to the ship. On examining the recorded data, we learned that both stations had not operated between mid December and mid April because of low battery voltage.

CCGS Henry Larsen was back in Smith Sound on the morning of August 26. Despite a low overcast, the helicopter was able to take two persons ashore to re-activate the weather stations at Pim Island and Cape

Isabella. The guy wires and hold-downs were repaired, the data loggers re-connected to the sensors and the reference direction for wind was checked. We added a 70 A-h battery to the energy reservoir at each site. The reservoir is maintained during the sunlit months by a solar panel; with the additional storage capacity we are optimistic that the stations will continue to log weather data throughout the dark months.

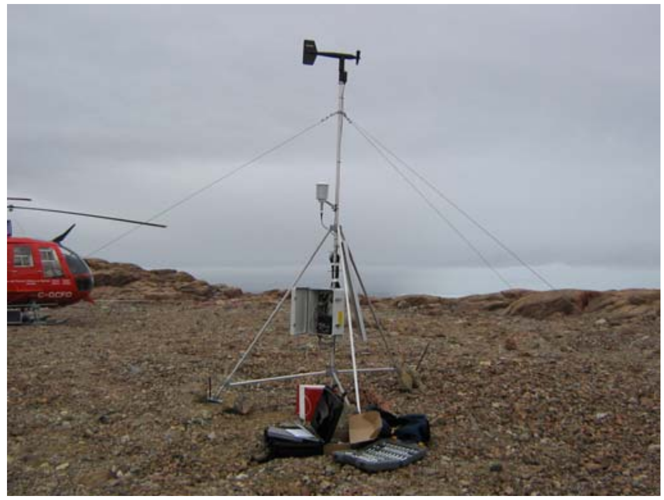


Figure 10. Weather station re-deployed at Cape Isabella. The wooden box painted in CCG colours contains the supplementary battery for the installation.

Complications

Problems with CTD Profiling Equipment

At the start of the trip we encountered a series of problems with CTD profiling equipment in close succession:

- The rheostat on the CTD winch did not provide smoothly varying control of speed because of internal corrosion; the problem was alleviated by emergency maintenance; this unit must be overhauled before re-use.
- Inoperable and intermittent telemetry between the Sea Bird SBE25 CTD probe (DFO modified) and the SBE33 control unit was traced to over-loading of the power-data interface module (PDIM); the latter is built into our probe, wherein it must at times to charge large capacitors needed to activate a bottle-triggering solenoid; it appears that the charging current was drawing down the power supply and disrupting the digital logic; the bottle triggering circuitry was disabled as an interim solution; a technical solution that allows bottle triggering must be implemented before re-use.
- The SBE29 pressure sensor on the SBE25 CTD probe failed; the failure was traced to a break in a weld on the oil-filled capillary tube linking the sensor and the environment; inertial stresses were concentrated at this weld in the old SBE design, since corrected; this problem was solved by installation of our spare pressure sensor; the damaged sensor will be returned to SBE for repair.
- The bottom-touch reed switch of the SBE25 CTD probe failed from fatigue; with no replacement on board, we were obliged to operate the CTD without the benefit of a touch-down signal.
- The back-up SBE19 CTD ceased recording partway through a cast; a definitive diagnosis was not made, but the problem disappeared when the battery (unwelded D-cells in a spring mounting) was adjusted; with cells secured in this way, this defect could re-appear.

Problems with Benthos Transponding and Release Equipment

We are using Benthos 867A and 866A release-transponders for this project. In order to extend battery life to 3-4 years our units were modified by Benthos to sleep for 2 minutes out of every 3. The modification complicates the enabling of the transponder and release functions via coded transmissions from the ship because the release is unresponsive two thirds of the time. In principal, frequent transmission of the enable command for three minutes should activate the transponder. In fact, many releases required a much longer period of blind transmission before they reacted. It is possible that multi-path propagation garbles the transmission in shallow water: the transmitted message is several seconds (several kilometres) in length. It might also be that the responsive-unresponsive cycle is longer than 3 minutes, or that the responsive fraction of the cycle is less than one third; the parameters of the wake-sleep cycle should be checked.

Our primary Benthos deck box (Model DS8000) was mistakenly loaded onto the CCGS Louis S St Laurent. Because this ship was operating in the Canada Basin in August, it was not possible to transfer the DS8000 from there to our ship. We were forced to operate without redundancy in this essential role.

The burden of responsibility fell upon our back-up deck unit, an ATM Model 891 leased from Benthos. This model promised functionality to control the duration and intensity of transmissions in addition to the basic functions of the DS8000. We had hoped that these new features might be useful in reducing the impact of multi-path transmission and thereby might improve our capability to communicate with the transponders. This deck unit proved unreliable, failing to enable sub-sea transponders at short (less than 500 m range) and delivering ranges subject to appreciable bias. Also, our unit suffered an electronic failure traced to loading of the DC power lines by the AC power supply. Fortunately, we were able to disable the AC power supply and continue to use the deck box on DC power. Future use of the ATM 891 as a transponding and release control unit is not recommended.

Unreliability of the Benthos deck box and of the transponder enabling function introduced appreciable uncertainty and delay into mooring recoveries. It may also have contributed to our inability to locate and release moorings at some sites.

Problems with Moorings

The mooring at KS09 is presumed lost, likely through snagging and removal by deep-daft ice. In 2006 the same fate was presumed for moorings lost from KS11 and KS15. Data from instruments on similar moorings recovered in 2006 revealed occasional push-downs by between 30 and 200 m, probably by passing icebergs. Other ice features of up to 70-m draft were detected by sonar in the array. We conclude that there are ice features in Kennedy Channel capable of snagging moorings. We note also that the use of small float strings in moorings used for CT-recorders provides some advantage in ice avoidance but not immunity from mishap.

The reason that moorings at KS04, KS06 and KS08 did not surface in 2006 is not known, although we suspect that free movement of the release mechanism was somehow obstructed. Initially, it seemed plausible that the released moorings were on a hair trigger and might surface at any time. However, when repeated visits to these sites over a two-week period confirmed their continued presence, we had hoped that they might remain in place until our return a year later. We were disappointed to discover this year that all three moorings had apparently separated from their anchors and drifted off.

The original moorings for pressure recorders in this project made use of a spooled line by which to retrieve the instrument when a pop-up buoy was released. In 2006, one of the two such moorings recovered had to be dragged up; we discovered that the float did not pop up because the line spool was obstructed by barnacles and would not turn. This year, moorings at two sites did not release pop-up floats when the 867A was activated, presumably for the same reason. Unfortunately in neither instance did circumstances permit recovery of the mooring by grappling.

We were unsuccessful in established contact with either transponder on one of the torsionally rigid moorings used for ADCP in Cardigan Strait. Since simultaneous failure of two transponders is very unlikely, and the mooring was rather deep (130 m) to suffer ice damage, we surmise that the mooring had broken free of its anchor and drifted away. The most plausible cause for its release is failure of one of the bands that secure the release housing to the mooring frame. If a band were to disintegrate through corrosion or weld failure, the release housing could swing away from the backbone of the mooring, separating the release hook from the release toggle and allowing the buoyant part of the mooring to float free.

Cleaning and Calibration of SBE37s

See Appendix 2 for a description of the cleaning procedure.

We completed a hydrographic section of Kennedy Channel by CTD to provide data for in situ calibration of conductivity sensors. Moreover, the design of the moorings for the SBE37, which allows appreciable pull-down in current to keep the instruments away from moving ice, provides frequent opportunities for inter-comparison of sensors on the same mooring: different instruments sample the same depth as drag forces on the mooring change with the tide. This permits frequent cross-checks on calibration during deployment.

Points of Interest in the Observations

Hydrographic cross-section of Lancaster Sound

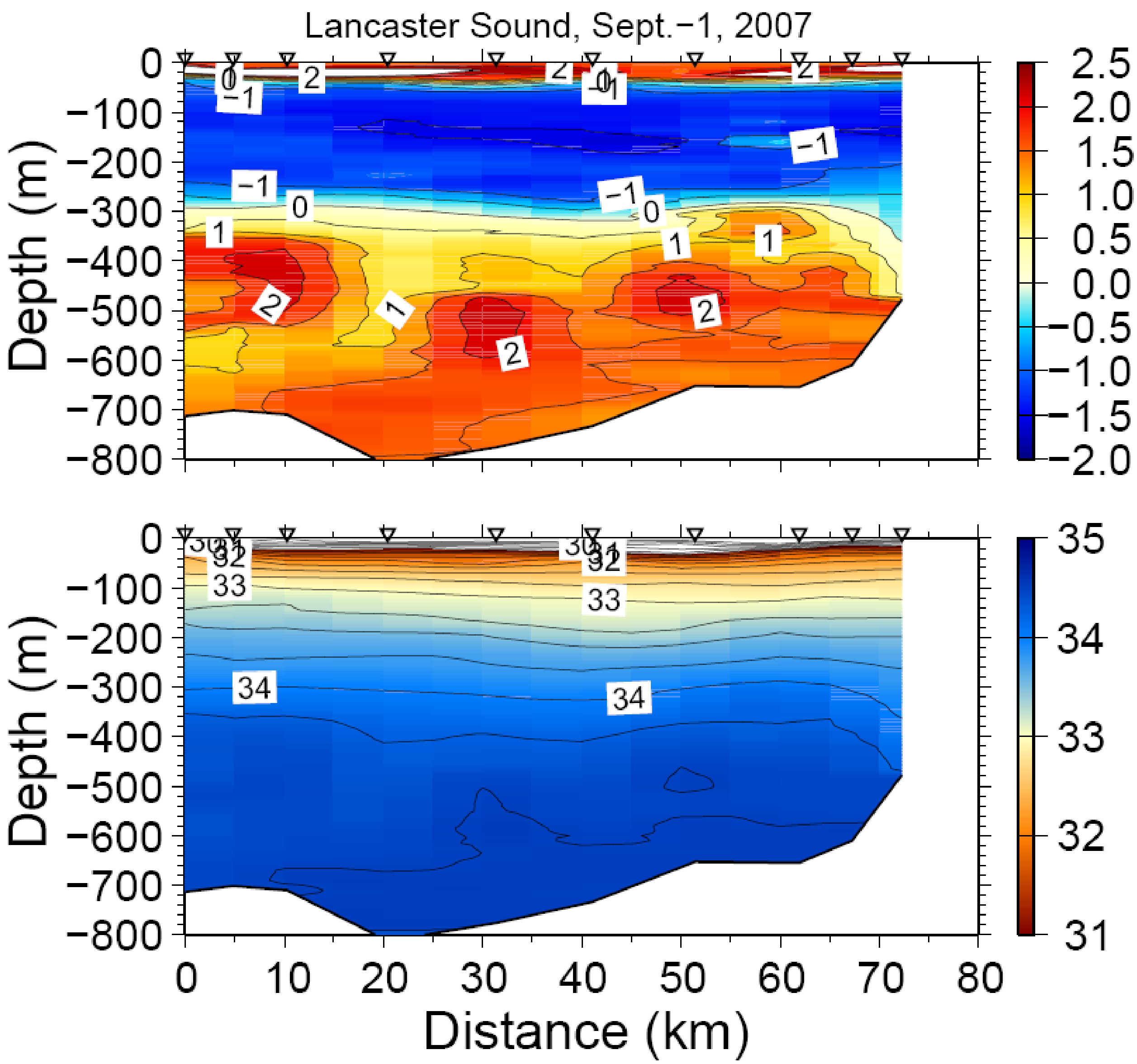


Figure 11. Detailed mapping of ocean temperature (top panel) and salinity across eastern Lancaster Sound. Note the three cores of warm (2ºC) seawater from the distant Atlantic that fill the sound at depths below 300 m. These warm waters are overlain by a thick layer of cold less saline Arctic out-flowing water. The intervention of this cold upper layer that isolates pack ice from warm ocean water is an important element in the preservation of multi-year ice within the CAA, and indeed throughout the Arctic Ocean in general.

Record-breaking ice floe in Nares Strait

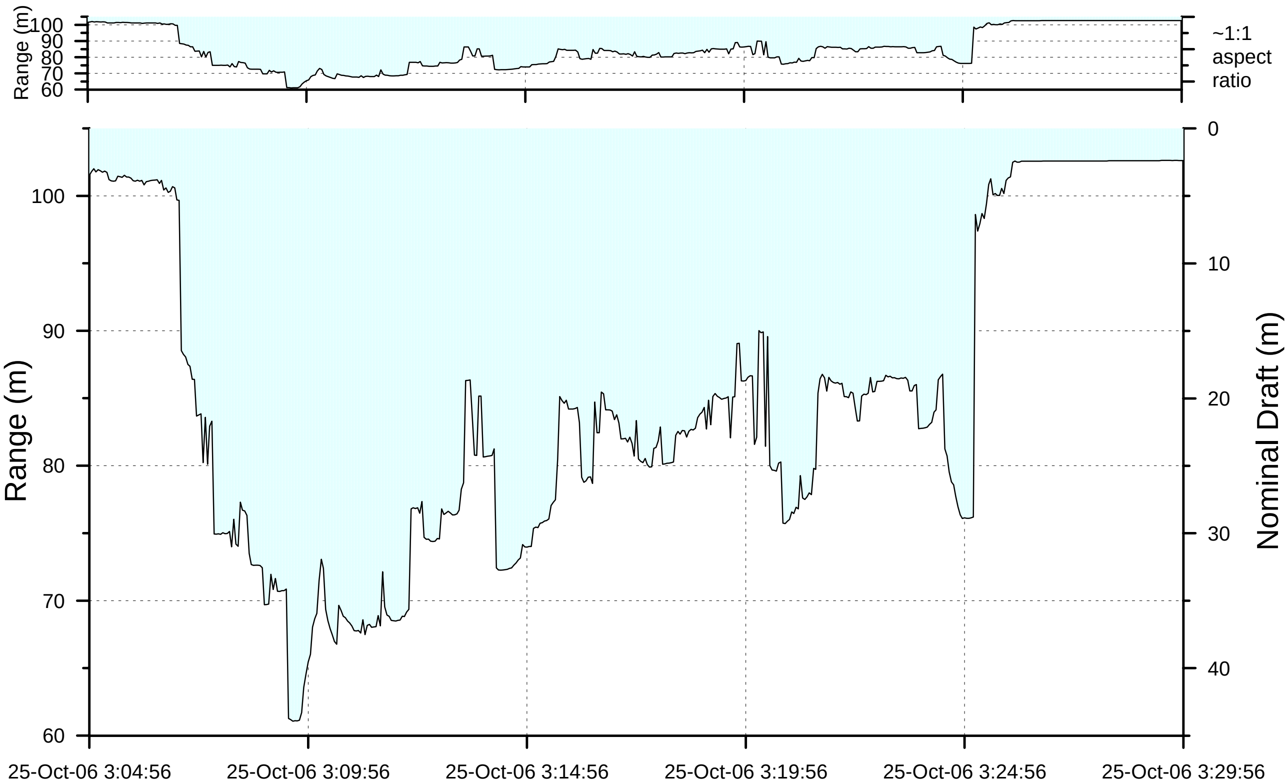


Figure 12. The under-side topography of an extremely thick ice floe passing over the ice-profiling sonar at Site KS30 in Nares Strait. The lower panel is an exaggerated view of the upper panel where extent and draft have the same scale. The floe's maximum draft of about 44 m rivals that of feature's observed only once before, by HMS Sovereign in 1976 north of Greenland. The average thickness of this floe is estimated to be almost 30 m.

Ice Thickness from Bore Holes

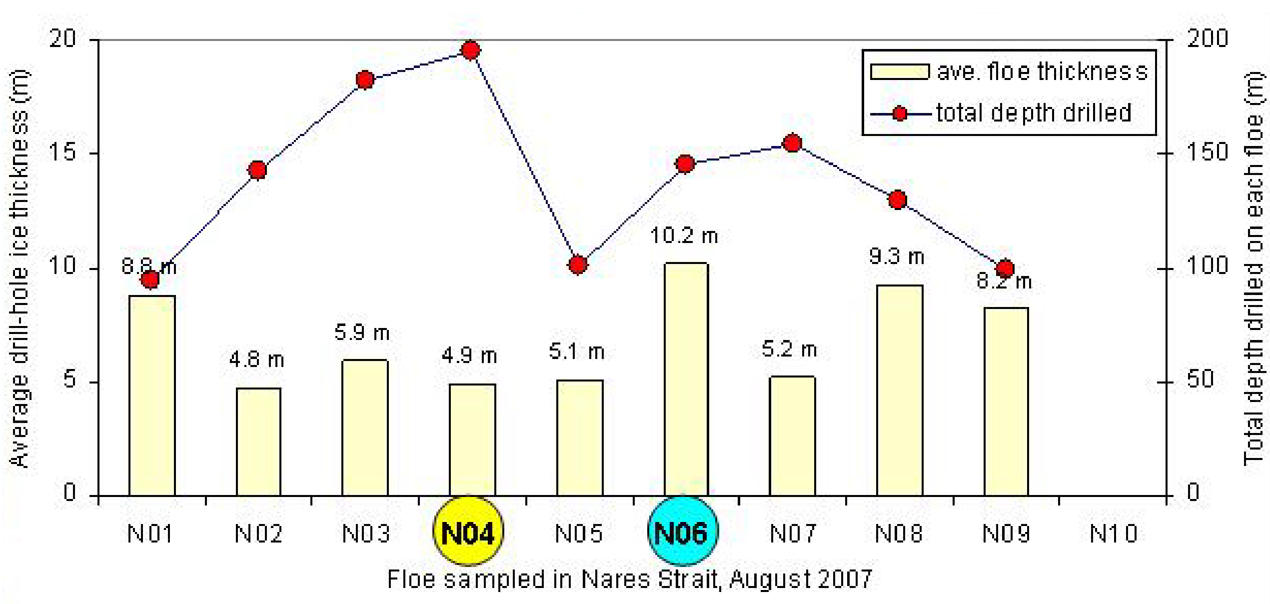


Figure 13. Average ice thickness from drill-hole surveys (20-30 holes) across 9 relatively level multi-year floes in Nares Strait. The overall average of about 7 m is typical of ice surveyed adjacent to the CAA in the 1970s

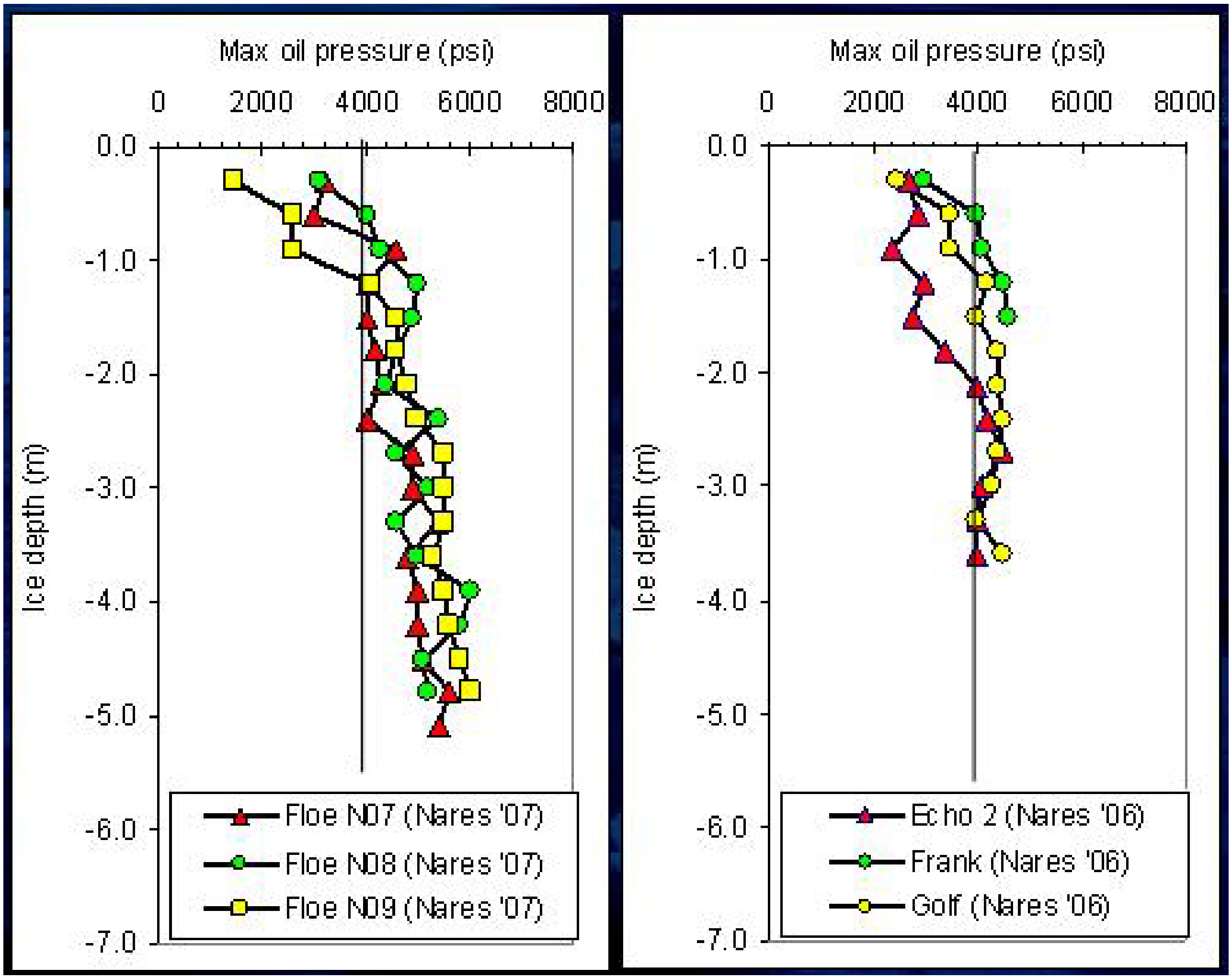


Figure 14. Preliminary data on the compressional strength of multi-year ice in bore holes drilled into floes in Nares Strait in 2007 (left) and 2006 (right). Data were acquired to greater depth in 2007 than in the preceding year. The ice was on average stronger in 2007, perhaps because the internal temperatures were lower this year.

Moorings in Place 2007-09

Site	Date	Latitude	Longitude	Instruments	Transponding Release
KS20	24 Aug-06	80º 31.706’ N	068º 39.197’ W	IPS4	2 x 866A, s/n 520, 529
KS30	24 Aug-07	80º 28.750’ N	068º 08.540’ W	IPS4, 2 x SBE37	2 x 866A, s/n 521, 528
KS04	25 Aug-07	80º 32.270’ N	068º 44.360’ W	LR-ADCP, SBE37	2 x 866A, s/n 515, 526
KS06	25 Aug-07	80º 30.230’ N	068º 27.330’ W	LR-ADCP, SBE37	2 x 866A, s/n 502, 511
KS08	23 Aug-07	80º 28.290’ N	068º 11.100’ W	LR-ADCP, SBE37	2 x 866A, s/n 504, 518
KS10	22 Aug-07	80º 26.131’ N	067º 53.579’ W	LR-ADCP, SBE37	2 x 866A, s/n 517, 524
KS12	22 Aug-07	80º 23.960’ N	067º 35.560’ W	LR-ADCP, SBE37	2 x 866A, s/n 506, 523
KS05	15 Aug-07	80º 31.189’ N	068º 35.730’ W	4 x SBE37	1 x 866A, s/n 507
KS07	21 Aug-07	80º 29.24’0 N	068º 18.341’ W	4 x SBE37	1 x 866A, s/n 509
KS09	21 Aug-07	80º 27.350’ N	068º 03.690’ W	4 x SBE37	1 x 866A, s/n 522
KS11	15 Aug-07	80º 24.97’0 N	067º 44.650’ W	4 x SBE37	1 x 866A, s/n 513
Discovery Harbour	07 Aug-03	81º 42.371’ N	064º 47.940’ W	DL3-PS	1 x 867A, s/n 108
Alexandra Fjord	10 Aug-07	78º 54.242’ N	075º 49.873’ W	DL3-PS, SBE4	1 x 867A, s/n 113
Foulke Fjord	29 Aug-06	78º 17.830’ N	072º 34.080’ W	DL3-PS, SBE4	1 x 867A, s/n 111
ACW07-1	30 Aug-07	76º 32.057’ N	090º 28.450’ W	WH-ADCP, SBE37	2 x 501, s/n Al, Shawn
ACW07-3	30 Aug-07	76º 32.405’ N	090º 22.938’ W	LR-ADCP, SBE37	2 x 501, s/n 4137, 6216

Weather Stations in Place 2007-08

Site	Date	Latitude	Longitude	Elevation ASL (ft)	Sensors
Cape Isabella	26 Aug-07	78º 21.075’ N	075º 04.756’ W	250	Wind, temperature, RH, SLP
Pim Island	26 Aug-07	78º 44.704’ N	074º 23.906’ W	840	Wind, temperature, RH, SLP

Status of Moorings from 2003, 2005 & 2006 for Recovery in 2007

Site	Date	Latitude		Longitude		Depth (m)	Type	Status
KS04	Aug-03	80	32.124' N	068	42.840' W	357	ADCP	Lost
KS06	Aug-03	80	30.162' N	068	27.240' W	363	ADCP	Lost
KS08	Aug-03	80	28.286' N	068	11.433' W	350	ADCP	Lost
KS07	Aug-06	80	29.250' N	068	19.227' W	367	CT	Recovered
KS09	Aug-06	80	27.167' N	068	03.936' W	320	CT	Lost
KS13	Aug-06	80	23.677' N	067	35.528' W	219	CT	Recovered
KS20	Aug-06	80	31.706' N	068	39.197' W	343	IPS	Not recovered
KS30	Aug-06	80	26.117' N	067	52.407' W	290	IPS	Recovered
Foulke Fjord	Aug-06	78	17.830' N	072	34.080' W	20	DL3-PS	Not recovered
Discovery Harbour	Aug-03	81	42.371' N	064	47.940' W	19	DL3-PS	Not recovered
Offley Island	Aug-03	81	18.408' N	061	48.824' W	20	DL3-PS	Lost
Scoresby Bay	Aug-03	79	54.654' N	071	21.388' W	21	DL3-PS	Lost
ACW05-1	Sep-05	76	32.045' N	090	28.346' W	130		Lost
ACW05-4	Sep-05	76	32.823' N	090	17.205' W	131		Recovered

Figure 15. CCGS Henry Larsen at Alexandra Fjord, 10 August 2007.

Assessment and Recommendations

Prior DFO experience with mooring projects in ice-prone waters had indicated that success was more likely when using the ice as a platform for such work than when looking for opportunities for ship access and activity. Our first and preferred choice in logistics was based on using aircraft from a field camp for work from the ice surface at a time when the ice was land-fast in Nares Strait. We mounted such an expedition in April 2005, but this failed under the onslaught of unforeseen extreme winds. Expedition using CCGS Henry Larsen were subsequently planned to fill the gap, acknowledging some likelihood of disappointment in the face of challenging summertime ice conditions within Nares Strait.

The CAT moorings have been in the sea for a long time. The probabilities of instrument failure caused by battery depletion, corrosion, release malfunction caused by biological fouling and loss of equipment to icebergs were potentially quite high.

On the positive side, new mooring designs developed for this project worked well. Although three of the eight compliant moorings supporting temperature-salinity sensors 30 m from the surface have been lost (7 of 27 instrument years lost), data from others indicate that they passed without mishaps beneath passing icebergs, in one case at a depth of 200 m. The 420-kHz ice-profiling sonar was effective from a depth of 100 m, where it was placed to minimize risk from icebergs; such long-range operation had not before been attempted.

We received excellent and willing technical support from all ship's departments. However, we should not overlook the fact that trips such as this demand specialized in-house expertise and experience. At present IOS is lacking human resource capacity for such demanding work and has absolutely no redundancy in the skill sets, experience and project familiarity of our Arctic field-going personnel. The viability and success of a field project with several years' investment of time and of money and equipment valued in the millions can be at extreme risk with loss, illness or injury of specific personnel. DFO faces a great challenge in staffing oceanographic moorings projects, particularly to meet the challenges of Canadian Arctic waters.

Mooring work from ships is very ice sensitive, especially at recovery. The completion of a mooring project may be impractical because of ice, even though the ship has the capability to reach the spot. Experienced judgement and patience are demanded of both the scientific leadership and the ship's officers, to achieve as much of the cruise plan as practical. We were fortunate that Captain John Vanthiel was sensitive to these constraints, and effective in his approach to these challenges.

We now have twice had first-hand experience of a mooring operation that was deferred for a full year beyond the planned two years interval by forces outside our control. Up here, there is no such thing as a short deferral – the basic time unit is one year. Moorings must be designed to be operable for at least 3 years with respect batteries and anodic protection. If instruments can also be powered to record data for this full period, then so much the better.

As we have now doing in the less accessible areas of the western Arctic, we should ideally plan for a short (i.e. 1-2 year) deployment-recovery cycle, but prepare the moorings and instruments for useful operation over 3-4 years. In Arctic waters, where biological fouling is slow, the principal requirements of this strategy are bigger battery packs and more corrosion protection. The rationale acknowledges that the overlapping windows of opportunity in ice conditions and icebreaker schedules are brief, so that relatively little can be accomplished in any one year. In a project such as this, the turn-around of moorings may need to be staggered over several years for maximum likelihood of success.

We need to equip science-tasked CCG icebreakers with the capability to deploy long-line moorings anchor first in close pack ice. For this we need an A-frame (and associated hydraulics), a removable rail section with chains and a windlass for paying out line under appreciable tension. Had we been so equipped this summer, we might have had opportunity to deploy the remaining two moorings that could not be streamed out because of compact ice conditions.

Mooring Designs

Ocean Current Mooring

This is a torsionally rigid mooring used to support an Acoustic Doppler Current Profiler (ADCP), zenith pointing and fixed heading, and a temperature-salinity recorder. There are 2 acoustic transponder-releases to provide redundancy in case of failure. This mooring in Nares Strait is a lighter version of that used in Hell Gate and Cardigan Strait, where flows are 2-3 times stronger.

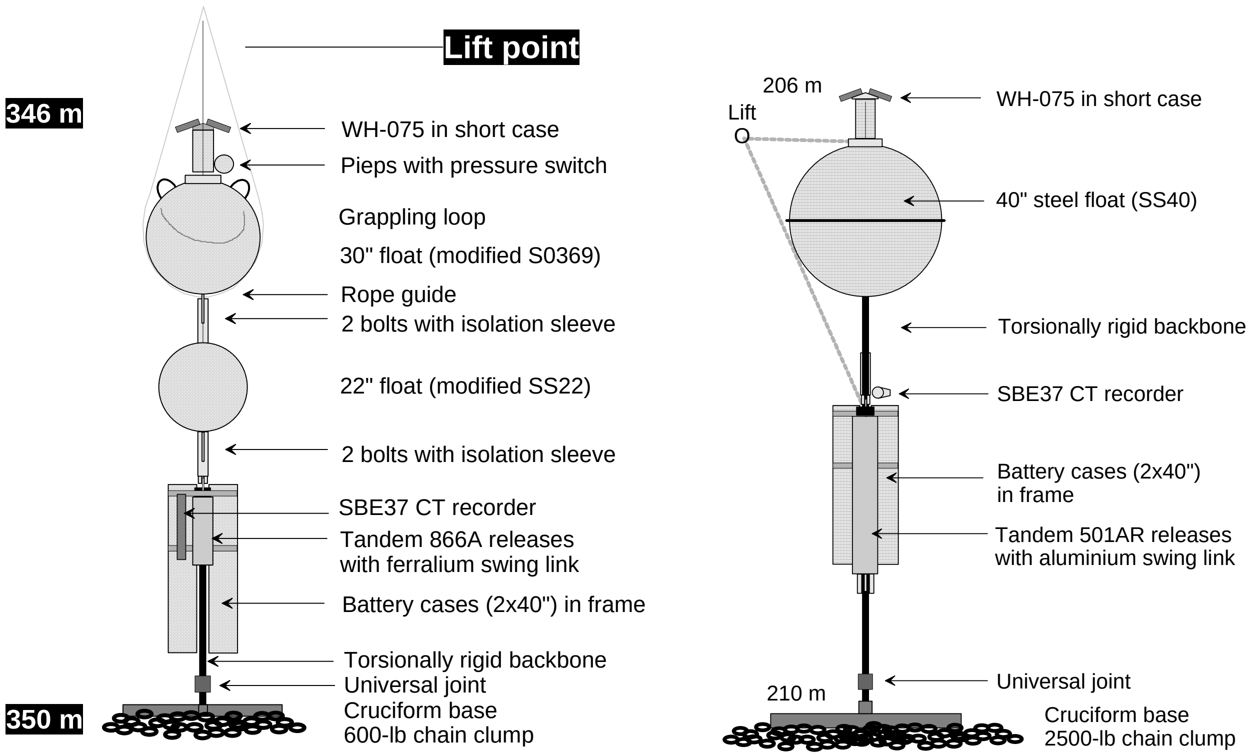
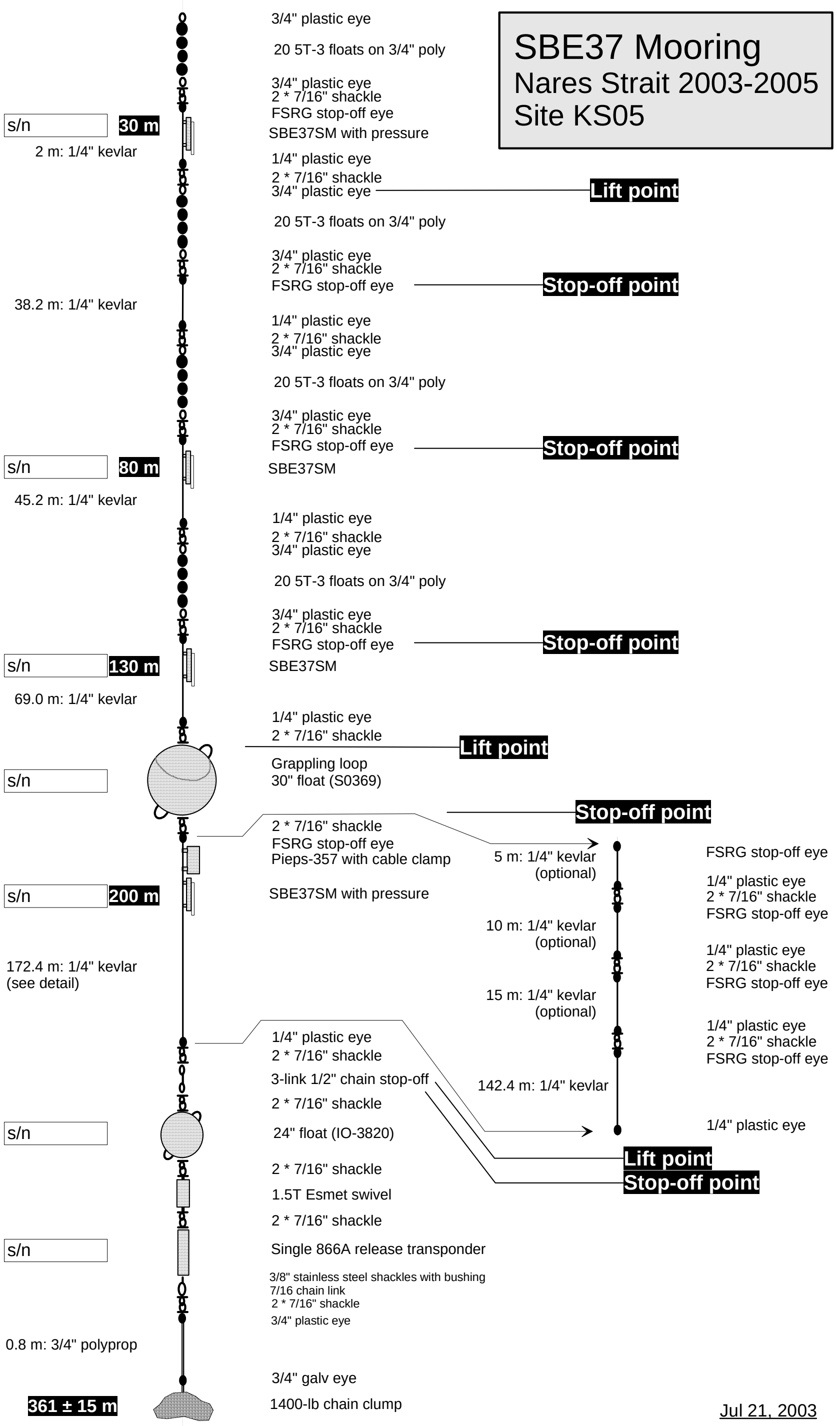


Figure 16. Moorings used to position acoustic Doppler current profilers (ADCPs) near the seabed where the geomagnetic field is not a reliable reference direction. These moorings do not twist. The ADCPs measure ice drift and ocean current at all depths in the water column. The heavy duty version at the right is used in Cardigan Strait.

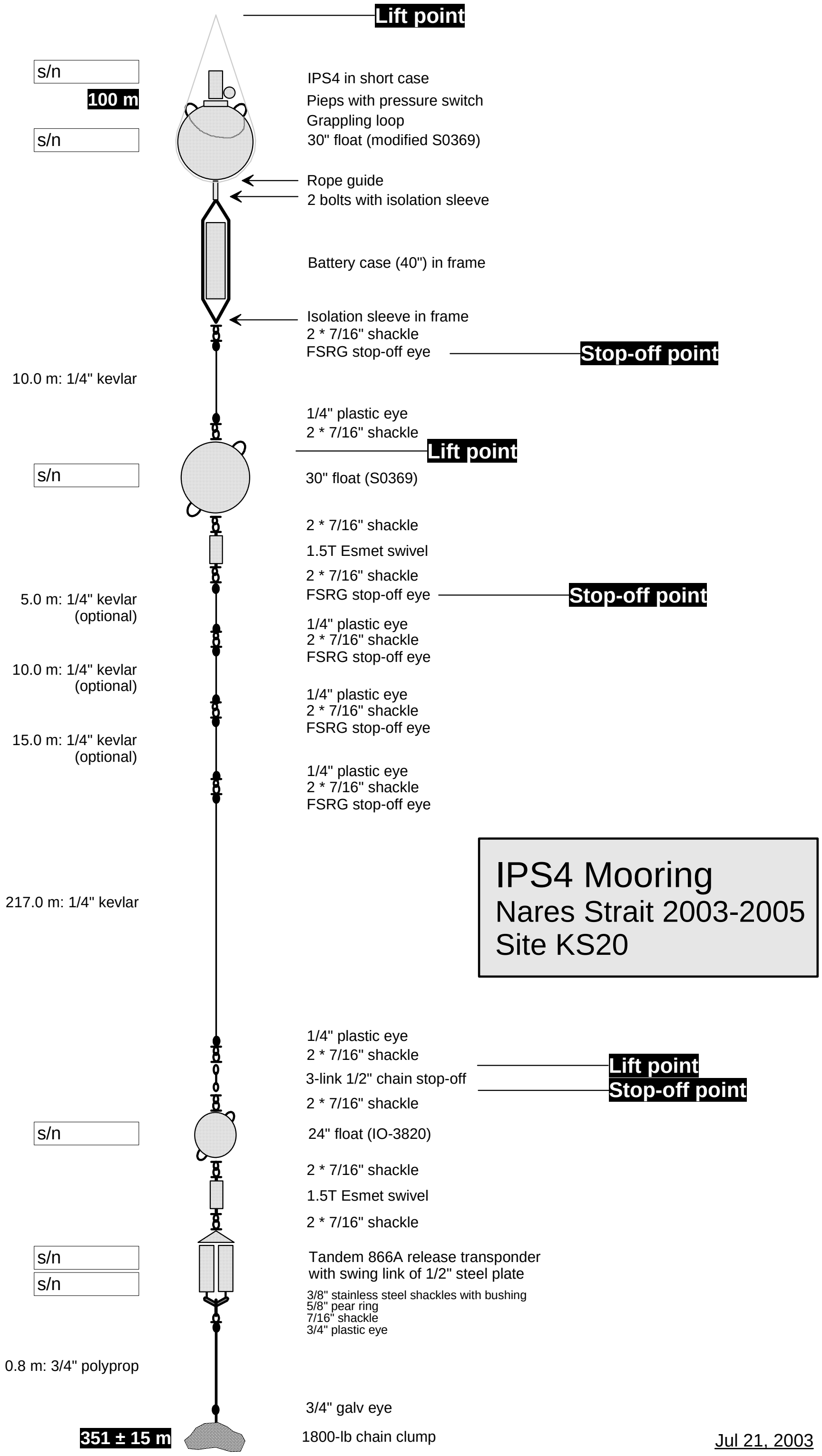
Temperature-Salinity Mooring

This is a taut-line mooring used to support temperature-salinity recorders at four levels between 30-m and 200-m depth. There is one acoustic transponder-release. Above 200-m depth, the buoyancy is small, so that the top of the mooring will pull down appreciably in strong current. This sensitivity is 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

This is a taut-line mooring used to support an ice-profiling sonar (IPS) at 100-m depth. There are two acoustic transponder-releases. Because measurements by the IPS are degraded by pull-down and tilt of the instrument, this mooring has significant buoyancy to make it stiff. A necessary consequence of buoyancy is a heavy anchor; at 1800 lb, this is the heaviest among the four mooring types. The IPS has been placed at the greatest depth consistent with effective operation (100 m) in acknowledgement of risk for icebergs.



Pressure Mooring

The pressure recorder is moored at shallow (20-m) depth. Unlike other moorings that float to the surface when the release disconnects the mooring from the anchor, release of this mooring permits a tethered float to surface. Pulling up on the tether lifts the mooring off the stake and allows recovery.

Because of their shallow deployment depth, these moorings are very vulnerable to drifting ice. We reduced this vulnerability by deploying in coastal embayments covered by fast (non-drifting) ice for much of the year and relatively sheltered from in-drifting ice in summer. Discovery Harbour and Foulke Fjord are probably the best of the sites in this respect.

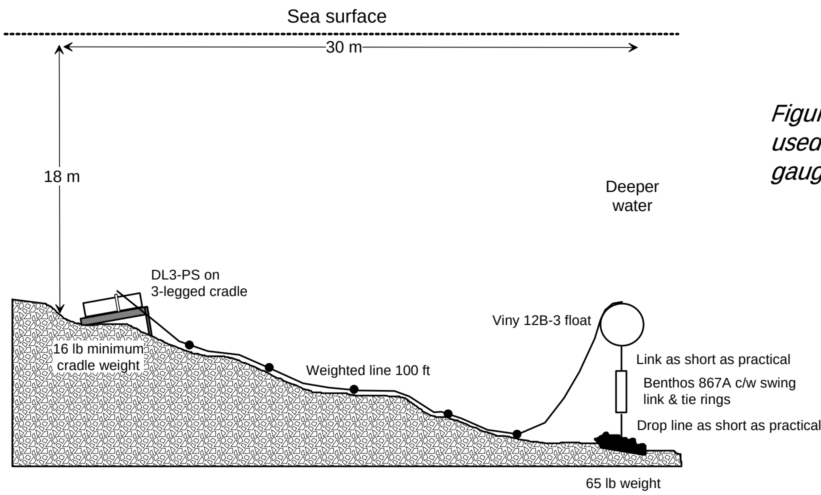


Figure 17. Schematic diagram of the mooring used in 2007 to deploy recording pressure gauges in shallow sheltered waters.

Deck Equipment and Scientific Workspace

CCGS Henry Larsen is not equipped for oceanographic work. The Institute of Ocean Sciences (DFO Science Branch) supplied several significant items of deck equipment which were shipped by truck from Victoria and St John’s in June:

- Swann 320 Work Winch (s/n 1304), 50 hp, with 1835 m of 3/8" 3x19 wire rope. Weight 6650 lb
- Hydraulic Power Pack, 50 hp: 230/460 volts, 112/56 amps, 60Hz complete with switchbox for 50 hp. Dimensions approximately 36" x 65" x 48". Weight 3000 lb
- 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 hydraulic power pack was chained just aft of the foredeck hatch. 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 and would have simplified the dragging activity. Unfortunately, such equipment was 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.

Equipment used for ice measurements was staged on the towing deck and in the adjacent (heated) Salvage Diving Locker.

The MOTAN logging system was based in the ship's engineering office on the upper deck.

Boat and Helicopter

We made frequent use of the ship's Fast-Response Craft (FRC, a 7-mm 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 access to interior areas of multi-year ice floes suitable for strength measurement and sampling.

Research Permits

Fisheries and Oceans Canada: Institute of Ocean Sciences Cruise No. 2007-52

Denmark Ministry of Foreign Affairs

Permission to work in Greenland waters was granted on 1 August 2007. JTF, File no.55.Dan.9-11.

Danish Polar Centre

Kirsten F. Eriksen, kfe@dpc.dk, +45 32 88 01 08

We were informed in 2006 that a science permit is not required for marine research near Greenland. However, we have provided the Danish Polar Centre with the work plan for CCGS Henry Larsen in 2007.

Nunavut Research Institute

Andrew Dunford, ADunford@nac.nu.ca

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 valid until December 31, 2006)

Measurements of second-year and multi-year ice – Nunavut Scientific Research Licence No. 0202607R-M (amendment to No. 0203706R-M valid until December 31, 2006)

Automatic weather stations. Information pending.

Northern Consultation

Drs Humfrey Melling and Michelle Johnston completed a 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

Screening document completed and signed by Robin Brown, Head Ocean Science Division, Pacific DFO.

Acknowledgements

We are very appreciative of Captain Vanthiel's strong commitment to completing the scientific programme for the International Polar Year on board *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 on-ice 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.

Appendix 1: Personnel

1	Humfrey Melling	M	250-363-6552	MellingH@dfo-mpo.gc.ca	Chief scientist
2	Andreas Münchow	M	302-831-0742	Muenchow@udel.edu	USA Lead scientist
3	Helen Johnson	F	44-118-378-5569	Helen.Johnson@earth.ox.ac.uk	Scientist: oceanography
4	Michelle Johnston	F	613-990-5141	Michelle.Johnston@nrc-cnrc.gc.ca	Scientist: ice properties
5	David Spear	M	250-363-6581	SpearD@dfo-mpo.gc.ca	Technician: moorings
6	David A. Riedel	M	250-363-6570	RiedelD@dfo-mpo.gc.ca	Scientist: support
7	Ron W. Lindsay	M	250-363-6592	LindsayR@dfo-mpo.gc.ca	Technician: electronics
8	Jonathon Poole	M	250-363-6593	PooleJ@dfo-mpo.gc.ca	Technician: mooring equipment
9	Berit Rabe	F	302-345-2679	beritrabe@yahoo.ca	Student: oceanography
10	Richard Lanthier	M			Technician: ice equipment

Appendix 2: Cruise Narrative

1st Report on Progress, Friday August 17

Canadian Arctic Through-flow Study, IPY

The ten members of the IPY CAT study travelled to St John's on Tuesday August 7 and assembled to join the CCG crew-change flight early the following morning. The scheduled 7-am departure was delayed by more than three hours while we awaited the lost baggage of the five team members who had arrived on the late flight from Victoria last evening. The charter flight to Thule Greenland via Iqaluit was uneventful. At 19:30 EDT on August 8 (Wednesday) CCGS Henry Larsen cast off from Thule and set course north.

Thick fog impeded progress to Smith Sound. Our first objective on August 9 (Thursday) was the retrieval of scientific equipment cached at Alexandra Fjord on the Ellesmere side, equipment required for ice-properties research by the group from NRC. Because fog rendered impractical the plan to collect the cache via helicopter, the ship continued on to Alex, dropping anchor at 22:30 in clearing fog.. Time on route was spent in finding, unpacking and organizing equipment and in setting up and testing the CTD (model SBE25) and the automatic camera (for ice thickness monitoring) systems. The former was not immediately functional and required appreciable effort in diagnosis and repair during the day.

Friday (August 10) dawned bright and clear. Cached equipment was quickly retrieved from shore, and a sensitive pressure recorder was placed on a shallow mooring sheltered between two small islands in the fjord. CCGS Henry Larsen was heading eastward to Smith Sound by noon. On route the NRC team was deployed via helicopter to survey a multi-year ice floe via drilling and EMI radar. Subsequently, automatic weather stations installed by the University of Manitoba in September 2006 at Pim Island and Cape Isabella were visited by helicopter for retrieval of data and assessment of needs for repair; both installations were operating, but both had shut down between mid December to mid April with low battery voltage; contrary to expectation, wind speed was not startlingly high at any time when the systems were operating. In the evening we initiated a hydrographic section eastward across Smith Sound at Cape Sabine. However the SBE25 CTD continued to have problems and failed completely on the third station. CCGS Henry Larsen drifted in the vicinity overnight.

A problem with the ship's cyclo-converter delayed starting on the following morning (August 11, Saturday) by about two hours. CTD profiling was resumed after 10:00 using the back-up SBE19 CTD. This recorded a fine down-cast but failed during the first back-haul. With both CTD probes out of service, CCGS Henry Larsen continued south-east to Foulke Fjord where a sensitive pressure recorder had been deployed last September. While CCGS Henry Larsen stood by, two personnel continued into the fjord via the fast-response craft (FRC). Unfortunately, they were unable to communicate with the acoustic transponder on the mooring and returned empty handed after three hours of effort. We picked up the Smith Sound hydrographic section at its eastern end about 21:00 and worked until mid-night, when the pressure sensor on the recently repaired SBE25 CTD failed. CCGS Henry Larsen drifted in the vicinity overnight.

We continued the hydrographic section using the SBE19 CTD in the morning (August 12, Sunday), finishing in mid afternoon. When the NRC group had completed a survey of their second multi-year ice floe, the ship set course northward through Kane Basin to the 230-m sill that limits through-flow from the Arctic to the Atlantic. A hydrographic section along the sill (2.5 km spacing) was completed overnight using the now operational SBE25 CTD. We were excited to observe 34.5-salinity water on the sill at 160 m depth; this water normally rests at 250 m or deeper in the Arctic Ocean and is capable of renewing the deep water of Baffin Bay once past this sill.

Monday August 13 was spent in Scoresby Bay, in an attempt to recover a pressure recorder positioned here four years earlier. At the same time, the NRC group surveyed a third multi-year ice floe just outside the bay to the south. Here again we had no success communicating with the acoustic transponder. Following our similar experience at Foulke Fjord, we now have heightened suspicion that the new ATM-891 deck box leased for this expedition from Teledyne Benthos has serious bug. Regrettably, our primary Benthos deck box did not make it on board. It was apparently moved by mistake from the Larsen staging area at IOS in June to that for the Louis, and is now marooned far out in the Canada Basin. The Kane Basin CTD section was continued northward to the southern entrance of Kennedy Channel overnight.

On Tuesday morning (August 14) CCGS Henry Larsen was positioned at the principal line of moored instruments for the CAT study. Following ice reconnaissance via helicopter in the morning, we were ready to move up to the line to start work. At this moment, the ship received news that a sailor's wife was seriously ill; the decision to disembark the affected sailor at Grise Fjord was quickly made and CCGS Henry Larsen changed course for this small community on Jones Sound, 400 nautical miles to the south, at about 13:00.

CCGS Henry Larsen was in transit to Grise Fjord for the remainder of Tuesday and Wednesday (August 14-15) and arrived off Grise Fjord in the early hours of Thursday. In the evening, we were able to take advantage of calm conditions in Jones Sound to run some in situ tests on the acoustic transponding system. We now understand that the Benthos ATM-891 has a bug that prevents its operation at short (less than 250 m) range; such a restriction could explain our inability to talk to transponders in Foulke Fjord and Scoresby Bay. We are reasonably confident that the ATM-891 will be effective at longer range; we simply need to stand off the locations of moorings when attempting to release them.

The sailor was taken ashore by helicopter first thing on Thursday morning (August 16). CCGS Henry Larsen was underway for the north by 11:00, following an ice reconnaissance flight by helicopter.

Today, Friday August 17, is our ninth day on board ship. We passed through Smith Sound at noon and expect to reach our work area at the southern end of Kennedy Channel by tomorrow morning. By that time, the diversion to Grise Fjord will have taken about four days.

So far the weather has been excellent, a consequence of persistent high atmospheric pressure over Greenland. With the exception of fog today and on our first day out, the visibility has been excellent and the scenery at its very best. Ice conditions have been quite severe, dominated by multi-year ice with most floes very thick and an abundance of giant floes (up to 10-km across). The NRC drill-hole data suggest that average floe thickness in excess of 10 m is not uncommon. The pack is moving towards Baffin Bay at 1-2 knots, so that conditions change rapidly. The high surface relief of these floes blocks the visibility of leads beyond about a mile; ice reconnaissance via helicopter has frequently been required.

2nd Report on Progress, Saturday August 25

Canadian Arctic Through-flow Study, IPY

CCGS Henry Larsen returned to Kennedy Channel late on Friday August 17. During the night we worked three quarters of the primary CTD section across the strait, until stopped by heavy ice on the Ellesmere side.

During Saturday, we tried to recover moorings at three sites under about five tenths ice cover on the Greenland side; sites further west were inaccessible in heavy pack. We were successful at two of these; a string of CT recorders and an ice-profiling sonar (KS30) were brought to the surface, with complete 12-month within all instruments. The CT mooring at KS09 did not respond to interrogation; we have subsequently concluded on the basis of repeated attempts that this mooring has been lost to ice. From site KS09 we also tried to communicate with transponders on two moorings that were deemed lost in 2006 (KS11, KS15). A response from the transponder on the KS15 mooring indicated that our modified Benthos 867A transponding release did in fact have the four-year endurance that we had planned. Unfortunately, the range revealed that this mooring had moved 7½ km from its deployment location. In parallel activity, the NRC team was deployed via helicopter to survey a multi-year ice floe near Franklin Island, their fourth of this expedition.

Our ship followed the Greenland side north-east ward towards Hall Basin during the evening. We completed a CTD section across the northern end of Kennedy Channel during the night and arrived at Offley Island on Petermann Fjord after breakfast on Sunday August 19. Our efforts to communicate with the transponder on a shallow mooring in the shelter of this island were unsuccessful, both from the ship 2.2 km distant and from the FRC at progressively shorter ranges. While working from the FRC, the Benthos transponding unit suddenly failed. Following subsequent unsuccessful attempts to snag the mooring via grappling line, we have concluded that this mooring also has succumbed to ice scouring sometime since its deployment four years ago. After the NRC ice-survey group was deployed in Polaris Bay (multi-year floe #5), we took the helicopter first to St Patrick Bay, to retrieve oceanographic flotsam reported by Parks Canada and next to Discovery Harbour, to investigate a pressure recorder positioned there in 2003. The transponder in Discovery Harbour was operational but the pop-up float did not surface when the release was activated. We surmise that biofouling during the intervening four years prevented unreeling of the recover line attached to the float. Unfortunately we were not able to deploy the FRC with grappling gear because access to the bay was blocked by ice. This mooring is well sheltered and will presumably remain in place for possible future recovery. During the evening, we completed a CTD section along the glacial ice front in Petermann Fjord seeking evidence of glacial-marine interaction beneath the floating ice tongue that extends out 100 km from the grounding line. CCGS Henry Larsen returned to southern Kennedy Channel overnight.

On Monday August 20 we were back looking for opportunities to recover moorings along the KS line. We were successful retrieving a string of CT recorders at KS07, but further west at KS20 (ice-profiling sonar) we were again thwarted by ice. Repeated attempts to communicate with paired transponders on three ADCP moorings (KS04, KS06, KS08) were made from both these sites; moorings at KS04, KS06 and KS08 were in place in August 2006 but did not surface when the releases were activated. Obviously separation of the buoyant and heavy parts of these moorings had not occurred. We had thought in 2006 that the obstruction of moving parts was likely weak and that disturbance by grappling gear would have shaken the instruments free. Unfortunately, dragging was not practical in 2006 because of ice obstruction and limited ship time. The obstructions must later have weakened to permit the moorings to drift away. They are now considered lost. Today the NRC group surveyed a sixth floe (roughly an 8-hour activity for four people – two NRC and two crew) and placed a satellite-tracked beacon upon it. We spent the evening finding the lost mooring from KS15 via triangulation using the acoustic transponder. It was tracked to a location south of the original and south of Cape Jefferson in about 77 m of water. A small iceberg was grounded close by as if to illustrate the cause of the displacement.

We started on August 21 again at KS20, selecting an ice-free pond in the pack and waiting to drift over the mooring for its release. Unfortunately the anticipated opportunity was lost with a change in the direction of drift. We then re-crossed the strait to bergy waters on the Greenland. Unsuccessful efforts to drag up the errant mooring from KS15 occupied the remainder of the day. A seabed littered with rock debris prevented tightening a loop around the moorings and repeatedly bent back the prongs on the grapples. Overnight, we completed a 12-hour CTD time series at KS09, seeking evidence of internal tides.

On Wednesday August 22 we were prepared to start deploying new moorings along the KS-line as well as to recover some of the elusive originals. The KS line is the ‘picket fence’ of moored instruments stretching from Ellesmere Island to Greenland that we need in order to measure volumes and properties of seawater passing down the strait. Again we spent more than four hours drifting in a patch of ice-free water towards KS20, only to be thwarted by erratic drift. We were successful, however, in using the same technique to reach the planned deployment sites and to drop Long Ranger ADCPs within pack ice at KS10 and KS12 on the Greenland side. However, the attempt at KS-08 failed because of ‘uncooperative’ ice. The NRC group today surveyed their seventh floe.

With time running short, we focused Thursday’s (August 23) activity upon the deployment of new moorings. Again with appreciable interference from drifting ice, a Long Ranger ADCP was deployed at KS-08 and strings of CT recorders at KS07 and KS09. Attempts to deploy at KS06 and KS11 were prevented by heavy ice. The new mooring at KS09 surprised everyone by re-surfacing shortly after deployment; for reasons not clear the long Kevlar line above the release float had parted during freefall of the anchor from the surface. After the release had been activated and recovered, the mooring was rebuilt and deployed for a second time without mishap.

August 24 was a bleak day with moderate wind, our first ‘weather’ after days of idyllic clear calm and sunny conditions. The focus of work was again mooring deployment, with successful installations of a string of CT recorders at KS11 and of ice-profiling sonar at KS30. Subsequent initiatives were blocked by heavy ice. However, the same ice provided joy for the NRC group, which completed its eighth ice-floe survey today. With time running out, the possibility of installing an array that spanned the strait was fading. Our frail hope was the forecast of south-west gales overnight, which gave some reason to expect more navigable ice conditions on the Ellesmere side tomorrow.

On Saturday morning, our optimism concerning improved ice conditions was rewarded. Under influence of a 30-knot south-west wind, the pack had diverged to permit a relatively unchallenged transit towards Ellesmere Island. We quickly deployed Long Ranger ADCPs at KS-06 and KS-04. Retrieval of the ice-profiling sonar at KS20 was again prevented by ice, as was access to KS03 to deploy a CT string. However, after patient waiting (6 hours) for a tide change and southerly ice drift we did deploy the CT string early in the evening at KS05. After the NRC group returned from their ninth ice-floe survey – a floe of 5-10 m thickness – we turned south. During the overnight transit to Smith Sound, we measured a longitudinal section by CTD of waters in the deep channel along the western side of Kane Basin.

Under the circumstances, I am content with the slightly skimpy array that we have established for the IPY. The failure to recover the ice-profiling sonar at KS-20 has little consequence, since it has batteries to operate for another two years. We will now turn our attention to the second location for Canadian Arctic through-flow, Cardigan Strait and Hell Gate at the southwest corner of Ellesmere Island. Instruments were placed in the remaining two pathways during other IPY expeditions earlier this summer, in Barrow Strait from CCGS des Groseilliers in early August and in Bellot Strait in late July.

3rd Report on Progress, Saturday September 1

Canadian Arctic Through-flow Study, IPY

On the morning of August 26 (Sunday) CCGS Henry Larsen was back in Smith Sound. Despite a low overcast, the helicopter was able to take two persons ashore to re-activate the weather stations at Pim Island and Cape Isabella. The guys wires and hold-downs were repaired, the data loggers re-connected to the sensors and the reference direction for wind was checked. We added a 70 A-h battery at each site; with the additional capacity the installations may continue to log weather data throughout the dark months. In the afternoon, we revisited Foulke Fjord to recover the pressure recorder moored there last August. We were able to communicate with the sub-sea transponder but the mooring did not surface after the release was activated. The two attempts to grapple the mooring, before the FRC was recalled in growing fog, were unsuccessful.

The ship continued southward overnight towards Grise Fjord in heavy fog. On Monday (August 27), the fog cleared sufficiently at Grise Fjord to pick up Sasa Petricic (CBC correspondent) by helicopter. We completed a CTD section across Fram Sound upon our arrival there in the late evening, in the face of ice, a 40-knot wind and strong tidal current coming down from Cardigan Strait.

We were at the site of oceanographic moorings in Cardigan Strait first thing on August 28. The release and recovery of the mooring on the east side of the channel was flawless, completed in 15 minutes. However, all attempts to establish communication with installation on the west side were unsuccessful, perhaps because of high background noise associated with the ship's machinery and the 3-knot current running at the time. The ship was forced off the site by rapidly drifting ice. However, we were able to complete a CTD section across the strait at the mooring line and another in the evening across the channel leading across Norwegian Bay towards Cardigan Strait. Deployment of the ice-floe team was not practical with the fog and poor visibility. The ship drifted in ice overnight.

On Wednesday August 29 the fog had lifted and visibility was good under overcast skies. The ice-survey team was deployed to a floe north-west of Cardigan Strait first thing, with Sasa Petricic along to film the activity. Plans to return to the reluctant mooring in Cardigan Strait were abandoned in declining visibility with snow showers. A short CTD section across the channel leading across Norwegian Bay towards Hell Gate was completed during evening hours.

On Thursday, despite a thorough effort, we were not able to recover the second mooring in Cardigan Strait. We tried to contact the mooring's transponders from the ship at various ranges, and subsequently deployed the transponding control unit in the FRC to escape high ambient noise around the ship. This mooring is presumed lost, most likely to mechanical failure. We proceeded subsequently to deploy ADCPs at two sites, one on the axis of the channel and one on the western wall. There was an unfortunate delay of 1-2 hours at the axial site when the power cable from a battery case to the ADCP was damaged while lifting the mooring; the cable was removed and re-spliced. Following completion of a CTD cast in Hell Gate, CCGS Henry Larsen turned eastward into Jones Sound.

The only activity on August 31 was the 11th survey of a multi-year floe, this time a relatively thin and decayed floe in Lady Ann Strait. By early evening we were heading south towards Lancaster Sound.

A hydrographic section at high resolution across Lancaster Sound at Cape Warrender was started shortly after midnight on September 1 and completed before 11:00. This is an important reference section in the eastern Canadian Arctic with first observation made in 1928; it has not to my knowledge been occupied for at least 10 years. We were rewarded with an interesting view of a very active interaction between the Arctic outflow and west-flowing Atlantic waters of the Greenland Current. On completion we continued on to Pond Inlet, dropping anchor in the evening.

With no seats available on flights to the south until September 4 (Wednesday), we have three days to fill here, one on board ship and two ashore, after CCGS Henry Larsen departs for fuelling at Nanisivik. Then we only get as far as Iqaluit before waiting another day for a flight to Ottawa and beyond – the joys of the Arctic.

This has been a difficult and frustrating field expedition. Our success at picking up the trophies of past initiatives definitely leaves something to be desired. However, we have done well in our new initiatives. We have an array of 16 moorings in place for the IPY. We have gathered valuable survey data on the thickness and strength of 11 multi-year ice floes – floes which are startlingly large, thick and strong when viewed in the context of shrinking multi-year ice coverage in the Arctic. We have also completed a wide ranging hydrographic snapshot of the north-eastern Canadian Archipelago from Hall Basin to Lancaster Sound. This is a good beginning. I look forward to being back here in 2009.

Appendix 3: Cleaning the SBE37 Conductivity Cells

1. Rinse off (gentle power washer) and brush exterior on deck.
2. Soak for a couple of hours in warm fresh water.
3. Download data whilst instrument is in bucket of water (do not allow cell to dry out). Back-up data and perform first quality checks.
4. Remove end caps and anti-foulant caps (wearing gloves[1]). Keep anti-foulant devices in a sealable plastic bag for later disposal, and store caps separately for washing.
5. Flush cell with warm (30ºC) fresh water for 5 minutes. Most easily accomplished under a mixer tap.
6. Stand in bucket of warm weak bleach solution (so that conductivity cell is immersed). Use 40 parts water to 1 part bleach, i.e. 250 ml bleach for a 10-litre bucket. Attach a syringe to the anti-foulant case on the top of the conductivity cell and agitate the bleach solution backwards and forwards through the cell for 5 minutes.
7. Leave to soak in bleach solution for at least 30 minutes.
8. Flush with warm fresh water under tap for another 5 minutes. Use a toothbrush/small paint brush to loosen biological growth on the exterior of cell (under the guard).
9. Stand in bucket of 1% Triton X-100 solution. Use 100ml solution for a 10 litre bucket. Attach a (different) syringe to the anti-foulant case on the top of the conductivity cell and agitate the solution backwards and forwards through the cell for a few minutes.
10. Leave to soak in Triton X-100 solution for about an hour.
11. Flush for a further 5 minutes with warm fresh water under tap.
12. Flush briefly with de-ionized water. Blow through to remove large droplets, and keep clean while drying.
13. Install new anti-foulant devices (wearing gloves) and yellow protective plugs to keep contaminants out.

Helen Johnson and Berit Rabe

[1] Triton-X is a strongly estrogenic compound, to which bare skin should not be exposed