Canadian Arctic Through-Flow 2006 Cruise to Nares Strait

CCGS Henry Larsen

August 9 – September 1, 2006

Institute of Ocean Sciences Cruise 2006-28

Humfrey Melling – Chief Scientist

Supported by Fisheries & Oceans Canada and the US National Science Foundation

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Also by the Canadian Federal Programme on Energy Research and Development

Collaborating Institutions: Institute of Ocean Sciences, University of Delaware, Oregon State University, National Research Council of Canada

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Overview

An Arctic Canada Ocean Watch was established in 1997 to monitor change in ice and ocean conditions within the Canadian Arctic Archipelago. It has since evolved into a component of the Canadian Arctic Through-flow (CAT) study, which is itself a component of the international Arctic Sub-Arctic Ocean Fluxes project. The latter supports observation of the climatologically important exchanges of seawater volume, salt and heat through all straits connecting the Arctic, Atlantic and the Pacific Oceans.

The Arctic Canada Ocean Watch has short-term (1-3 year) and long-term goals. In the short term, ACW is exploring the seasonal and interannual variability of currents through the Canadian Arctic Archipelago and evaluating new technology for such measurements. Long term goals are 1) to develop an effective and affordable method for monitoring fluxes of ice and water through the Canadian Arctic Archipelago; 2) to understand the forcing of and controls on these fluxes so that they may be realistically incorporated within models used for the prediction of climate.

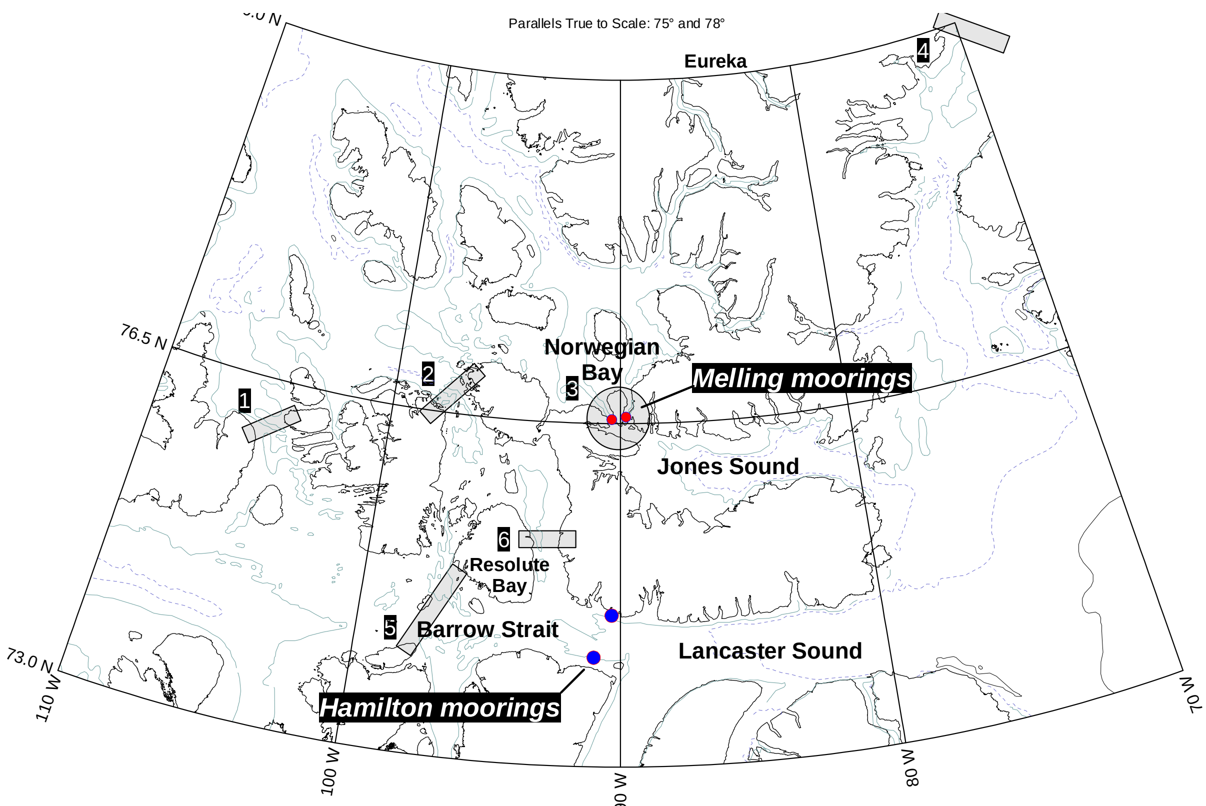


Figure 1. Areas of interest for Canadian Arctic Through-flow: 1) Byam Martin Channel. 2) Penny Strait. 3) Cardigan Strait, Hell Gate, Fram Sound. 4) Nares Strait. 5) Barrow Strait. 6) Wellington Channel. In August 2006, the CCGS Henry Larsen worked in Nares Strait which enters the north-east corner of this map.

All significant transports of seawater and ice through the Canadian Archipelago are funnelled through either Nares Strait, Hell Gate / Cardigan Strait or Barrow Strait. DFO and its collaborators are now measuring flows via all three pathways. For the observational project in Nares Strait, the Institute of Ocean Sciences has a partnership with two US institutions (University of Delaware, Oregon State University) supported by the US National Science Foundation. IOS independently maintains moorings to measure current in Cardigan Strait and Hell Gate, while complementary efforts in Barrow Strait are carried out by the Bedford Institute of

Oceanography with support from the Canadian Programme on Energy Research and Development (PERD), US NOAA and the University of Washington.

Elements of the Scientific Programme

Area of Operation

Nares Strait, from Smith Sound to Hall Basin (see map). Activity was concentrated on a section across the southern end of Kennedy Channel at 80.5°N.

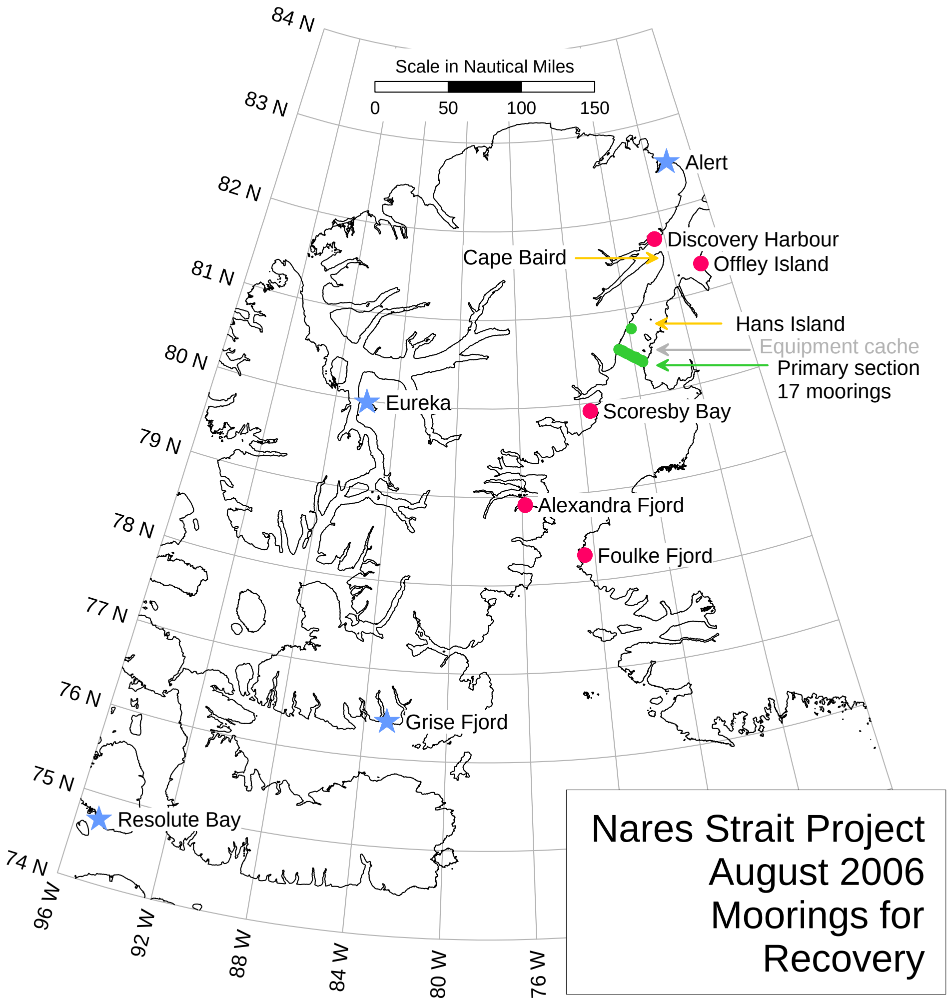


Figure 2. Locations of oceanographic moorings along Nares Strait, installed from USCG Healy in August 2003. At the named coastal sites (red dots) there is a pressure recorder at 20-m depth within a few hundred metres of shore. Most moorings are in deeper water (200-400 m) on the green line across Kennedy Channel.

Nares Strait Mooring Project

The oceanographic activity was the primary focus of this cruise by CCGS Henry Larsen. The lead scientists, Humfrey Melling from the Institute of Ocean Sciences and Andreas Münchow from the University of Delaware, were supported by a team of seven from Canada, the US and the UK.

Twenty-three moorings had been placed in Nares Strait from USCGC Healy in August 2003. These moorings carried instruments to measure and record measurements of current, ice drift, ice thickness, seawater temperature, salinity and sea level. The observations have been supplemented over this period by observations of ice conditions and drift via microwave imaging from satellite and by simulations of wind channelling through the Strait using computer models adapted from weather forecasting.

The tasks for the oceanographic team on CCGS Henry Larsen were:

- Recover 23 oceanographic moorings: 18 from deep (350 m) water and 5 from shallow (20 m) bays accessible only by boat
- Service recovered instruments and mooring components
- Re-deploy moorings to continue the programme of observation through the IPY
- Complete oceanographic sections by CTD profiles on several transects of the Strait

Multi-year Ice Project

The cruise has supported three additional projects on an opportunistic basis, all oriented towards multi-year sea ice – its detection, its strength and forces resulting from its collision with the ship's hull.

Michelle Johnston from the National Research Council was on board to continue her study of the bore-hole strength of ice in floes of various ages and states of decay.

The tasks for Michelle and her suite of volunteer assistants were:

- To measure bore-hole strength and various physical properties of selected second-year and multi-year ice floes
- Find and re-measure up to 3 floes tagged with position and homing beacons early during the expedition

Global Ice Loads on CCGS Henry Larsen

Michelle installed an autonomous measurement and recording package (MOTAN) to monitor the kinematic response of CCGS Henry Larsen to collisions with ice floes. The recorded data permit caloculation of global loading of the ship when working in pack ice.

Improved Marine Radar for Navigation in Ice

Barb O'Connell of CCG Icebreaking Services supervised the installation and operation of a "Sigma" signal-processing card on one of the ship's radars. The experimental display was available to ship's officers for use and evaluation during the conduct of the scientific programme.

Schedule

Scientific personnel left home on Tuesday August 8, 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 Wednesday evening and arrived in the work area at the southern end of Kennedy Channel on Saturday morning, August 12.

We worked in this area for the better part of 5 days, with primary focus on the oceanographic activity.

CCGS Henry Larsen left the work area for Pond Inlet, 550 nautical miles to the south, at mid afternoon August 16 (Wednesday). The ship arrived early on Saturday and spent 3 days in a joint exercise with the Canadian Armed Forces. She arrived back in the work area on Thursday morning (August 24) after an absence of 7½ days. Although the scientific team made progress during this time in the assessment of data and the servicing of instruments already retrieved, critical opportunities were lost for ship work during a time of relatively benign ice conditions.

On our return, ice conditions deteriorated rapidly with the influx from the North of thick, compact multi-year pack with large floes. This ice seriously constrained options for oceanographic activity, but conversely provided valuable opportunities for the other two ice-related components of the scientific programme. After a frustrating 3½ days, during which time very few of the oceanographic objectives were met and risk to the ship progressively increased, Captain Broderick withdrew the ship from Kennedy Channel and headed south (August 27).

On the following day, NRC sampled a floe in Kane Basin, and the oceanographic team deployed a sea-level recorder in Foulke Fjord on the 29th. But an attempt to deploy such a recorder in Alexandra Fjord was thwarted by heavy ice.

Team members reached Pond Inlet on the 31st, flew south to Iqaluit on the September 1st, to Ottawa on the 2nd and home on the 3rd.

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.

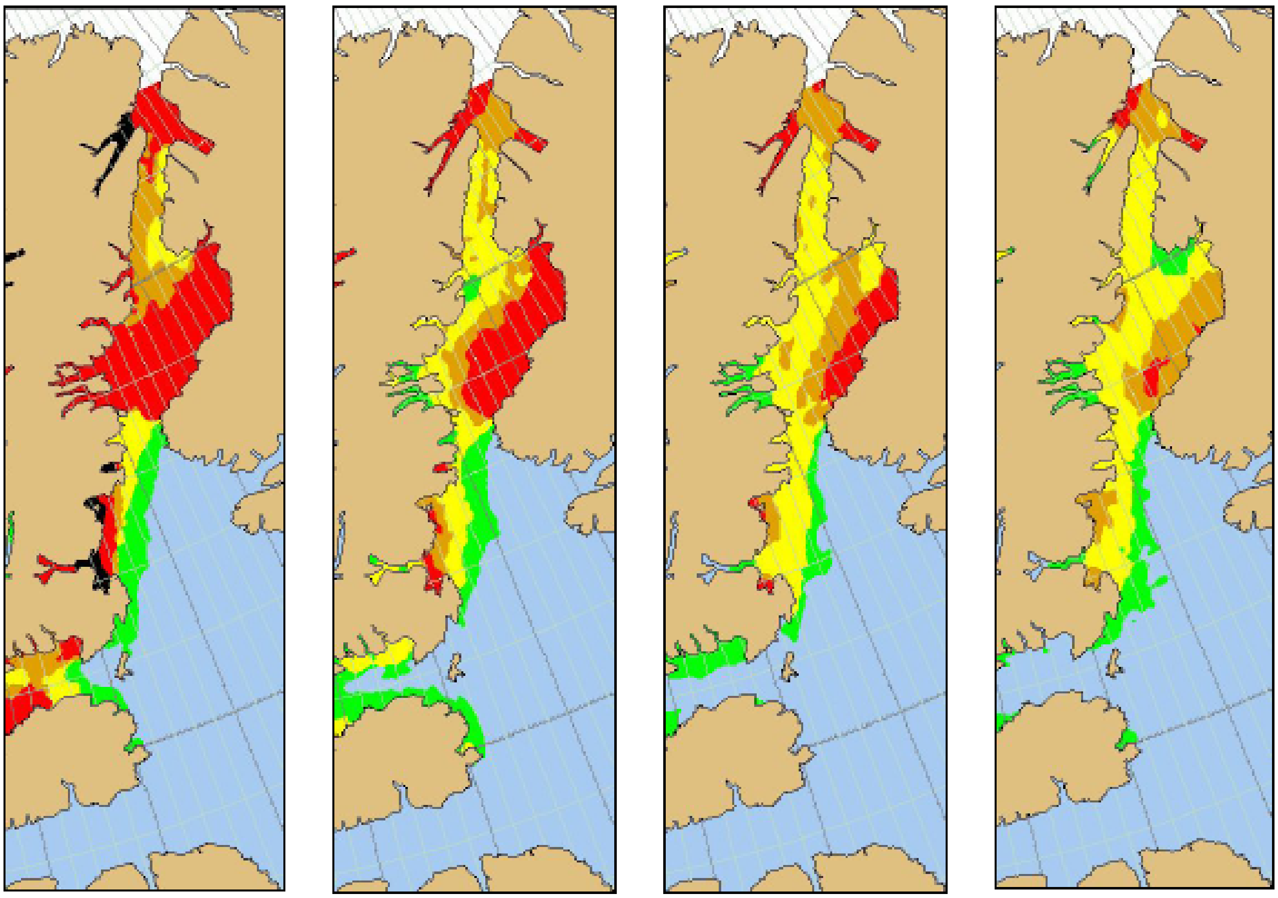
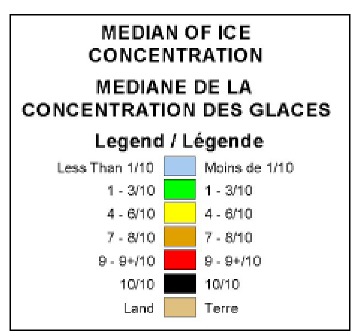


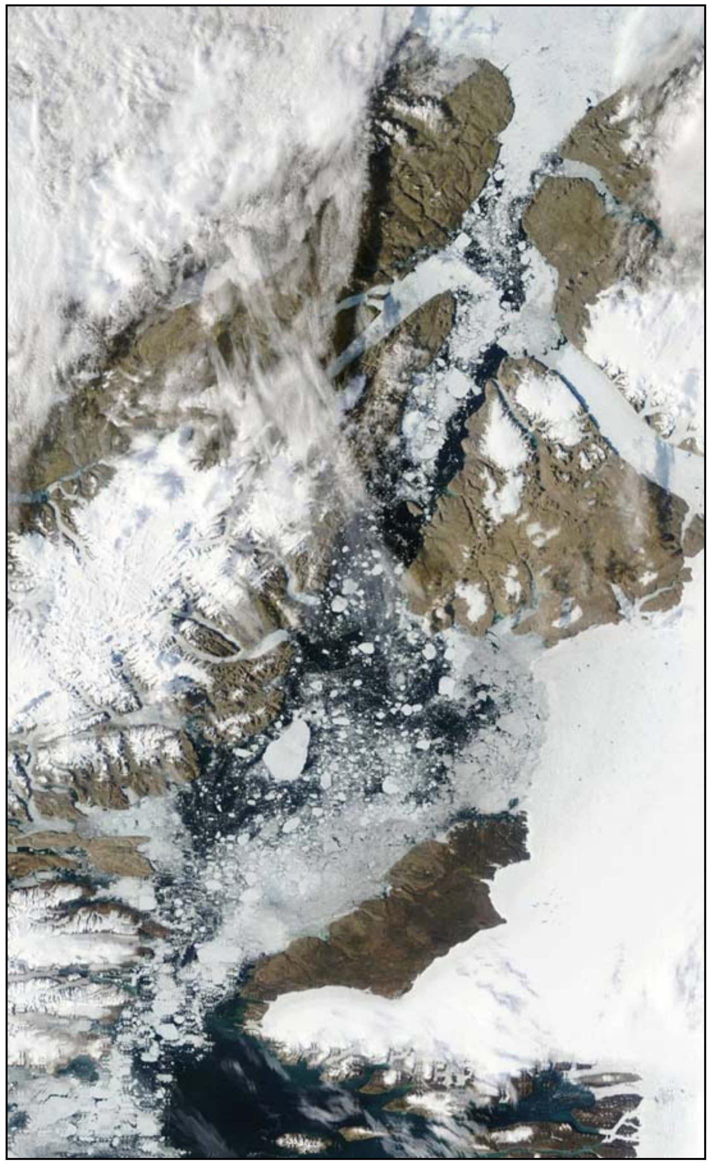
Figure 3. Median concentration of sea ice in Nares Strait at weekly intervals during August. . Dates are 6th, 13th, 20th and 27th (legend below). Charts from the Canadian Ice Service.

Median conditions are approximately static at 4-6 tenths concentration the last two weeks of August, with the exception of decaying pack 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 2006 were close to the median climatological state, except that timing was advanced. This anomaly reflects the earlier collapses of ice bridges, across Smith Sound in mid July and across Robeson Channel in late July. The adjacent satellite image (MODIS) reveals ice streaming south from Smith Sound and on the move throughout Nares Strait already on July 31, two weeks ahead of normal.



The ice charts on the following page display ice conditions on August 12, when we arrived in Kennedy Channel, on August 22, when returning from Operation Lancaster in Pond Inlet, on August 24 when back in Kennedy Channel and on August 28. The science programme had been abandoned 12 hours earlier when CCGS Henry Larsen turned south in the face of deteriorating ice conditions.

During our first 3 days in Kennedy Channel, conditions were difficult in the eastern half of the principal section (7-8 tenths) and good in the western half (2 tenths). But by August 15, the concentration was high enough to be challenging over most of the section.

There was a strong north-easterly on August 17, after we had left for Pond Inlet, which packed ice against the western shore and left a good fraction of the section relatively clear of ice. Unfortunately, we were not around to take advantage of this opportunity. After August 22, Kennedy Channel filled rapidly with multi-year ice (blue colouring indicates multi-year ice at more than 4 tenths concentration). By the time of our return on the 24th, the ice was providing few opportunities for continuation of the oceanographic programme. Conditions at the time of the last chart shown (August 28) were quite similar in terms of ice concentration and multi-year ice fraction to the climatology for September 10 (not shown).

Almost all floes encountered were multi-year ice. When we arrived in Kennedy Channel, the floes present were relatively thin (est. 3 m) and soft. But by the time of our return on the 24th, floes in the working area were much thicker (est. 5m), harder and larger (see photograph on the right). This was archetypal multi-year ice and not to be underestimated.

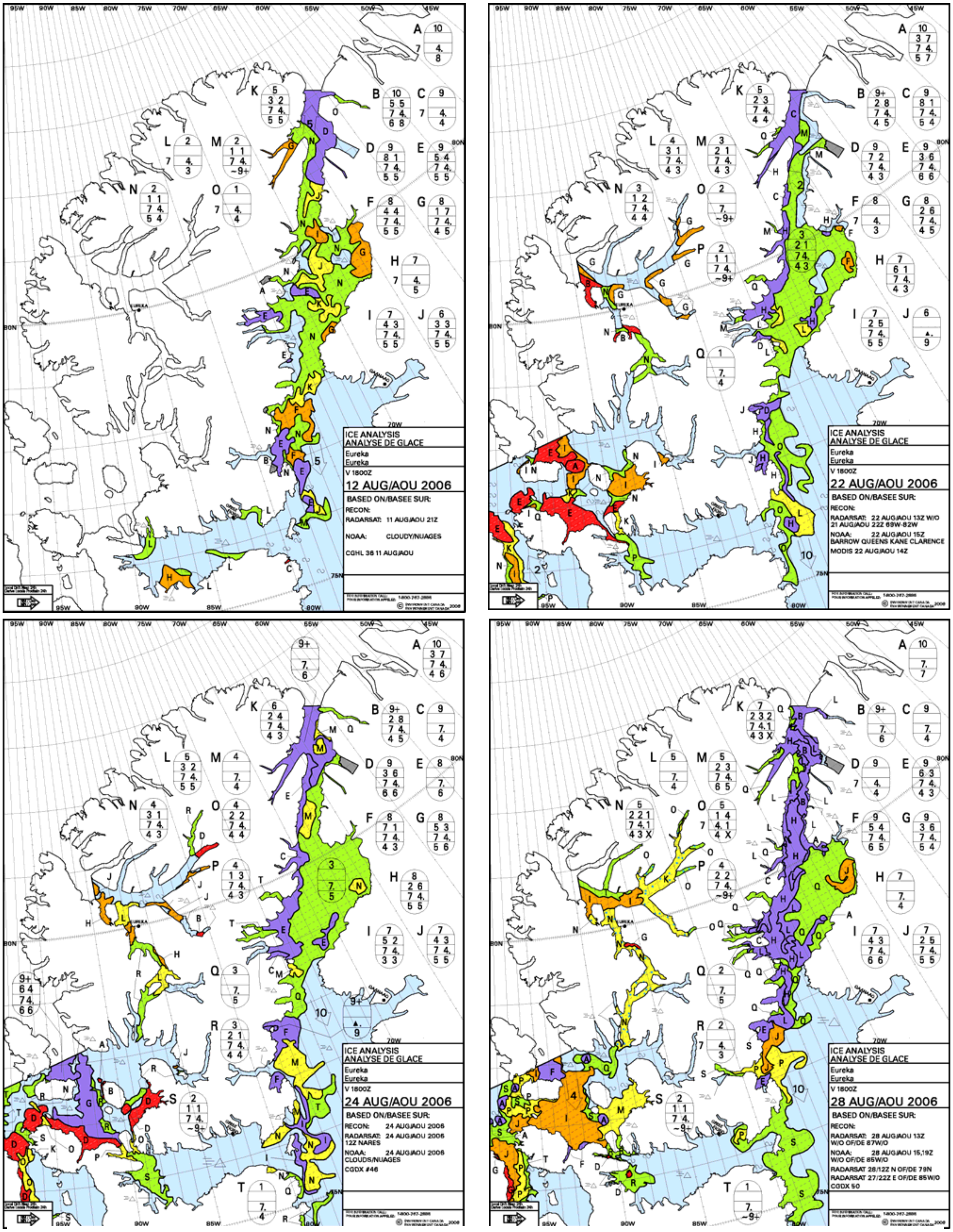


Figure 4. Charts illustrating ice conditions during the Larsen cruise. Note the rapid deterioration between August 21, when Larsen was at Pond Inlet, and August 28.

Oceanographic Array

The principal section of the oceanographic array included 17 moorings. There were 8 taut-line moorings each carrying 4 temperature-conductivity-pressure sensors. These were interleaved with 7 Long Range ADCPs on short torsionally rigid moorings, measuring current profiles, ice drift, pressure, temperature and conductivity. An 8th ADCP was deployed 30 km to the north-east on the Ellesmere Island side. Two taut-line moorings carried ice-profiling sonar for ice-draft measurement.

The main section was complemented by instruments measuring pressure at 5 locations spanning the length and width of Nares Strait, at Discovery Harbour and Offley Island in the north, at Scoresby Bay on Kane Basin and at Alexandra and Foulke Fjords in the south.

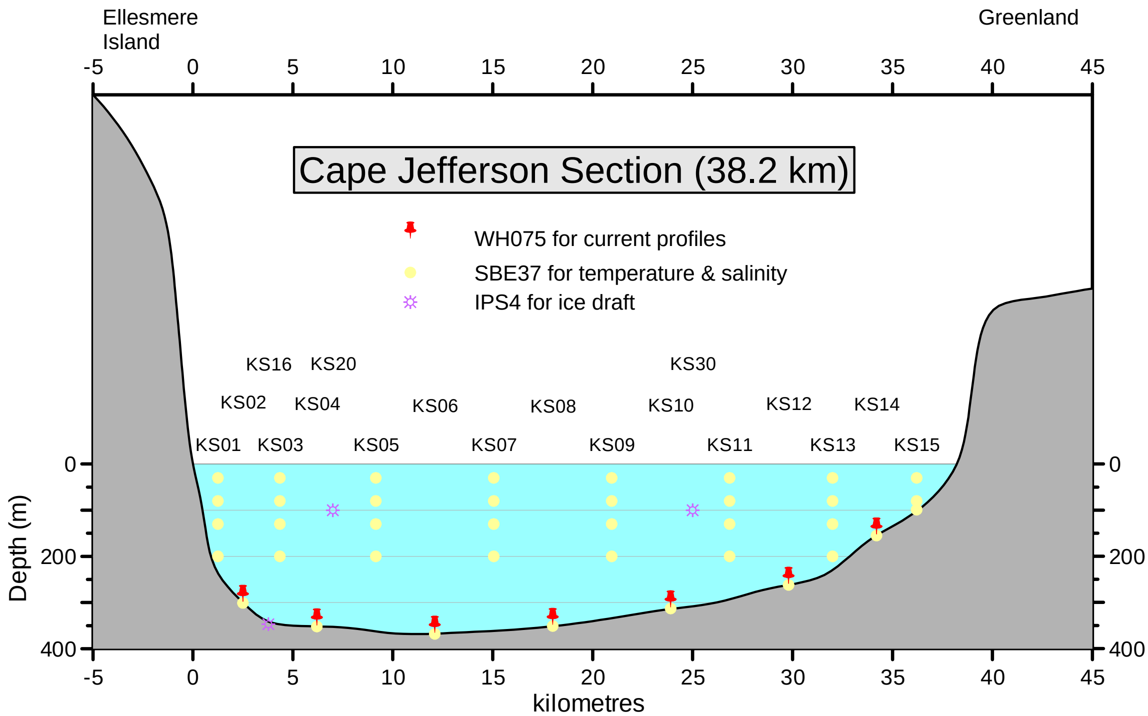


Figure 5. Arrangement of oceanographic instruments on the section across Kennedy Channel.

Accomplishments

Mooring Recovery

Moorings carrying temperature-conductivity recorders were recovered at KS01, KS03, KS05, KS07, KS09 and KS13. There was no response from release-transponders on the moorings deployed at KS11 and KS15, despite several prolonged attempts to enable them at different times.

Moorings carrying Long Range ADCPs were recovered at KS02, KS10, KS12, KS14 and KS16. Moorings at KS04, KS06 and KS08 did not surface, despite activation of both release units.

Moorings carrying ice-profiling sonar were recovered at both KS20 and KS30.

Moorings carrying pressure recorders were retrieved at Alexandra and Foulke Fjords. That in Foulke Fjord did not surface on command and was retrieved by grapple. Access to similar installations at Scoresby Bay, Discovery Harbour and Offley Island was prohibited by ice.

Mooring Data Recovery

Complete 3-year observational records were retrieved from all 29 temperature-conductivity recorders on moorings recovered.

Complete 3-year observational records were retrieved from both ice-profiling sonars.

Complete 3-year observational records were retrieved from 4 of the 5 Long Range ADCPs recovered. One ADCP, at KS16, had a small leak past the O-ring seal which disabled its operation after about a month. A second ADCP also leaked, but appears to have returned useful data despite anomalies in some engineering data recorded.

Complete 3-year records were retrieved from both shallow pressure recorders.

In summary, full data records were obtained from 14 of the original 23 moorings deployed in 2003.

There were no serious occurrences of corrosion.

Bio-fouling over 3 years was minimal, except in Foulke Fjord.

Dragging for ADCP Moorings

Dragging for the pressure recorder at 23-m depth in Foulke Fjord was straightforward. Lightweight grappling gear was deployed from 7-m fast-response craft, which circled the known location several times bfore the line was pulled in.

Dragging is a complex activity from the Henry Larsen, where the wire is deployed over the ship's side, from the well deck and the ship's manoeuvrability is limited at low (< 2 kt) speed. In Kennedy Channel, congested ice provided few opportunities to attempt this procedure and significant ship drift and current created rapidly evolving challenges. The strategy involved drifting down on the mooring while moving astern across the drift and paying out the wire. When a cross-channel set was complete up-drift of the mooring, the ship was to drift past the mooring, still paying out wire. Finally the ship was to move forward again across the drift to complete a C-shaped loop on the seabed. At this point, the ship would hold station and wind in the wire. In the 3 or 4 opportunities presented, not even the first step could be completed to specification.

Issues with Moorings

The moorings at KS11 and KS15 are presumed lost, perhaps through snagging and removal by icebergs. Data from instruments on a companion mooring indicate that they were forced down from 30 to 200 m, probably by a passing berg. Other ice features of up to 70-m draft were detected by sonar in the array. Depth of water at one of the lost moorings, KS15, was only 109 m.

The reason that moorings at KS04, KS06 and KS08 did not surface is not known, although obstructed movement of the release mechanism is suspected. This might be a consequence of biological fouling. Possible implosion of floatation (depth rated for 380 m) was ruled out by submerging one of the recovered floats to 450-m depth without damage. Floats at the 3 sites were 360-m deep. It was originally thought that the released moorings were on a hair trigger and might surface at any time. However repeat visits to 2 of the 3 sites over a two week period confirmed their continued presence at the seabed.

Leaks into ADCPs are thought to have occurred during performance testing from USCGC Healy before deployment in 2003. Corrosion streaks within the housing indicate the water entered across the base-plate seals and ran towards the transducer end. Leakage must have occurred when the ADCP was pointing down, ,as it was during testing. The base plate of the short-case ADCP is secured against a double O-ring seal (bore and face) by 8 bolts. On the 5 ADCPs recovered, none of these bolts were properly tightened. At their operating depth of 350 m, pressure on the base plate would have been quite sufficient to compress the O-rings for a tight seal. But the ADCPs were tested at a few metres depth, suspended by a yoke attached to the base plate. With this suspension, the appreciable weight and inertia of the instrument on inadequately tightened bolts will plausibly have allowed movement at the seals and infiltration of seawater.

There was a leak into one of the battery cases on an ADCP mooring. However, the redundant and independent battery was sufficient to operate the instrument for 3 years.

The float-release mechanism at Foulke Fjord failed to function because of heavy encrustation by barnacles. No such growth occurred at Alexandra Fjord, on the opposite side of Smith Sound.

We used Benthos 867A and 866A release-transponders for this project. Since the standard model lacks sufficient battery capacity for a long deployment, our units were modified by Benthos to sleep for 2 minutes out of every 3. This modification was successful in prolonging battery life for 3 years (and probably longer). But because the release is completely unresponsive 66% of the time, the modification did introduce challenge to the enabling of the transponder and release functions. In principal, repeated frequent transmission of the enable command for 3 minutes should activate the transponder. In actual fact, about half of the releases required much longer period of blind transmission before they sprung to life, for reasons that are not clear. Initial suspicions of excessive wind-wave or ship noise were ruled out, as were suspicions that the sound level transmitted by the deck unit might be too high for use at short (300-500 m range). It is possible that multi-path transmission is a problem in shallow water, since the transmitted message is several seconds (several kilometres) in length.

Cleaning and Calibration of SBE37s

See Appendix 2 for a description of the cleaning procedure.

It was our intention to acquire a full cross-section by CTD before recovering moorings, to provide an in situ calibration of conductivity sensors. This was not possible.

After cleaning and before redeployment, we clustered the SBE37s from each mooring and lowered them to 20-m depth in Pond Inlet, to collect comparative data at 1-minute intervals for about 20 minutes.

The design of the moorings for the SBE37, intended to keep the instruments away from moving ice by having them pull down significantly in current, provides frequent opportunity for inter-comparison of sensors on the same mooring. As drag forces on the mooring change with tidal currents, instruments pass sequentially through the same depth. This behaviour enables a continual cross-check of calibrations throughout the period of deployment.

Mooring Deployment

Moorings carrying temperature-conductivity recorders were deployed only at KS07, KS09 and KS13 before heavy ice precluded access the sites on the Ellesmere side (KS01, KS03, KS05).

Moorings carrying ice-profiling sonar were deployed at KS20 and KS30.

No ADCPs were deployed because their preparation for redeployment was not complete at the time that ice closed in.

A mooring with pressure recorder was deployed in Foulke Fjord. An attempt to deploy in Alexandra Fjord was blocked by ice.

Figure 6. Operating the CTD over the port rail of CCGS Henry Larsen

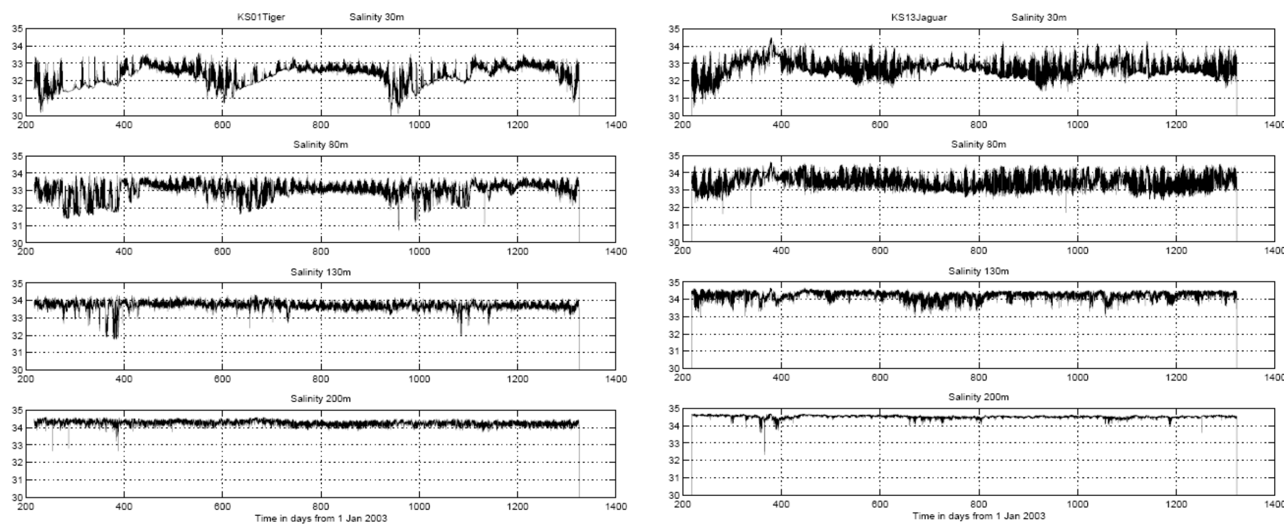
Observations by CTD

Because of a compressed schedule and difficult ice conditions, only one oceanographic section of Kennedy Channel was initiated, and this was terminated 2/3 of the way across from Greenland by heavy ice. Our modified SBE25 CTD probe was deployed at 10 locations. We used a compact and fast electrically powered winch equipped with 2000 m of 1/8" conducting cable. Data were relayed to an SBE33 deck box and computer for real-time inspection and recording. Unfortunately, the deck box failed after cast 6 and subsequent data were logged internally without real-time quality assessment.

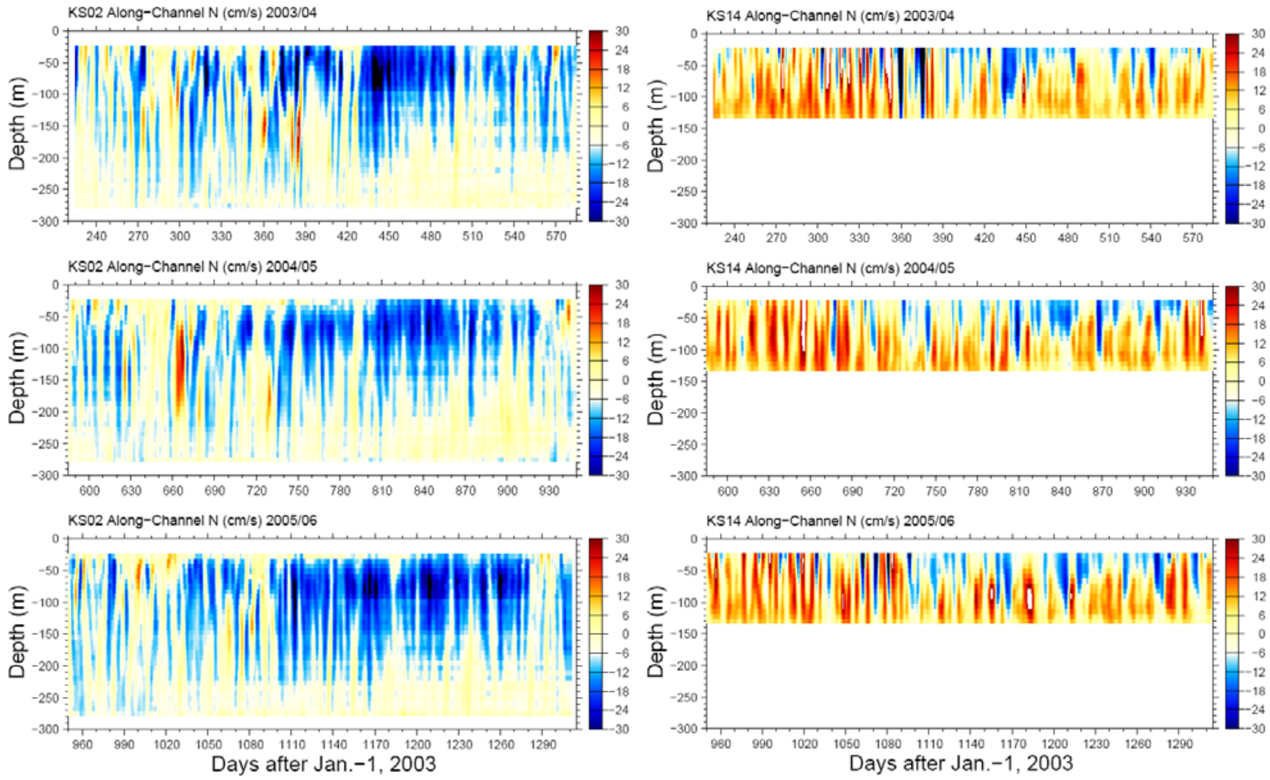
Only seawater pressure, temperature and conductivity were logged. An optional SBE43 dissolved-oxygen sensor was not interfaced to the SBE25 logger during these casts. Water samples were not collected. However, CCGS Louis S St-Laurent will support a geochemical-tracer survey in northern Baffin Bay and Smith Sound in late September, as a second component of the 2006 activity in this project.

A Glance at the Ocean Observations

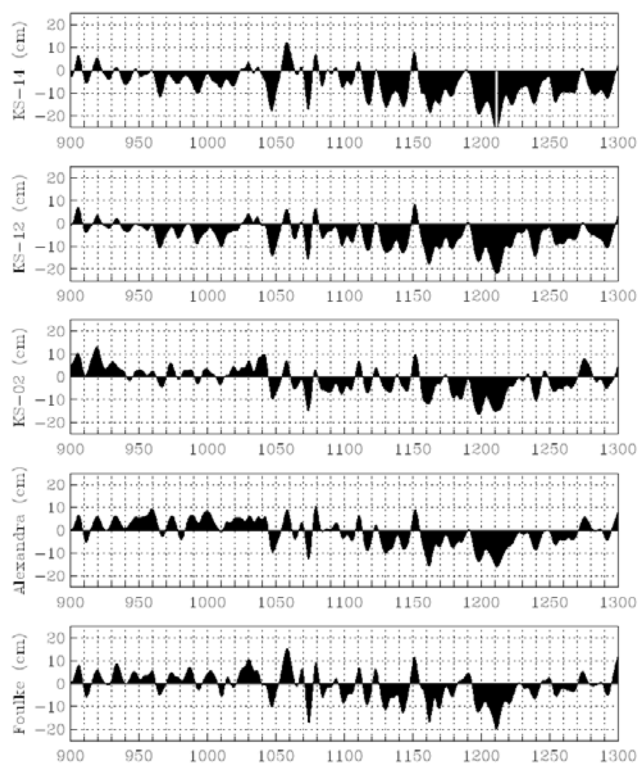
The figures below display times series of salinity at four depths from the moorings closest to the western (left frame) and eastern (right frame) sides of Kennedy Channel. At the upper levels, there is a clear seasonal cycle with lowest salinity during the summer months. Curiously for a channel supporting a southward flux of fresh-water, any consistent cross-channel depression of isohalines towards Greenland is subtle near the surface, although there is a more obvious tendency towards this condition in summer. However a deepening of isohalines towards Canada may be present year-round at 80-m depth and is certainly seen at 130-m depth. The deepest level of measurement is roughly the depth of the Nares Strait sill in Kane Basin. The salinity at this depth on the Greenland side (34.5) is comparable to that of deep water in Baffin Bay.



Measurements of along-channel current (with tides removed) are displayed in a colour-coded representation in the following pair of figures (west side on the left and east on the right). Two features are immediately apparent. First is the vertical banding of colour indicative of strong variations in flow on the time scale of weather events (3-10 days). Second is the difference in dominant colour between the two sides – average current on the Greenland side is northward and that on the Canadian side (indeed over most of the section) is southward. The darker blues near the surface on the Canadian side, and the switch to blue near the surface on the Greenland side are evidence of negative (or southward) shear in the flow towards the surface. This implies a shoaling of isopycnal surfaces towards Greenland, but this is not particularly obvious in the figures above. The final aspect of note is the tendency for stronger southward flow near the surface across the entire strait during the winter (February through July) when ice is land-fast.

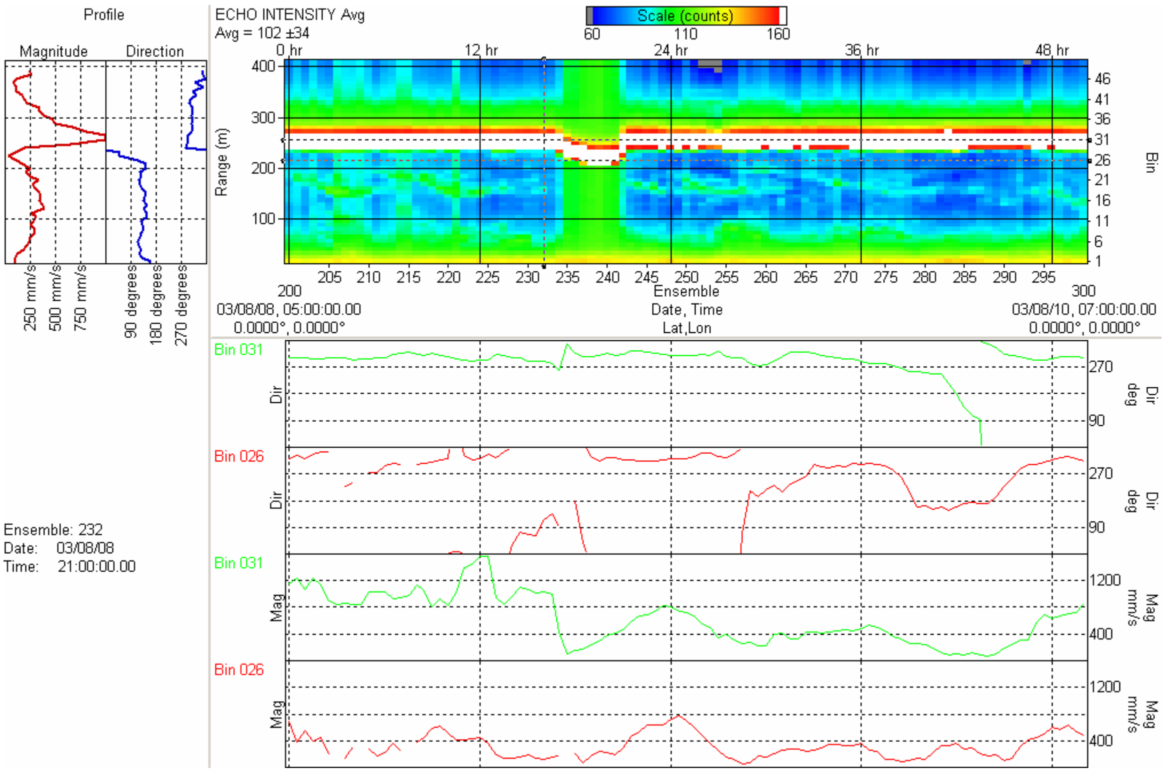


Observations of total hydrostatic pressure were recovered from 20-m depth near the southern end of Nares Strait (Alexandra & Foulke Fjords) and from the line of ADCPs at about 300-m depth across Kennedy Channel. Time series of variations for about a year of measurement, with the large (± 2.5 m) tidal oscillations removed, are compared in the figure on the right. Oscillations are very coherent across the array of sites and again fluctuations in the 3-10 day range of period characteristic of weather are most evident. Both characteristics suggest that the atmospheric signal is dominant. However, the somewhat constrained (30 mb) range of variation may be indicative of partial adjustment in the ocean via the inverse barometric effect and other mechanisms. A more detailed analysis is required.



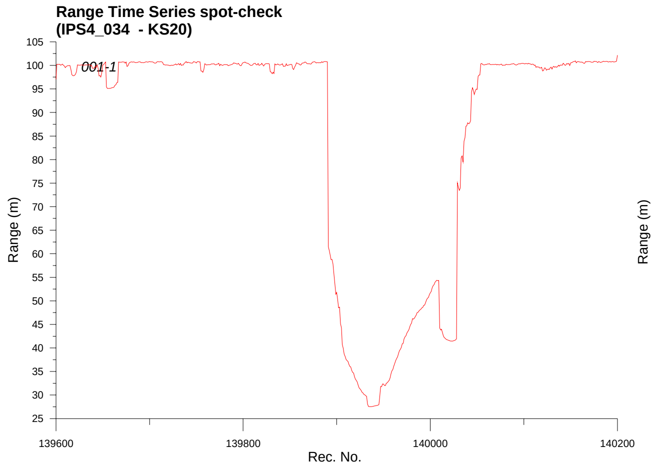
Measurements of ice drift and of ice draft were acquired by sonar. The former can be derived from the surface echo to the ADCP, and the latter is the primary purpose of the ice profiling sonar. In addition, we have occasional data from the pressure sensors within the SBE37s deployed at shallow depths that record push-down of the mooring by ice features of deep draft. The most extreme record indicates push-down from 30 to 200-m depth.

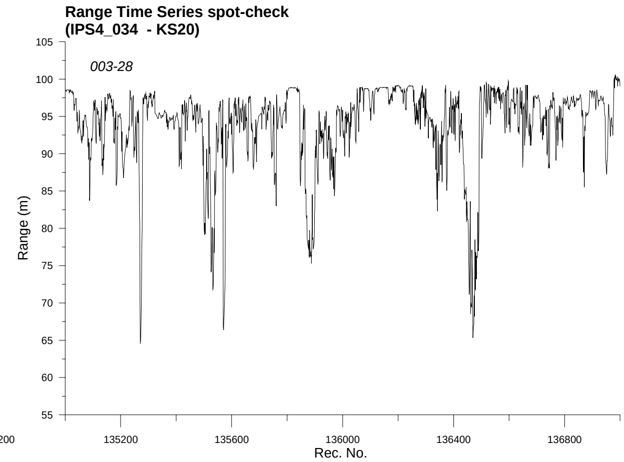
Ice drift was zero during fast-ice conditions in winter, but within open pack in summer it frequently exceeded the speed of current at 30-m depth by a factor of 2. The illustration below displays data from an event in August 2003, when pack ice moving at about 1 m/s along 270º heading (Bin 31 traces) collided with an iceberg of 40-m draft (Bin 26 traces, ensembles 233-242) moving at less than 20 cm/s in the opposite direction. The failure of sea ice against the berg apparently generated appreciable noise at



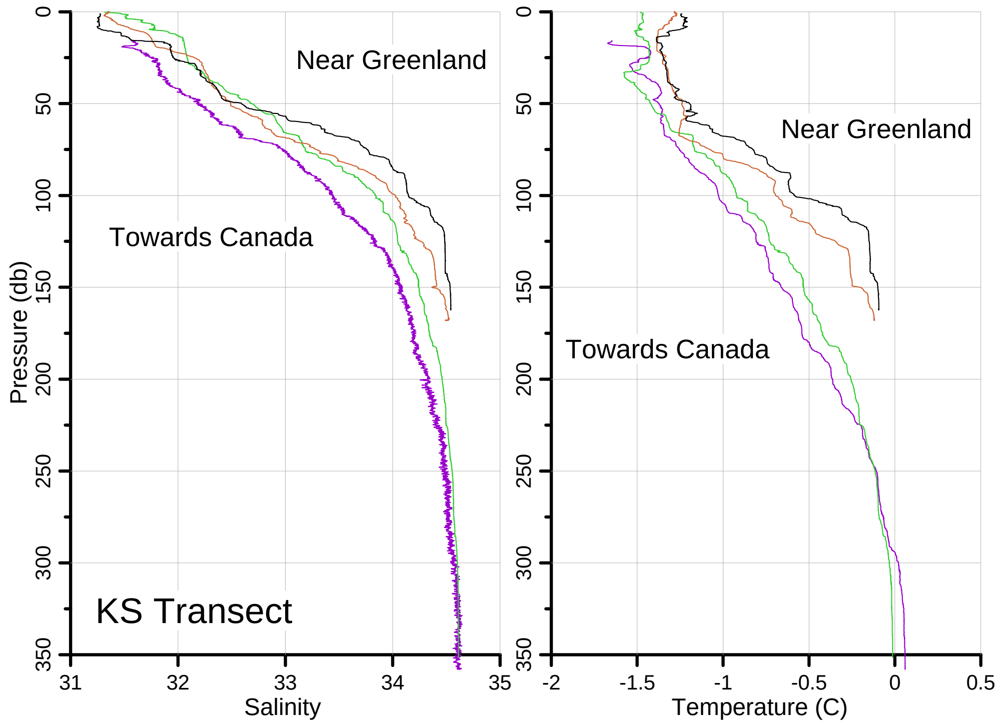
75 kHz, to which the ADCP is sensitive. This is evident as the band of green (top colour frame) that swamps all but the ice echo during the interval of interaction.

The plot on the left below displays the range to the underside of an ice feature that extends to a depth of 75 m and requires about 10 minutes to pass over the sonar. Based on its steep sides and extreme draft, this is presumed to be an iceberg. The adjacent plot displays a trace of draft typical of deep-draft ridge keels (here about 35 m deep) in pack ice; the features are much rougher in shape and sides slope more gradually to maximum draft.





The incomplete hydrographic section acquired by CTD provides a clearer indication of baroclinic adjustment across the strait than do the preliminary time series illustrated above. The figure below displays 4 profiles spanning the easternmost 2/3 of Kennedy Channel at the mooring line. There is a clear shoaling towards Greenland of the 33-isohaline by about 25 m, the 34-isohaline by more than 50 m and the 34.5-isohaline by about 100 m.



Moorings Re-deployed

Site	Date	Latitude	Longitude	Instruments	Transponding Release
KS20	24 August	80º 31.706' N	068º 39.197' W	IPS4, s/n 034	2 x 866A, s/n 520, 529
KS30	25 August	80º 26.117' N	067º 52.407' W	IPS4, s/n 035	2 x 866A, s/n 521, 528
KS13	25 August	80º 23.677' N	067º 35.528' W	4 x SBE37	1 x 866A, s/n 522
KS09	25 August	80º 27.167 N	068º 03.936' W	4 x SBE37	1 x 866A, s/n 508
KS07	25 August	80º 29.250' N	068º 19.227' W	4 x SBE37	1 x 866A, s/n 521
Foulke Fjord	29 August	78º 17.830' N	072º 34.080' W	DL3-PS, SBE4	1 x 867A, s/n 111

Figure 7. View northeast up Kennedy Channel on August 26, showing concentrated cover of heavy multi-year ice drifting down from the Lincoln Sea

Assessment and Recommendations

Prior experience of IOS 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 fighting the ice with a ship for opportunities of 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. The expedition using CCGS Henry Larsen was subsequently planned to fill the gap, acknowledging some likelihood of disappointment in the face of challenging summertime ice conditions within Nares Strait.

Moreover, by August 2006, with the passage of 3 years since instruments were placed in the Strait, the probabilities of instrument failure caused by battery depletion, release malfunction caused by biological fouling and loss of equipment to icebergs were potentially quite high.

In view of these factors, our achievements within our brief 8-day window of opportunity should not be under-rated. We recovered 15 of 23 moorings, on which all but one of the 38 instruments operated successfully and recorded data for more than 3 years. Few other mooring groups attempt such long deployments and fewer yet retrieve such long data records from them. We believe that 2 of the remaining 8 moorings have been lost to icebergs. But 3 of this number, which could not be accessed because of heavy ice, are presumably still in place, and the other 3 are confirmed in position at the seabed, unable to disconnect from their anchors.

We had some uncertainty that the Benthos releases specially modified for this project would be operable after 3 years. This concern was unwarranted; battery voltages of the recovered units remained high and should be sufficient to power the releases until our return next year. As a check, we will retain several releases under test with their original batteries over the next 12 months.

Moorings of three novel designs developed for this project worked well. Data recovered from the Long Range ADCPs showed no indication of directional instability in the torsionally rigid moorings used. Echoes from plankton were sufficiently strong to yield current data all the way to the surface at a range of 350 m. Although two of the eight compliant moorings supporting temperature-salinity sensors at within 30 m of the surface were 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, although such long-range operation had not before been attempted. Both of the pressure recorders on moorings at 20-m depth placed by divers from Healy survived the ice and remained at a fixed and stable depth over the 3-year period.

We also received excellent and willing technical support from the ship's engineering department. However, we should not overlook the fact that trips such as this demand specialized 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 has a very serious in relation to the staffing of oceanographic moorings projects, particularly to meet the unique 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 without losing equipment. We were fortunate that Captain John Broderick 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.

What should be different next time?

First, as we have now doing in the less accessible areas of the western Arctic, we must 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 minimal, 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.

Second, we need a better capability/strategy for dragging up moorings using our icebreakers. Distasteful though it may be, dragging is the last resort for mooring recovery. The moorings that failed to surface in Kennedy Channel this year were already equipped with tandem releases, to provide redundancy. Moreover, in each instance, both releases operated. IOS has moorings of the same overall design that have been used in Cardigan Strait since 1998. Unfortunately, despite our most conscientious efforts, we still had to face the grapple.

Third, 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 would have had opportunity to deploy the remaining three temperature-salinity moorings that could not be streamed out because of compact ice conditions.

Properties of Multi-year Ice

Over a three week period, from 9-31 August, Michelle Johnston (NRC) was able to measure the properties of six floes. CALIB (Argos tracked) beacons were provided by Canadian Ice Service for the purpose of tagging three of the floes. Because the CALIB beacons do not readily provide real-time positions of the mobile floes, homing beacons were also deployed to find the floes when at close range (less than 10 km). As a result, we were able to re-sample one of the floes after a six-day interval. The information gathered on that floe provided a window into the changes in ice properties that occur during the thaw season. The two other floes on which beacons were installed might also have been sampled again, but operational and ice constraints prevented this.

Property measurements including ice thickness, ice temperature and salinity and the confined compressive strength of the ice (borehole strength) were measured to depths as great as 3.6 m. When possible, one of the three test holes was drilled into ponded ice. This was easier towards the end of the trip when ponds were capped by 5-10 cm of new ice. The floes ranged from 500-2750 m in diameter and from 2.5 m to more than 11 m in thickness. In each of the sampled floes, the lowest temperature in the uppermost 3 m was -2.6ºC. The salinity of the uppermost 3 m of ice was 3.5 ppt or less. In general, the ice strength was lowest in the uppermost 0.60 m, increased to a depth of 1.30 m and then remained relatively constant to a depth of 3.60 m. In a few cases, the strength of the ice plummeted at depths of 1.30, 1.50 and 2.70 m (all in different floes). Those bands of low strength ice were likely due to the presence of large voids or slush layers, given the condition of the extracted ice cores.

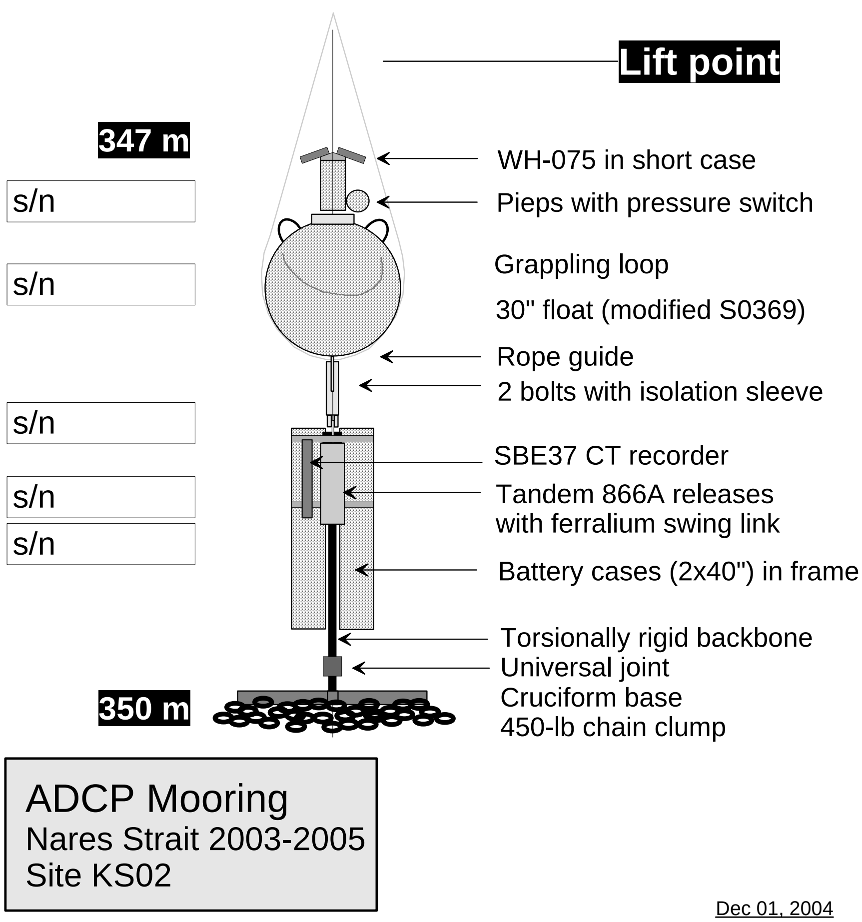
The ice strength program can be considered a success. The properties of six multi-year ice floes were measured, including one sampled twice. The homing beacons were a workable aid for finding floes so that their properties could be measured more than once. The three beacons that we installed, along with information about beacons that scientists at SAMS had installed on ice in the Lincoln Sea, provided extremely valuable information about the trajectories of multi-year ice floes in an area where virtually no data exist.

I would like to have collected more data during the three weeks spent onboard the CCGS Henry Larsen, especially given that, in the past, I have sampled a similar number of floes in much less time. Part of that difference was because there were two field programs competing for the ship's resources (even though there was considerable synergy between the programs). Other complications included the time spent trouble shooting my equipment and my failure to have brought an assistant with me (which meant that my sampling was limited to times when either crew or Humfrey's colleagues were available to help). It also took some time to see how the two different field programs would mesh. Another limitation was that I needed the helicopter to access ice floes, and that had its own limitations. In the past, the helicopter has been given more latitude as to its range and the length of time it is away from the ship (it remains with us during sampling). By far the biggest challenge was having the ship called away after only 5 days on site – one precious week was lost. We experienced first hand how such interruption in a very short working 'window' can jeopardize a field study.

Mooring Designs

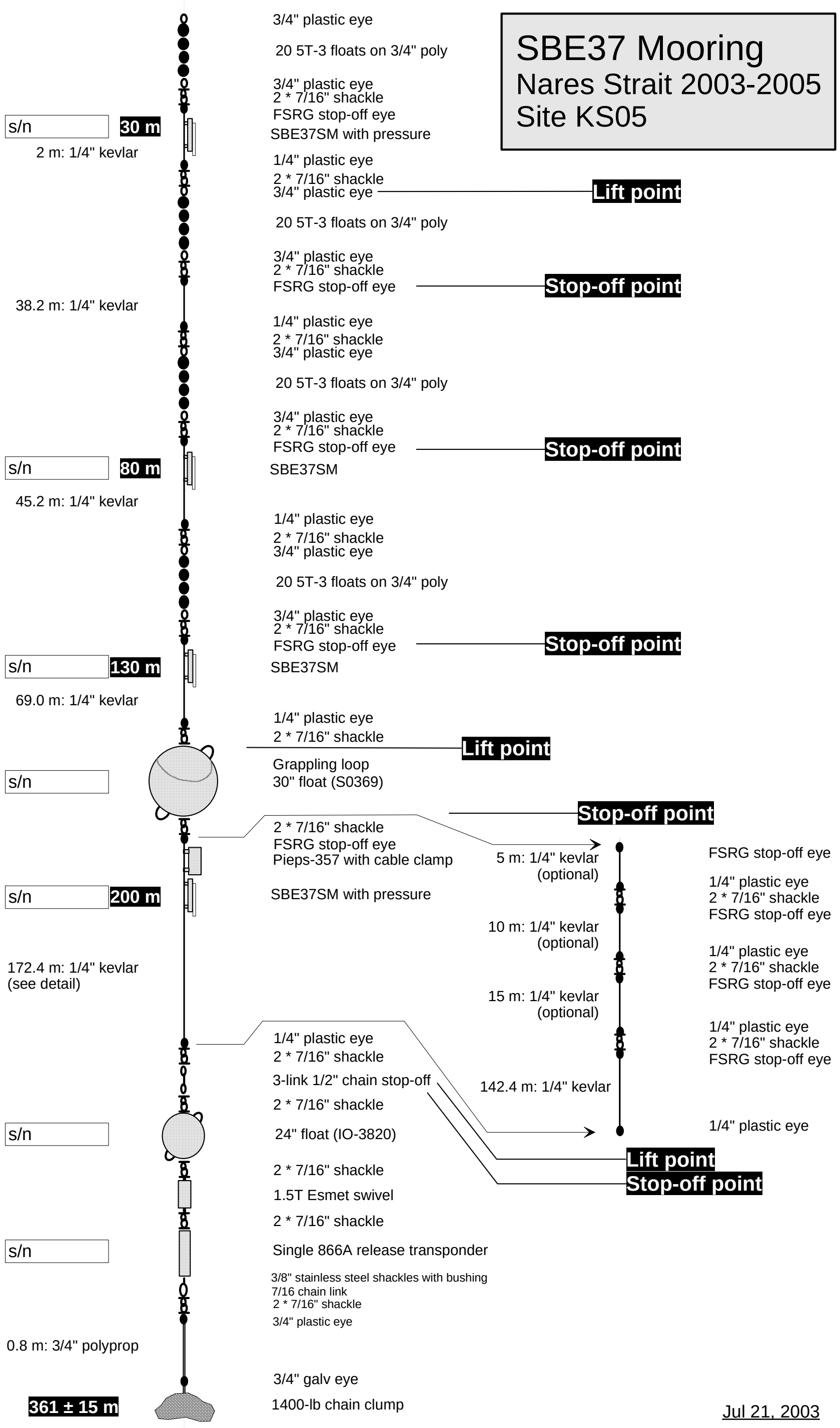
Ocean Current Mooring (8 sites)

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 is a more compact, lighter version of the mooring used to measure current in Hell Gate and Cardigan Strait, where flows are 2-3 times stronger.



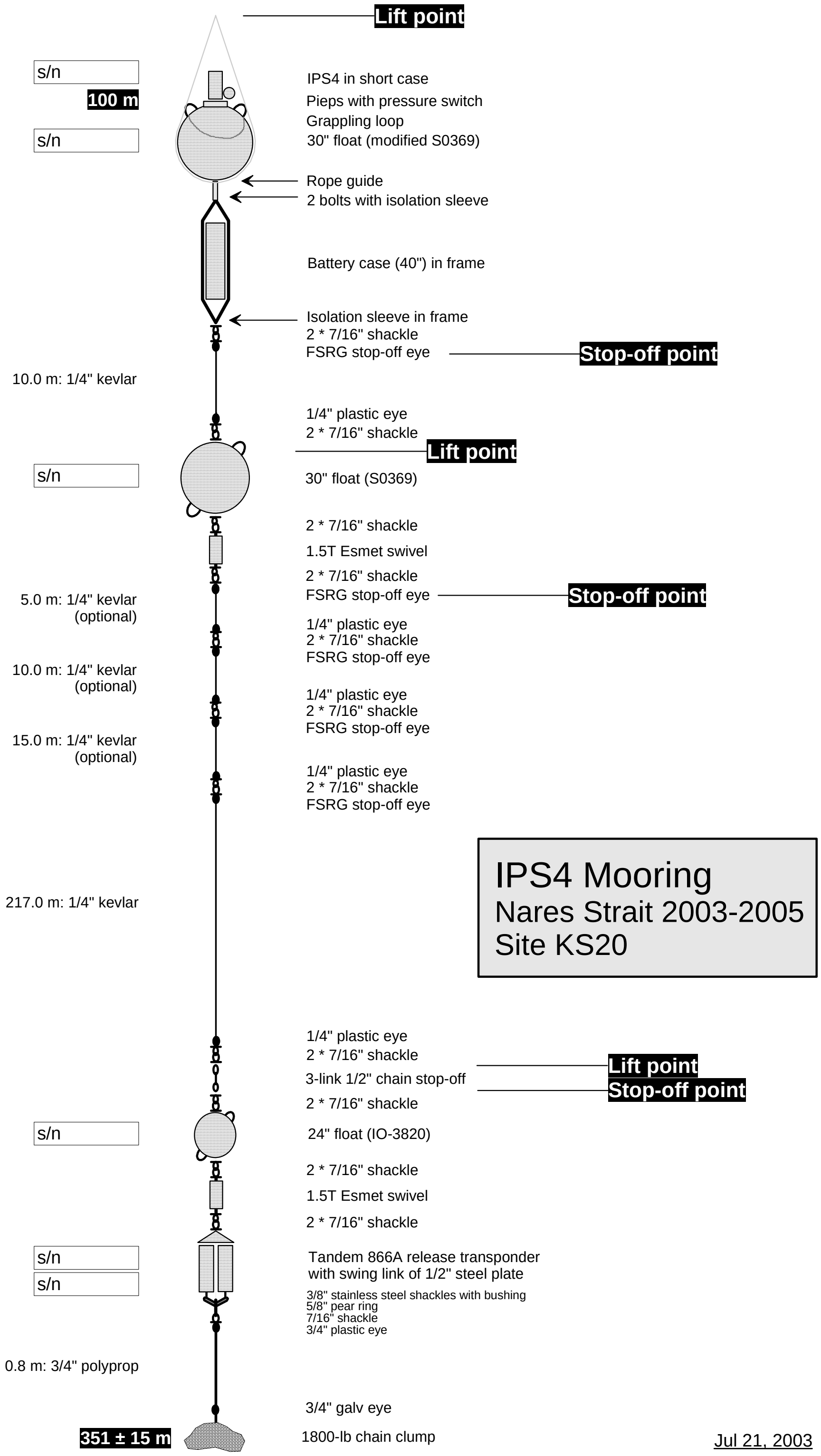
Temperature-Salinity Mooring (8 sites)

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 (2 sites)

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 (5 sites)

This is an unconventional mooring which was positioned at 20-m depth by divers from Healy. Divers hammered a metal stake into the seafloor to provide a stable foundation for the instrument during the 2-3 year deployment. 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 sites in this respect. The other three are exposed to drift ice in some directions.

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 used for the oceanographic project to retrieve a 19,000-lb cache of equipment via sling from the Greenland shore at Lafayette Bay. The required 3-4 hours of flying. The 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

Danish Polar Centre

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

DPC #522-248: Variation & forcing of fluxes through Nares Strait and Jones Sound – DPC permit not required, as communicated by Poul Henrik Sorensen, Liaison Officer, August 1, 2006, via e-mail.

DPC #522-259: Multi-year ice properties – DPC permit not required, as communicated by Kirsten Fadnæs Eriksen, Liaison Officer, May 9, 2006, via e-mail.

Nunavut Research Institute

Jennifer Cockwell, JCockwell@nac.nu.ca

Variation & forcing of fluxes through Nares Strait and Jones Sound – Nunavut Scientific Research Licence No. 0204406R-M received July 24 2006

Measurements of second-year and multi-year ice – Nunavut Scientific Research Licence No. 0203706R-M confirmed August 1, 2006

Canadian Environmental Assessment Act

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

Acknowledgements

The support to the scientific programme from Captain Broderick, his officers and crew of *CCGS Henry Larsen* has been professional, enthusiastic and of the highest quality. We are very appreciative, fully realizing the often conflicting demands of multi-tasking in remote regions of the Arctic.

Specifically, we acknowledge the efficient receipt and handling of our scientific cargo; the installation of the laboratory and workshop containers, the hydraulic power pack, the Swann work winch, the CTD winch and the boom for deploying the CTD; the eager participation officers and crew in the NRC ice-measurement programme. We note the ingenuity and effort of the ship's company in responding to adversity and oversight in the progress of our work. Without this help, we would have been much less effective.

Appendix 1: Personnel

Humfrey Melling	Institute of Ocean Sciences, DFO	MellingH@dfo-mpo.gc.ca	Chief scientist
Andreas Münchow	University of Delaware, USA	Muenchow@udel.edu	USA Lead scientist
Helen Johnson	University of Reading UK	sws04hlj@reading.ac.uk	Scientist: oceanography
Michelle Johnston	National Research Council of Canada	Michelle.Johnston@nrc-cnrc.gc.ca	Scientist: ice properties
Bob Macdonald	Biologica Environmental Services, Contract	Bob@biologica.bc.ca	Technician: mooring
David A. Riedel	True North Scientific, Contract	RiedelD@dfo-mpo.gc.ca	Scientist: support
Ron W. Lindsay	Institute of Ocean Sciences, DFO	LindsayR@dfo-mpo.gc.ca	Technician: electronics
Jonathon Poole	Square Wave Marine Technology, Contract	PooleJ@dfo-mpo.gc.ca	Technician: equipment
Scott Rose	Institute of Ocean Sciences, DFO	RoseS@dfo-mpo.gc.ca	Technician: equipment
Berit Rabe	University of Delaware, USA	beritrabe@yahoo.ca	Student: oceanography
Barb O'Connell	Ice-breaking Programme, CCG	oconnellb@dfo-mpo.gc.ca	Ice-radar project
Jim Lundy	Rutter Technologies, Contract	jlundy@rutter.ca	Technician: radar

Appendix 2: Cruise Narrative

Evening of August 13

We have now worked 2 days on the line in southern Kennedy Channel where there are 17 moorings. Working in sometimes challenging, but not impossible ice conditions, we have recovered 6 moorings. All have been intact and we appear to have complete 3-year records of observations from each instrument. Data deterioration associated with bio-fouling (acoustic transducers & conductivity cells) has been negligible over this period. And we have only instance of corrosion (IPS4 end cap), and this has not been lethal to the instrument or its operation.

The CCGS Henry Larsen is quite noisy, and this characteristic has slowed acoustic communication with sub-sea transponding releases at times. We may also have been jamming our own communications by transmitting sound at too high an intensity. We are new to Benthos releases and still on the learning curve.

We may have a design problem with the torsionally rigid mooring used to support the Long Ranger ADCPs. At two sites we have activated both releases on such a mooring without having the mooring surface. At a third site we had to activate the second release before the mooring would surface, despite prior release of the first. We suspect insufficient clearance for moving parts in the release assembly and likely have a suitable correction to the design before redeployment. But we will have to drag up these two recalcitrant moorings, and possibly some of the remaining 5 such moorings before corrections can be made. I think this work will keep us quite busy until we must leave for the Party at Pond Inlet after 3 more days here. Re-deployments of serviced moorings must await our anticipated return later in the month.

Weather conditions and cruise priorities have not so far favoured the NRC ice-strength project (Michelle Johnston). However, we put Michelle onto a nice multi-year floe adjacent to the ship this evening, where she completed a test of all her equipment, and collected some useful data with assistance from Dave Riedel.

The rapid-scanning radar brought on board by Barb O'Connell is not operational, but the new digital processor has been connected to conventional radar. The output of this radar is quite an improvement over the competition especially within a few miles of the ship.

Evening of August 15

We have continued to work the main line of moorings during the 2 days since my last report.

Tuesday began in fog and evolved into clearer overcast weather with 25-kt wind. We attempted to recover 7 moorings in the eastern half of Kennedy Channel. One was recovered, five were impractical because of ice conditions and we were not able to communicate with the sixth. The failure to make contact with the release on the sixth mooring may have been a consequence of noisy conditions (turbulence around the rapidly drifting hydrophone, wind and wave conditions) or may mean that the mooring was no longer there (iceberg?). But, we have found easy communication with the Benthos releases to be elusive, and the mooring may be there but simply unresponsive.

Since compact ice in the western half of the Strait precluding our work on moorings there, we spent Tuesday afternoon in Lafayette Bay, slinging 14 of the 21 chains drums cached there (7 tons) to the ship. At the same time, Michelle Johnston (NRC) working with 3 IOS'ers was able to measure the mechanical properties of a multi-year ice convenient within the bay.

We awoke on Wednesday to heavy fog after drifting in ice near the working area overnight. Skies cleared at about 1 o'clock, and with the emotional boost of sun and beautiful scenery we were able to visit 7 mooring sites during the afternoon. Moorings were recovered at three of these sites, but we were unable to contact releases at two sites (same issue as noted above). Ice precluded activity at a sixth. At the seventh, a Long Ranger ADCP, both releases claimed to have released, but the mooring did not surface. This mooring is now the third on our dragging list.

Wednesday (tomorrow) is our last day here before the week-long sortie to Lancaster Sound. We have one more mooring in the deep waters of the Strait yet to visit. We will not have time between now to visit the shallow sites on Hall Basin where sea-level gauges must be retrieved. However, we hope to have a reasonably complete inventory of equipment to service during our travelling interlude.

Evening of August 17

CCGS Henry Larsen left our principal area of interest in southern Kennedy Channel early on Wednesday evening. The ship is bound for Pond Inlet, 550 nautical miles to the south, where she is required for a joint exercise with DND vessels on Sunday and for a visit of dignitaries on Monday. Following this 7-8 day interruption, we hope to resume the scientific programme in Nares Strait next Thursday (August 24). Because we need an estimated 7 days of working time to complete the project, there is a serious conflict between our requirement and the scheduled presence of the Henry Larsen to attend crew change for the Terry Fox at Resolute Bay on August 31; the sailing time from Kennedy Channel to Resolute Bay is 3-4 days, depending on ice and weather.

Wednesday began in fog, which soon cleared to provide our most idyllic day to date. Visibility was amazing, with mountains on Robeson Channel visible from a distance of 120 nautical miles. The sea was flat calm and the sun noticeably warm. However, the cool air facilitated the formation of a thin skim of new ice (grease ice) – a reminder that summer up here does not last long.

Despite perfect weather, the pack ice was in control of our activity all day. In the late morning we reached a mooring about 13 miles west-southwest of Hans Island; the equipment was recovered without incident after a half-hour wait for an awkwardly placed floe to drift away. We worked southwest during the afternoon, successively visiting 3 the sites where dragging was required to retrieve a mooring. We started to set the dragging wire at the first site in marginal ice conditions, but soon terminated the operation as a large floe drifted in. Ice conditions at the two other sites were quickly judged unsuitable for dragging and no attempt was made. Fast current (up to 1 kt), strong wind, plentiful ice and appreciable depth (350-400 m) make dragging a challenging activity in Nares Strait. We ended our day with the successful recovery of a mooring under 3 tenths pack ice close and close to the mountainous eastern shore of Ellesmere Island. The floats popped up among the ice floes and were skilfully disentangled by the boat crew before tow to the ship.

Our evening's plan to retrieve the remainder of our cache from Lafayette Bay on the Greenland side was cancelled on discovery of damage to a trimming fin on the ship's helicopter. The grounding of the machine also curtailed planned evening sampling of a multi-year ice floe by the NRC group. A backup plan to lodge the Henry Larsen into a suitable floe before landing a scientific party was also not practical.

The Henry Larsen made good progress south overnight, and was near the Bache Peninsula in the morning. With time in hand, we diverted into Alexandra Fjord where a sea-level recorder was moored in a sheltered location by divers from the Healy in 2003. Despite my doubts of its survival in shallow water, the recorder was recovered as envisaged, quickly and without incident.

There follows a summary of our progress towards objectives for the CCGS Henry Larsen in the Nares Strait programme.

OCEANOGRAPHIC COMPONENT

The harvest of data has been excellent. Of the 38 instruments recovered to date, 37 have provided complete 3-year records of observations. The simplest instruments measure 2 oceanographic variables; the most complex (the ADCPs) each measure almost 100 time series. Sampling intervals range between 3 seconds (Ice profiling Sonar) and 30 minutes (ADCP). Our non-performer is an ADCP that operated for only 3 weeks until a leak through an O-ring seal shut it down.

Of the 8 moorings carrying Doppler sonar, 5 have been recovered. The other 3 remain at the seabed, likely because the buoyant part of the mooring is snagged and still coupled to the anchor, despite activation of the acoustic releases. We anticipate that a jostling of these 3 moorings should be sufficient to bring them up. We know where they are and plan to jostle them appropriately with dragging gear when opportunity permits.

Of the 8 moorings carrying temperature-salinity recorders, 6 have been recovered. We have attempted communication with the releases on the 2 remaining moorings without success. However, since we have had difficulty communicating with about half the releases eventually activated, we are confident that these moorings can be retrieved. Moreover, data from the 11 moorings now recovered provide no evidence of ice in this area deep enough to snag and perhaps carry off such moorings.

Of the 5 moorings measuring pressure at sheltered coastal locations, 1 has been recovered.

Planned CTD sections across the channel have not been completed.

One third of the steel chain cached at Lafayette Bay has been transferred to the Henry Larsen. This material is needed as dead weight anchor for the moorings on re-deployment.

Instruments and mooring equipment already on board will be serviced during our week away. With the exception of anchors, 14 moorings will be ready for re-deployment at the time of our return to Nares Strait. Since instrument performance has been excellent, we anticipate that moorings yet to be recovered can be serviced for re-deployment with quick turn-around.

ICE STRENGTH COMPONENT

The MOTAN system for measuring global ice loads on the Henry Larsen is working well and has recorded a number of significant "hits" from multi-year floes.

Michelle Johnston's work on the ice has been impeded by problems with her equipment (hydraulic pump, auger motor head) and by my heavy emphasis on recovering moorings during the first 5 days of activity. She has completed a partial sampling of one floe and a more complete set of strength measurements on a second. She is far short of her goal of a complete suite of measurements on at least a half dozen multi-year floes.

RADAR DEVELOPMENT

The new Sigma Processor is working well on the standard ships radar. The rapid scanning (120 rpm) radar installed on the Henry Larsen for these trails is not working.

Evening of August 21

CCGS Henry Larsen has just weighed anchor at Pond Inlet and is eastward bound towards Baffin Bay. Anticipating about 60 hours in transit, we will resume the oceanographic work in Kennedy Channel on Thursday August 24. Fortunately, we have not been idle during our absence in the south. Data recorded by our instruments during 2003-2006 have been examined and assessed for proper functioning of the equipment (and of course for the signals of scientific interest). We have accomplished a significant fraction of the refurbishment of the instruments and moorings – cleaning, damage repair, new batteries, new anodes, re-calibration and performance testing – required before redeployment. With these tasks in hand by the time we return to Kennedy Channel, we will be able to focus on equipment yet to be retrieved and on the redeployment of the Nares Strait array.

The joint exercise with DND at Pond Inlet was blessed with good weather and went smoothly. There were quite a few journalists in attendance and our scientific programme, and its significance from the perspective of sovereignty and multi-tasking of CCG icebreakers were noted. I talked briefly with Patricia Bell of CBC, and more extensively with journalists from Canadian Press (Edmonton) and from Up Here Magazine (Yellowknife). These reporters had come direct from the Beaufort Sea Conference in Tuk and appeared informed and interested in how our work fitted within a larger framework. Primary concerns were sea ice, climate change in the North and shipping in the Northwest Passage.

The concentration of activity and attention on Pond Inlet seems indicative of a strong DND interest in the possibility of establishing a base there – airfield, docking facility, fuel capability, presence, etc. Both the community and Nunavut seem supportive.

Evening of August 25

For 2½ days, from the evening of August 21 to the morning of August 24, CCGS Henry Larsen was in transit from Pond Inlet to southern Kennedy Channel. We stopped briefly at Foulke Fjord, on the Greenland side of Smith Sound, to retrieve an instrument deployed there to measure sea level. Beyond Smith Sound, the waters of Kane Basin were heavily cluttered with icebergs, primarily tabular, among ice floes at perhaps 2 tenths concentration.

On arriving in Kennedy Channel (morning, August 24), CCGS Henry Larsen was overtaken and hailed near Cape Jefferson by a small Danish patrol vessel (100 feet). The vessel picked its way a few miles further north through heavy ice before turning and heading back down to Kane Basin.

Our first tasks were visits to two sites where we had been unable to communicate with transponders on the moorings. Because we were unsuccessful once again to provoke a response, we believe it likely that the moorings are no longer in place, perhaps carried off by icebergs. We know from the pressure records from one of the recovered moorings that some instruments had been pushed down to 200 m by a passing berg, fortunately without mishap. These moorings, which extend to within 30 m of the surface, were carefully designed with icebergs in mind. However, they may not withstand all types of iceberg encounter.

Late on Thursday morning, the remainder of the 10-ton cache of chain at Lafayette Bay on the Greenland coast was transferred to the ship.

Next, we toured the 3 sites where dragging is required to bring recalcitrant moorings to the surface. As on several previous visits, ice at all of the sites created an environment unsuitable for dragging.

Ice conditions have deteriorated appreciably during our week-long absence at Pond Inlet. Pack ice fills the western half of the channel at high concentration, and is present at about 5 tenths concentration in the eastern half. Hall Basin, where we have 2 sites measuring sea level, is even more heavily obstructed. All floes are thick multi-year ice from the Lincoln Sea, which make navigation here just as threatening as it was 35 years ago, when the Louis S St Laurent struggled all the way to Alert. The floes are much thicker, larger and less deteriorated that the ice that populated our working area when we were here earlier in the month. Average thickness in the 4-5 m range seems typical. Michelle Johnston, here to study ice strength, has not reached seawater in several holes drilled to 11-m depth. Air temperature today was -3 C. Despite bright sunshine, new ice (nilas) has been forming in sheltered areas adjacent to old floes and melt ponds are freezing

During Thursday afternoon, we started the redeployment of moorings, setting out one ice-thickness sonar. The deployment activity continued today with the placement of another ice-thickness mooring and 3 moorings that form about half of the cross-channel array for temperature-salinity. After a few teething problems, deployments have been quick and effective, barring the usual delays for encroaching ice.

Towards the end of the day, we were fortunate to discover a patch of relatively ice-free water over site KS08, where dragging is required. Captain Broderick initiated two sets of the grapples, but both were not completed because of excessive ship drift in rapid tidal flow. Dragging is a complex activity from the Henry Larsen, where the wire is deployed over the ship's side, from the well deck, and ice and current create rapidly evolving challenges.

Michelle Johnston (NRC) has completed almost full suites of measurements on 2 multi-year ice floes in the last 2 days, with on-ice assistance from ship's officers, crew and members of the oceanographic team.

We now have had a total of 7 days of operational time within in Nares Strait.

Evening of August 27

Saturday (August 26) arrived bright, clear and calm. With light wind and a temperature of -2 C overnight, nilas was widespread, particularly in the colder water around the ice floes. After drifting all night in lighter pack (3 tenths) near the Greenland coast, CCGS Henry Larsen moved after breakfast into the denser pack farther west. Our objectives were the deployment of three remaining temperature-salinity moorings and the grappling of three ADCP moorings that refused to surface on their own. But the floes were too compact, thick and large to permit deployments at selected sites. Fortunately, we found an ice-free area at KS08 large enough to attempt dragging. The wire was deployed twice, but in both instances ship's drift at 0.7 kt was too rapid to encircle the mooring with wire before drifting past it. Encroachment of heavy ice precluded a third attempt.

Reconnaissance by helicopter as far north as Hall Basin revealed the continued and rapid southward drift of large and very thick old floes from the Lincoln Sea. Robeson Channel and much of Hall Basin and the northern half of Kennedy Channel were packed with such ice. With planned mooring work presently out of the question, we returned to the Greenland side and in early afternoon started a CTD section across

Kennedy Channel following the line of moorings. Our progress was stopped by ice one third of the way across. But one scientist's pain is another's pleasure; Michelle Johnston was able to complete the survey of another suitable floe without venturing far from the ship.

Fortuitous conditions today (August 27) provided the opportunity for CTD profiles at 4 additional sites, completing about 2/3 of the 40-km section before being stopped by ice. Meanwhile, the helicopter was again launched for ice reconnaissance. On receiving the ice report in the early afternoon, Captain Broderick decided to retreat from Kennedy Channel. Although we anticipate opportunities tomorrow to deploy sea-level gauges in Smith Sound and for Michelle Johnston to conduct surveys on one or two old floes, the scientific programme (far from completion) has been abruptly terminated.

This expedition has been a sober demonstration of the unpredictability and difficulty of ship-based oceanographic research from ships, even capable icebreakers, during the short navigation season in the Canadian high Arctic.

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.

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