Fisheries and Oceans Canada
Pêches et Océans Canada
Oceans and Science
Océans et Sciences

Key Findings from International Polar Year 2007-2008 at Fisheries and Oceans Canada: Executive Summary

IPY·API
2007·2008
International Polar Year
Année polaire internationale
ᓄᓇᕐᔪᐊᑉ ᑲᔾᐱᖕᒋᑦᑕ ᐅᑭᐅᖕᒐ

Canada

Published by:

Communications Branch
Fisheries and Oceans Canada
Ottawa, Ontario
K1A 0E6

DFO/2010-1667

Cat. No. Fs23-560/1-2010E
ISBN 978-1-100-15840-2 paper

Cat. No. Fs23-560/1-2010E-PDF
ISBN 978-1-100-15841-9 PDF

Printed on recycled paper.

The electronic version of this report is available on our website: **www.dfo-mpo.gc.ca/science**

For more information or additional copies of this report, please contact the Communications Branch of Fisheries and Oceans Canada at the address above, or e-mail: **info@dfo-mpo.gc.ca**
Tel.: 613-993-0999
Facsimile: 613-990-1866
TTY: 1-800-465-7735

On the front cover, from top to bottom:

Working on the Canadian Arctic Through-flow Study (CAT), marine technician Jo Poole prepares a sophisticated, four-beam Doppler sonar on board CCGS *Henry Larsen* before it was dropped to the seabed to measure currents and ice drift in Nares Strait during 2007-2009. Photo: DFO

A walrus (*Odobenus rosmarus*) with a satellite tag on its tusk, is basking in the sun on a rocky shoreline of the Arctic Ocean. When they are warm, the blood flow to their skin surface is increased to dump excess body heat, which makes them look slightly pink. Photo: DFO

Arctic waters are sampled aboard CCGS *Louis S. St-Laurent* by physical oceanographer, Sarah Zimmerman.
Photo: © Paul Galipeau, 2007.

Livee Qulualiq of Nunavut is shown using an Iridium satellite phone to stay in touch with his community while out on a field mission. His knowledge of bowhead habitat and behaviour was necessary to researchers during a search for bowhead whales (*Balaena mysticetus*) in the eastern Arctic. Photo: DFO

The CCGS *Louis S. St-Laurent* awaits the return of IPY researchers seeking ice samples, at 78N 150W. Photo: © Luc Rainville, Applied Physics Laboratory, University of Washington, 2007.

The background photo shows the blue water, sky and the Arctic Ocean horizon from the deck of the CCGS *Louis S. St-Laurent*.
Photo © Paul Galipeau, 2007.

Table of Contents

Photos, L to R: DFO, DFO, © Paul Galipeau, 2007

Canada and International Polar Year Key Findings and Accomplishments

Earlier International Polar Years as well as ongoing Northern research identified major changes taking place in Canada's Arctic. The International Polar Year (IPY) 2007-2008 has resulted in filling in some of the gaps in our understanding of these changes and their impacts, such as enhanced understanding of Arctic ocean circulation, fluxes through the Archipelago, ice status, freshwater inputs, and the complex interplay with biodiversity and biological hot spots such as flaw leads. Beyond the scientific legacy including baseline data and new technologies, the IPY leaves behind a web of partnerships and a new generation of young scientists.

While the integrated picture will require time to assemble, with most of the fieldwork completed in 2007-2008, some key findings have already emerged:

- In 2007 and 2008, summer sea-ice extent in the Arctic reached a record-breaking minimum, and multi-year ice was reduced in extent and thickness.
- Sea-ice plays an important role in almost every aspect of the environment, for example, reducing the ocean response to storms. Open water increases surface winds which influence sea-surface currents, upper-ocean mixing and sea-surface temperatures, linking back to climate change and variability.
- Decreasing ice volume has led to an increase in the flux of organic carbon to the Arctic Ocean's seafloor. Using sediment cores collected from Arctic marine systems, researchers are exploring the burial of this organic carbon and its conversion back into carbon dioxide to learn more about the Arctic Ocean's role in the carbon cycle.

Profound changes are impacting the Arctic Ocean:

- The waters of Fram Strait Branch, of Atlantic origin, have warmed by as much as 0.5 degrees C since the year 2000.
- Upper ocean stratification is increasing due to an accelerated hydrological cycle and greater ice melt.
- The outflow of water through Fram Strait is 55,000 cubic kilometres per year and of that, the freshwater outflow is 3,600 cubic kilometres per year – more than 10 times the flow of the Mackenzie River. This through-flow may slow the global deep-ocean circulation that drives the Gulf Stream and plays an influential role in climate.
- The Arctic Ocean is becoming increasingly acidic due to the increase in anthropogenic carbon dioxide emissions and the continued addition of low alkalinity sea-ice melt water to the seasonal mixed layer.

These changes are in turn driving major impacts on ecosystems:

- In Hudson Bay, as the sea-ice declines the system is shifting from a polar bear/seal system with Inuit hunters at the apex to one dominated by cetaceans with killer whales at the apex. This shift is eroding Inuit traditional subsistence culture.

- Surveys of Traditional Inuit Ecological Knowledge (TEK) reveal uncommon sightings of marine mammals that would not normally be seen in Hudson Bay, including fifty-three individual killer whales identified from nine different sightings. Other uncommon sightings include humpback whales, Greenland shark and harp seals.
- The state of the Hudson Bay/James Bay ecosystem, as well as how specific species might respond to climate change and variability, are being further assessed through studies of the distribution, movements and critical habitat of beluga whales and Arctic chars.
- The study of the area of persistent open water in the Arctic known as the Circumpolar Flaw Lead System is exploring the importance of climate processes in changing the nature of this system and the effects of these changes on the marine ecosystem, contaminant transport, carbon fluxes and greenhouse gases.

CCGS *Henry Larsen*, support vessel to the IPY CAT study, Petermann Fjord, 20 August 2009. The tiny waterfall is actually 200m high! The glacier is unnamed. This majestic fjord is more than 1100 m deep and bordered by cliffs rising shear to 900m above sea level. It harbours a stream of ice that flows off the Greenland ice cap to form a floating ice shelf, 20 km wide and 70 km long. Since 90% of its original 600m thickness melts locally, the shelf contributes to fresh-water flow down Nares Strait, the central focus of CATs. Here the CATs' team completed surveys to find and sample the emerging melt water. Photo: DFO

Introduction

The Government of Canada's $150 million investment in International Polar Year (IPY) was focused on two themes: climate change impacts and adaptation, and the health and well-being of Northern peoples. Fisheries and Oceans Canada (DFO) principal investigators led six of the 51 IPY science projects funded under the Canadian program, all within the climate stream. DFO scientists also collaborated on many other IPY projects.

In addition to being one of the major science questions of our time, climate change has a bearing on many aspects of DFO's mandate within the Government of Canada, including habitat and fisheries management, species at risk, small craft harbours, and maritime safety and security. DFO's involvement in IPY provided insights into how climate is driven by the ocean/ice system in the Arctic as well as the state of the Arctic environment, the major impacts of climate change on the Arctic, and how climate change is affecting the ecosystems and aquatic animals upon which Northern residents depend.

The findings of IPY research, carried out in collaboration with Northern communities and peoples, are a step toward the development of strategies for the management and conservation of species and for adapting to the changing Arctic. These findings also provide solid results on which to base future science in the Arctic.

Globally, the Arctic Ocean and its connections from the Pacific to the Atlantic Ocean are now seen to be important drivers of global ocean currents. The changes in the heat budget in the Arctic due to reduced sea ice create a vicious cycle that enhances warming. Significant increases in temperature and sea levels are occurring, with the potential for global shifts in ecosystem behaviour. These potential changes are affected by chemical changes such as ocean acidification and hypoxia (low oxygen).

In Canada's Arctic, the local human dimension of climate change impacts was demonstrated in IPY projects. Traditional knowledge of ecology, weather, ice and marine mammals was shown to be important. Among the findings emerging from the research is an acknowledgement that improved community monitoring in the region is needed, and that long-term Arctic monitoring networks and a comprehensive observational system are necessary in order to deepen our understanding of Canada's polar environment.

Coincident with the climate change focus of International Polar Year, in 2008, DFO established a national research effort, the Climate Change Science Initiative (CCSI). Under the CCSI, climate change research at DFO is focused on understanding the role of oceans in regional climates to better predict and manage future climate change impacts; assessing impacts and vulnerabilities of climate change on ecosystem composition, structure and function; and investigating emerging issues that affect ecosystem health, including hypoxia and ocean acidification.

Major IPY Projects led by Fisheries and Oceans Canada

Canada's Three Oceans (C3O) –Principal Investigator: Dr. Eddy Carmack

Changes within the ice cover, water column and ecosystems of the Arctic Ocean are closely linked to the global system, particularly to the bordering subarctic Pacific and Atlantic, and must be explored in this context. Changes due to global climate change and variability are expected to be the "biggest and fastest" and to have the greatest impacts at high latitudes.

The Canada's Three Oceans (C3O) project (2007-2011), in partnership with the ongoing international Joint Ocean Ice Study (JOIS), set out to gather integrated, multidisciplinary baseline information on the physical, chemical and biological structure of subarctic and Arctic waters around Canada. This baseline will provide:

Dr. Eddy Carmack. Photo: DFO

- a solid foundation for assessing and quantifying ongoing and future changes to both the shelf and basin regions of the western Arctic Ocean;
- valuable knowledge for addressing emerging issues such as warming, ice cover retreat, species invasion, hypoxia and acidification; and
- a solid basis for practising good governance and decision-making related to the management and conservation of species and for adapting to the changing Arctic.

Principal investigator Dr. Eddy Carmack of the DFO Institute of Ocean Sciences led a C3O team of scientists from both Canadian and foreign governments as well as academia. The team collected data along a 15,000-kilometre stretch of marine Canada through both Arctic and subarctic waters, linking the eastern Pacific, Arctic and western Atlantic. Data was collected from the surface to the seabed, from the smallest organisms (viruses) to the largest (whales), and from the Pacific to the Arctic to the Atlantic. Such far-reaching research was made possible with the help of two Canadian Coast Guard icebreakers and crews that carried out two annual missions, traversing the Northwest Passage, from the east and the west.

C3O research has identified changes already underway in the Arctic Ocean, including:

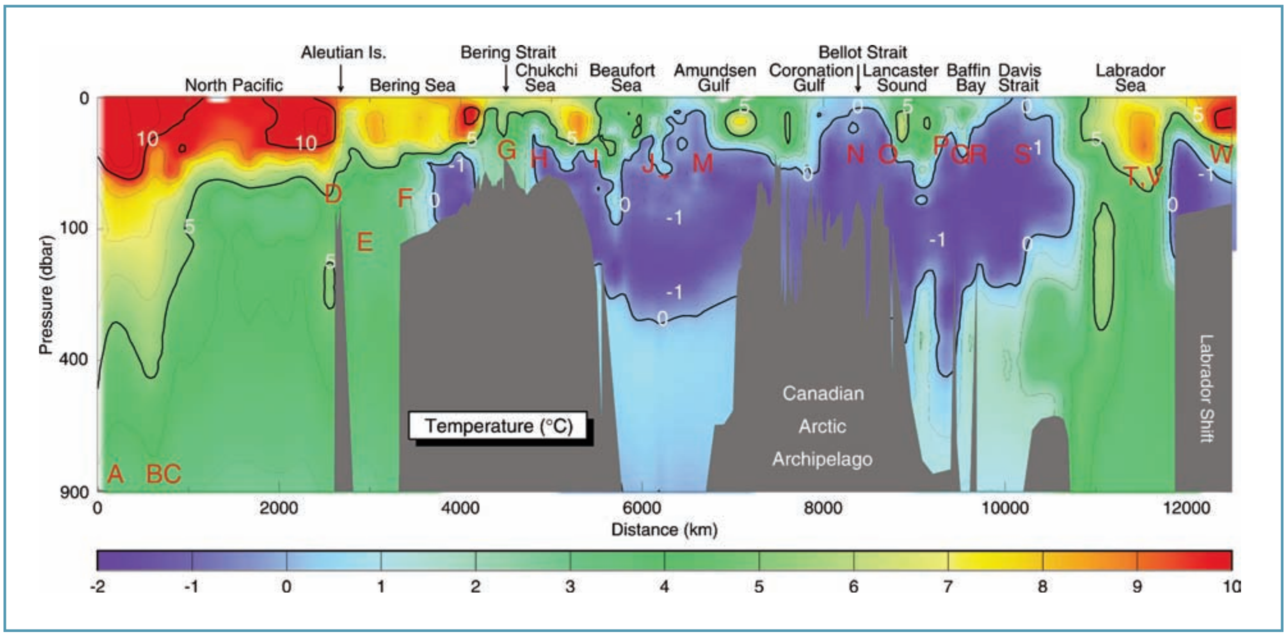
- **Ocean Warming:** Ocean temperature and related structural changes have been observed from top to bottom, including the seasonal mixed layer. Waters of Atlantic origin, in particular the Fram Strait Branch have warmed by as much as 0.5°C since the year 2000. Ecosystem changes are likely to be greatest in the seasonal mixed layer, where substantial temperature increases are associated with ice removal and lowered albedo (less reflection of the sun's radiation). This may push biota beyond their thermal limits or lead to pelagic communities that favor smaller micro-organisms. Warming may also result in the breakdown of current barriers and invasion of new species into Arctic waters.

- **Causes and Consequences of Sea-ice Retreat:** During the primary IPY field years of 2007 and 2008, summer sea-ice extent in the Arctic reached a record-breaking minimum and a reduction in the extent and thickness associated with reduced multi-year ice. Oceanographic processes affecting sea-ice extent associated with the inflow of Pacific-origin water were identified and monitored. Increased volumes of low salinity and low-alkalinity sea ice melt are accumulating in the Beaufort Gyre with major biological implications.

- **Altered Salt-Stratification:** An accelerated hydrological cycle combined with greater ice melt in summer is increasing upper ocean stratification which may inhibit the flux of nutrients into the sunlit euphotic zone (region of photosynthesis) and potentially alter food webs.

- **Shifting Ocean Currents, Fronts and Barriers:** Fronts and water mass boundaries play an important role in global change. One example of altered circulation is the apparent intensification and southeastward shift of the Beaufort Gyre during the 2000s.

- **Changes by Advection:** Findings also point to changes within the Arctic caused by advective processes (the horizontal flow of sea water as a current) originating in subarctic regions. For example, significantly warmer Atlantic-origin Fram Strait Branch water reached the Northwind Ridge along the western reaches



Based on measurements taken by the Canada's Three Oceans research team in the summer of 2007, a vertical section extending from Victoria in the Pacific to Halifax in the Atlantic reveals ocean temperatures ranging from -2ºC (dark blue) to 10ºC (dark red) from the North Pacific to the Labrador Sea. The measurements, taken at depths of up to 900 dbars (1 dbar equals about a metre), will increase our understanding of the changing ocean climate.

of the Canada Basin in 2002 and subsequently spread across most of the southern basin interior by 2007. The advection of subarctic water masses, and their modification upon entering the Arctic Ocean and moving across the pan-Arctic system, has fundamental impacts on ice cover, ocean properties and ecosystem dynamics.

- **Invasion of non-Indigenous Species and Altered Food Webs:** Regional warming may lead to the break down of current barriers and invasion of species not usually found in Arctic Ocean waters.
- **Ocean Acidification:** A decrease in ocean pH — caused by the increase in anthropogenic carbon dioxide (CO_2) emissions, which dissolve in surface waters to form carbonic acid — is exacerbated in the Arctic Ocean by the continued addition of low alkalinity sea ice meltwater to the seasonal mixed layer. This subsequently decreases the saturation state of calcium carbonate. (The saturation state is the degree to which seawater is saturated with a mineral such as calcium carbonate. It is denoted by the Greek symbol Ω. Fully saturated water has a saturation state of Ω =1.0. Water with Ω of less than 1 is undersaturated and the mineral will tend to dissolve. Water with Ω of more than 1 is oversaturated and the mineral will tend to precipitate.) In 2008, the upper waters of the Canada Basin had already become undersaturated with respect to aragonite, a relatively soluble form of calcium carbonate found in plankton and invertebrates. This will affect calcifying biota and the composition of marine ecosystems in general.
- **Hypoxia:** the Arctic Ocean shows high resilience to hypoxia owing to relatively strong ventilation (the sinking of oxygen-rich surface waters to depth).

The original and ongoing goal of C3O is to gather data over a long enough time period to quantify change. The research team hopes to turn over a major portion of C3O monitoring methods to local coastal communities within the coming decade so they can carry out as much marine monitoring as possible to aid ongoing climate change studies. Another goal is to link the large-scale view of C3O to the regional issues of coastal communities.

Canadian Arctic Through-flow Study (CATs) – Principal Investigator: Dr. Humfrey Melling

The Canadian Arctic Through-flow Study (CATs), a component of the international Arctic Sub-Arctic Ocean Fluxes (ASOF) project, investigates flows of fresh water, sea water and sea ice that pass from the Arctic Ocean to the Labrador Sea through the Canadian Archipelago. This exchange between the world's oceans is a critical component of global ocean circulation, the hydrologic cycle and climate.

Led by Dr. Humfrey Melling, the CATs team installed recording instruments in four ocean gateways between the Arctic and the Atlantic for the two years of IPY — Nares Strait, Cardigan Strait, Lancaster Sound and Bellot Strait — to monitor ocean currents, salinity, temperature, ice drift and thickness. During expeditions to install and retrieve instruments, the team surveyed the thickness and strength of ice floes and sampled seawater to measure trace chemicals that reveal the composition and origins of the through-flow. Automatic weather stations measured surface wind and air temperature within Nares Strait, and computer models incorporating new data were used to test understanding of through-flow and its impacts on ocean climate and ecosystems.

Working on the Canadian Arctic Through-flow Study (CAT). Photo: DFO

Key results of CATs to date include:

- The magnitude of Canadian Arctic Through-flow: Outflow of Arctic water at 1.75 million cubic metres per second (totalling 55,000 cubic kilometres per year); outflow of fresh water at 115,000 cubic metres per second (totalling 3,600 cubic kilometres per year), more than ten times the flow of the Mackenzie River;
- The proportions of sea water from the nutrient-rich Pacific (40%) and from the Atlantic (60%);
- The proportions of flow through Nares Strait (45%), Lancaster Sound (40%) and Cardigan Strait/Hell Gate (15%);
- Model simulations that replicate these observed proportions and indicate that water flows in response to a small (approximately 10 cm) difference in sea level between the Beaufort Sea and Baffin Bay;
- The through-flows move in relatively narrow (10 km) 'rivers' that do not fill the full width of the straits;
- The through-flow is 80% larger when ice is drifting than when it is land fast. The flow under fast ice is both isolated from the wind and slowed down by friction with the ice;
- Channelling of airflow through Canadian Arctic straits creates very strong winds that act to enhance through-flow when ice is not land fast;
- Very thick old sea ice remains common in the Canadian High Arctic, despite the large recent decrease in the presence of such ice in the Arctic Ocean.

With a warmer global climate, more fresh water will enter the Arctic Ocean via Pacific inflow, increased precipitation and northern rivers. The outflow of fresh water will increase to establish a new Arctic freshwater balance. The outflow ultimately returns fresh water to the tropical oceans where it originated.

Changes in the storage and through-flow of fresh water from the Arctic Ocean will likely impact ecosystems of the Arctic and eastern Canadian waters. Fresh water is less dense and doesn't mix well with saltier, deeper ocean water, forming a "cap" over the surface of the ocean that impedes mixing. Mixing is the mechanism that drives the upward movement of nutrients to nourish plankton growing near the surface, the foundation of the Arctic food chain. It also drives an upward flow of oceanic heat to the surface, which has the potential to melt sea ice.

Suppressed convective mixing in the Labrador Sea, a possible consequence of fresh water delivery from the Arctic, may slow the global deep-ocean circulation that plays an influential role in the Earth's climate.

Results from CAT will provide scientists with new insight into the changes that are taking place, and enable them to refine predictions about future Arctic climate change and its impacts on Arctic ocean circulation, marine ecosystems and human activities.

Impacts of Severe Arctic Storms and Climate Change on Arctic Coastal Oceanographic Processes – Principal Investigator: Dr. William Perrie

Arctic storms seem to be growing in strength as the global climate warms, causing concern about the impacts on coastal lands and waters, which play a vital role in the daily lives and culture of Northerners. To explore this issue, DFO research scientist Dr. William Perrie of the Bedford Institute of Oceanography is leading a major IPY project to investigate the effects of intense storms and severe weather on oceanographic processes in the Southern Beaufort Sea and the Western Canadian Arctic. The findings are providing valuable information about the impact of storms on coastal communities, expected use of coastal marine environments, Arctic lifestyle, aquatic species, and activities related to offshore resource development.

Arctic storms influence marine winds, waves, currents, ice, storm surges, coastal erosion and sediment transport. These oceanographic processes can be affected by variability and changes in the intensity and direction of storms associated with climate change and warming, which alter the areas of open water and ice cover. Increased open water in the Arctic affects weather.

The research team is gathering information on key storm and ocean processes in the region. This project is essentially a computer modelling study using a combination of archived surface and

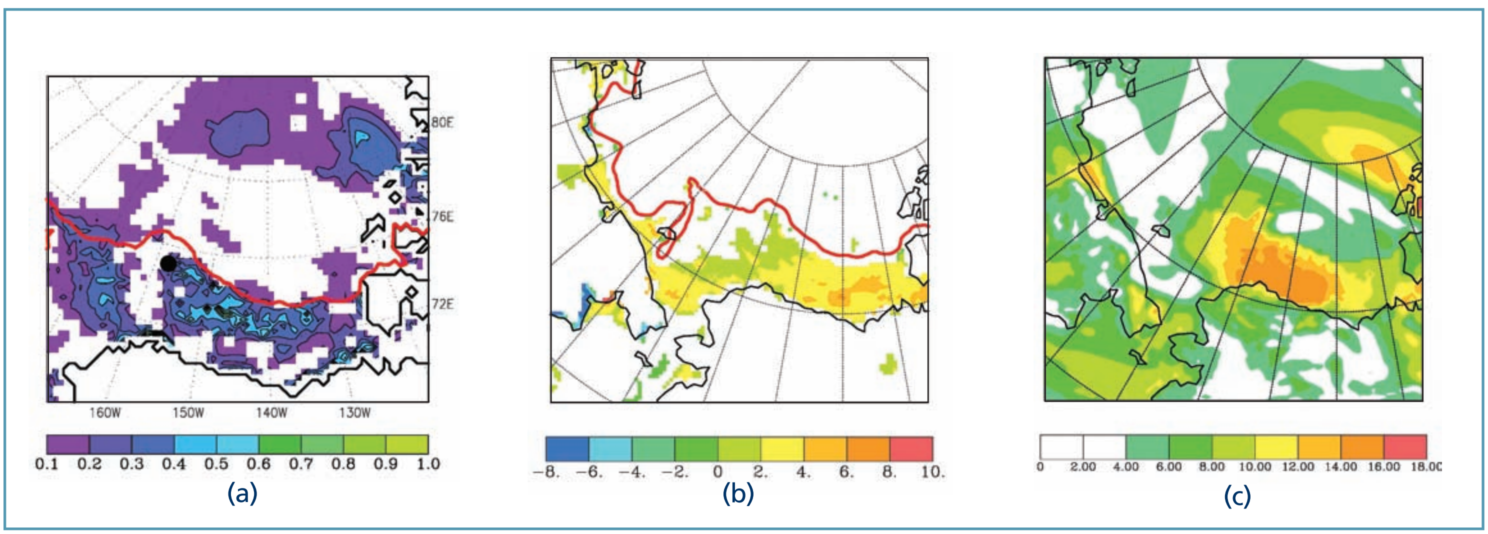


Figure 1. (a) Speed (m/s) of surface current at 0:00 UTC 31 July 2008, (b) differences of surface temperatures (°C) at 12:00 UTC 31 July 2008 between coupled and uncoupled runs, (c) coupled model wind field. Only the absolute values greater than 1 °C are shown. Red lines show the simulated ice edge by CRCM-CIOM. Black dot represents the storm center at 0:00 UTC 31 July. The thick red line represents simulated ice edge.

upper-air station data, as well as data from the U.S. National Centers for Environmental Prediction (NCEP) global, the North America Regional Reanalysis (NARR) in the U.S.A., the United Kingdom's Hadley Centre (sea ice), and 20-year wind and wave hindcast data for the Beaufort constructed by the Meteorological Service of Canada (MSC). The impacts of severe storms are explored using coupled atmosphere-ice-ocean model simulations of episodic storms, sediment transport, coastal erosion, ice cover and movement for the Beaufort Sea and neighbouring areas.

Key results to date include:

- The identification of atmospheric circulation patterns for extreme wind events along the Beaufort coast, including complex cyclogenesis processes (low-pressure circulation atmospheric patterns), which have been identified in association with an especially extreme storm surge event in the region.
- The Mackenzie River plume has a large-scale influence on the surface waters of the continental shelf region, with fresh water extending several hundred kilometres from the mouth of the river. Impacts of coastal storms are readily evident on currents and ocean properties in the plume-ocean interactions.
- Storm intensification can be influenced by open water expanses during the summer/early autumn season. Bigger waves can form in larger areas of open water and storms can have potentially more of an impact on coastlines. Research into the role of increased open water on Arctic storms during summers uses a coupled atmosphere-ice-ocean model to simulate ocean surface fluxes during a storm that moved from the Chukchi Sea into the Beaufort Sea in late July 2008. The findings reveal that the dominant ocean-surface response to the storm occurs over open water regions. Maximum storm-induced surface currents can reach 0.7 m/s (metres per second) and upper-ocean mixing can result in sea surface cooling of up to 6°C in coastal waters of the southern Beaufort Sea coast, whereas no significant sea surface temperature response is seen in the area covered with sea ice.
- Model results also reveal that increased open water in the Chukchi and Beaufort seas significantly increases the surface winds associated with a storm by as much as about 4 m/s. The surface current associated with the storm is mainly located in the open water, and is very weak in the area covered with sea ice. Thus, ice plays an important role in reducing the ocean responses to the storm, which has implications in light of global climate change and variability.

Arctic coastal communities are vulnerable to storm surges and coastal erosion. Photo: Tuktoyaktuk, NWT, Steve Solomon, NRCan, 2000.

The results of this research will provide useful information toward the development of adaptation strategies relevant to coastal communities.

Global Warming and Arctic Marine Mammals (GWAMM) – Principal Investigator: Dr. Steven Ferguson

The monitoring of apex predators including polar bears, seals and whales is providing valuable knowledge about marine ecosystem change in the Arctic and the drivers of change. Global Warming and Arctic Marine Mammals (GWAMM), an IPY study led by Dr. Steven Ferguson of the DFO Freshwater Institute, is exploring:

- how marine mammals will adapt to global warming and the possibilities for future survival;
- the relationship between warming temperatures and the habitats of polar bears, seals and whales; and
- the potential effects of global warming on reproduction and how marine mammals will survive.

The GWAMM team developed a community-based monitoring network in the greater Hudson Bay region of the Canadian Arctic through which it is working with Inuit communities during their subsistence hunts to collect biological samples from marine mammals. Prey species representing parts of the marine environment are also being gathered. A reference collection of samples from the complete food web is being developed to build a model of trophic interactions from marine mammals down to nutrients and phytoplankton. Sample analysis will provide new knowledge about marine mammal genetics, reproduction, foraging ecology, disease and stress.

GWAMM is also a network project that links to other marine mammal research projects in the region including satellite-telemetry movement studies of polar bears; seals and whales; photo-identification of bowhead and killer whales; the use of chemical signals to understand whale and seal diets; and tracking predation effects caused by invasive species such as killer whales.

While data analysis for GWAMM is still ongoing, preliminary findings include, in part:

- As sea ice declines, the Hudson Bay marine ecosystem is shifting from a polar bear-seal system with Inuit hunters at the apex to one dominated by cetaceans with killer whales at the apex. This shift is eroding Inuit traditional subsistence culture;
- Contaminant levels increase both with late *and* early spring breakups and create problems associated with the continuing loss of sea ice;
- Movements of polar bears and ringed seals differ. Preliminary satellite telemetry results reveal that seals take refuge on sea ice in winter to avoid polar bear predation, while

In the Belcher Islands, Johnassie Ippak (left) and Lucassie Ippak (second from left) of Sanikiluaq, Nunavut, and graduate student Carie Hoover (right) of the University of British Columbia assist DFO research scientist Dr. Steven Ferguson (second from right) and on a research project exploring the effects of climate change on Arctic marine mammals. The research involves, in part, attaching satellite transmitters to ringed seal to track and study their movements. Photo: DFO, 2008

With declines in sea ice in Hudson Bay, killer whales are replacing polar bears as the apex predator in the marine food web. Photo: DFO, 2007

bears select areas that increase opportunities to successfully hunt seals in spring. Thus, with warming and loss of sea ice, both species are predicted to do poorly. Results will assist in predicting how these species will respond to continued loss of sea ice.

- Invasion of non-indigenous species is increasing. Evidence has accumulated to connect the loss of sea ice with the increased number of killer whales sighted in Hudson Bay waters. Fifty-three individual killer whales were identified from nine different sightings;
- Traditional Inuit Ecological Knowledge (TEK) indicates that killer whales are a relatively new addition to the marine mammal fauna of Hudson Bay and that their increasing presence and predation may be causing demographic problems for bowhead whales and may eventually impact narwhal and beluga whales. Inuit knowledge of killer whales indicates that killer whales feed largely on marine mammals and not fish. This research confirmed the value of combining TEK with western science to understand the activities of a predator living at low densities and capable of moving rapidly across vast scales.
- In TEK surveys, local hunters report uncommon sightings of other marine mammals that would not normally be seen in Hudson Bay including humpback whales, Greenland sharks and harp seals. This is likely associated with the continued loss of sea ice.

Ultimately, the findings will provide Northerners with the information necessary to adapt to a rapidly changing world where Arctic marine mammal populations are showing demographic strain due to polar warming. The research will also inform the development of strategies for species conservation and management.

Pan-Arctic Tagging of Beluga Whales (PATOB) – Principal Investigator: Dr. Mike Hammill

Using a blend of traditional ecological knowledge (TEK) and western scientific approaches, Dr. Mike Hammill at DFO's Maurice Lamontagne Institute is leading an IPY study on the distribution, movements and critical habitat of beluga whales. The findings will help improve the management of beluga, which are an integral part of the traditional subsistence Inuit culture. The research will also provide insights into the state of the Hudson Bay-James Bay ecosystem and how beluga will adapt to climate change, which may impact migration corridors, seasonal foraging patterns, and potentially increase competition as more temperate species expand into their range. Because of their major role in the Arctic ecosystem, the health of the beluga is important to all Arctic life.

Hunting, initially by commercial whalers, reduced eastern Hudson Bay and Ungava Bay beluga numbers. These stocks are now classified as 'endangered' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Management activities over the last decade have reduced harvest levels, however, continued access to beluga remains important to the Inuit subsistence culture.

Tracking beluga using satellite telemetry, the team is gathering information about their habitats, migration patterns, foraging behaviour and over-wintering areas at a fine scale. Telemetry also provides water column temperature and salinity profiles that can contribute to modelling of weather and climate changes. This information is combined with traditional knowledge and observations of local people. TEK reflects the resource use and ongoing observational experience of local people, which exceeds the geographic and time scales examined by most scientific studies and certainly that of the IPY program. The researchers are also collaborating with other international beluga tagging programs.

Researchers fit a beluga whale with a satellite telemetry device to track its movements and learn more about its migration patterns and habitat. The device also gathers environmental data from the Hudson Bay-James Bay ecosystem for use in climate and weather modelling. Photo: DFO, 2008

Major findings of PATOB to date include:

- Genetic analyses of skin tissue have identified several stocks of beluga in the Hudson Bay complex. This has revealed that eastern Hudson Bay animals form a different stock from other beluga in Hudson Bay (e.g., western Hudson Bay), and James Bay beluga may also show sufficient differentiation, but sample sizes are still quite small. These findings show strong agreement with trace metal analysis of beluga skin tissue which is being used, along with isotopes, to further validate stock identification. Isotope ratios and trace metals may also provide insights into foraging behaviour of beluga.
- James Bay beluga over-winter in James Bay, providing further evidence that this is a distinct stock of animals. The uniqueness of this stock also shows that the more conservative management approach that separates Eastern Hudson Bay beluga from James Bay beluga must be maintained.
- Beluga are much fatter and in better condition when they begin the spring migration back towards Hudson Bay than they are during the fall migration from Hudson Bay.
- The fall, northward migration by belugas is mainly along the coast since the animals benefit from a northward flowing current that strengthens during the fall. The timing of this migration appears to be linked to water temperature. Changes in ice formation and water temperature may alter migration patterns of beluga and impact hunting opportunities for Nunavik Inuit. For example if the fall migration of animals into Hudson Strait is delayed, then whales will be passing in front of Hudson Strait communities at a time of year when days are shortening, reducing access to whales.
- Whales undergo an inshore-offshore movement that appears to be linked to general tidal changes.

Over the last 15 years, satellite transmitters have been deployed on more than 100 beluga whales around the world. International collaboration within PATOB provides the opportunity to complete meta-population analyses across several ocean basins, to examine differences in habitat characteristics, movement patterns and habitat use between relatively sedentary beluga (Cook Inlet, Alaska & Svalbard, Norway) and very migratory beluga (Hudson Bay, west Greenland). These global comparisons will improve our understanding of how beluga have evolved within their polar environments and will assist in developing predictions of how beluga might respond to larger scale climatic changes.

Climate Variability and Change Effects on Chars in the Arctic – Principal Investigator: Dr. James Reist

Arctic chars are important to the culture and economy of Northern peoples, and are considered a keystone species in freshwater and near-shore marine environments. Their widespread distribution and sensitivity to environmental effects at many levels in Arctic ecosystems makes them key indicators of the overall health of northern aquatic ecosystems, many aspects of which are at significant risk from increased climate variability and change. Dr. James Reist of the DFO Freshwater Institute is leading an IPY project that investigates the effects of climate change and variability on biodiversity in chars, and the relevance of the effects for those using Arctic char.

Dr. James Reist with an Arctic char in Quttinirpaaq National Park, 2007. Photo: DFO

Since Arctic chars form the basis of household and commercial fisheries, the ability of Northerners to adapt to change requires vital information on the roles in the ecosystems, thermal ecology, biodiversity, and mercury contaminant interactions of this species.

Research activities include assessing: char biodiversity and trophic (feeding) variation in the Canadian North and its role in ecosystem structuring and function; the thermal ecology (temperature histories) of chars and how climate change might affect these; the link between climate change and the bioaccumulation of mercury; and changes in char populations as directly observed through community-based monitoring.

Key results to date include:

- Arctic char collected from Lake Hazen and surrounding lakes in Quttinirpaaq National Park, Northern Ellesmere Island, Nunavut, confirmed the presence of three forms of Arctic char (large, small and benthic) in Lake Hazen, rather than the two forms (large and small) initially thought to occur there. Since Arctic char is the only fish present in fresh waters in this area, the three forms appear to act as distinct ecological species performing different roles in the ecosystem.

- Recent extension of research to lake trout and lake trout-dominated systems in the Western Arctic suggest hidden levels of biodiversity also exist for this char species; whether these act like Arctic char ecological species is unknown.

- High levels of biodiversity in char species complicate understanding the effects of climate change and predicting its impacts (and thus preparedness), however this might give chars greater inherent resiliency to adapt to climate change.

- Length-at-age declines with latitude for anadromous (sea-run) and lake-dwelling chars and age-specific growth rates are variable over latitude. Climatic fluctuations can have both direct physiological effects on Arctic char growth patterns as well as indirect effects through changes in ecosystem dynamics such as prey availability. Developing appropriate management responses for chars to climate change is thus complicated.

- Trace elements in otoliths or ear stones are good indicators of age, thermal regimes and types of environments (freshwater, estuarine, marine) used by chars. Analyses of otoliths using different trace elements will likely enable discrimination among Dolly Varden stocks of the northwestern Arctic, comparison of ambient and occupied thermal regimes by young chars, and detection of variations in life history.

- Investigations of interactions of life history and trophic ecology with climate changes and contaminant concentrations in coastal Arctic lakes revealed that sea-run (anadromous) lake trout have lower mercury concentrations than resident (i.e., freshwater-only) lake trout, while sea-run and resident Arctic char have similar mercury concentrations. Lake trout have lower concentrations of mercury in lakes where sea-run populations of Arctic char are also present. Interpreted in the context of climate change, these findings indicate that if climate warming negatively affects the success of marine migrations for Arctic chars and lake trout, there will likely be impacts on contaminant concentrations in these fishes. The findings are significant for coastal northern communities that use lake trout and Arctic chars as a food source, because subsistence fishers could potentially decrease their fish-derived mercury intake by preferentially fishing and eating Arctic chars rather than lake trout, or by preferentially using anadromous rather than resident lake trout (i.e., catch them at sea).

Arctic char from Lake Hazen on Ellesmere Island, Nunavut, 2007. Photo: DFO

The findings of this research will also aid in the development of conservation and management strategies to ensure the sustainability of chars, the continued availability of as a food source, and the vitality of the entire northern aquatic ecosystem. This in turn will help Northerners adapt to the changing Arctic.

Key IPY Projects with collaboration from Fisheries and Oceans Canada

Circumpolar Flaw Lead System Study (CFL) –Principal Investigator: Dr. David Barber (University of Manitoba) and co-leader, Dr. Gary Stern (DFO)

Also key to scientific knowledge of the Canadian Arctic is the major IPY study led by Dr. Dave Barber from the University of Manitoba, Centre for Earth Observation Science. Through the Arctic winter in the Beaufort Sea, the Canadian research icebreaker *CCGS Amundsen* and a multidisciplinary team of scientists from 15 countries undertook the Circumpolar Flaw Lead System Study (CFL). The study, in an area of persistent open water known as a flaw lead, examined the importance of climate processes in changing the nature of a flaw lead system, and the effect of these changes on the marine ecosystem, contaminant transport, carbon fluxes and greenhouse gases. DFO senior research scientist Dr. Gary Stern was a study co-leader, with a focus on contaminants. Dr. Stern's team focused on how climate change could alter contaminant transport processes and cycling, contaminant pathways (biomagnification) and levels, and the health of Arctic aquatic ecosystems. Contaminants pose a hazard to Arctic fish and marine mammal health, and to Northerners who harvest them as part of their traditional diet. Results from the CFL study are expected to help assess the vulnerability of coastal Inuit communities to climate change; project the impacts of climate change on traditional food security and community health; and help provide information to develop adaptation strategies.

The Carbon Cycle in the Canadian Arctic and Sub-Arctic Continental Margin

Organic carbon cycling in Arctic marine systems is expected to be highly sensitive to climate change and critically important in terms of feedback. Climate change can increase atmospheric CO_2 by enhancing the oxidation of released or exposed organic carbon (positive feedback), or it can provide more opportunities for carbon fixers to convert CO_2 to organic carbon (negative feedback). The Arctic Ocean contains the largest relative shelf area of all oceans (approximately 50 percent) and receives large inputs of dissolved and particulate material from rivers. The previous establishment of budgets for organic carbon and sediments for this ocean set the stage for the construction of mass balances for other elements undergoing geochemical cycling.

According to IPY research on carbon in the Arctic Ocean led by Dr. Charles Gobeil of the Université du Québec, and involving DFO senior research scientist Dr. Robie Macdonald, decreasing ice volume during the past 50 years has led to an

Dr. Charles Gobeil (right) has taken many sediment cores in the Arctic Ocean, including a deep core, at approx. 3500 metres, at the North Pole. Also in the tiny sediment lab on board the CCGS *Louis S. St. Laurent*, graduate student Marie-Ève Randlett and Dr. Robie Macdonald, author of "The Organic Carbon Cycle in the Arctic Ocean". Photo: DFO, 2008 increase in flux of organic carbon to the Arctic Ocean's seafloor. Sediment cores were collected in Davis Strait, Baffin Bay, the Canadian Archipelago and the Beaufort, Chukchi and Bering Seas. Core samples are currently undergoing analysis for a number of major and trace elements (Mn, Fe, S and others) and organic biomarkers (e.g., hydrocarbons, sterols, terrestrial plant products). From these data the research team is developing two parallel stories: one story is about the burial of organic carbon based on the types of molecules that remain in the sediments, and the other is about the conversion of organic carbon back into CO_2 based on elements that respond to the intensity of organic carbon metabolism. The balance between these two processes determines the Arctic Ocean's role in the carbon cycle and future change will occur through altering that balance.

The results of the sediment core measurements will help us to understand how organic carbon metabolism affects the cycles of other elements, and how we can apply the records of these other elements to understand present and past carbon cycling in the Arctic. Elements like manganese, cadmium and molybdenum have been applied as indicators of past ocean conditions; as such, understanding of their basin-scale behaviour in the Arctic is necessary before we can apply them to understanding past conditions in the Arctic Ocean or use them to monitor future change. Because the Arctic Ocean is semi-enclosed, we can for the first time produce basin-scale budgets that will have importance for understanding the cycling of these elements in other oceans as well. Our results demonstrate strong regional contrasts in sediment accumulation rates in sources of material from land or the ocean, in the sequestration of organic carbon into sediments, and in the overall chemical composition of the sediments.

Determining the Diet of Greenland Sharks in a Changing Arctic

The Greenland shark is the largest fish (up to seven metres) and one of only two shark species that regularly inhabit the Arctic seas. Since these sharks can be very numerous in the Arctic, their impact on the ecosystem is likely to be large. However, nothing is known of their movements, and thus their capacity to move to take advantage of food supplies in other areas, or to avoid fishery mortality. DFO research scientist Dr. Steven Campana is working in collaboration with principal investigator Dr. Aaron Fisk at the University of Windsor to satellite tag 10 Greenland sharks in the eastern Arctic to monitor their movements, water depth and temperature for periods of up to a year after tagging. The results were startling, showing long-distance migrations of more than 1,000 kilometres by most of the sharks. Many sharks dove to depths of up to one kilometre. These results indicate that a single population is likely to extend over broad areas of the eastern Arctic, and that Greenland sharks are much more mobile than was previously thought, making them a system-wide predator in the Arctic Ocean.

Engaging Communities in the Monitoring of Zoonoses for Country Food Safety Concerns in Canada

The safety of "country food" in the Canadian Arctic is a concern to Northerners due to the potential presence and threat of zoonotic diseases. To address this issue, DFO biologist Ole Nielsen is participating in an IPY project to better understand wildlife and disease ecology in order to determine potential public health risks related to the consumption of raw contaminated game meats. The main goals of the project, led by

In this photo, provided by Manon Simard of the Makivik Corporation, we see Inuit eating bowhead whale meat, an element of their traditional country food diet.

Manon Simard (Nunavik Research Centre, Makavik Corporation), are to:

- establish the distribution of *Trichinella sp, Toxoplasma gondii, Anisakidae* worms, *E. coli 0157* and *Salmonella spp* in the traditional food of Northerners;
- set up laboratory facilities in Nunavik, N.W.T., and Nunatsiavut, N.L.;
- train local people in wildlife sampling and diagnosis of the five diseases of interest;
- develop, refine and validate simplified (field) diagnostic tests for *Toxoplasma gondii*; and
- develop a Canadian web-based database of Arctic wildlife diseases that can be accessed by all Northerners.

To date, the research team has tested more than 200 fish and 109 marine mammals for Anisakidae nematodes and 690 Arctic mammals and birds for cold resistant *Trichinella* (*T. nativa* and *Trichinella* T6). New results from this study, combined with climate data and archived samples and data, will enable scientists to better assess the impacts of food- borne diseases on human health in a warming Arctic and allow Northerners to take control of testing for diseases of most concern.

Arctic Surface Ocean – Lower Atmosphere Study (SOLAS)

DFO senior research scientist Dr. Michael Scarratt participated in the Arctic SOLAS (Surface Ocean - Lower Atmosphere Study) led by Dr. Maurice Levasseur of the Université Laval. This IPY project explores the interactions between sea ice, water circulation, marine microbiological activity and emissions of gases – including carbon dioxide (CO_2), nitrous oxide (N_2O), volatile organic compounds (VOCs), halocarbons, and dimethylsulfide (DMS) – from the ocean to the Arctic atmosphere. The study seeks to answers to two key questions regarding the influence of marine processes on Arctic climate: 1) How will the increased flow of Pacific waters through the Canadian Archipelago affect the dynamics of climate-active gases in the ocean, and 2) How will these gases be affected by a reduction of sea-ice cover, and increased areas of open water? Two missions aboard the Canadian research ice-breaker CCGS *Amundsen* enabled the SOLAS team to make an extensive survey of these trace gases and aerosols in the High Canadian Arctic, from Baffin Bay to the Beaufort Sea. Among the findings to date: the first measurements of the greenhouse gas nitrous oxide (N_2O) in sea ice reveal it is present at approximately 30% of atmospheric levels. Such undersaturation suggests that sea-ice may act as a source of N_2O to the atmosphere during freeze-up and a sink for N_2O during break-up. This process helps to explain the known seasonal variations of N_2O in the atmosphere.

Arctic Freshwater Systems: Hydrology and Ecology

The multidisciplinary Arctic Freshwater Systems project combines field-based, laboratory, and modelling studies to assess the hydrology and ecology of northern freshwater ecosystems including a range of Canadian Arctic lake, riverine and delta freshwater systems. Co-led by Drs. Fred Wrona and Al Pietroniro of Environment Canada, this initiative involves a network of 31 investigators (including Dr. James Reist of the DFO Freshwater Institute), more than 60 collaborators, and more than 70 student/post-doctoral researchers. The project addresses four major research priorities:

- **Freshwater Flux and Prediction:** Improving process-level understanding and modelling capability of snow, rain, runoff, evaporation, and change in water dynamics and storage in key polar aquatic environments, leading to better estimates of freshwater flow to the Arctic Ocean;

Photo courtesy of Nikolaus Gantner, a postdoctoral fellow seen here, doing Arctic char research towards his PhD.

- **Nutrient Flux and Prediction:** Gathering new information and developing new modelling capabilities for ice jam flooding during spring break-up in the Mackenzie Delta (a key event that helps replenish water and nutrients in the Delta lakes) and nutrient transport to the Beaufort Sea;
- **Aquatic Ecosystem Hydro-ecology and Ecological Integrity:** Improving understanding of how climate variability and change will impact the biodiversity and ecology of Arctic freshwater systems, and developing a unique legacy database of freshwater biodiversity (structure and function) and related environmental information on Arctic freshwater ecosystems (lentic and lotic); and
- **Community-based Capacity Building and Outreach:** Developing and providing tools and capacity in northern communities for improved community-based monitoring and assessment of the status and trends of the health and integrity of Arctic freshwater ecosystems.

A major sub-component of the Arctic Freshwater Systems project deals with the potential effects of climate variability and change on freshwater ecology of tundra lakes in the Mackenzie Upland Region in the western Canadian Arctic. The shorelines of many upland tundra lakes found in the region are subject to slumping into the lake as the underlying permafrost thaws. Such slumping is used as an analogue for the effects of climate change as the frequencies of these slumps are expected to increase under a warming climate. These slumps deliver substantive sediments, organic materials and nutrients to the lakes. Dr. Reist contributes to the studies to understand the effects of the slumps on the lake water chemistry, and food webs including fishes such as lake trout, northern pike and whitefish. Dr. Reist is associated with this work due to its relevance to inland fisheries important to indigenous peoples of the area.

This research has also helped the development of a unique legacy database including information on aquatic biota (e.g., benthic insects, fishes) that will be one of Canada's contributions to the international IPY legacy Circumpolar Biodiversity Monitoring Programme (CBMP) under the Conservation of Arctic Flora and Fauna (CAFF) working group of the Arctic Council.

The Mackenzie River Delta, seen here in an ENVISAT/MERIS satellite image acquired in September, 2009, is a complex hydrological and ecological system that was the focus of multidisciplinary study during IPY. Data gathered during IPY combined with new modeling capabilities are improving our knowledge of how the river provides nutrient transport to the Beaufort Sea, and during events such as ice-jam flooding during spring break-up, how the river replenishes the water and nutrients in hundreds of Delta lakes. Image courtesy of European Space Agency, via Joost van der Sanden/Canada Centre for Remote Sensing/NRCan.

Project Contacts

Canada's Three Oceans (C3O) – Dr. Eddy Carmack, Institute of Oceans Sciences, Fisheries and Oceans Canada, P.O. Box 6000, 9860 West Saanich Road, Sidney, B.C., V8L 4B2 Canada; eddy.carmack@dfo-mpo.gc.ca; Tel: 250-363-6585

Canadian Archipelago Through-flow Study (CAT) Dr. Humfrey Melling, Institute of Ocean Sciences, Fisheries and Oceans Canada, P.O. Box 6000, 9860 West Saanich Road, Sidney, B.C. V8L 4B2 Canada; humfrey.melling@dfo-mpo.gc.ca, Tel: 250-363-6552

Climate Variability and Change Effects on Chars in the Arctic (CVC) – Dr. James Reist, Arctic Fish Ecology and Assessment Research Section, Freshwater Institute, Fisheries and Oceans Canada, 501 University Crescent, Winnipeg, Manitoba, R3T 2N6 Canada; jim.reist@dfo-mpo.gc.ca; Tel: 204 983 5032; Fax: 204 984 2403

Global Warming and Arctic Marine Mammals (GWAMM) – Dr. Steve Ferguson, Freshwater Institute, Fisheries and Oceans Canada, 501 University Crescent, Winnipeg, Manitoba R3T 2N6 Canada; steve.ferguson@dfo-mpo.gc.ca; Tel: 204-983-5057

Impacts of Severe Arctic Storms and Climate Change on Arctic Coastal Oceanographic Processes – Dr. William Perrie, Bedford Institute of Oceanography, Fisheries and Oceans Canada, 1 Challenger Dr., P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2 Canada; william.perrie@dfo-mpo.gc.ca; Tel: 902-426-3985

Pan-Arctic Tagging of Beluga Whales (PATOB) – Dr. Mike Hammill, Maurice Lamontagne Institute, Fisheries and Oceans Canada, CP 1000, Mont-Joli, Quebec G5H 3Z4 Canada; mike.hammill@dfo-mpo.gc.ca; Tel: 418-775-0580

Arctic Freshwater Systems: Hydrology and Ecology – Dr. Fred Wrona, Environment Canada, Aquatic Ecosystem Impacts Research Division, Dept. of Geography P.O. Box 3050, Victoria, British Columbia V8W 3P5 Canada; fred.wrona@ec.gc.ca; Tel: 250-363-8901; Fax: 250-363-3345; and Dr. Al Pietroniro, Environment Canada, Hydrometric Monitoring, Lasalle Academy 373 Sussex Drive, Ottawa, Ontario K1A 0H3 Canada; al.pietroniro@ec.gc.ca; Tel: 306-975-4394

Arctic SOLAS – Dr. Maurice Levasseur, Département de biologie, Pavillon Alexandre-Vachon, local 2071A, Université Laval, Québec G1V 0A6 Canada Maurice.Levasseur@bio.ulaval.ca; Tel: 418-656-2131 poste 3207; Fax: 418-656-2339

The Carbon Cycle in the Canadian Arctic and Sub-Arctic Continental Margin – Dr. Charles Gobeil, Institut national de la recherche scientifique, Centre Eau, Terre & Environnement, 490 de la Couronne, Québec, QC G1K 9A9 Canada; charles_gobeil@ete.inrs.ca; Tel: 418-654-2589; Fax: 418-654-2600

Circumpolar Flaw Lead System Study (CFL) – Dr. David Barber, Canada Research Chair in Arctic System Science, Director, Centre for Earth Observation Science, 476 Wallace Building, Fort Gary Campus, University of Manitoba, Winnipeg, Manitoba, R3T 2N2 Canada. dbarber@cc.umanitoba.ca; Project website: http://www.ipy-cfl.ca/; Tel: 204-474-6981; Fax: 204-272-1532

Engaging communities in the Monitoring of Zoonoses for Country Food Safety Concerns in Canada – Manon Simard, Nunavik Research Centre, Makavik Corporation, P.O. Box 179 Kuujjuaq, Quebec, J0M 1C0 Canada m_simard@makivik.org; Tel: 819-964-2925 ext. 259 Fax: 819-964-2230

Greenland Sharks – Dr. Aaron Fisk, Great Lakes Institute for Environmental Research, 401 Sunset Avenue, University of Windsor, Windsor, Ontario, N9B 3P4 Canada. afisk@uwindsor.ca; Tel: 519-253-3000 ext. 4740; Fax: 519-971-3616

There are various methods to measure sea-ice thickness remotely, but no method beats the accuracy of a tape measure down a drilled hole. Here a team from Canada's National Research Council is drilling a systematic (and exhausting) pattern of survey holes for this purpose through a thick floe of multi-year ice. Ice temperature and strength are measured in selected spots. Through such surveys, CATs has demonstrated that floes with average thickness as much as 15 m remain common in waters of the Canadian polar shelf, despite their growing scarcity in the Arctic Basin. Photo: DFO, 2009