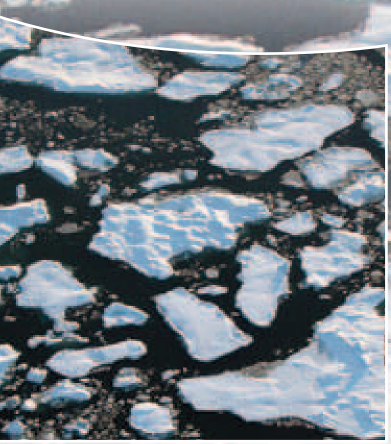
Environment Canada Environnement Canada

Environment Canada's International Polar Year Achievements



Canada

Environment Canada's International Polar Year Achievements

June 2010

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Cover photo credits

Left: Drifting pack ice in the Beaufort Sea, Summer 2007
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Centre: Team members of OASIS at rest on the ice near Barrow Alaska, 2009
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Right: Sub-Arctic tundra, Nunavik, October 2004
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MESSAGE FROM THE ASSISTANT DEPUTY MINISTERS

While many Canadians will never have the opportunity to travel to the Arctic, we are all connected in some way with this extreme and beautiful environment. The Arctic environment sustains important habitat for many mammal and bird species, the northern territories and provinces provide important natural resources, Arctic peoples contribute to the well-being and prosperity of Canada, and often Arctic weather conditions affect even the most southern regions of our country. No matter where in Canada you live, there are intrinsic connections with the Arctic, yet it is only with our modern understanding of the Earth system that we have begun to realize how far-reaching the connections between the Arctic and the rest of the world really are. The linkages span physical, biological, chemical and human systems and the work to understand them is just beginning.

Environment Canada is proud to have been a major participant in the International Polar Year 2007–2008. We have a long history of research in the North with an international reputation for excellent science. In fact, the Meteorological Service of Canada has participated in every IPY since the first in 1882. For IPY 2007–2008, Environment Canada's research contributions span the breadth of our science mandate, from weather, water, snow and ice, to the transport and fate of contaminants in the northern environment, to Arctic wildlife and ecosystems.

The IPY 2007–2008 had a strong focus on collaboration, and was an opportunity for research teams from many nations to work together to cooperatively advance polar science and knowledge. This is important, because many key scientific questions remain beyond the capacity of individual nations to answer. For Environment Canada researchers, collaboration has meant building on existing partnerships while seeking new ones, such as with researchers living and working in the North and northern communities.

This report presents an overview of Environment Canada's efforts and contributions during the IPY 2007–2008. It describes some of the early scientific advancements that have been made, the innovative new ways of doing research that were developed, and most especially highlights the important role of collaborative partnerships. The impact of IPY does not end with the close of the official observation period. Far from being over, the work of analysing IPY data will continue for decades to come and many new insights will continue to be gained. We hope that this report will also serve as a catalyst, opening the doors to new collaborations and ideas in pursuit of a better understanding of the polar regions and their role in the global Earth system.

Brian T. Gray
Assistant Deputy Minister
Science and Technology Branch

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Assistant Deputy Minister
Meteorological Service of Canada and
Permanent Representative of Canada with WMO

Photo: Keith Levesque, ArcticNet

CCGS *Amundsen* in Saglek fjord, northern Labrador

EXECUTIVE SUMMARY

1 International Polar Year in Canada

Canada's participation in the fourth International Polar Year (IPY) 2007–2008 involved unprecedented cooperation nationally and internationally, bringing together more than 1750 researchers from government agencies, universities and northern communities and over 240 international collaborators from 23 countries. Field studies took place at more than 100 sites across Canada's northern regions, including research conducted aboard five Canadian Coast Guard (CCG) icebreakers.

A significant factor in shaping the nature of Canada's participation in IPY 2007–2008 was the federal government's commitment of $150 million in new funds to a dedicated IPY program. The Government of Canada Program for IPY 2007–2008 funded 45 Canadian IPY projects with $98 million in direct research funding under two research themes of particular importance to Canada:

1. Science for Climate Change Impacts and Adaptation
2. Health and Well-being of Northern Communities

Funds were also allocated to data-management initiatives; to projects to ensure the health and safety of scientists and communities conducting IPY research; to enhance the capacity of northern research regulatory bodies; outreach and communication activities; and capacity-building initiatives.

The Government of Canada Program for IPY 2007–2008 recognized that to do research in the Arctic today, it is important for scientists to work closely with Canadian northern residents, who know and understand the land and who may bring with them generations of valuable traditional knowledge. Canadian IPY projects saw collaboration on an unprecedented scale with Aboriginal peoples and northern communities, governments and organizations, through partnering with northern researchers, meaningful participation of communities in project design and implementation, outreach activities, and skills training to build long-term northern research capacity.

2 Environment Canada scientists are principal investigators on five IPY projects

2.1 Arctic Freshwater Systems: Hydrology and Ecology

Environment Canada scientists lead the Arctic Freshwater Systems project, a multidisciplinary initiative of field-based and laboratory studies assessing the hydrology and ecology of northern freshwater ecosystems. The project is divided into four themes: Freshwater Flux and Prediction; Nutrient Flux and Prediction; Aquatic Ecosystem Hydro-ecology and Ecological Integrity; and Community-based Capacity Building and Outreach. There are 33 sub-projects involving 31 investigators, more than 60 collaborators, many graduate and undergraduate students, post-doctoral fellows, and northern residents. Preliminary results indicate that, over the past 30-plus years, summer low-water levels in the lower (outer) Mackenzie Delta may have increased by an amount equivalent to three times the local sea-level rise over the same period. There is also evidence of a recent decline in river-ice breakup events in the delta that historically have been an important control on annual peak water levels as ice-jam flooding replenishes the delta lake water. Unexpectedly high nutrient levels during the ice-breakup period have also been documented.

2.2 Variability and Change in the Canadian Cryosphere (CRYO)

Environment Canada researchers set out to capture the current state of Canada's cryosphere (defined as snow, lake and river ice, sea ice, permafrost and frozen ground, glaciers and ice caps), to determine how fast this dominant feature of Canada's landscape is changing and why. The Cryosphere project involves 33 experts in remote sensing of the cryosphere, climate analysis and climate modelling from Environment Canada, Natural Resources Canada, Canadian universities and the private sector. Researchers also collaborated with northern communities in cryospheric monitoring by utilizing traditional knowledge and linking it with remotely sensed information. Project investigators have produced snow-cover maps that incorporate the only long-term daily estimates of snow cover for the Northern Hemisphere. They are also now able to quantify long-term changes in snow melt dates, and they have collected what is likely the only available observational dataset on snow albedo controls at a scale suitable for comparison to global circulation climate models.

2.3 Intercontinental Atmospheric Transport of Anthropogenic Pollutants to the Arctic (INCATPA)

Through the Intercontinental Atmospheric Transport of Anthropogenic Pollutants to the Arctic (INCATPA) project, Environment Canada, as part of an international network of researchers, is tracking the movements of mercury and persistent organic pollutants (POPs) from sources distant to the Arctic and how climatic processes influence their presence. IPY funding enabled the refinement and expansion of the INCATPA network to incorporate new contaminant data for the western Canadian Arctic. This information will help determine how these chemicals may impact Arctic ecosystems and the health of Northerners. Researchers are still analysing data collected on both POPs and mercury during IPY. Preliminary PCB concentrations measured in the air at Little Fox Lake in 2007 showed that PCB congener patterns change on a daily basis, indicating a shift in pollution sources.

2.4 Understanding Ozone and Mercury in the Air over the Arctic Ocean (Ocean-Atmosphere-Sea Ice-Snowpack OASIS-CANADA)

Under the OASIS-CANADA project, Environment Canada researchers are investigating the annual springtime disappearance of mercury and ozone from the air near the ground along the Arctic coastline. Scientists speculate that this phenomenon is caused by the interaction of sunlight, snow and ice in the presence of low temperatures over the sea ice. OASIS investigators want to determine whether the disappearing mercury ends up in the Arctic food chain and how recent climate changes may be affecting the disappearance of mercury and ozone during the Arctic spring. Researchers operated over widespread areas of the sea ice, working from research camps, cruising along the Beaufort Sea on the Canadian research icebreaker CCGS *Amundsen*, and taking measurements from a drifting French sailboat that covered most of the Arctic Ocean. They also employed special ocean-monitoring buoys left out on the Beaufort Sea and Hudson Bay ice to move around by themselves and collect data.

2.5 The Observing System Research and Predictability Experiment (THORPEX) Arctic Weather and Environmental Prediction Initiative (TAWEPI)

With the THORPEX Arctic Weather and Environmental Prediction Initiative (TAWEPI), Environment Canada scientists are developing and validating a regional Numerical Weather Prediction (NWP) model over the Arctic during IPY. The experimental model, called Polar-GEM, is a twin of the Environment Canada operational regional GEM (Global Environmental Multi-scale) model, used for one- to two-day weather forecasts. TAWEPI investigators also did modelling research and data-assimilation studies to enhance weather and environmental prediction (WEP) capabilities in polar regions and to improve our understanding of the Arctic and its influence on world weather. The project has involved various research divisions of Environment Canada, in collaboration with the Canadian Meteorological Centre (CMC), the Canadian Ice Service, the Department of Fisheries and Oceans (DFO), various Canadian universities and other IPY projects.

3 Environment Canada scientists are co-investigators or team members on five IPY projects

3.1 Arctic Wildlife Observatories Linking Vulnerable EcoSystems (ArcticWOLVES)

ArcticWOLVES is a circumpolar study of tundra food webs and associated ecosystem processes. Environment Canada scientists are working in conjunction with numerous collaborators to determine the relative importance of resources and predators in structuring Arctic food webs and quantify their interactions. They are also documenting direct and indirect impacts of climate change on terrestrial animal biodiversity to forecast future impacts on animal populations. ArcticWOLVES involves an international network of wildlife observatories and researchers, including more than 60 Canadian investigators.

3.2 Climate Change Impacts on Canadian Arctic Tundra Ecosystems (CiCAT): Interdisciplinary and Multi-scale Assessments

CiCAT is a large-scale terrestrial ecology project linking Arctic researchers studying soil, vegetation, carbon fluxes and ecosystem modelling, and undertaking community-based monitoring. The researchers are assessing climate change trends and impacts on tundra ecosystems and northern communities. Environment Canada scientists were involved in two components of CiCAT: producing remotely sensed habitat maps for Arctic shorebird population monitoring; and providing information for larger wetland inventory and land-classification projects.

3.3 Climate Variability and Change: Effects on Char in the Arctic (CVC)

Arctic Char are fundamental to the social and cultural well-being of many northern communities and form the basis of household and commercial fisheries. The Climate Variability and Change (CVC)-IPY project investigated char biodiversity and examined the species' life history and thermal ecology, combined with community-based monitoring. The Canadian CVC-IPY project involves researchers and Northerners in an international network for research and monitoring of char that addresses common issues of char/climate interactions, encourages information exchange and will be a lasting IPY legacy.

3.4 Polar Ecosystems in Transition: An Interdisciplinary Case Study of the Effects of Climate Change on Temporal Trends in Contaminant Accumulation, Foraging Ecology and Human Use of Polar Bears (*Ursus maritimus*)

The Polar Ecosystems in Transition project gathered scientific and Inuit knowledge on changes in Polar Bear ecology. It examined the foraging ecology of Polar Bears in selected populations and recorded Inuit knowledge of the subject in one of the populations. Environment Canada scientists led a study that directly linked climate change and contamination of wildlife by persistent organic pollutants (POPs). The team analysed various chemical contaminants in Polar Bears and related the concentrations of these contaminants to variations in bear diets due to sea-ice changes in recent decades. This research is significant for Northerners who depend on both seals and Polar Bears and who have considerable concern about their own exposure to toxic chemicals.

3.5 Canadian Arctic SOLAS Network (Surface Ocean – Lower Atmosphere Study): Ocean Production of Trace Gases in the Arctic and their Impact on Climate)

SOLAS investigators are studying the environmental interactions of trace gases such as carbon dioxide (CO_2), nitrous oxide (N_2O), volatile organic compounds (VOCs), halocarbons, and dimethylsulfide (DMS). These trace gases affect the climate in various ways, either as greenhouse gases, or as sources of aerosols—which scatter and absorb solar energy in the atmosphere. Biological processes in the world's oceans, especially those involving phytoplankton and bacteria, play an important role in the cycles of these gases. Scientists expect that increased areas of open water and changes in ocean circulation and temperature will alter the biological and chemical processes that produce and consume climate-active gases and aerosols.

4 Environment Canada is a partner providing in-kind support (no direct IPY funds)

Environment Canada played various research roles for IPY. In the first four projects described in this section, Environment Canada scientists were either co-investigators or brought considerable experience and expertise to projects led by other organizations. Environment Canada provided in-kind support to the five final projects referenced.

4.1 Circumpolar Flaw Lead System Study (CFL) – University of Manitoba

The Circumpolar Flaw Lead system study investigated changing climate processes in the flaw lead system, which forms when the pack ice moves away from the coastal fast ice and creates recurrent and interconnecting polynyas (areas of open water). These open regions served as a unique Arctic laboratory for studying physical and biological ecosystem variables of the flaw lead. The CFL system study engaged 350 researchers from 27 countries and used the Canadian research icebreaker CCGS *Amundsen* as a mobile, specially outfitted research platform to conduct large-scale system-level multidisciplinary research that included overwintering the ship in the Beaufort Sea. An important component of CFL has been to consider traditional knowledge together with Western science to gain a more comprehensive understanding of changes now occurring in the Arctic.

4.2 Polar Environment Atmospheric Research Laboratory (PEARL) – University of Toronto

Environment Canada's research at PEARL is providing new, high-quality data on Arctic precipitation patterns, a key factor in understanding a changing climate. IPY funding has allowed Environment Canada to install highly sophisticated monitoring equipment, including the Precipitation Occurrence Sensor System (POSS). The data should also provide a useful baseline to improve space-based measurement of precipitation. Our insight into the complex relationships between surface and atmospheric interactions and radiation, clouds and precipitation are important contributions, not only to understanding Arctic changes, but changes in the weather and climate of all Canadians.

4.3 How Seabirds Can Help Detect Ecosystem Change in the Arctic – Memorial University

The Seabirds project set out to assess changes in Arctic marine food webs by studying key forage species (Arctic Cod, capelin, Lantern Fish and crustaceans) and their seabird predators. Collaborating with Inuit and Newfoundland and Labrador hunters and fishers, the scientists collected seabirds to determine not only their diet but also their foraging behaviours and reproductive performance. They also gained insights into seabird movements with new electronic tracking devices called geolocators, which enable year-round monitoring and assessment of potential biological impacts of climate variation. The project is also very important to circumpolar collaboration, with the methods and results to be used by the Arctic Council's Conservation of Arctic Flora and Fauna (CAFF) Initiative.

4.4 Monitoring Impact of Global Change on Caribou and Wild Reindeer and Links to Human Communities (CARMA) – Yukon College

CARMA is an international network for assessing the ongoing vulnerability of the world's wild *Rangifer* (reindeer and caribou) herds to global changes. It has been underway for six years and includes researchers, habitat specialists, climate experts, veterinarians and disease ecologists, community representatives and management agencies from countries with wild *Rangifer* herds from Canada to Russia to Norway to Iceland. CARMA is part of a system of networks under the Circumpolar Biodiversity Monitoring Program (CBMP). Achievements of the CARMA network include the establishment of a standardized monitoring protocol across the Arctic and the development of decision-support tools for managing individual herds.

4.5 Other Projects Receiving Environment Canada in-kind Support

Environment Canada provided in-kind support to the following projects:

- Inuit Sea Ice Use and Occupancy Project – Carleton University
- Impacts of Severe Arctic Storms and Climate Change on Arctic Oceanographic Processes – Fisheries and Oceans Canada
- Ocean Freshwater Fluxes through the Canadian Archipelago – Fisheries and Oceans Canada
- Thermal State of Permafrost: A Canadian Contribution to the International Permafrost Association's International Polar Year Project – University of Ottawa
- Determining the Diet of the Greenland Shark in a Changing Arctic – University of Windsor

Further information can be found on the Canadian IPY website:
(http://www.ipy-api.gc.ca/pg_IPYAPI_050-eng.html).

5 Conclusion

Environment Canada scientists are contributing significant skills and expertise to the IPY projects described in *Environment Canada's International Polar Year Achievements* report. It has also provided infrastructure and support to these projects, including Canadian ice, aviation, marine and public forecasts. Through the research opportunities and funding provided by IPY, Environment Canada has strengthened its northern research capabilities, addressing significant knowledge gaps and expanding into new areas that will be vital in a dynamic, rapidly changing environment. Each project has provided new discoveries and opened further questions for northern science. Canada's approach of combining scientific activity with the expertise and traditional knowledge of Aboriginal peoples and northern communities has revealed new insights and a more comprehensive understanding. IPY 2007–2008 was not the end, it's just the beginning of a new era of awareness and knowledge of the Arctic.

Photo: ARQX Archive, Environment Canada

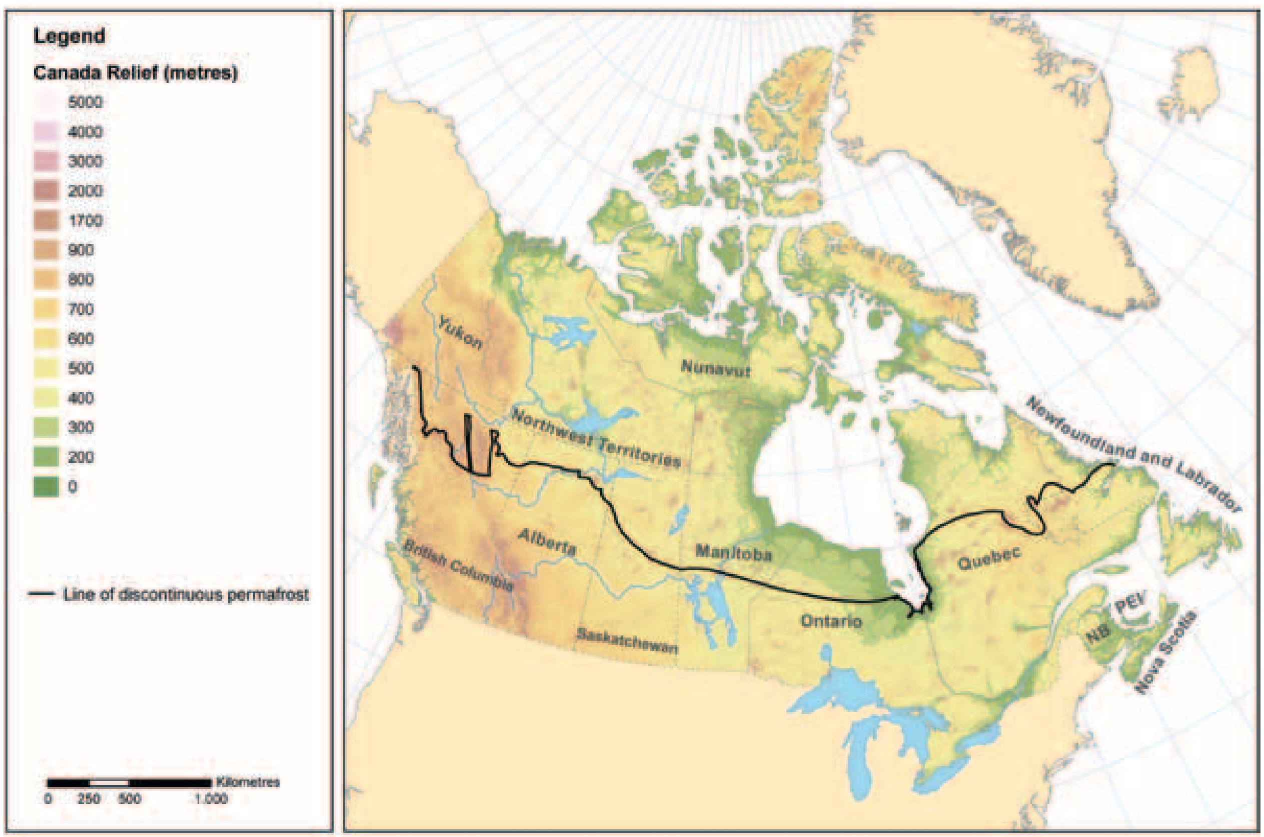
Eureka, Nunavut near the Environment Canada facility.

1 INTRODUCTION

Canada's North

The polar regions are integral components of the Earth system. They are coupled to the Earth's global climate, ocean circulation, biogeochemical cycles, and the ecosystems on which humans depend. Through these connections, the Earth's high latitudes respond to and drive changes elsewhere. The poles have sometimes been described as the Earth's early warning systems—regions where changes in global climate are amplified and accelerated due to the unique geography of oceans, snow and ice. Today, the polar regions are changing faster than any other regions on Earth.

Canada is a northern nation, accounting for approximately 25% of the circumpolar Arctic territory. "The North" forms a fundamental part of our heritage and identity. Canadians define the Arctic in many ways: the Arctic Circle, North of 60° latitude, the tree line, the 10°C July isotherm, and by regions of permafrost. Yet regardless of definition, we agree that significant portions of the Canadian geography are indeed "northern." These regions hold an amazing diversity of landscapes, climates, ecosystems and wildlife, as well as the Aboriginal peoples who have lived there for millennia.



Source: Base map modified from *The Atlas of Canada*, Natural Resources Canada, 2006

Figure 1 Canada's International Polar Year study area

Note: Areas north of the southern limit of discontinuous permafrost represent 40% of the Canadian landmass.
Datafiles for the permafrost line from U.S. National Snow and Ice Data Center, Boulder, CO.

Canada's Arctic regions are currently undergoing rapid changes in their natural, economic, political and social environments. From warming permafrost and changing weather patterns, to decreasing sea-ice cover, changes in the physical environment have broader implications for Arctic ecosystems and the livelihood and well-being of northern communities. It is vital that we understand how Arctic systems are changing and what this will mean for both Northerners and the rest of the world.

History of International Polar Years

International Years have been organised for many disciplines and a wide range of themes for over 100 years. The United Nations designates International Years in order to draw attention to and encourage international action on major issues with global importance and planet-wide ramifications. With the endorsement of the World Meteorological Organisation (WMO), a specialized agency of the U.N., and the International Council for Science (ICSU), the international polar research community planned the fourth International Polar Year for 2007–2008. It was timed to mark the 125th anniversary of the first International Polar Year (1882–83), the 75th anniversary of the second IPY (1932–33), and the 50th anniversary of the International Geophysical Year (1957–58).

The concept for an International Polar Year first arose from an awareness that the answers to some fundamental questions regarding the Earth's meteorology and geophysics were likely to be found at the poles and also from an understanding that these answers could not be achieved by any one nation working alone. Sponsored by the International Meteorological Organization (IMO), the WMO's predecessor, 12 nations participated in the first IPY. Canada hosted three Arctic research stations where studies focused primarily on the Earth's climate, weather and geomagnetic field. The first IPY set an important precedent for the future of international scientific cooperation.

The second IPY was initiated by the IMO in an effort to investigate the global implications of the newly discovered atmospheric "jet stream." Forty nations participated in spite of the economic constraints of the Great Depression. Researchers and explorers took advantage of advances in motorized air, land and sea transportation as well as new instrumentation to establish 40 permanent Arctic observation stations and the first-ever research station inland from Antarctica's coast. Research during the second IPY provided a new understanding of the role of the Arctic in driving global climate; geomagnetic studies helped to improve aircraft navigation; and studies of solar radiation and the aurora were fundamental for improving radio communication.

The third IPY became the International Geophysical Year of 1957–58. Employing the most advanced technologies available at the time, particularly rockets and radar, researchers from 67 nations made tremendous strides in the understanding of the Earth and its atmosphere. Among the world's many accomplishments during the IGY was the discovery of the Van Allen radiation belts encircling the Earth, which had implications for satellite technology and space travel, the first estimates of the size of Antarctica's ice mass, confirmation of the theory of continental drift, and the beginning of the space age. *Sputnik* was just the first of ten satellites launched during the IGY. A major political advance was also made with the signing of the *Antarctic Treaty* in 1959.

The International Polar Year 2007–2008

Scientific awareness of the importance of the polar regions to Earth's climate systems is greater than ever, and knowledge of the changes occurring in these regions is fundamental to our understanding of environmental change on a global scale. Policy-makers urgently need to be provided with key information to underpin sustainable development. More than ever, the scope and scale of polar research challenges lie beyond the capabilities of individual nations or traditional scientific disciplines. By stimulating and guiding an intensive burst of effort, IPY 2007–2008 has aimed to accelerate progress towards providing the required policy-relevant answers.

Building on the foundation of previous Polar Years, the IPY 2007–2008 was conceived to be an intensive burst of internationally coordinated, interdisciplinary scientific research and observations. The main geographic focus was the Earth's high latitudes, but studies in any region relevant to the understanding of polar processes or phenomena were encouraged. The official observation period was from 1 March 2007 to 1 March 2009, allowing for observations in both polar regions throughout the seasonal cycle.

To guide the development of IPY 2007–2008, the international polar research community participated in creating *A Framework for the International Polar Year 2007–2008* (http://ipy.arcticportal.org/images/uploads/framework.pdf). In addition to six general research themes (status of the polar regions; past, present and future change; global linkages; new scientific frontiers in the polar regions; polar regions as vantage points; and the human dimension), the framework identified a number of overarching objectives.

In order to advance the state of polar science there was an emphasis on research activities and observations that would not otherwise have been undertaken and which would lay the foundation for major scientific advances. As with past polar years, IPY 2007–2008 aimed to develop and embrace new technological and logistical capabilities.

International cooperation has been a fundamental objective of all IPYs. The 2007–2008 IPY was organised to strengthen international coordination of research and enhance collaboration and cooperation, including from nations not traditionally involved in polar research. This included optimising the use of available polar observation systems, logistical assets and infrastructure.

IPY 2007–2008 had a strong interdisciplinary emphasis, linking researchers across different fields to address questions and issues lying beyond the scope of individual disciplines. The active inclusion of the social sciences and the identification of the human dimension as a research theme was a fundamental development that has set IPY 2007–2008 apart from previous polar years.

IPY 2007–2008 promoted education and outreach activities that would raise the awareness, interest and understanding of polar residents and their community institutions, as well as educators, students, the general public and decision-makers worldwide about the polar regions and the value of polar research and observations.

Lastly, the IPY 2007–2008 framework identified three major legacy objectives:

- Broad-ranging archives of samples, data and information regarding the state and behaviour of the polar regions to provide references for comparison with the future and the past, all to be made available in an open and timely manner;
- Observation sites, facilities and systems to support ongoing polar research and monitoring as the basis for observing and forecasting change; and
- A new generation of polar researchers and experts to carry on polar research into the future.

International Polar Year in Canada

Canada's participation in IPY 2007–2008 involved unprecedented cooperation nationally and internationally, bringing together more than 1750 researchers from government agencies, universities and northern communities, and over 240 international collaborators from 23 countries. Field studies took place at more than 100 sites across Canada's northern regions, including research conducted aboard five Canadian Coast Guard (CCG) icebreakers.

A significant factor in shaping the nature of Canada's participation in IPY 2007–2008 was the federal government's commitment of $150 million in new funds to a dedicated IPY program, the largest single investment in Arctic research made in Canada to date and one of the largest investments of new funds for IPY among the 60 participating nations. Additionally, other Canadian involvement in IPY was carried out with support from a variety of other smaller non-IPY specific sources and programs, such as the Special Research Opportunity funding administered by Canada's Natural Science and Engineering Research Council.

Horizontally managed by six federal departments (Indian and Northern Affairs; Environment Canada; Fisheries and Oceans; Health Canada; Industry Canada; and Natural Resources Canada), the Government of Canada Program for IPY funded 45 Canadian IPY projects with $98 million in direct research funding. In support of a comprehensive Canadian IPY program, funds were also allocated to:

- support overarching national polar data-management initiatives;
- ensure the health and safety of scientists and communities conducting IPY research;
- enhance the capacity of northern research regulatory bodies;
- support outreach and communication activities; and
- develop and deliver capacity-building initiatives, including education and training opportunities for youth and Northerners, to enhance participation in northern scientific research.

While maintaining the overarching objectives of the IPY 2007–2008, the Government of Canada Program funded research projects relevant to two particular priorities for Canada:

Climate change impacts and adaptation

- Multidisciplinary observations and analysis of the Arctic climate system
- Process studies and impact modelling related to climate, the physical environment and society
- Climate-system links between northern regions and the rest of the globe
- Ecosystem and community vulnerability, resilience and adaptive capacities

Health and well-being of northern communities

- Reducing health disparities, improving health outcomes and well-being
- Building and sustaining healthy, resilient communities
- Examining the links between climate change, human health and well-being

The Government of Canada Program for IPY recognized that to do research in the Arctic today, it is important for scientists to work closely with Canadian northern residents, who know and understand the land and who may bring with them generations of valuable traditional knowledge. Canadian IPY projects saw collaboration on an unprecedented scale with Aboriginal peoples and northern communities, governments and organizations through partnerships with northern researchers, meaningful participation of communities in project design and implementation, outreach activities, and skills training to build long-term northern research capacity.

Environment Canada participation in IPY 2007–2008

Environment Canada's participation in IPY 2007–2008 is consistent with its mandate to preserve and enhance the quality of the natural environment; conserve Canada's renewable resources; conserve and protect Canada's water resources; forecast weather and predict environmental change. Environment Canada has been one of the most active Canadian research organizations in IPY 2007–2008.

Environment Canada researchers led five IPY projects investigating how to better predict the North's complex weather, the state and health of northern freshwater systems, the impacts of a changing climate on snow and ice, and the sources, movement and alteration of contaminants in the northern environment and food web. In addition, Environment Canada partnered or collaborated on 14 projects led by other organizations.

The purpose of this report is to describe in greater detail Environment Canada's research program for IPY 2007–2008, including significant achievements, innovations and preliminary findings. IPY provided support to many collaborative endeavours and partnerships. For each project described herein we highlight the broader research context and provide details on how the research contributes to our understanding of Arctic systems.

ENVIRONMENT CANADA METEOROLOGICAL SERVICES SUPPORTING IPY

As the federal department housing Canada's national meteorological and hydrological service, Environment Canada also had a role in providing important weather, marine and sea ice information and specialized services to ensure the safety of Canadian and foreign IPY researchers working in Canada's North as well as project specific research data requirements. Through the support of the Government of Canada Program for IPY, services were provided to researchers using a dedicated web portal and ftp site. Here is a sample of some of the meteorological services that were provided:

- Visualizations of forecasted wind, blizzard, and fog/stratus conditions out to 48 hours.
- Custom mappings of polar satellite imagery for the Canadian High Arctic and Arctic Basin all the way to the geographic north pole.
- New sea ice products including RADARSAT mosaics corresponding to bi-weekly regional ice charts, Quikscat and RADARSAT mosaic sea ice animations.
- On-request targeted weather and sea ice products and support services for IPY science projects and expeditions to support their field logistics and research data requirements.

As part of IPY logistics legacy projects funded by the Government of Canada Program for IPY, Environment Canada made improvements to its forecasting systems that will leave a lasting legacy of better weather predictions for Canada's northern communities.

By moving research results into operational systems, improvements were made to the regional operational numerical weather forecasting system for the Arctic region:

- Extending the regional operational high resolution modelling domain northwards to cover the Arctic in its entirety
- Increasing the output frequency of the northern forecast models by introducing two additional daily model runs
- Implementing systems to improve our ability to predict precipitation type in the Arctic
- Implementing a new radiation scheme which improves the physics of the operational models and provides, for example, better Arctic night-time temperature predictions.

Environment Canada also upgraded its polar-orbiting satellite passive image acquisition and processing system located in Resolute Bay, Nunavut. The combination of a new reception system and improvements in our ability to send images and data to forecast offices in the south has given forecasters and the public access to higher resolution imagery for northern regions.

Photo: ARQX Archive, Environment Canada

Eureka, Nunavut

2 ENVIRONMENT CANADA SCIENTISTS ARE PRINCIPAL INVESTIGATORS ON FIVE IPY PROJECTS

2.1 ARCTIC FRESHWATER SYSTEMS: HYDROLOGY AND ECOLOGY

Principal Investigators: *Fred J. Wrona[1] and Al Pietroniro[2]*

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Environment Canada Co-Investigators: *Spyros Beltaos, Barrie Bonsal, Joseph Culp, Bruce Davison, Raoul Granger, Robert Kent, Philip Marsh, Robert Phillips, Terry Prowse, William Schertzer, Christopher Spence and Taina Tuominen*

The Project's Scope

The Arctic Freshwater Systems project is a multidisciplinary initiative consisting of a combination of field-based and laboratory studies assessing the hydrology and ecology of northern freshwater ecosystems. The project involves systems and process-based research, monitoring and modelling of the hydrological, climatological, limnological and ecological components of a range of Canadian Arctic lake, riverine and delta freshwater systems. It is comprised of 33 individual sub-projects and involves 31 investigators, more than 60 collaborators, many graduate and undergraduate students, post-doctoral fellows, and northern residents. Field research was conducted at a range of sites and communities across Canada's northern regions, including the Yukon, Northwest Territories, Nunavut, Nunavik (northern Quebec), Nunatsiavut (northern Labrador), plus sites in northern Saskatchewan and Manitoba (see map Figure 2).

Through its various sub-projects, the Arctic Freshwater Systems project aims to improve our process-level understanding of freshwater and nutrients in northern aquatic systems and to develop predictive models for freshwater and nutrient flux. Research also focused on attaining new insights into how climate variability/change is affecting the ecological structure and function of aquatic ecosystems. New synoptic data were obtained on freshwater biodiversity and related ecosystem information which has resulted in the development of a unique legacy database that will contribute to the international IPY legacy Circumpolar Biological Monitoring Programme (CBMP) under the Conservation of Arctic Flora and Fauna (CAFF) Working Group of the Arctic Council. Since continued environmental monitoring will be critical, several sub-projects also led the development of new assessment approaches and monitoring capacity in northern communities.

THE PROJECT IN BRIEF

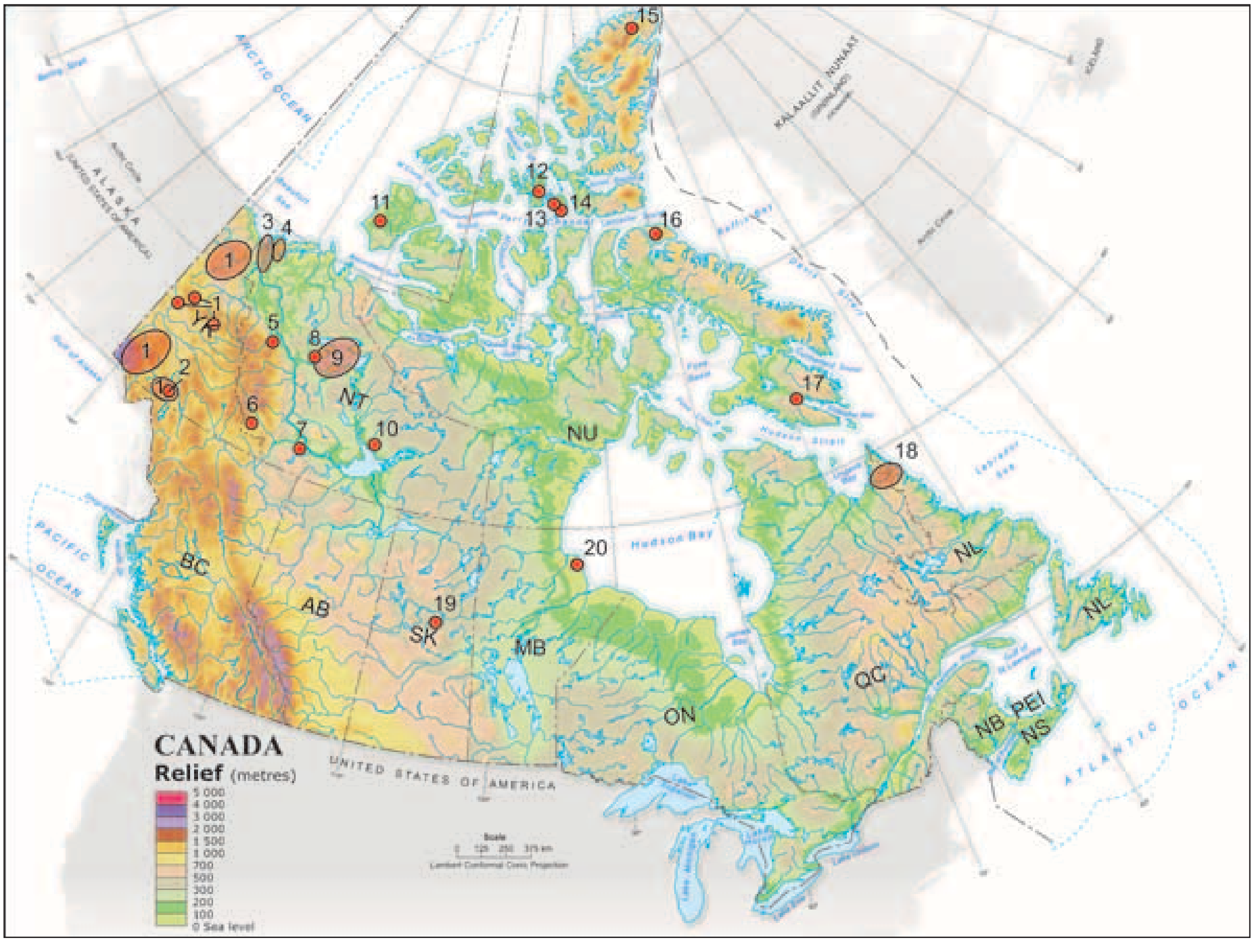
ARCTIC FRESHWATER SYSTEMS

Based on its four research priorities, the Arctic Freshwater Systems: Hydrology and Ecology project is divided into four themes

1) **Freshwater Flux and Prediction:** improved process-level understanding and modelling capability for snow, rain, runoff, evaporation and change to water dynamics and storage in key polar aquatic environments.
2) **Nutrient Flux and Prediction:** new information for modelling ice jam flooding during spring breakup (a key event that helps replenish water and nutrients in the Mackenzie Delta) and nutrient transport to the Beaufort Sea.
3) **Aquatic Ecosystem Hydro-ecology and Ecological Integrity:** improved understanding of how climate variability/change will impact circumpolar freshwater biodiversity and related ecosystem structure and function.
4) **Community-based Capacity-building and Outreach:** establishing community-based environmental monitoring involving Environment Canada's Canadian Aquatic Biomonitoring Network (CABIN).

Theme 1 Leads: John Pomeroy and Al Pietroniro
Theme 2 Leads: Lance Lesack and Phil Marsh
Theme 3 Leads: Fred Wrona and Joseph Culp
Theme 4 Leads: Rob Kent, Robert Phillips and Chris Spence

Photo: © Photos.com, 2010



Source: Base map modified from *The Atlas of Canada*, Natural Resources Canada, 2006
Map credit: Peter Di Cenzo, Environment Canada

1. Yukon Aquatic Biodiversity Assessments
2. Wolf Creek Experimental Basin
3. Mackenzie Delta
4. Mackenzie Upland Region
5. Gayna River
6. Nahanni National Park
7. Scotty Creek
8. Deline
9. Great Bear Lake
10. Baker Creek Research Watershed
11. Banks Island
12. Polar Bear Pass
13. Resolute
14. Mecham River
15. Quttinirpaaq National Park
16. Sirmilik National Park
17. Iqaluit
18. Torngat Mountains National Park/Koroc River Watershed
19. Crean Lake
20. Wapusk National Park

Figure 2 Location of field sites across northern Canada where significant research activities were undertaken by the Arctic Freshwater Systems project

Shaded regions indicate areas where a suite of river and/or lake sites were surveyed.

1) Freshwater Flux and Prediction

How important is freshwater to Canadian polar regions and how may its availability change in the future? To investigate the current state of Canadian polar freshwater, including water in the Arctic Islands, researchers conducted field observations at existing long-term monitoring locations (sites which already had monitoring instruments in place), as well as at remote locations with little or no instrumentation.

Through field campaigns, data assimilation, and process studies the freshwater flux and prediction projects are collectively improving our understanding of changes in snow cover, runoff, wetlands and perennial snow patches in key polar environments during IPY and into the future. Investigators are using new knowledge of atmospheric and hydrological processes to develop a suite of models to assess the effects of climate variability and change on cold regions and Arctic freshwater systems. The various models address blowing snow and snowmelt, runoff and spring breakup in rivers, as well as evaporation, storage and circulation in lakes, among other factors. Some of the models are new, but researchers are also making improvements to existing models by incorporating better representation of physical processes.

Canadian communities throughout the Arctic as well as scientific, commercial and other operations in the region will benefit from the insights delivered by this research as the project results will help support more accurate and cost-effective planning and management of Canadian polar freshwater resources.

Innovation: a new surface runoff model

At the forefront of the modelling activities is the development of a fully-coupled atmospheric-land surface-runoff model. This complex and challenging scientific endeavour uses global and regional climate models to predict atmospheric temperature and moisture conditions at an instant in time. These data are then used by a land surface model to calculate evaporation, soil moisture and runoff amounts. The model then routes the runoff down the river channel to the mouth of the basin. Ideally, the land surface model will also feed evaporation and other data back to the climate model to be used to calculate atmospheric conditions for the next time interval.

2) Nutrient Flux and Prediction

Working with university collaborators, Environment Canada researchers are improving their capability to model the water and nutrient flow through the Mackenzie River Delta, both during spring breakup and the open-water seasons. They are working across a vast area: the Mackenzie River is the fourth largest northward flowing river in the world, with a catchment area of about 1.8 million km^2, discharging about 280 km^3 of water into the Beaufort Sea through the Mackenzie Delta.

The project analyses data on ice jam locations that form in Mackenzie Delta channels, including water levels, jam thickness and dynamic waves resulting from ice jam releases. This information is critical to modelling ice-jam flooding during the spring breakup, a key event that helps replenish water and nutrients in the upper and middle delta.

This new knowledge is also strengthening long-term modelling of Mackenzie River water and nutrient flows to the Beaufort Sea, and potential responses to climatic variability and change. Results from this study will improve assessments of the freshwater budget of the Beaufort Sea/Arctic Ocean and provide new data on the magnitudes of the input of nutrients, dissolved organic carbon and suspended sediments from the Mackenzie Basin into marine ecosystems.

Early results: change in delta water levels, unexpectedly high nutrient levels

Preliminary results indicate that, over the past 30-plus years, summer low-water levels in the lower (outer) Mackenzie Delta may have increased by an amount (0.3 m) equivalent to three times the local sea-level rise (0.1 m) over the same period. Such an amplification of recent sea-level rise had not been expected and may be a result of enhanced storm surges in response to receding Arctic sea-ice or coastal backwater effects on the river flow. There is also evidence of a recent decline in river-ice breakup events in the delta that historically have been an important control on annual peak water levels as ice-jam flooding replenishes the delta lake water. Less frequent breakup events are resulting in lower water levels in the lakes located at higher elevations further away from the Beaufort Sea. These two observed changes in the system (via two differing global change mechanisms) have potential impacts on fish habitat in the delta and will affect overall biodiversity of the system.

Initial results have documented unexpectedly high nutrient levels during the ice-breakup period, with substantially higher levels of total suspended sediments and dissolved organic carbon in Mackenzie river-water than reported in previous research (i.e. where the breakup period was not characterized and incorporated into yield amounts).

Photo: Spyros Beltaos, Environment Canada

Jennifer Nafziger (University of Alberta) and Tom Carter (Environment Canada) measuring the velocity of ice floes during 2008 spring breakup of the Mackenzie River at Tsiigehtchic, Northwest Territories.

3) Aquatic Ecosystem Hydro-ecology and Ecological Integrity

How will circumpolar freshwater biodiversity be impacted by climate variability and change and related environmental stressors? Sub-projects of the Arctic Freshwater Systems project addressing this question are contributing to the International IPY Arctic Freshwater BIOdiversity Research and Monitoring NETwork (Arctic-BIONET) and to the Circumpolar Biodiversity Monitoring Programme (CBMP) of the Arctic Council.

Aquatic biodiversity assessment

Project team members, working in partnership with Parks Canada and northern communities, have collected new data to provide a baseline on water conditions, fish and benthic invertebrates found in streams and rivers across the Canadian Arctic. Researchers are using the data to build a reference benchmark for assessing human influences and the impacts of climate change on the ecology of northern streams and rivers. This information may help northern communities better understand and adapt to climate variability and change by supporting improved management of the freshwater fisheries that are vital to local diets and for commercial and sport purposes.

Arctic Char and related fishes of the genus *Salvelinus* are key to this assessment because they are essential components of freshwater, estuarine and near-shore marine aquatic environments of the circumpolar north. In an example of collaboration between different IPY projects, Environment Canada provided habitat data for an IPY research project led by Jim Reist of Fisheries and Oceans Canada (Climate Variability and Change [CVC]: Effects on Char; see Section 3.3) which aimed to provide the biological context for CVC effects on char, including climate effects on mercury bioaccumulation. Environment Canada advised on the study design, helped develop sampling protocols, assisted with sampling and data collection, and provided other key ecosystem information.

Mackenzie upland lakes studies

A warming climate will likely cause significant thawing of permafrost resulting in the phenomenon of "shoreline retrogressive thermokarst slumping" (SRTS), a slumping and melting of shorelines which delivers much of the sediment, organic material and nutrients to freshwater systems across the Arctic.

SRTS may affect the water quality and ecology of these water bodies, and scientists have postulated that the pelagic (organisms living in the water column) and benthic (organisms and plants associated with the substrate) environments might be especially sensitive to permafrost-induced ecological change. This hypothesis became the focus of Arctic Freshwater Systems project team members conducting multidisciplinary climatological, hydrological and ecological research in upland tundra lakes in the Mackenzie Upland Region, Northwest Territories.

Early results: significant differences between disturbed and undisturbed lakes

A significant difference was found between lakes disturbed by SRTS and those that were undisturbed (no SRTS) for macrophytes, invertebrates, underwater light attenuation, water chemistry and some sediment variables. Generally, sediments in undisturbed lakes were rich in organic material and some micronutrients, while SRTS-disturbed lakes had sediments richer in calcium, magnesium and strontium, a higher water-column transparency, and the presence of better developed benthic invertebrate and macrophyte communities. In addition, the lakes disturbed by shoreline slumping were found to be less tea-stained (i.e. lower dissolved organic carbon) and were clearer than undisturbed lakes. This finding is counter-intuitive and opposite to what would be predicted from Alternate Stable State Theory (ASST) developed for temperate lake systems.

Using SRTS as an analogue for climate change-induced landscape effects, preliminary results suggest that a warmer climate will dramatically change the aquatic food web structure of tundra lakes located in areas of ice-rich permafrost. Changes in primary production and microbial processes in response to climate warming are also likely to alter the flux of carbon dioxide to the atmosphere.

A major innovation in monitoring technology was developed and tested during this research program. It is the design and implementation of a fully-automated buoy and mooring system for continuous water quality and lake ice dynamics monitoring. The data collected will allow researchers to investigate the effects of changing ice-cover on key water quality parameters and allow for better prediction of the consequences on aquatic food webs and related productivity.

INNOVATION

DAILY YEAR-ROUND MONITORING: THE AUTOMATED ICE-WATER QUALITY BUOY

For researchers, continuous monitoring of changes in the physical and chemical properties of lakes—and collecting data in real time—is essential. For Arctic systems, several key questions need to be addressed: precisely when does lake ice form and how does it grow over winter? When is breakup in spring? How much light penetrates through the lake ice in winter? And how is water quality altered (chemistry, temperature, oxygen levels) by changing ice conditions?

Tracking day-to-day conditions, however, can pose huge logistical problems, since study locations are remote and often accessible only by helicopter or float plane. IPY researchers needed to find a way to collect data that did not require expensive transport and lodging for field personnel and equipment, and that would continue to work during bad summer weather and harsh winter conditions.

The Arctic Freshwater Systems project, working with AXYS Technologies Inc., developed a prototype automated ice buoy and subsurface mooring system to do the job remotely. The system is similar to those developed for the OASIS project (see Section 2.4), in that solar power and sealed internal batteries will keep the monitoring system operating year-round.

The subsurface mooring includes a tethered array of five water quality sondes that will measure changes in temperature, dissolved oxygen and other water quality parameters at multiple depths in the lake, and an ASL Ice Profiler Sensor to measure the development, growth and decay of the lake ice cover through the cold season. Through a system developed by AXYS Technologies Inc., called WatchMan500™, data will be transmitted to the adjacent ice buoy and processed on-board the buoy.

On the ice buoy itself, a cluster of weather instruments will measure wind speed, wind direction, air temperature, relative humidity and air pressure. Li-Cor sensors above and below the surface will measure incoming solar radiation and light penetration into the lake water (through ice in winter), and an additional near-surface water quality sonde on the buoy will provide near-surface water quality data to augment the information collected deeper in the lake using the subsurface mooring.

The data will be transmitted to the Water and Climate Impacts Research Centre at the University of Victoria (or other locations) via Globalstar satellite telemetry. Since WatchMan500™ and Globalstar telemetry have two-way capability the system can also be managed remotely, including configuration and diagnostics of both the ice buoy and subsurface mooring components. When the research ends, an acoustic release on the subsurface mooring will free all components so they can be easily recovered from the lake.

The ultimate objective of developing this buoy-based monitoring system is to deploy an array of systems in the Canadian Arctic in order to provide a more comprehensive understanding of how a changing lake-ice cryosphere will affect the structure, functions and food-web dynamics (including fish species critical for subsistence and northern community use) of lakes in the Canadian Arctic.

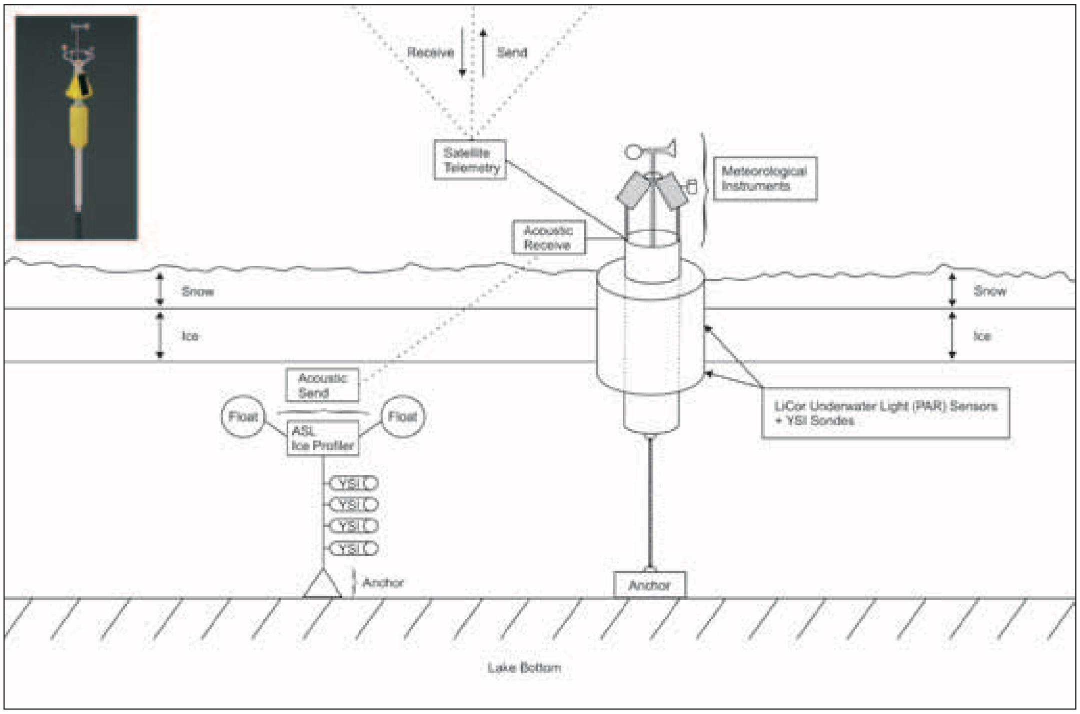


Photo inset: Peter di Cenzo, Environment Canada

Figure 3 Automated ice-water quality buoy schematic

Limnology and heat budgets of Great Bear Lake

Great Bear Lake, is one of Canada's non-Laurentian Great Lakes, according to Environment Canada scientist Dr. Fred Wrona, yet we knew little about it before IPY investigators carried out the most spatially intensive and extensive research ever conducted there. The work included meteorological observations at Deline and Lionel Island and observations of lake temperatures, currents and light transmission in the water column. Researchers can now apply climatic scenarios to the meteorological time-series and models to examine potential changes to the lake temperature structure.

Collaboration with northern communities

People from the community of Deline, Northwest Territories (NWT), were engaged in the project; some were trained and hired for the field work. Great Bear Lake is very important to the community for fishing, transportation and tourism income. The scope and level of scientific data collection would not have been possible without the significant amount of traditional ecological knowledge and community support that was provided.

4) Community-based Capacity-building and Outreach

Environment Canada's northern Canadian Aquatic Biomonitoring Network (CABIN) is a community-based monitoring program that engages northern residents directly in data collection and monitoring of the health and integrity of local freshwater ecosystems. Archived information, collected locally, will provide valuable baseline information on the current state of aquatic ecosystems. This initiative offered residents at long-term monitoring sites a variety of programs to build aquatic environmental and biomonitoring capacity within their communities. As well as workshops, field training sessions, apprenticeships and related outreach, the program developed two popular information products:

- Through a web-based e-learning program for remote northern communities, colleges and interested citizens have access to experts and field certification under CABIN (http://cabin.cciw.ca/intro.asp).
- A user-friendly comprehensive *Guide to Designing and Conducting Aquatic Biomonitoring in Northern Canada* was developed, serving as an aquatic companion piece to the widely used Northern Waters: *A Guide to Designing and Conducting Water Quality Monitoring in Northern Canada*.

COLLABORATING WITH NORTHERN COMMUNITIES

CABIN AND THE EXPERIMENTAL SCIENCE PROGRAM

An introduction to the CABIN approach to biomonitoring is becoming part of the curricula of high schools in the Northwest Territories. It is a perfect fit for the Experimental Science Program—a "learning-by-doing" program which features field work in conjunction with classroom instruction.

The CABIN module will be incorporated through a contract with Sahtu Renewable Resources and in conjunction with the Government of the Northwest Territories Department of Education Culture and Employment. It promises to increase high school students' interest in CABIN and general aquatic ecosystem monitoring, and may encourage young people to seek post-secondary environmental training and certification. A strategy is also being developed to incorporate CABIN into college curricula in the North through a partnership with Aurora College.

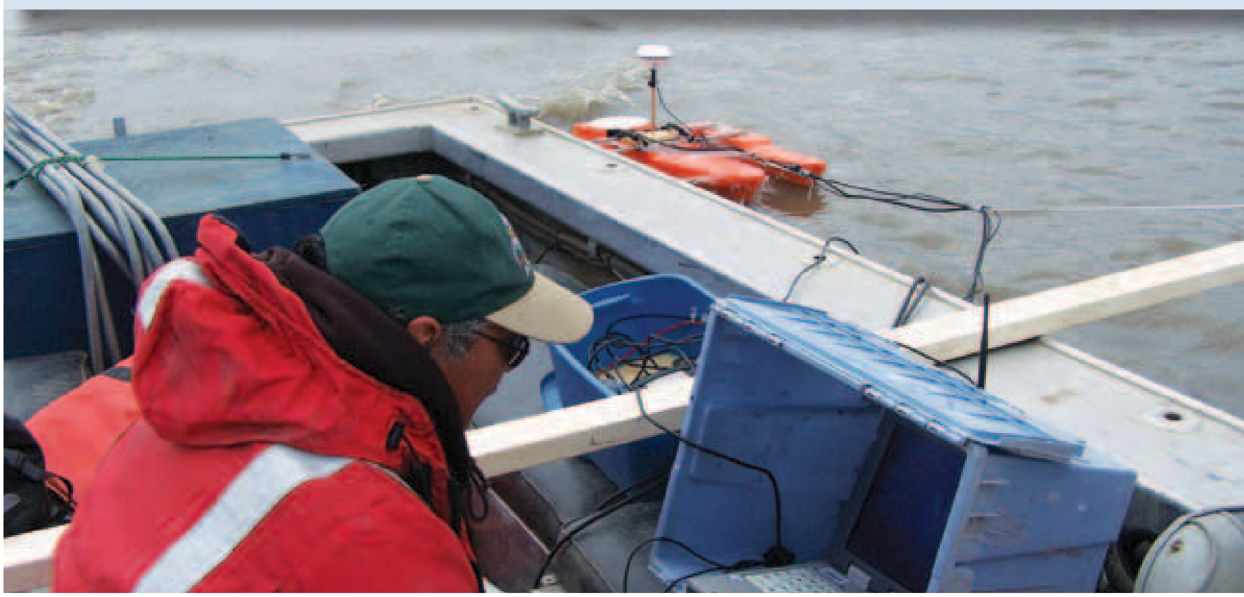


Photo: Dale Ross, Water Survey of Canada, Environment Canada

A northern resident trained and hired to assist with the Arctic Freshwater Systems project uses an Acoustic Doppler Current Profiler (ADCP) mounted on a towable catamaran in the Mackenzie Delta, 2007. The ADCP instrument determines flow velocities across the river channel.

Highlights

Environment Canada trained and hired numerous community residents, and local high school and college students to assist with field work, collection of samples and data, and laboratory analyses. For example, one Northerner from Inuvik, NWT, hired during the Freshwater IPY project, gained sufficient experience and skills in gauging water levels and flows in the Mackenzie Delta to be hired into a permanent full-time position with the Water Survey of Canada.

Other outreach activities included community consultations and meetings, visits to colleges and schools, presentations, websites and posters. Local residents shared their expertise about the health and integrity of local freshwater ecosystems and were informed of the nature and significance of the research—what researchers were trying to find out and why—and updated on the findings: what had been learned as the work progressed.

2.2 VARIABILITY AND CHANGE IN THE CANADIAN CRYOSPHERE (CRYO)

Principal Investigator: *Anne Walker, Environment Canada, Science and Technology Branch, Atmospheric Science and Technology Directorate, Climate Research Division, Climate Processes*

Environment Canada Co-Investigators: *Chris Derksen, Tom Carrieres, Tom Agnew, Terry Prowse, Barrie Bonsal, Ross Brown, Xiaolan Wang, Bin Yu, Xeubin Zhang, Roger De Abreu, Paul Bartlett, Diana Verseghy, Ed Chan, Robert Crawford, Greg Flato and Murray MacKay*

The Project's Scope

Researchers participating in Environment Canada's Variability and Change in the Canadian Cryosphere project set out to capture the current state of the Canada's cryosphere (defined as snow, lake and river ice, sea ice, permafrost and frozen ground, glaciers and ice caps) to determine how fast this dominant feature of Canada's landscape is changing and why. With the new information, scientists can better represent the cryosphere in Canadian climate models, which will enhance projections of future climate change.

Project teams were led by 33 experts in the fields of remote sensing of the cryosphere, climate analysis and climate modelling from Environment Canada, Natural Resources Canada, Canadian universities and the private sector. The investigations involved the analysis of satellite data and images as well as historical data records, coupled with wide-ranging field measurements such as the first systematic measurements of the physical and chemical properties of snow cover across the tundra and taiga landscape of North America. Beginning in April 2007, Environment Canada scientists and university co-investigators conducted several field campaigns across northern Canada, including the three territories and northern Quebec. These ground-based surveys produced datasets which provided key information on the state of the cryosphere—making an important Canadian contribution to the IPY snapshot of the North and serving as a baseline for assessing future changes.

Researchers also collaborated with northern communities on cryospheric monitoring by utilizing traditional knowledge and linking it with remotely sensed information.

THE PROJECT IN BRIEF

VARIABILITY AND CHANGE IN THE CANADIAN CRYOSPHERE

Capturing the current state of the cryosphere: snow, lake and river ice, sea ice, permafrost and frozen ground, glaciers and ice caps

1) Enhanced cryospheric datasets for the IPY snapshot.
2) Cryosphere-climate variability: analysing 50 years of data to improve projections of future climate change.
3) Better cryospheric process modelling with the Canadian Land Surface Scheme (CLASS) to enhance the land surface component of climate models.
4) Global and regional-scale simulations of the cryosphere.
5) Information for safer navigation: developing map-based products depicting ice conditions in Nunavik and Nunavut, including river-ice and sea-ice mapping.

Photo: Christian Marcotte, Environment Canada

Arial view of Ellesmere Island, 2005

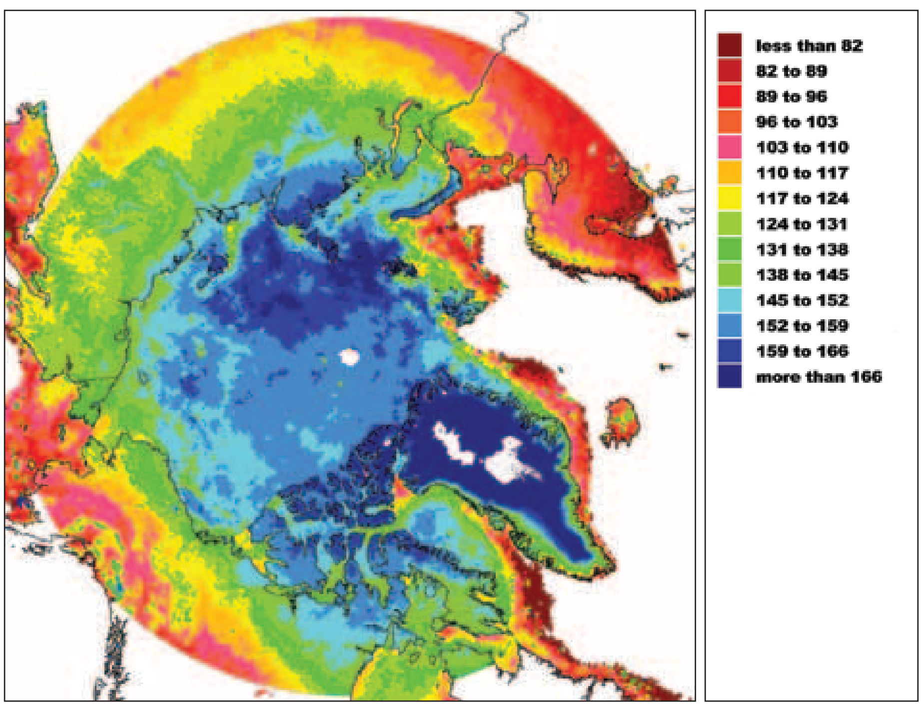
1) Enhanced Cryospheric Information for the IPY Snapshot

To better monitor cryospheric variables in northern Canada, investigators developed satellite-based capabilities and took both aircraft and field measurements to acquire new baseline data on the current state of the cryosphere.

Significant aspects of the work were done by separately funded university collaborators who explored the state of the ice caps in Canada's Arctic and developed satellite-based retrieval capability for lake ice thickness. For example, in collaboration with Joint Task Force North and the Canadian Rangers, Operation Nunalivut 2008 produced new baseline measurements of the health of the Canadian ice shelves by undertaking a traverse on Ellesmere Island from Eureka to Alert. In the process, researchers from the University of Ottawa and Trent University observed the dramatic fracturing of Ward Hunt Ice Shelf.

First extensive surface and airborne measurements

Three major sub-Arctic tundra field campaigns yielded thousands of kilometres of high-resolution airborne passive microwave data with close to 100 km of continuous snow-depth measurements. The investigators also recorded over 200 ice-thickness measurements along the airborne microwave radiometer flight lines. Such extensive and detailed surface measurements coupled with high-resolution airborne data has never been acquired before.



Map credit: Libo Wang, Environment Canada

Figure 4 New satellite-based capabilities used to detect pan-Arctic cryosphere melt onset (terrestrial and marine)

Legend: Julian date of the year of snow-melt onset.

New pan-Arctic snowmelt onset and end-date records were also produced for the 2000–2008 period. These data are important indicators of climate variability and change. The data will further our understanding of seasonal snow cover duration over the entire Arctic region, including both terrestrial and marine (sea ice) surfaces. Analysis of satellite-derived onset and end dates has shown a clear trend towards earlier melt onset in the Arctic region.

Early findings: New long-term daily estimates of snow cover

Project investigators from Environment Canada and Natural Resources Canada have produced snow cover maps that incorporate the only long-term daily estimates of snow cover for the Northern Hemisphere. They are also now able to quantify long- term changes in snow melt dates and they have collected what is likely the only available observational dataset on snow albedo controls at a scale suitable for comparison to global circulation climate models.

2) Cryosphere-climate Variability over 50 Years

Cryosphere-climate variability research involves identifying natural and human influences on the Arctic climate through the collection and analysis of multiple datasets on snow, river ice, sea ice, glaciers and ice caps. Researchers have documented the variability and change in cryospheric variables over the 50-year period since the International Geophysical Year in 1957. With this data, they are investigating links and feedbacks to the Arctic climate system and the roles of natural and anthropogenic forcing. The findings indicate that human activities have already influenced the Arctic climate, with increased precipitation and reductions in sea ice cover. Scientists are now using the data to improve projections of future climate change and inform the development of adaptation strategies.

3) Representing Arctic Cryospheric Processes in CLASS

The Canadian Land Surface Scheme (CLASS) is the land surface component of the Canadian global and regional climate models. Investigators evaluated the ability of CLASS to simulate cryospheric processes at the local and regional scale and to validate new parameterizations for snow cover and sub-grid lakes. Enhancements will improve simulations of the cryosphere.

Researchers used field measurements to improve the representation of canopy-snow interaction in CLASS. Correspondingly, the models themselves helped inform the interpretation and design of measurements, leading to the development of better algorithms. This will provide more realistic energy and water budgets when CLASS is employed in coupled simulations for developing climate change scenarios.

4) Global and Regional-scale Simulations of the Cryosphere

Researchers investigated cryosphere-climate interactions and feedbacks and climate model capabilities, utilizing historical and future scenarios generated by the Canadian Global Climate Model (CGCM3) and the Canadian Regional Climate Model (CRCM) coupled with CLASS. The results are providing new insight into the capabilities and uncertainties for simulations over high latitudes.

Highlights

Environment Canada researchers now have a better understanding of some of the sources of variation and uncertainty in predicting the way temperatures and other climate variables will respond to global warming. This work has important practical consequences, including improved predictions of future climate change, which can contribute to the development of economic activities and adaptation strategies for northern residents.

5) Better Information for Local Communities

Safer navigation

Since many Inuit depend on frozen rivers and sea ice for transportation routes to carry out traditional hunting and fishing activities, changing cryospheric conditions pose a major threat to their way of life. The Variability and Change in the Canadian Cryosphere project therefore generated information on local river-ice and sea-ice conditions to help residents plan safe navigation routes.

Project investigators used satellite radar images to develop map-based products depicting ice conditions for several communities in Nunavik and Nunavut. In consultation with local residents, investigators integrated traditional knowledge and terminology into these products. Workshops in northern communities introduced the maps and trained local residents in their interpretation and use.

River-ice maps generated by investigators at the INRS-ETE (University of Quebec) have been posted on the Kativik Regional Government website (http://climatechange.krg.ca/kuujjuaq.html). Local high school students in Kuujjuaq helped validate the maps by taking photographs of river-ice conditions. They also helped translate the maps into Inuktitut.

Noetix Research Inc., a private-sector partner on the project operating the Floe Edge Service, began providing sea-ice mapping for the communities of Pangnirtung, Cape Dorset and Igloolik in 2007. (The floe edge is the boundary where the floating sea ice meets the stationary land-fast ice along the shoreline).

DASHING THROUGH THE SNOW—FOR 4000 KILOMETRES

For one month in 2007, U.S. and Canadian IPY researchers set out to probe the nature of the northern cryosphere, undertaking a marathon expedition across the top of the continent. Chris Derksen and Arvids Silis of Environment Canada's Climate Research Division (CRD) took part in the Canadian leg of the journey—a 4000-km trek across the northern landscape.

The SnowSTAR expedition produced the first-ever systematic measurements of snow cover across the tundra and taiga of North America. Investigators took thousands of individual measurements to characterize the physical and chemical properties of the snow cover, providing data to refine satellite remote sensing imagery of the cryosphere.

This traverse was the first field campaign of the Variability and Change in the Canadian Cryosphere project. The American team left Fairbanks, Alaska, on March 16, 2007, and the Canadians joined them at Daring Lake, Northwest Territories, on April 17. Together, they covered the remaining 1083 km of the traverse in ten days, arriving in Baker Lake, Nunavut, on April 26. Throughout the trek, carried out by snowmobile, the researchers updated the

SnowSTAR 2007 website daily with text, photos and voice dispatches (via satellite phone uplink). Fifty schools across the United States and Canada participated in the expedition through the daily website updates, tracking the progress of the traverse.

Between Daring Lake, NWT and Baker Lake, Nunavut, the expedition stopped at 25 intensive-sampling sites; here, researchers measured the snow density and depth, as well as the snow-water equivalent (the amount of water contained within the snowpack). They also analysed the stratigraphy or layering of the snow and its chemical composition, including the amount of black carbon (soot) and mercury. These datasets supported several Canadian and American IPY projects. The snow-cover data provided new information on the spatial variability of snow cover and helped scientists validate new satellite measurements of snow-water equivalent being developed at Environment Canada.

Upon arrival in Baker Lake the entire team participated in an all-school assembly at the primary school, meeting with classes from grades 6 through 12. People in the community attended a public meeting on the evening of April 27.

Map credit: Matthew Sturm, CRREL (U.S. Army Cold Regions Research and Engineering Laboratory), New Hampshire

Figure 5 Map shows the route of the 4000-km Arctic traverse undertaken by two Canadian and five U.S. scientists from Fairbanks, Alaska to Baker Lake, Nunavut in 2007

As the opening field campaign of the IPY Cryosphere project, the traverse acquired the first-ever systematic measurements of snow cover across the tundra and taiga of North America.

2.3 INTERCONTINENTAL ATMOSPHERIC TRANSPORT OF ANTHROPOGENIC POLLUTANTS TO THE ARCTIC (INCATPA)

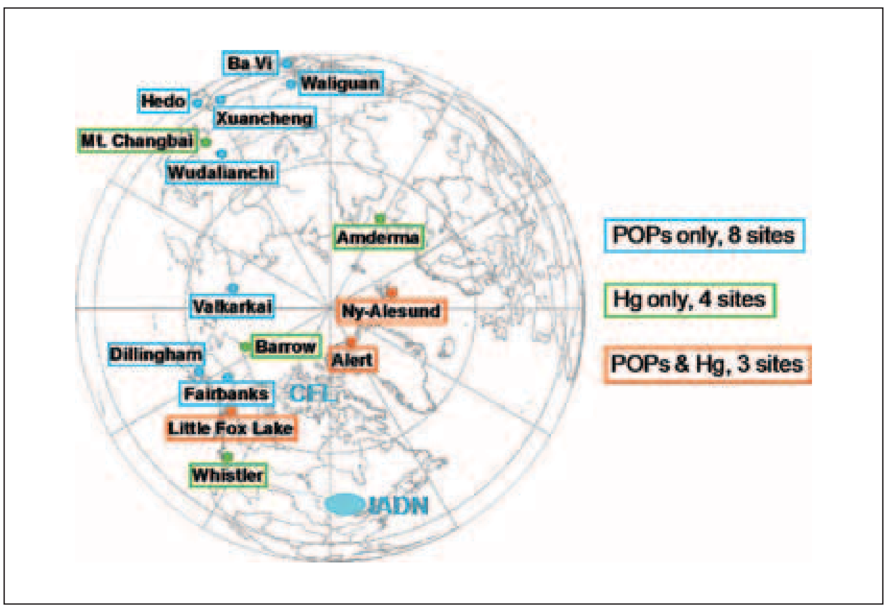
Principal Investigator: *Hayley Hung, Environment Canada, Science and Technology Branch, Atmospheric Science and Technology Directorate, Air Quality Research Division, Processes Research*

Environment Canada Co-Investigators: *Yi-Fan Li, Alexandra Steffen, Jianmin Ma, Ashur Dastoor, Tom Harner and Ed Sverko*

The Project's Scope

The Intercontinental Atmospheric Transport of Anthropogenic Pollutants to the Arctic (INCATPA) project measured toxic chemicals generated by human activity that are carried in the air to the Arctic, deposited at the Earth's surface and potentially affect the health of humans and wildlife.

Under the INCATPA project, an international network of researchers is tracking the movements of mercury and persistent organic pollutants (POPs) from sources distant to the Arctic and examining how climatic processes influence their presence. INCATPA researchers expanded and refined monitoring systems in Canada, working with researchers around the Pacific Rim to perform simultaneous air sampling of these pollutants in the Canadian, American and Russian Arctic and in potential source regions in Asia (see Figure 6).



Map credit: Yushan Su, Environment Canada

Figure 6 Map showing locations of INCATPA-related monitoring stations where atmospheric contaminants are measured

Although INCATPA-related research began some 17 years ago under Canada's Northern Contaminants Program (NCP) led by Indian and Northern Affairs Canada, no measurements of atmospheric mercury had yet been taken and there were only limited POPs measurements in the western Canadian Arctic. Furthermore, data on atmospheric concentrations of mercury and POPs were sparse for the Asia-Pacific region. This lack of information made it difficult to gauge the impact of transport events from this region on western Arctic contamination.

IPY funding enabled the refinement and expansion of the INCATPA network to incorporate new contaminant data for the western Canadian Arctic. This information will help determine how mercury and POPs may impact Arctic ecosystems and the health of Northerners.

THE PROJECT IN BRIEF

INCATPA

An international network of researchers tracking the movements of mercury and persistent organic pollutants (POPs) from faraway sources to the Arctic

1) Refining and expanding contaminant data collection.
2) Modelling pollutant movements: determining the prevalence of these pollutants in the Arctic and the influence of climate.
3) Providing information that will help determine how these chemicals may impact Arctic ecosystems and the health of Northerners: communicating information to northern communities, scientific advisors and the general public.

Photo: © Photos.com, 2010

1) Refining and Expanding Data Collection

Determining where pollutants originate

Mercury and POPs (including PCBs, some pesticides and combustion by-products) are toxic chemicals that persist in the environment. They can be carried from their original emission sources over intercontinental distances, travelling in air or water. The atmosphere is the primary and most rapid pathway of pollutant transport to the Arctic.

By measuring levels of POPs and mercury in the air, researchers can determine the quantity carried to the Arctic from external sources. In cold environments like the Canadian Arctic, these chemicals can be deposited at the Earth's surface and accumulate in wildlife. Northern people can in turn accumulate these contaminants to levels that may put their health at risk.

Knowing the source of the pollutants and precisely how they travel is also essential. INCATPA researchers are working internationally across the Arctic regions of Canada, Russia and the USA to measure mercury and POP levels. These measurements are being taken during the same time period by researchers on the other side of the Pacific Ocean, who are measuring around potential source regions. The results, which are currently being analysed, will tell us where these chemicals came from, the relative contributions of different regions and the climatic conditions that influence their movement to the Arctic. This knowledge is supporting the Government of Canada's work with other countries (e.g. under the *Stockholm Convention on POPs*) to limit the production, use and emissions of POPs and mercury and consequently reduce the entry of these pollutants into Canada's Arctic.

Building better networks

The INCATPA air sampling network for POPs and mercury builds on existing air monitoring stations under the Canadian-operated NCP, the Arctic Monitoring and Assessment Programme (AMAP), the Global Atmospheric Passive Sampling Network (GAPS), and the Integrated Atmospheric Deposition Network (IADN). In some areas, air monitoring of POPs and mercury is decades-old. Stations at Alert, Nunavut, and Ny-Ålesund, Norway, have conducted monitoring since the 1990s under the NCP and AMAP.

Under the IPY, Canada began its measurements of POPs and mercury at Little Fox Lake, Yukon. New locations in Russia, Alaska, China and Vietnam also joined the network. Measurements will continue until spring 2010. During IPY, INCATPA is also benefiting from the pollutant air sampling activities of other projects. This includes IPY projects Circumpolar Flaw Lead system study (see Section 4.1), the Ocean Atmosphere Sea Ice and Snow interactions in Polar Regions (OASIS) study (see Section 2.4), and the international Contaminants in Polar Regions (COPOL) project.

Researchers held a first INCATPA workshop in Toronto in fall 2008 to share early results, discuss challenges and set timelines. To validate the INCATPA-generated data, 25 laboratories in different countries compared analytical results for POPs in a quality-assurance study. This is the first large-scale international quality-assurance study for atmospheric trace organic analysis. Results generally showed good comparability within a factor of two and that variability was dependent on specific chemicals.

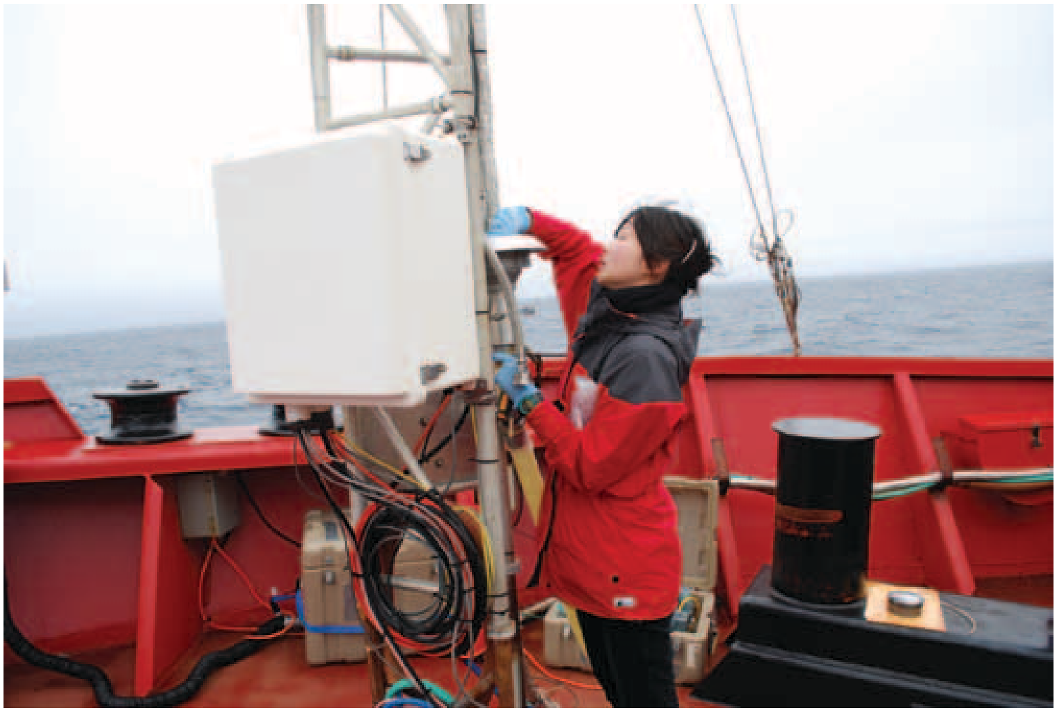


Photo: Vincent Ho, 2008

INCATPA principal investigator Hayley Hung taking air samples aboard the Canadian research icebreaker CCGS *Amundsen*.

Early results

Researchers are still analysing data on POPs and mercury collected during IPY, as a full dataset is required to obtain a comprehensive understanding of the goals set out by INCATPA. Preliminary PCB air concentrations measured in 2007 at Little Fox Lake showed that the PCB congener patterns change on a daily basis, thus indicating a shift in pollution sources.

2) Atmospheric Transport Modelling

Source regions of mercury and POPs have changed over the past decade or two. For example, in the 1980s, mercury emissions came largely from Europe and the Soviet Union; today, the primary source of mercury is Asia. With the Arctic environment changing, just as are source regions of pollutants to the Arctic, it is important to understand how pollutants arrive in the Arctic and how their behaviour will be affected by climate change. INCATPA researchers are working with computer models that simulate pollutant movements into the Arctic. By coupling POPs and mercury air concentration data from the ground with global atmospheric transport models, they are working to assess the potential impact of climate change on the transport of pollutants to the Arctic region.

POPs transport modelling

INCATPA researchers are currently upgrading two global atmospheric transport models for POPs: the Canadian Model for Environmental Transport of Organochlorine Pesticides (CanMETOP) and the Multicompartment Environmental Diagnosis and Assessment (MEDIA) model. The upgrades include:

- quantifying the impact of intercontinental atmospheric transport on POPs
- developing a theory and modelling study on global distillation and atmospheric transport of POPs; and
- improving modelling algorithms and parameterization.

Mercury transport modelling

Mercury transport modelling using the Global/Regional Atmospheric Heavy Metals model (GRAHM) includes several components of the INCATPA program, including:

- Identifying sources of mercury reaching the Arctic
  - Asia contributes between 29 and 37% of atmospheric and deposited mercury.
  - Asian emissions generate more long-range transport events than other emission source regions.
  - North America, Russia and Europe each contribute 5 to 10% of atmospheric mercury in the Arctic.
  - North America is an important source of deposited mercury only south of Yukon .
  - Case studies of long-range transport (LRT) events at Little Fox Lake and other sites are ongoing.
- Developing new parameterization of high-latitude Gaseous Elemental Mercury (GEM) deposition and re-emission
  - Researchers have compared model-predicted mercury and observed GEM fluxes and meteorological parameters at Ny-Ålesund, Norway. They found GEM deposition and emission to be most highly correlated with modelled mercury deposition and wind strength, respectively. Based on this analysis, a new parameterization was introduced into the GRAHM.
  - Processes affecting the behaviour of mercury within the snow pack are currently being researched.
- Assessing the impact of climate change on the LRT of mercury to the Arctic (future work)
  - Input meteorological scenarios predicted by the climate models into GRAHM.
  - Investigate how possible future changes in concentrations of other atmospheric chemicals will affect the behaviour of atmospheric mercury.

Atmospheric mercury depletion events (AMDEs) at Alert: climate change effects

The full mercury dataset collected under INCATPA will soon be available for modelling and final analysis. Researchers have also analysed the longer-term atmospheric mercury data set from Alert specifically to assess the impact of climate change on mercury deposition in this region based on data collected between 1995 and 2007. Results show that the temporal distribution of AMDEs at Alert has changed over that period. Local AMDEs also exhibit a complex relationship with local temperature and wind direction; the physical and chemical processes involved are being investigated in greater detail in the

OASIS-CANADA IPY project (see Section 2.4 below). The data provide a basis for further exploration of how changes in climate may affect the deposition of mercury to the Arctic environment, and this research may provide additional clues about the mechanism and location of mercury-depletion events.

3) Information for Northerners and Youth

The INCATPA project has conducted information sessions for northern communities, scientific advisors and the general public. To make the scientific information and research on contaminants accessible and relevant for northern communities, the project team collaborated with the Council of Yukon First Nations to prepare an IPY INCATPA/NCP storyboard, a PowerPoint presentation, a brochure, a poster and a colouring book. These materials were presented at science fairs, Aboriginal gatherings, science camps and various First Nations general assemblies.

The INCATPA project was also featured in a youth-generated exhibit titled "On Thin Ice – Youth Respond to International Polar Year" at the Ontario Science Centre, Toronto, in fall/winter 2008–2009.

INNOVATION

PASSIVE BUT CLEVER: DEPLOYING NEW AIR-SAMPLING DEVICES

The INCAPTA project set out to sample the air at remote locations across the western Arctic, but there was a snag. Traditional sampling devices require a power supply to operate a pump, which forces the air through a cartridge to collect the chemicals being monitored. The need for power and frequent maintenance was a distinct disadvantage in remote locations.

Newly developed flow-through type "passive" samplers provided the answer. These devices provide greatly increased sampling rates by forcing the wind to blow through the sampling medium, which consists of a series of polyurethane foam plugs. No power supply is needed to run the sampler. Vanes on the body of the sampler help it orient into the wind so that the wind does all the work. Small, battery-operated data loggers then store the air-flow information for later retrieval.

Researchers at the University of Toronto helped Environment Canada develop the design for the new samplers with funding provided by the Natural Sciences and Engineering Research Council of Canada and the Northern Contaminants Program. With IPY and Northern Contaminants Program funding, two samplers have been deployed in the Arctic.

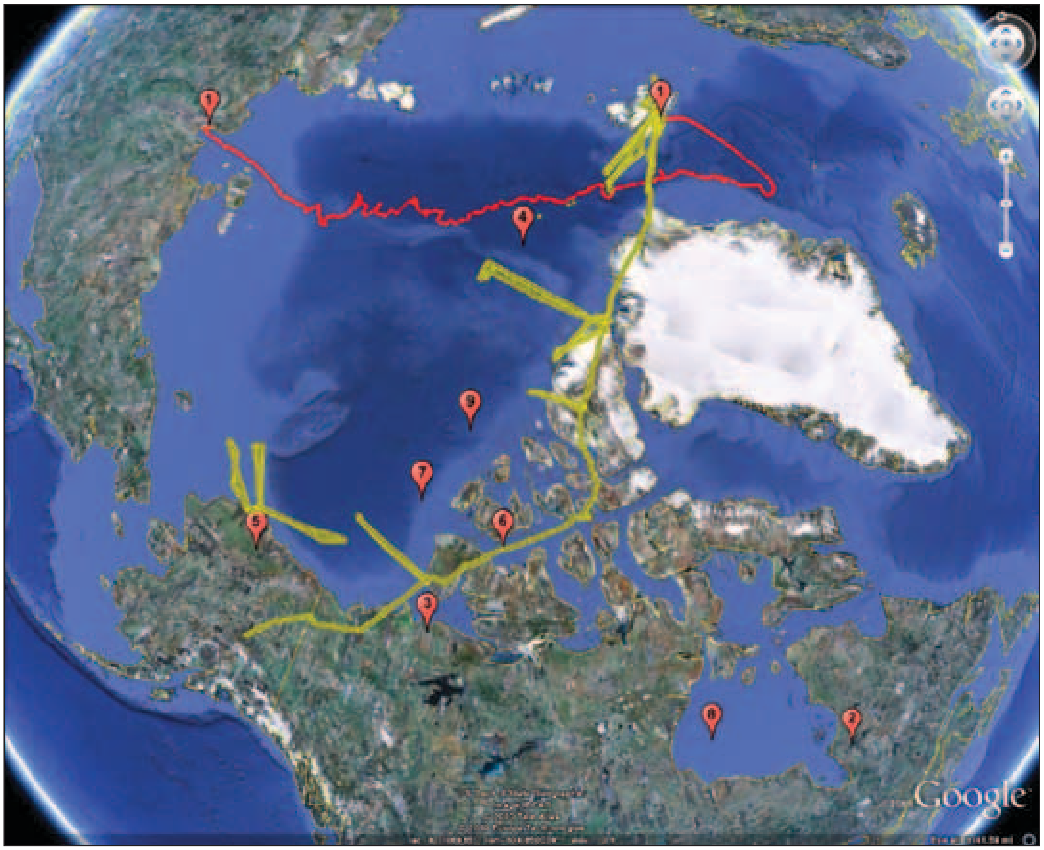
Photo: Hang Xiao

Flowthrough air sampler at Little Fox Lake, Yukon, 2009.

2.4 UNDERSTANDING OZONE AND MERCURY IN THE AIR OVER THE ARCTIC OCEAN (OCEAN-ATMOSPHERE-SEA ICE-SNOWPACK OASIS-CANADA)

Principal Investigator: *Jan Bottenheim, Environment Canada, Science and Technology Branch, Atmospheric Science and Technology Directorate, Air Quality Research Division, Measurements and Analysis Research*

Environment Canada Co-Investigators: *Alexandra Steffen, Ralf Staebler and Stoyka Netcheva*



Map credit: Jan Bottenheim, Environment Canada

Legend

1. Track of TARA drift (September 2006–January 2008)
2. COBRA (Kuujjuarapik/Whapmagoostui, February–March 2008)
3. CFL (CCGS *Amundsen*, February–April 2008)
4. ASCOS (Swedish icebreaker *Oden*, August 2008)
5. Barrow-09 (February–April 2009)
6. Track of Polar-5 (April 2009)
7. O-buoy-1 (deployed since October 2009)
8. O-buoy-3 (Canadian O-buoy-1, Hudson Bay, deployed February 2010)
9. O-buoy-4 (Canadian O-buoy-2, Arctic Ocean, deployed March 2010)

Figure 7 Map of OASIS-CANADA field locations

The Project's Scope

Every year when the sun comes up in the Arctic spring, the potent greenhouse gas ozone and the toxic chemical mercury disappear from the air near the ground along the coast of the frozen ocean. Scientists believe this phenomenon is caused by the interaction of sunlight, snow and ice in the presence of low temperatures over the sea ice.

Under the OASIS-CANADA project, Environment Canada researchers are investigating the disappearance of these chemicals. The information will help scientists to better understand the cycling of mercury and ozone in the Arctic. Ultimately, OASIS investigators want to determine whether the disappearing mercury ends up in the Arctic food chain and how recent climatic changes may be affecting the disappearance of mercury and ozone during the Arctic spring. What will happen to the ozone and mercury with further losses of sea ice due to global warming? And given the documented problem of long-range transport of various pollutants to the Arctic, what will happen to atmospheric pollution levels if there is less ozone in the air?

Earlier research on this topic was restricted to studies along the coast. OASIS research included data collection over widespread areas on the sea ice, working from research camps, cruising along the Beaufort Sea on the Canadian research icebreaker CCGS *Amundsen*, and taking measurements from a drifting French sailboat, the *Tara*, that covered most of the Arctic Ocean. The scientists also employed special ocean-monitoring buoys left out on the Beaufort Sea and Hudson Bay ice to travel by themselves and collect data. The aim was to take every opportunity to enhance the amount of information on the chemicals of interest: and benefits were accrued not only to this project, but to other related projects (see Circumpolar Flaw Lead system study, Section 4.1).

Researchers working at the wide-ranging sites took air samples and collected a multitude of other data, including snow samples and meteorological information. With this data, researchers have a measure of the composition of air at these locations, as well as comprehensive baseline information which will be useful for monitoring future changes.

THE PROJECT IN BRIEF

OASIS-CANADA

Investigating the spring depletion of mercury and ozone in the lower atmosphere over the Arctic

1) Expanding monitoring with the OOTI (Out-On-The-Ice) mobile lab: the newly deployed OOTI sled, which can be towed anywhere a snowmobile can go, measures ozone, mercury, carbon dioxide, bromine oxide and meteorological conditions.
2) Deploying solar-powered instruments: using "O-buoy" ocean buoys, investigators can monitor year-round concentrations of ozone, carbon dioxide and other chemicals over the water.

Photo: Carlye Calvin © UCAR

Frost flowers form over the ice on the Beaufort Sea, Barrow, Alaska, 2009.

1) Expanding Monitoring with State-of-the-art Equipment: the OOTI (Out-On-The-Ice) Mobile Lab

The OASIS investigators used new, state-of-the-art equipment to expand the reach of their monitoring and investigate Arctic atmospheric chemistry in places that were previously inaccessible. Their data is shedding more light on the episodic depletion of ozone and gaseous mercury in the lower atmosphere in the Arctic spring—one of the biggest global mysteries in atmospheric chemistry research.

OOTI is a sled that researchers outfitted with equipment capable of measuring how fast chemicals move between the air and the snow and ice. The OOTI sled, which took about five years to develop, is a self-sufficient, battery-operated mobile lab measuring ozone, mercury, carbon dioxide, bromine oxide and meteorological conditions. It can be towed anywhere a snowmobile can go.

OOTI sits on the ice and allows samples to be collected and analysed on the spot. Investigators move the sled from one site to the next, close to open water, where it can monitor conditions for one day or several days. Researchers have brought the OOTI sled system on many field campaigns, including on the frozen Hudson Bay, off the coasts of Alaska over the Arctic Ocean, and aboard the *Amundsen* icebreaker, which was drifting south of Banks Island (see Section 4.1).

Photo: Ralf Staebler, Environment Canada

The Out-On-The-Ice mobile lab (OOTI), loaded with instruments to measure the movement of chemicals between the atmosphere and the surface, on the frozen ocean south of Banks Island, 2008.

Monitoring mercury

Researchers are analysing the OOTI data to identify trends in and draw conclusions about mercury cycling, with the aim of understanding more about the phenomenon of mercury disappearance. Mercury is a major contaminant of concern for Arctic wildlife and northern residents. The atmosphere is known to be an important vector of mercury transport over long distances and there is evidence that mercury is transported through the atmosphere to the Arctic from as far away as Asia (see the INCATPA project, Section 2.3). However, there is still a great deal of uncertainty about the cycling and fate of mercury once it is in the Arctic environment.

Photo: Carlye Calvin © UCAR

Environment Canada researcher Sandy Steffen using a sampling instrument to measure atmospheric mercury concentrations near a field of frost flowers over the Beaufort Sea offshore from Barrow, Alaska, March 2009.

Highlight

By using the OOTI, together with field expeditions on the *Amundsen* and other ships, OASIS researchers gathered mercury data over a wide area of the Arctic seas. This work culminated in a large, joint IPY atmospheric research effort with U.S. scientists at Barrow, Alaska, in 2009. At Barrow, investigators deployed sophisticated atmospheric sampling equipment never before used on the Arctic sea ice. Working closely with local Inupiat, Environment Canada scientists overcame some considerable logistical problems to move their equipment through the difficult icy terrain (see boxed text below).

Already, they have proven that, with the collaboration, focus and funding provided by IPY, it is possible to undertake sophisticated, even unprecedented, research and monitoring in one of the most hostile environments on Earth.

WORKING WITH NORTHERN COMMUNITIES

THERE'S NO SUBSTITUTE FOR LOCAL EXPERTISE

The practicalities of Arctic research testify to the importance of local know-how. This fact was brought home to Sandy Steffen of the OASIS-CANADA project when she set out to do her research in Barrow, Alaska. Sandy relies on highly sophisticated instruments to provide precise and detailed measurements of mercury and other components of the atmosphere, but these instruments have serious limitations in the Arctic environment. One of her measuring devices, for example, is the Tekran™ mercury vapour analyser. With all its accoutrements, it weighs about 180 kg and requires some four kilowatts of power. As many of its components are made of glass, the device is also quite delicate: just getting the instruments in place is a challenge. In Barrow, the challenge seemed quite insurmountable.

But the Inupiat of Barrow have, "an incredible skill set," says Steffen. Their knowledge of the local environment helped guide the day-to-day research operations and overcome logistical challenges. Community support also kept the project running smoothly in practical ways, from cutting holes in metre-thick ice for water sampling, to keeping generators running, to ferrying supplies, and completing a trail through 10-m-high ice boulders. Inupiat hunters provided valuable protection against Polar Bears at research sites too. One curious Polar Bear even licked the lens of one of Steffen's colleague's optical instruments! "Trying to clean off bear spit in the cold makes life difficult," says Steffen.

The important partnership between the researchers and the community continued throughout the project at Barrow. Despite their own years of experience in northern research, the investigators found there was no substitute for the intimate local knowledge the Inupiat had gained over time.

Photo: Ralf Staebler, Environment Canada

Community residents and scientists clear the trail offshore from Barrow Alaska.

2) O-buoys: Solar-powered Instrumentation

OASIS investigators designed and built ocean buoys housing solar-powered instruments to measure year-round concentrations of ozone, carbon dioxide and other chemicals. They released a buoy into the Beaufort Sea which will collect air samples as it travels with the sea ice and ocean currents for as long as it survives the harsh conditions. The data are retrieved via satellites and transmitted to laboratories for analysis.

ELECTRONIC MONITORING BUOYS: RELIABLE SENTINELS IN A HARSH ENVIRONMENT

In collaboration with colleagues from Purdue University, the University of Alaska and the U.S. Army Corps of Engineers, Environment Canada scientists have developed a floating platform for studying Arctic weather. The first "O-buoy" was deployed on the Beaufort Sea with the aim of advancing our understanding of the atmospheric chemistry occurring in this remote region of the world.

Land-based measurements and ship-board studies can't provide a complete picture of atmospheric chemical processes over the Arctic Ocean. This is especially true in more remote areas and during the months of darkness. Scientists believed that an automated buoy system could provide invaluable atmospheric and meteorological measurements. Such buoys could be deployed year-round to report regularly on chemical mechanisms and transport pathways, thereby greatly advancing understanding of the Arctic's unique atmospheric chemistry. Developed with IPY funding, the O-buoy is fulfilling the scientists' wishes.

The fully automated O-buoy can drift with the ice and ocean currents for up to a year, taking measurements of ozone, bromine monoxide, carbon dioxide and meteorological variables over Arctic sea ice. From these measurements, scientists can interpret a whole range of ocean/atmosphere/sea ice/snow pack interactions. The first O-buoy was put to the test near Barrow, Alaska, from February to May 2009. It has now been redeployed in multi-year sea ice in the Beaufort Sea.

The buoy can operate under harsh Arctic conditions with minimal human assistance. It is equipped with batteries and solar panels, which can provide all its energy needs in the summer. The solar panels also serve to recharge the batteries. Electronics on board allow daily transmission of data via satellite to remote laboratories. Once-a-year maintenance should be adequate, say the system's designers. A key requirement for the O-buoy was that it its instruments operate at a controlled temperature but at minimal power cost, since winter operation would be battery powered. The designers put the three main instruments at the bottom of the O-buoy to sit below the ice and maintain a near-constant temperature of about –1.5°C.

The first O-buoy built with Canadian funds was deployed in Hudson Bay from Churchill, Manitoba in February 2010. A second was deployed in the spring of 2010 in the Arctic Ocean off Borden Island in conjunction with a seabed mapping mission in support of Canada's claim under the *UN Convention on the Law of the Sea*.

An important part of the legacy of IPY, O-buoys can greatly expand our weather monitoring capacity in the Arctic. Continuing the OASIS analysis of the disappearance of atmospheric ozone and mercury over the frozen Arctic ocean will be just one of the tasks the O-buoys undertake in the years to come as they continue to contribute to our understanding of the changing Arctic environment.

2.5 THE OBSERVING SYSTEM RESEARCH AND PREDICTABILITY EXPERIMENT (THORPEX) ARCTIC WEATHER AND ENVIRONMENTAL PREDICTION INITIATIVE (TAWEPI)

Principal Investigator: *Ayrton Zadra, Environment Canada, Science and Technology Branch, Meteorological Research Division, Atmospheric Numerical Weather Prediction Research*

Environment Canada Co-Investigators: *Greg Flato, Jocelyn Mailhot, Paul Vaillancourt, Louis Garand, Pierre Pellerin, Stephane Belair, Saroja Polavarapu and Mark Buehner*

The Project's Scope

Environment Canada's ability to predict the weather is one of the notable technological successes of the last century. Modern weather and environmental prediction (WEP) capabilities have helped safeguard our social and economic well-being and no have doubt saved many lives. However, with small populations concentrated in remote communities, weather prediction for Canada's North has not received the same degree of study as for the country's more densely populated southern regions.

Concerns about amplified climate change at higher latitudes coupled with increasing levels of economic activity in the Arctic have brought attention to the issue. Northerners, many who have long used traditional knowledge to understand the weather, are also concerned, since the unusual weather changes they are now seeing make it difficult to understand day-to-day and seasonal environmental variability.

To improve predictions of Arctic weather, Environment Canada forecasters require a better understanding of northern weather and climatic processes. With the THORPEX Arctic Weather and Environmental Prediction Initiative (TAWEPI), IPY has provided the international context for a Canadian-led initiative to improve WEP capabilities for the Arctic.

The overarching project, THORPEX (The Observing System Research and Predictability Experiment) is an international research and development program created to address the weather-related challenges of the 21st century. THORPEX aims to accelerate improvements in the accuracy of one-day to two-week high-impact weather forecasts.

The primary objective of TAWEPI was to develop and validate a regional Numerical Weather Prediction (NWP) model over the Arctic during IPY. The experimental model, called Polar-GEM, is a twin of the Environment Canada operational regional GEM (Global Environmental Multi-scale) model, used for one- to two-day weather forecasts. TAWEPI investigators also did modelling research and data-assimilation studies to enhance WEP capabilities in polar regions and improve our understanding of the Arctic and its influence on global weather patterns.

The project has involved various research and development divisions of Environment Canada, including at the Canadian Meteorological Centre (CMC) and the Canadian Ice Service, in collaboration with researchers at the Department of Fisheries and Oceans (DFO), Canadian universities and other IPY projects.

THE PROJECT IN BRIEF

TAWEPI

Developing and validating a regional Numerical Weather Prediction (NWP) model

1) The Polar-GEM: developing, testing and extending the experimental model's capability to enhance weather and environmental prediction in northern regions.
2) Northward extension of forecast models: collaborating with the Canadian Meteorological Centre to develop a new regional weather forecast model that includes an Arctic extension; the model will provide an ideal platform for future transfer of research findings proposed by TAWEPI researchers.
3) Research outreach: TAWEPI datasets are available to all IPY researchers, include complete weather maps and chemistry. Data generated by sub-project GEM-BACH IPY are archived in the SPARC Data Center (www.sparc.sunysb.edu/html/user_ipy.html).

Global outreach: TAWEPI is part of THORPEX, an international research and development program.

Photo: Martin Fortier, ArcticNet

Cliffs of Gibbs Fjord, Baffin Island, Nunavut

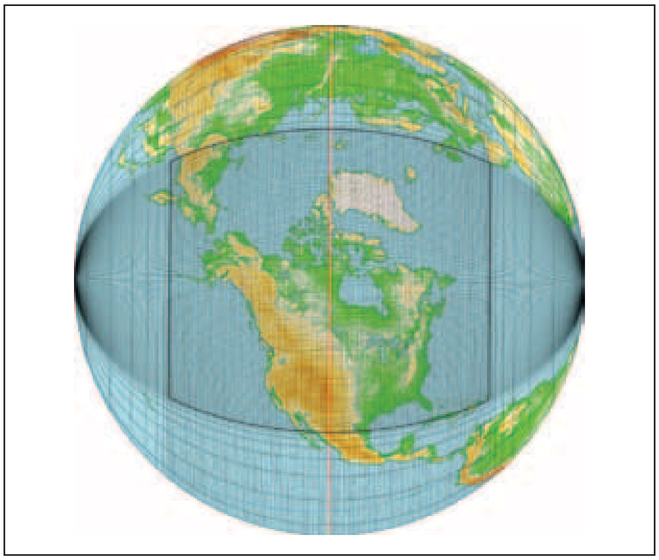
1) Developing the Polar-GEM

TAWEPI's research activities, which began in April 2007, led to the development of Polar-GEM. Investigators used a research version of the model covering the Arctic basin and surrounding regions to study the representation of radiative and cloud processes in weather forecasts. Researchers also tested a multi-layer snow model coupled to sea-ice and blowing-snow parameterizations, describing processes over the various types of surfaces of the Arctic environment such as sea-ice, tundra, glaciers and ice caps. Using an extension of the GEM model, they also generated analyses of the stratosphere for 2007–2008, including estimates of the ozone field.

TAWEPI investigators developed a methodology to validate model forecasts of cloud and radiation using satellite data. They conducted a sensitivity study, revealing how weather patterns and weather disturbances originating from various regions of the globe may impact on Arctic weather, and archived the 2007–08 results. A state-of-the-science sea-ice model is being adjusted to improve the sea-ice representation in the Arctic.

2) Extending the Model Northward: Collaboration with the CMC

To develop the Polar-GEM model TAWEPI investigators worked closely with the CMC. This collaboration has been one of the most important aspects of TAWEPI. In March 2009, a new version of the CMC's regional model became operational. This model generates short-term forecasts (up to 48 hours) for the entire country. One major change in this model was a northward extension of its central domain (the higher-resolution area indicated in Figure 8), which now covers most of the Arctic basin. This provides an ideal platform for future transfer of research findings and improvements proposed by TAWEPI researchers.



Source: Environment Canada

Figure 8 Grid of Canadian Meteorological Centre's new regional model

Note: Only every fifth grid-point is shown. The model core, indicated by a thick black line, has a horizontal resolution of 15km and now includes most of the Arctic basin.

3) Research outreach

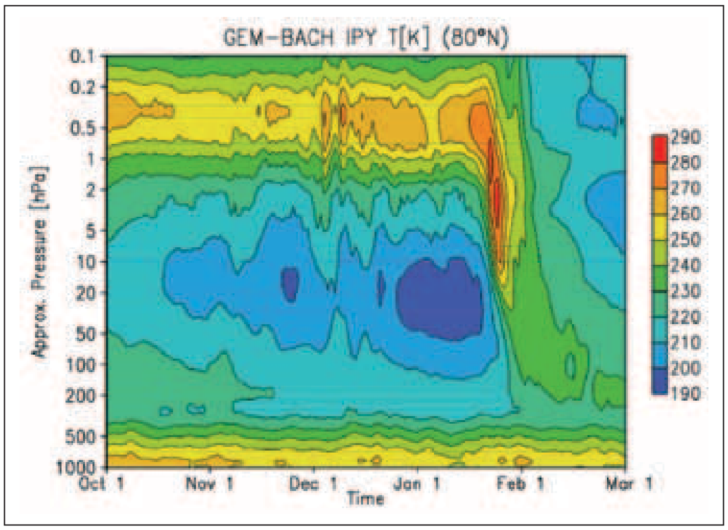
GEM-BACH IPY project

The GEM-BACH IPY initiative, a Canada–Belgium collaboration, has provided a dataset of the evolving, analysed state of the atmosphere every six hours for the duration of the IPY period. This includes all meteorological variables as well as the full, three-dimensional distribution of chemical species (atoms and molecules subjected to chemical processes) that are relevant to the stratosphere.

Researchers produced the analyses using a developmental version of Environment Canada's forecast system. Stratospheric chemistry calculations were performed by a comprehensive online chemistry package provided by the Belgian Institute for Space Aeronomy (BIRA). Because the analyses have global coverage, they facilitate the study of interactions between the polar regions and the rest of the atmosphere. The resulting data, available from the SPARC IPY repository (see URL above), are already proving useful in investigations of various dynamic processes and ozone variability. The data are also helping investigators interpret ground-based trace-gas measurements.

Highlights

The Northern polar stratosphere regularly experiences very strong disturbances which are associated with an abrupt temperature increase and which often culminate in a disruption of the polar atmospheric circulation. Such sudden stratospheric warmings have significant implications for ozone chemistry and their effects penetrate well into the troposphere. The 2009 warming, one of the strongest on record, was well captured in the GEM-BACH IPY analysis. A time-series of the zonal-mean temperature field at 80°N during the last five months of IPY (Figure 9) clearly shows the sharp rise in temperature near January 24, 2009. The stratospheric winds (not shown) completely reverse during this period and do not recover until late March.



Source: M. Reszka and S. Polavarapu, Environment Canada

Figure 9 GEM-BACH IPY analysis of zonal-mean temperature at 80°N from October 1, 2008 to March 1, 2009

Validating models with comparative analysis

Environment Canada researchers collaborated with the University of Toronto to compare GEM-BACH IPY analyses with Fourier Transform Infrared (FTIR) measurements of trace-gas column amounts. There is excellent agreement between the two datasets for ozone measured at Eureka, Nunavut, in 2007; in particular, the representation of short-term ozone variability is remarkably consistent. Similar correspondence was found for other species throughout the IPY period. The observations have helped to validate the model results, and in turn, the model results help to place the observations within the wider context of atmospheric circulation.

Transferring the technology

The TAWEPI modelling projects and data-assimilation studies will advance the development of the experimental Polar-GEM system. Investigators expect to transfer the results to the CMC. This process of WEP research and development should provide improved day-to-day forecasting with a better representation of Arctic weather and environmental trends.

3 ENVIRONMENT CANADA SCIENTISTS ARE CO-INVESTIGATORS OR TEAM MEMBERS ON FIVE IPY PROJECTS

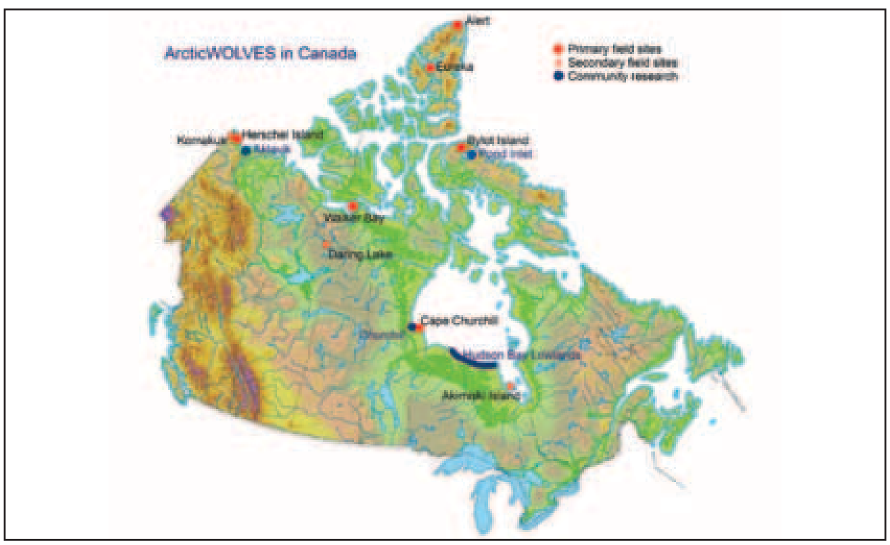
3.1 ARCTIC WILDLIFE OBSERVATORIES LINKING VULNERABLE ECOSYSTEMS (ARCTICWOLVES)

Principal Investigator: *Gilles Gauthier, Laval University*

Environment Canada Co-Investigators: *R.I. Guy Morrison and Josée Lefebvre*

The Project's Scope

ArcticWOLVES is a circumpolar study of tundra food webs and associated ecosystem processes. Environment Canada scientists are working with numerous collaborators to measure the current impacts of climate change on wildlife and predict future impacts through modelling. Researchers have two primary goals. They are working to determine the relative importance of resources and predators in structuring Arctic food webs and quantifying the interactions. They are also documenting direct and indirect impacts of climate change on terrestrial animal biodiversity, to forecast future impacts on animal populations.



Source: Josée Lefebvre, Environment Canada

Figure 10 Map showing project field sites and community research locations

ArcticWOLVES involves an international network of wildlife observatories and researchers, including more than 60 Canadian investigators. Field work at six primary study sites (see Figure 11) in Nunavut, Yukon and northern Manitoba has been a major part of the project in Canada.

In Canada, ArcticWOLVES is linked with CiCAT (Climate change Impacts on Canadian Arctic Tundra), another IPY project, in which Environment Canada biologists are collecting seabird and habitat data (see Section 3.2).

THE PROJECT IN BRIEF

ARCTICWOLVES

A circumpolar study of tundra food webs and associated ecosystem processes

1) Extensive monitoring of wildlife species: An international network is monitoring several tundra species and their trophic interactions (plants/herbivores/predators).
2) Insights on wildlife and climate change: Researchers are assessing the possible effects of the rapidly warming climate in areas like the northern Yukon, where they found significant changes in the distribution and abundance of a wide variety of species such as passerines, raptors and butterflies.

Photo: Josée Lefebvre, Environment Canada

Céline Maurice, Environment Canada wildlife technician, observing a Red Knot (an Arctic shorebird) near Eureka, Ellesmere Island, 2008.

1) An International Ecological Network for Monitoring Wildlife

The international network of researchers has extensively monitored the abundance, timing and success of reproduction, habitat use and diet of several key wildlife species. During IPY, researchers also studied annual plant production and arthropod diversity and abundance at each site. The multi-year data allow for a comparative approach and will provide input for modelling these interactions at several sites.

A key component of the project focuses on trophic interactions among birds and mammals of the tundra. Understanding these interactions is essential for evaluating the sensitivity of tundra ecosystems to disturbance.

A feature of the project is to simultaneously document changes occurring in a large number of wildlife species at a number of sites over a large geographical range using standard protocols. This approach provides important spatial replicates which enable scientists to make strong inferences about tundra ecological processes. In addition, variability among sites will give insights at different spatial scales and permit a comparative approach.

The species being studied include herbivorous geese and small mammals (such as lemmings), insectivorous shorebirds, avian predators (raptors and tundra seabirds) and mammalian predators (Arctic and Red foxes and weasels). In addition, more intensive studies are focusing on topics such as the:

- scale of movements by predators;
- importance of habitat use by small mammals in predator/prey interactions;
- effect of climate on the synchrony between resource abundance (such as insects or plants) and the reproduction of herbivorous and insectivorous birds; and
- effect of climate on the release of soil nutrients by microbes during the spring thaw and its subsequent uptake by herbivores through forage plants.

The research has incorporated traditional knowledge to enhance understanding of the abundance and distribution of wildlife species.

Photo: Josée Lefebvre, Environment Canada

Wildlife technicians Francis St-Pierre and Christian Marcotte of Environment Canada's Canadian Wildlife Service installing traps to evaluate population abundance of lemmings at Eastwind Lake, Ellesmere Island, July 2009.

2) Insights on Wildlife and Climate Change

The researchers have found increasing evidence that predators may play a key role in controlling the tundra food web. They have measured the seasonal and annual movements of several predators, determining that in some cases the movements were greater than anticipated. They found new evidence, for example, that Snowy Owls range over wide areas seasonally and annually. Some female Snowy Owls tracked with satellite transmitters spent significant time far out on the sea ice, likely preying on seabirds. This suggests that the owls may be impacted by climate change effects on sea ice.

Other bird species may also be affected by climate warming, since it will have a negative impact on the synchrony between hatching times and the timing of peak availability of food (either plants or insects) on the breeding grounds. This could reduce bird populations. Plant/herbivore interactions, too, could be vulnerable to climate warming. Warming could disrupt nutrient release in soils in winter and spring, since plants and soil processes respond strongly to temperature increases. This would negatively affect plant growth and hence food availability for herbivores.

The changing climate may have already affected northern Yukon species, where researchers found evidence that significant changes have occurred in the distribution and abundance of a wide variety of species like passerines, raptors and butterflies in recent decades. Researchers believe this could be linked to the rapid climate warming currently observed in this area.

Photo: Francis St-Pierre, Environment Canada

Slidre Fiord, Ellesmere Island, near Eureka and Environment Canada base camp for IPY ArcticWOLVES project, 2007.

3.2 CLIMATE CHANGE IMPACTS ON CANADIAN ARCTIC TUNDRA ECOSYSTEMS (CICAT): INTERDISCIPLINARY AND MULTI-SCALE ASSESSMENTS

Principal Investigator: *Greg Henry, University of British Columbia*

Environment Canada Co-Investigators: *Vicky Johnston and Jennie Rausch*

The Project's Scope

CiCAT is a large-scale terrestrial ecology project linking Arctic researchers studying soil, vegetation, carbon fluxes and ecosystem modelling and undertaking community-based monitoring. The researchers are assessing climate change trends and impacts on tundra ecosystems and northern communities. Environment Canada scientists were involved in two components of CiCAT: producing remotely sensed habitat maps for Arctic shorebird population monitoring and providing information for larger wetlands inventory and land classification projects.

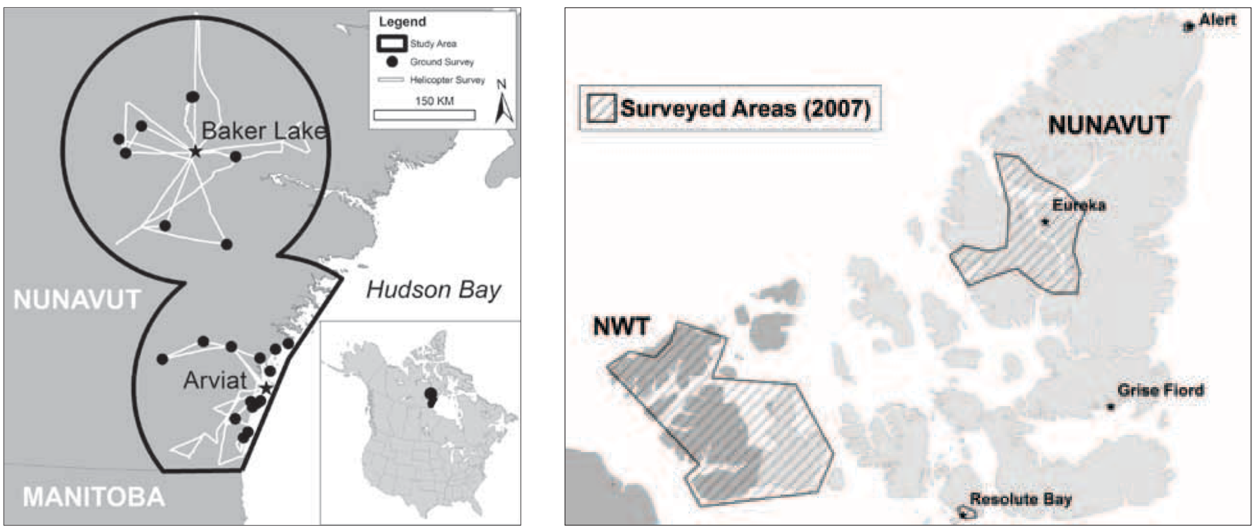


Figure 11 Project survey areas: wetland mapping of mainland barrens near Baker Lake and Arviat, Nunavut (left) and shorebird surveys in Queen Elizabeth Islands, Northwest Territories and Nunavut (right)

THE PROJECT IN BRIEF

CICAT

A large-scale terrestrial ecology project linking Arctic researchers studying soil, vegetation, carbon fluxes and ecosystem modeling and utilizing community-based monitoring

1) Habitat mapping for shorebird monitoring: supplying habitat information for the Arctic component of the Program for Regional and International Shorebird Monitoring (Arctic PRISM) and other wildlife survey programs, and uncovering new information about breeding shorebirds of the Queen Elizabeth Islands. The study indicated the likely importance of inland areas to shorebirds and waterbirds, a finding which may alter our estimates of population size of Arctic-breeding shorebirds.
2) Wetland classification and inventory: contributing data to other IPY studies of peat-based wetlands and land-cover types along the unmapped coastal regions, including Nunavut's Kivalliq coast.

1) Habitat Mapping for Arctic Shorebird Population Monitoring

Populations of most species of Arctic shorebirds appear to be declining. Climate change will further stress these birds on their breeding grounds. Although they are aware of the problem, wildlife managers have been hampered by limited information on population sizes and long-term population trends.

The Canada–United States Arctic Program for International and Regional Shorebird Monitoring (Arctic PRISM) was established several years ago to track shorebird numbers in the Arctic. A major impediment, however, has been the lack of habitat maps. Biologists need accurate maps to extrapolate their survey results and estimate total population sizes. This IPY project provided the necessary habitat information to produce accurate, season-appropriate maps for use in PRISM and other wildlife survey programs.

Environment Canada biologists began monitoring Arctic shorebirds several years ago in response to widespread shorebird population declines as noted on migratory routes throughout southern Canada and the United States. Accurately estimating shorebird numbers during migration is difficult. Better estimates can be obtained from the northern breeding grounds, where the birds are more stationary. Breeding ground monitoring yields population estimates allowing scientists to identify trends in populations over time. For IPY, Environment Canada researchers completed reconnaissance-type surveys in the Queen Elizabeth Islands and on the mainland barrens (near Arviat and Baker Lake, Nunavut). They collected ground-control point data for wetlands, and searched for shorebird "hot spots." With the data, researchers can refine the selected areas for conducting future PRISM surveys.

Photo: Jennie Rausch, Canadian Wildlife Service, Environment Canada

A Red Knot nesting on Fosheim Peninsula, Ellesmere Island, Nunavut, 2007.

Early findings: some shorebirds are equally abundant away from the coast

The IPY information is also helping biologists learn more about Barrenland breeding shorebirds, where little was known before. The shorebird monitoring has uncovered new information about the likely importance of inland areas. In the past, most waterbird surveys in the Canadian Arctic focused on coastal regions. However, Environment Canada biologists believed the much larger inland area might contain significant numbers of birds, even if densities are low. Through the IPY investigations, biologists found that gulls and terns were concentrated along the coast, whereas all other birds were equally abundant away from the coast. The results question the assumption that Arctic shorebirds and waterbirds are mostly found close to coastlines. Previous population estimates of some species, which are based solely on Arctic coastal surveys, may therefore be low.

2) Wetland Inventory and Land Classification

In collaboration with other IPY projects, Environment Canada biologists collected ground-control point data and habitat information to feed into a larger wetland inventory and land-cover (habitat) classification mapping project.

Identifying peat-based wetlands

Melting permafrost releases carbon dioxide into the atmosphere. This is likely to accelerate global warming. Scientists expect that frozen peat will be the main producer of this carbon dioxide, but they are unsure how much peat, primarily under wetlands, exists in the Canadian Arctic. During IPY, Environment Canada investigators surveyed two major parts of the Canadian Arctic to identify areas of peat-based wetlands and estimate how much peat exists in these areas.

Linking field studies with remote-sensing data

Environment Canada researchers also carried out field studies to investigate other land-cover types along the Hudson Bay coastal region using remote-sensing data. This allowed the researchers to delineate the region's wetland habitat—useful information for species monitoring and population estimation. The project will include a classification scheme of the land-cover types, a thematic map of the study area displaying the distribution of cover types, a biological description of each land-cover type and a summary of the overall habitat classification of the area.

Environment Canada conducted helicopter-assisted fieldwork to classify the habitat of previously unmapped coastal region. The ground and aerial investigators gathered detailed habitat information, including general land-cover type (such as shrub thicket) and ground cover percentages within the land-cover type (e.g. percent shrub, graminoid, moss). At each site, researchers also took a series of photographs of the land cover, and collected additional information such as slope, substrate and moisture regime. This field data will guide land classification methods using remotely sensed imagery.

The habitat classifications will also be useful both for PRISM and the Canada Wetlands Inventory. As well, Environment Canada researchers are working with the Nunavut Department of the Environment to incorporate the IPY results into the Kivalliq Habitat Mapping project, a habitat classification scheme which had been missing coverage for the Hudson Bay coastal region.

BUILDING CAPACITY IN THE NORTH

A VALUABLE LINK WITH THE COMMUNITY

Environment Canada CiCAT researchers hosted a Community Outreach Program science camp for middle school and high school students in Arviat, Nunavut, in May 2008. During a week of games, lectures and field studies, the students learned about shorebirds, climate change and careers in biology. By week's end, they knew all about the different types of shorebirds around the region and how climate change will affect birds and their habitat.

In hands-on outdoor sessions, students learned how to identify birds in their region, to take and filter water samples, do a vegetation survey, read a map and use a global positioning system (GPS). Community elders joined the group for afternoons where they shared their knowledge about shorebirds and birds in general.

"It was a really great week," says Environment Canada biologist Jennie Rausch, and an important "chance to interact with kids." Jennie also believes the science camp helped forge a link with the community. In her subsequent field studies in the area, local residents would often stop by to discuss her work and share their knowledge of the area.

Photo: Tamika Mulders, Yellowknife, NWT, 2008, Qitikliq Middle School, Arviat, Nunavut

Elders and middle school teachers share knowledge about birds and memories of hunting with students and biologists who took part in IPY outreach activities in Arviat, Nunavut.

3.3 CLIMATE VARIABILITY AND CHANGE: EFFECTS ON CHAR IN THE ARCTIC (CVC)

Principal Investigator: *James Reist, Department of Fisheries and Oceans*

Environment Canada Co-Investigators: *Fred Wrona and Derek Muir*

Arctic Char and related fish species are important components of Arctic freshwater, estuarine and near-shore marine ecosystems and serve as key integrators for monitoring change occurring in these systems. Char are fundamental to the social and cultural well-being of many northern communities and form the basis of household and commercial fisheries. The ability of Northerners to adapt to change requires vital information on the thermal ecology, biodiversity and mercury (Hg) contaminant interactions of char.

Char function as key integrators for monitoring change to northern aquatic ecosystems. Environmental threats to the diversity of char include projected climate change-related temperature increases for 60–90°N latitudes, contaminant exposure, resource exploitation of the fishery and industrial and human development of the Canadian North. The CVC-IPY project was conducted in two parts. The first investigated char biodiversity using genetic and morphological approaches and examined life history and thermal ecology using otolith microchemistry and stable isotope techniques. Research was conducted in areas across the Canadian Arctic (western Northwest Territories, Nunavut, Nunavik and Nunatsiavut). The understanding gained from these results will provide the biological context in which to place climate variability and change effects on this key resource.

THE PROJECT IN BRIEF

CLIMATE VARIABILITY AND CHANGE: EFFECTS ON CHAR IN THE ARCTIC

Arctic Char key integrators for monitoring change

1) Variation in char biodiversity and trophic (food web) ecology are being assessed together with temperature histories and mercury bioaccumulation.
2) Community-based monitoring is used to assess changes in char populations.

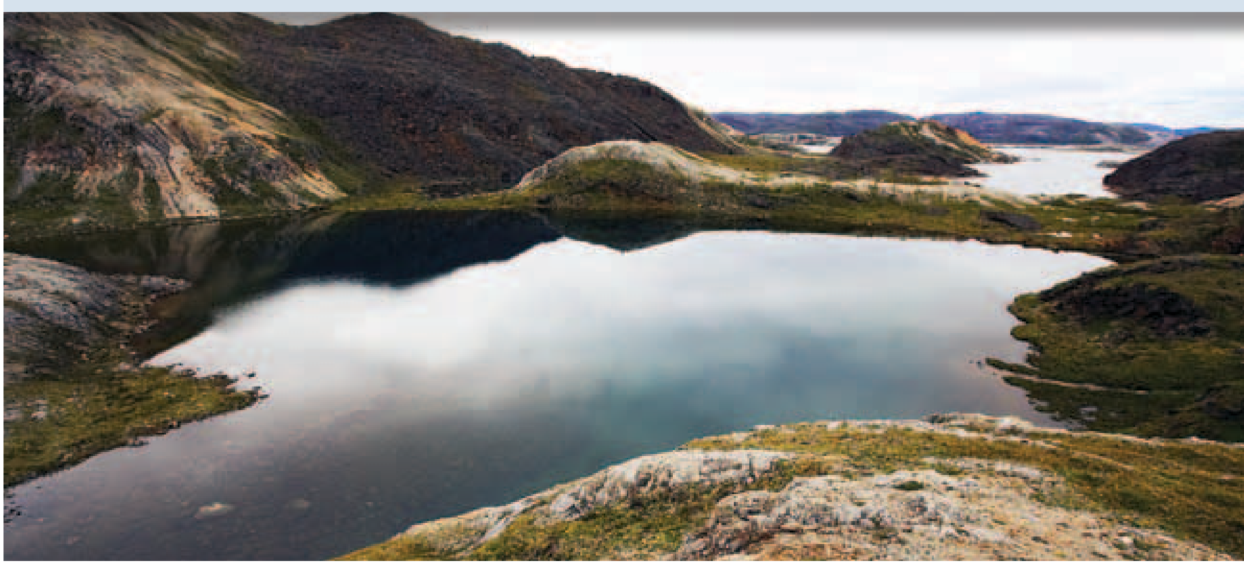


Photo: © Photos.com, 2010

The second part of the project developed community-based monitoring to assess local char biodiversity in Sachs Harbour, Kuujjuaaq and Nain. It links understanding derived from the research elements with char biodiversity and ecology observable locally by Northerners. This approach can be used as a model in other northern communities.

The Canadian CVC-IPY project is part of an international network of researchers and Northerners doing research and monitoring of char. The network addresses common issues of char/climate interactions and encourages information exchange; it will be a lasting legacy of IPY. Plans are already being considered for post-IPY collaboration with researchers involved in the Arctic Freshwater Systems project to study the ecological responses in tundra lakes of the Mackenzie Upland Region, Northwest Territories.

Recent progress

Field research conducted in the summer of 2007 at Lake Hazen (Ellesmere Island) documented three co-occurring ecophenotypes (large form, small form and dwarf benthic form) of Arctic Char. Sampling in Lake Hazen and other lakes in Quttinirpaaq National Park, in the Resolute Bay area, in Bathurst Inlet area and in Labrador documented char populations, investigated food web structure and mercury bioaccumulation, and collected young char to investigate their thermal ecology. Genetic relationships within and among chars from Transbaikalia (northeastern Siberia) were investigated and placed into the global context.

Mercury in arctic food webs

Researchers investigated how interactions among life history, trophic ecology and climate change affect contaminant concentrations in coastal Arctic lakes. Preliminary findings revealed differences in mercury concentration between sea-run (higher) and resident Lake Trout, while sea-run and resident Arctic Char were found to have similar mercury concentrations. Furthermore, mercury concentrations in resident Lake Trout were lower in lakes with sea-run Arctic Char. These findings link understanding of fish diversity with documentation of body burdens of contaminants such as mercury and highlight the need to consider both ecological and life history variables when predicting potential impacts of climate change or industrial development.

To investigate the transfer of mercury to Arctic Char, fish were collected from 27 landlocked lakes and the abiotic characteristics of these lakes were recorded. Often, char is the only fish species in these lakes. Biomagnification of mercury in the food chain was observed and food webs were compared among lakes. One finding is that mercury concentration was positively related to the catchment-to-lake area. Mercury sources to the lakes are not fully known and at this point in the research no single causal factor has been attributed to mercury levels in char (e.g. climate factors did not affect mercury levels directly).

BUILDING CAPACITY IN NORTHERN COMMUNITIES

CVC AND ARCTIC CHAR

Linking research with local observation

When James Reist of Fisheries and Oceans Canada began an investigation of char biodiversity, life history and thermal ecology, he spread his net widely, calling upon Environment Canada scientists to work with him upon such key issues as study design, sampling protocols, and sampling and data collection. His working partners also included residents of northern communities. At several locations across the Canadian Arctic, the researchers developed community-based programs to assess and monitor local char biodiversity and aid in local sampling. This linked the research component directly with biodiversity observable locally by Northerners. Researchers will, in turn share the results with various northern communities, to act as a model for similar programs. Additionally, outreach and education programs have been developed and delivered in northern communities (e.g. Sachs Harbour, Kugluktuk, and Cambridge Bay) to more fully inform and involve northern youth, fishers and resource co-managers.

3.4 POLAR ECOSYSTEMS IN TRANSITION: AN INTERDISCIPLINARY CASE STUDY OF THE EFFECTS OF CLIMATE CHANGE ON TEMPORAL TRENDS IN CONTAMINANT ACCUMULATION, FORAGING ECOLOGY AND HUMAN USE OF POLAR BEARS (*URSUS MARITIMUS*)

Principal Investigator: *Elizabeth Peacock, Government of Nunavut*

Environment Canada Co-Investigators: *Robert Letcher and Ian Stirling*

The Project's Scope

The Polar Ecosystems in Transition project gathered scientific and Inuit knowledge on changes in Polar Bear ecology. The project examined the foraging ecology of Polar Bears in selected populations and recorded Inuit knowledge of the subject in one of the populations. The study examined how the accumulation of contaminants in one population has changed with rising temperatures.

As part of this wide-ranging IPY investigation, Environment Canada scientists led a study that directly linked two global environmental issues: climate change and contamination of wildlife by persistent organic pollutants (POPs). The Environment Canada team studied Polar Bears, the apex Arctic marine predator. The goal of the project was to analyse various chemical contaminants in the bears and relate the concentrations of these contaminants to variations in bear diets due to sea-ice changes in recent decades.

Researchers examined recent time-related changes in tissue levels of POPs in bears from seven management zones in Nunavut and the Northwest Territories. This involved comparing tissue samples from 2007–2008 with those from 2001–2002, to determine changes in levels of POPs. They also looked at longer-term (1991–2007) trends, using archived fat biopsies, to assess trends of both formerly used (legacy) contaminants and emerging POPs in western Hudson Bay bears.

THE PROJECT IN BRIEF

POLAR ECOSYSTEMS IN TRANSITION

Directly linking two global environmental issues: climate change and contamination of wildlife by persistent organic pollutants (POPs)

1) Tracing contaminant movement through the food web: the team analysed various chemical contaminants in Polar Bears and related the concentrations of these contaminants to variations in bear diets due to sea-ice changes in recent decades.
2) Identifying trends: results suggest that the effects of climate change could combine with other stressors such as toxic contaminants to perhaps compound the adverse effects of climate-related changes on the Arctic and its wildlife.

Photo: Elizabeth Peacock, Government of Nunavut

A Polar Bear on the tundra, Davis Strait region of Labrador, 2008.

1) Tracing the Movement of Contaminants Through the Food Web

The study looked at three broad categories of chemicals of particular concern for the Arctic and for Polar Bears:

- formerly used or "legacy" chemicals, including PCBs and organochlorine pesticides such as DDT and chlordane;
- recently or currently used chemicals such as polybrominated diphenyl ethers (PBDEs), which are used in furniture and electronics; and
- new or emerging chemicals such as polyfluoroalkyl compounds (PFCs), which are used in water-repellent coatings on carpets and furniture and in non-stick coatings for cookware.

All of these are of serious concern because of their persistence in the environment and their potential to accumulate or biomagnify in Arctic food chains.

Working with hunters

To identify dietary and trophic differences among bear populations, the researchers used tissue samples collected from hunted bears. Working with Northwest Territories and Nunavut agencies and local hunters and trappers associations, the researchers obtained fat, liver and muscle samples from 120 bears over two years. They analysed the samples for POPs and for stable carbon and nitrogen isotopes (SIs) and fatty acids (FAs); the latter are used as "ecological tracers" in food web and diet studies. The researchers also obtained blubber samples from seals in areas used by the Polar Bear populations under study, and analysed these samples for FAs and SIs for comparison with those measured in the bears.

Earlier fatty acid research had demonstrated that the Polar Bears of western Hudson Bay feed on two ice-associated prey, Ringed Seals (*Pusa hispida*) and Bearded Seals (*Erignathus barbatus*), and two open water-associated prey, Harbour Seals (*Phoca vitulina*) and Harp Seals (*Phoca groenlandica*). The distribution of these seal species in Hudson Bay is linked to the location and extent of sea ice.

Early findings: shortened periods of ice cover alter exposure to POPs

The researchers hypothesized that changes in sea-ice conditions also result in changes in the western Hudson Bay bears' feeding ecology, which in turn alters exposure to persistent, bioaccumulative and toxic anthropogenic contaminants. Indeed, the new analysis found that in years with a shortened period of ice cover, the SI values were consistent with a lower proportion of ice-associated seals in the bears' diet, and consequently, a relative increase in their diet of water-associated seals.

2) Identifying the Trends

Although the researchers are still analysing the large volume of data, some trends are clear. PFCs and PBDE flame retardant levels were highest in bears from the southern Hudson Bay population and lower but comparable among the other Polar Bear populations. Based on deviations from a diet of Ringed Seal blubber, dietary differences partially explained the geography-dependent differences of the levels and patterns of several POPs in Polar Bears. PBDE levels in bears appear to be somewhat lower now than they were in 2001–2002, which may reflect changes in rates of use of these chemicals in more southerly latitudes.

In the study of longer-term trends in western Hudson Bay Polar Bears, the researchers examined sea ice mediated diet change (as a function of climate change) in relation to impacts on levels of POPs. Data analysed to date indicate an increased consumption of water-associated seal species in years of earlier sea-ice breakup. This diet shift led to greater contaminant exposure over time compared to that expected for a diet of ice-associated seals.

These results show a link in the variation of sea ice and diet to altered POP exposure which suggests that not only will climate change directly affect the Arctic and its wildlife, but it could combine with other stressors such as toxic contaminants and perhaps compound the issue. This work is very significant for Northerners who depend on both seals and Polar Bears and who have considerable concern about their own exposure to toxic chemicals.

3.5 CANADIAN ARCTIC SOLAS NETWORK (SURFACE OCEAN – LOWER ATMOSPHERE STUDY): OCEAN PRODUCTION OF TRACE GASES IN THE ARCTIC AND THEIR IMPACT ON CLIMATE

Principal Investigator: *Maurice Levasseur, Laval University*

Environment Canada Research Co-Investigators: *Richard Leaitch and Sunling Gong*

The Project's Scope

SOLAS investigators are studying the environmental interactions of trace gases in the Arctic, hoping to gain new insights into climate change. Gases such as carbon dioxide (CO2), nitrous oxide (N_2O), volatile organic compounds (VOCs), halocarbons, and dimethylsulfide (DMS) affect climate in various ways, either as greenhouse gases or as sources of aerosols, which scatter and absorb solar energy in the atmosphere. Biological processes in the world's oceans, especially those involving phytoplankton and bacteria, play an important role in the cycles of these gases.

There are uncertainties regarding how climate change in the Arctic influences the dynamics of these trace gases in the ocean, ice and atmosphere. However, scientists expect that increased areas of open water and changes in ocean circulation and temperature will alter the biological and chemical processes that produce and consume climate-active gases and aerosols.

Securing ocean-surface and lower-atmosphere data. The Canadian Arctic SOLAS Network project explored a complex set of interactions involving sea ice, water circulation, marine microbiological activity and emissions of the various gases from the ocean to the Arctic atmosphere. The researchers want to know how these marine processes might influence Arctic climate. Specifically, how will the increased flow of Pacific waters through the Canadian Archipelago change climatically important trace gases emitted from the Arctic Ocean, and how will these gases be affected by a reduction of sea-ice cover and increased areas of open water?

To find the answers, the Arctic SOLAS team joined researchers from several other IPY projects on two annual expeditions of the Canadian research icebreaker *Amundsen*. On the missions, the researchers collected new oceanographic and atmospheric data on the distribution and cycling of DMS, N_2O, and VOCs across the Canadian Archipelago. They could then relate these measurements to the distribution and chemical characteristics of aerosol particles. Data from the first cruise in 2007 provided a baseline against which they compared data collected during the 2008 expedition.

THE PROJECT IN BRIEF

CANADIAN ARCTIC SOLAS NETWORK

Studying the environmental interactions of certain trace gases to gain new insights into climate change

Securing ocean surface and lower atmosphere data: scientists on the Canadian research icebreaker CCGS *Amundsen* collected a coordinated set of oceanic and atmospheric measurements of trace gases relevant to climate across the Northwest Passage.

Photo: Martin Fortier, ArcticNet

CCGS *Amundsen* in the Amundsen Gulf.

Highlights

The Arctic SOLAS team's research resulted in a unique, coordinated set of oceanic and atmospheric measurements of trace gases across the Northwest Passage. Researchers used temperature, salinity and oxygen isotope measurements to characterize the water masses, analysed ocean mixing processes at work in each region and measured the changes in concentrations of related constituents in the lower atmosphere. The combined measurements of DMS in the water and air, and of atmospheric concentrations of DMS oxidation products, are a first for the northern Canadian Archipelago. Their preliminary findings suggest production of N_2O at the water/ice interface, removal of methanol and acetone from the atmosphere by the bacteria that produce DMS and new particle formation in DMS-rich areas.

4 ENVIRONMENT CANADA IS A PARTNER PROVIDING IN-KIND SUPPORT (NO DIRECT IPY FUNDS)

Environment Canada played a variety of research roles during IPY. On the four projects described in this section, Environment Canada scientists were either co-investigators or brought considerable experience and expertise to projects led by other organizations. The remaining projects listed at the close of this section are included to acknowledge the in-kind support provided and reflect the collaborative role of Environment Canada.

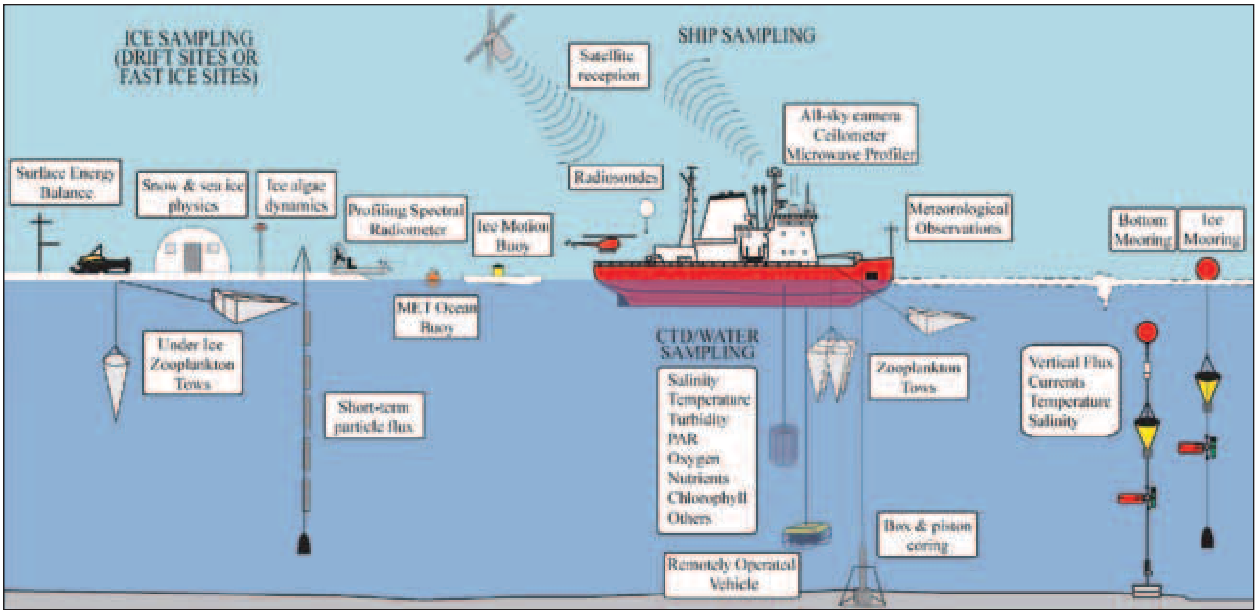
4.1 CIRCUMPOLAR FLAW LEAD SYSTEM STUDY (CFL)

Principal Investigator: *Dave Barber, University of Manitoba*

Environment Canada Research Co-Investigators: *Jan Bottenheim, Alexandra Steffen, Ralf Staebler, Hayley Hung and Terry Bidleman*

The Circumpolar Flaw Lead system study engaged 350 researchers from 27 countries and used the CCGS *Amundsen* as a specially outfitted (see Figure 12) mobile research platform to conduct large-scale system-level multidisciplinary research. There were ten separate but interconnected sub-projects covering oceanography, sea ice, marine food webs, gas fluxes, contaminants, modelling (using new CFL data) and the human dimension. Outreach was conducted on-board the ship with visits and exchanges of knowledge with local communities, through student programs and use by the media. Where it is appropriate, CFL is integrating the physical, chemical and biological sciences with Inuvialuit traditional knowledge ("two ways of knowing").

The study investigated changing climate processes in the flaw lead system—a perennial characteristic of the circumpolar Arctic marine system, by overwintering in the Banks Island (Beaufort Sea) flaw lead during the period September 2007 to August 2008. The flaw lead forms when the pack ice moves away from the coastal fast-ice and creates recurrent and interconnecting polynyas (areas of open water). These open regions served as a unique Arctic laboratory for studying physical and biological ecosystem variables of the flaw lead. Through an interview process with elders and hunters from Sachs Harbour and Paulatuk, NWT, traditional knowledge will be viewed with Western science to gain a more comprehensive understanding of changes now occurring in the Arctic. Over the long term, policy-makers can use the findings of CFL to inform decisions regarding management of the Arctic Ocean, climate impacts and adaptation in this region.



Source: Dave Barber, University of Manitoba

Figure 12 Schematic diagram of CCGS *Amundsen* in the Circumpolar Flaw Lead study showing scientific equipment and activities used on the ship and at ice camps

Intercontinental atmospheric transport of anthropogenic pollutants to the Arctic: weekly air measurements of contaminants

Air measurements of persistent organic compounds (POPs) and mercury were conducted at the ice camp near the ship to generate data comparable to air-monitoring activities operated under the Environment Canada-led INCATPA project. INCATPA researchers were on board to collect air samples for the purpose of increasing the spatial coverage of the network and helping determine how concentrations of pollutants vary from one part of the Canadian Arctic to another, and potentially to capture pollutant transport episodes. Related Environment Canada research studied air-water partitioning of POPs from the *Amundsen* to obtain a better understanding of the physical and chemical processes at play in order to develop appropriate air transport models.

INNOVATIONS

MEASURING OZONE CONCENTRATION AT HEIGHTS OF MORE THAN 1 KM

Researchers from Environment Canada's IPY-OASIS project participated in CFL by supplying information gathered utilizing the OOTI (out-on-the-ice) mobile lab, including mercury sampling, a detailed examination of the atmospheric boundary layer, and temperature, humidity and wind profiles. One unprecedented measurement involved measuring ozone concentration at heights greater than 1 km. The results will help scientists answer questions about the thickness of the depleted layers and establish details concerning their onset and demise.

4.2 POLAR ENVIRONMENT ATMOSPHERIC RESEARCH LABORATORY (PEARL)

Principal Investigator: *James Drummond, University of Toronto*

Environment Canada Co-Investigators: *David Hudak, Bruce McArthur and Tom McElroy*

The Project's Scope

PEARL (Polar Environment Atmospheric Research Laboratory) is a facility for Arctic research located at Eureka on Ellesmere Island, Nunavut, at 80°N, about 1100 km from the North Pole. The main laboratory was built in 1992, on a ridge approximately 15 km from the Eureka weather station for the study of stratospheric ozone by Environment Canada's Atmospheric Environment Service. Since being leased to the Canadian Network for the Detection of Atmospheric Change (CANDAC), under the leadership of James Drummond, the original facility has been upgraded and new modular laboratory facilities built to accommodate additional research activities in air quality and climate change. PEARL now consists of three laboratories: the Ridge Lab (PEARL), ØPAL (Zero-altitude PEARL Auxiliary Laboratory) and SAFIRE (Surface and Atmospheric Flux, Irradiance, and Radiation Extension) that house a variety of atmospheric monitoring instruments, including lidars (laser-based instruments for detecting atmospheric particles), radars, radiometers, spectrometers and photometers. All of this is operated in close collaboration with the Environment Canada Weather Station, which provides infrastructure support and accommodations to CANDAC personnel.

THE PROJECT IN BRIEF

PEARL

A self-contained facility for High Arctic research

High-quality data on Arctic precipitation: the Precipitation Occurrence Sensor System (POSS) bistatic Doppler radar system developed by Environment Canada provides key information on precipitation patterns and their variability in the High Arctic. The data can also provide baseline validation to improve space-based measurement of precipitation.

The IPY-PEARL project is part of an international circumpolar research network, International Arctic Systems for Observing the Atmosphere (IASOA), that includes facilities in several countries to develop and employ sophisticated instrumentation to observe the Arctic atmosphere from the surface up to 100 km. IPY provided the opportunity for researchers from Great Britain, Argentina, Germany and Japan to collaborate at Eureka. For the IPY period, observations at PEARL have been intensified through several new research projects studying various Arctic atmospheric components such as temperature, wind, clouds, radiation and precipitation.

IPY funding has allowed Environment Canada to install highly sophisticated monitoring equipment, including the Precipitation Occurrence Sensor System (POSS), at Eureka which is providing new, high-quality data on Arctic precipitation. With this new data from ØPAL, Environment Canada scientists aim to study precipitation patterns in the High Arctic.

Photo: Steve Brady, Environment Canada, 2009

Precipitation Occurrence Sensor System (POSS) used to measure precipitation in the Arctic.

With the much improved ground-based data coming in from PEARL, researchers hope to develop algorithms that will refine and improve space-based techniques for analysing and forecasting precipitation. In the longer-term, this IPY project should yield valuable data for improving weather forecasting in the Arctic and continent-wide.

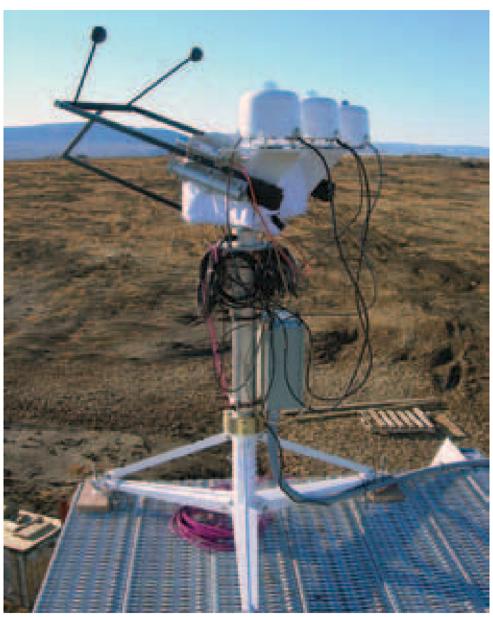


Photo: Ormanda Niebergall, Environment Canada, 2007

An Active-eye Solar Tracker is used to obtain accurate measurements of direct solar radiation and diffuse (all-sky) and infrared radiation from the Arctic sky at Eureka, Nunavut.

Photo: Paul Loewen, 2007

The Zero altitude PEARL Auxilliary Laboratory (ØPAL) built by Environment Canada and used to study atmospheric change at Eureka, Nunavut

INNOVATION

GETTING A HANDLE ON ARCTIC PRECIPITATION WITH POSS

Measuring Arctic precipitation is a difficult business. "Traditional precipitation gauges are notoriously inaccurate," says Environment Canada research scientist David Hudak, "Particularly in the windy environments where research facilities like PEARL are located. Satellite measurements work, but are difficult due to the Arctic's long season of darkness and the drastic temperature extremes."

To solve the problem, Environment Canada deployed the Precipitation Occurrence Sensor System (POSS), a small bistatic Doppler radar which reports the occurrence, type and intensity of precipitation in automated observing stations such as ØPAL.

With the equipment in operation, Environment Canada atmospheric scientists in Downsview and King City, Ontario, can download data transmitted from ØPAL and analyse precipitation parameters and relationships. Fortunately, CANDAC has an on-site staff supporting many different research projects and ensuring all the instruments run smoothly in the harsh Arctic environment. When Environment Canada's precipitation monitoring equipment needed a new sensor, for example, CANDAC personnel took care of the problem, and high-quality weather data continued streaming into Environment Canada's laboratories.

The solar and infrared radiation regimes in the Arctic differ from southern latitudes because, for part of the year, the sun never sets, while during winter, the sun never rises. In order to better understand how the surface radiation budget is affected by these radiation regimes, which in turn affects near-surface meteorology, a sophisticated set of solar and infrared radiation sensors were installed at the CANDAC SAFIRE laboratory. This new installation is part of the World Climate Research Programme Baseline Surface Radiation Network (BSRN) and the World Meteorological Organization (WMO) Global Climate Observing System (GCOS). When these observations are integrated with those of the National Oceanographic and Atmospheric Administration (NOAA) Study on Environmental Arctic Change (SEARCH), scientists will be able to better understand the surface energy budget, a key component to understanding how the Arctic surface is changing and how these changes are impacting near-surface weather conditions. Understanding these changes is extremely important, especially in the Arctic, because of the impact that they have on surface vegetation. These observations and their subsequent analyses will also aid in the development of more sophisticated weather forecast models and the improvement of our present climate models.

The climate of the Arctic is changing more rapidly than other parts of the globe which also has an impact on temperate climates. Our understanding of the complex relationships between surface and atmospheric interactions and among radiation, clouds and precipitation is therefore an important contribution not only to understanding change in the Arctic, but to changes in the weather and climate of all of Canada.

4.3 HOW SEABIRDS CAN HELP DETECT ECOSYSTEM CHANGE IN THE ARCTIC

Principal Investigator: *W.A. Montevecchi, Memorial University*

Environment Canada Co-Investigators: *Tony Gaston, Grant Gilchrist, Mark Mallory and Keith Hobson*

The Project's Scope

Researchers have long known that seabirds are efficient samplers of the marine environment. They range widely and are highly varied in their behaviour and diet. For these reasons, when researchers set out to assess changes in Arctic marine food webs, they opted to use Thick-billed Murres and other seabird species as indicators. As well as using the birds to study the marine environment, they wanted to know the biological consequences for the birds, as climate change disrupts past feeding habits by altering distributions of forage fish species.

Map credit: Nick White and Paul Regular, Memorial University

Figure 13 Location map of seabird colonies where IPY monitoring was conducted

This project builds on earlier surveys of marine bird diets at a network of globally significant breeding colonies from Nunavut through the Labrador Current to the Low Arctic waters off Newfoundland. Researchers studied crucial "downstream" (Labrador Current) changes and their relationship to variations in High Arctic marine food webs and ecosystem processes.

The Newfoundland-Labrador Shelf, which is the most southerly and largest penetration of Low Arctic waters into the North Atlantic, is driven by the Arctic water of the Labrador Current. On the shelf, sites of ocean productivity and energy transfer among trophic levels intersect in the pelagic zone: in this zone, seabirds and other top predators forage on prey concentrations. To analyse the population dynamics of seabirds and forage species and to gauge the health of the ecosystem, biologists need to understand these biological "hot spots" and habitat use by top predators. This is particularly important in winter when oceanographic and weather conditions are most extreme and the physiological tolerances of seabirds are most challenged.

THE PROJECT IN BRIEF

HOW SEABIRDS CAN HELP DETECT ECOSYSTEM CHANGE

Thick-billed Murres and other species can serve as indicators, helping researchers to assess climate-induced changes in Arctic marine food webs

1) Seabirds as indicators of changes in the food web: collaborating with seabird hunters and fishers to collect samples for the analysis of seabird diet and determine changes in foraging behaviour due to climate change.
2) Improved seabird monitoring: gaining insights into murre movements through the development of electronic tracking devices called geolocators, which will enable year-round monitoring and assessment of potential biological impacts of climate variation.

1) Seabirds as Indicators of Changes in the Food Web: Tracking Marine Forage-species Assemblages

In recent years, researchers have noted changes in the biology of seabirds and marine mammals, including altered breeding times and dietary changes. In some cases animals have switched from ice-associated fish to lower Arctic and warmer-water species with lower nutritional value.

These changes in the diet and foraging patterns of seabirds reflect changes in forage fish assemblages, which in turn reflect the climatic changes which have been ongoing in the Arctic for decades. In northern regions, earlier ice breakup in Hudson Bay has led to dietary shifts for Thick-billed Murres. Ice-associated Arctic cod has been replaced by capelin. Up until the 1990s, capelin were a relatively insignificant part of murre diets; in recent years, they have become the main prey species fed to nestlings.

Collaborating in seabird sampling

The IPY research centred on key forage species (Arctic Cod, capelin, Lantern Fish and crustaceans) and their seabird predators. Collaborating with Inuit and Newfoundland and Labrador hunters and fishers, the scientists collected seabirds to determine not only their diet but also their foraging behaviours and their reproductive performance.

The researchers studied the birds over multiple regional and ocean-basin scales. Simultaneous research in the High and Low Arctic allowed scientists to evaluate influences of High Arctic climate on marine life in Low Arctic ecosystems. Analysis could then reveal climate-associated changes in forage-species assemblages.

Seabird dietary data collected during the IPY served to extend data collected from the 1970s to 1990s. The dataset could be used to assess recent changes in forage fish and zooplankton diversity and distribution associated with changes in sea-ice coverage and water temperature.

2) Improved Seabird Monitoring

Environment Canada investigators used electronic tracking devices called geolocators to record bird movements, placing them on Thick-billed Murres at two breeding colonies in the Eastern Canadian Arctic: Coats Island and The Minarets (*Akpait*). At the same time, vessel surveys conducted around colonies described ocean conditions and the distributions of birds, fish, invertebrate and marine mammals. Seabird dietary information was collected simultaneously at colonies and at sea. By integrating these data, researchers will be able to assess the influence of oceanic climate change on Arctic marine food webs.

Early findings: Geolocators reveal complex picture of seabird habitat use

The geolocator results gave a much more accurate picture of murre movements—and there were some surprises. Murres from different colonies differed significantly in the nature and location of wintering areas they used and the timing of their southward migrations. Previous studies based on bird band recoveries suggested that Thick-billed Murres that breed in Hudson Bay and in the High Arctic migrated with the southward-flowing Labrador Current, spending the winter on the Labrador and Newfoundland coasts and on the Grand Banks. Information provided by the geolocators, however, suggested that the picture is more complex. Many birds may spend the early part of the winter farther north than previously assumed. Biologists had formerly believed that birds from Coats Island left Hudson Bay in September. Instead they found that the exodus of Coats Island breeders from Hudson Bay occurred only after mid-November.

These findings have implications for many aspects of murre biology and ecology. For example, patterns of contaminant accumulation could differ markedly between these populations. The geolocator technology will enable year-round assessment of potential biological impacts of climate variation for both Low and High Arctic species and populations, and scientists will be able to assess the birds' year-round ocean habitat use.

This IPY project is also very important to circumpolar collaboration with the methods and results to be used by the Arctic Council's Conservation of Arctic Flora and Fauna (CAFF) initiative. CAFF has a mandate to address the conservation of Arctic biodiversity and communicate the findings to the governments and residents of the Arctic, helping to promote practices which ensure the sustainability of the Arctic's living resources.

INNOVATION

FOLLOWING WHERE THE MURRES FLY

Monitoring seabirds on their breeding ground can be tricky, but tracking them during migrations and following the birds to their wintering areas over inaccessible landscapes poses far greater challenges. Previously, scientists derived the most information on seabird movements from recovered leg bands. Unfortunately, this made for heavily biased sampling: bands are collected only after the bird dies and hunters, fishers or other collectors are not evenly distributed.

Investigators solved the problem with a newly designed electronic tracking device known as a geolocator. Geolocators were previously used on large seabirds such as albatrosses and penguins, but they are becoming increasingly miniaturized, making it possible to deploy them on smaller birds. Geolocators weighing less than 10 g are now available; this size works for murres (*Uria* spp.) without unduly restricting their movements. In the IPY study, Environment Canada scientists placed geolocators on Thick-billed Murres (*Uria lomvia*) at two breeding colonies in the Eastern Canadian Arctic: Coats Island and The Minarets (*Akpait*).

These miniature bird-borne data loggers track and record behaviour as seabirds forage around colonies. A wet/dry switch records when the birds touch down on the water or take off. In addition, the tiny geolocators record information on light levels. Investigators can use these features to determine when birds begin and end their time at a colony, to map migratory routes and monitor winter habitat use.

Based on the IPY experience, Environment Canada scientists are taking a new approach to seabird monitoring. They have reduced banding of murres and intend to use geolocators instead to look at movements and wintering areas.

Photo: Kerry Woo, Canadian Wildlife Service, Environment Canada

On Coates Island in Hudson Bay, biologist holds a Thick-billed Murre outfitted with a geolocator that will provide data on the bird's location during migration and overwintering.

4.4 MONITORING IMPACT OF GLOBAL CHANGE ON CARIBOU AND WILD REINDEER AND LINKS TO HUMAN COMMUNITIES (CARMA)

Principal Investigator: *Don Russell, Yukon College (Emeritus Environment Canada)*

Environment Canada Co-Investigator: *Wendy Nixon*

The Project's Scope

CARMA is an international network which focuses upon the impacts of global climate change on the world's wild *Rangifer* (reindeer and caribou) herds. It is part of a system of networks under the Circumpolar Biodiversity Monitoring Program (CBMP). Environment Canada coordinates Canadian input to the CBMP.

Map credit: Don Russell, Environment Canada

Figure 14 Current status of the main migratory herds across the circumpolar North

For the latest status on each caribou herd visit:
http://carmanetwork.com/display/public/Herd+Overview

The CARMA network includes countries having wild *Rangifer* herds from Canada to Russia to Norway to Iceland. This international assemblage, which has been underway for six years, includes researchers, habitat specialists, climate experts, veterinarians and disease ecologists, community representatives and management agencies.

Although Aboriginal communities have experienced and coped with caribou abundance and scarcity for millennia, Western science has only been accumulating (more or less) systematic data over the last 40 years: a period that started with caribou lows, continued with almost universal increases and during the recent decade, has been characterized by dramatic widespread population declines. Also during this 40-year period, at least in North America, the management of the herds has shifted from central government regulation to more local control sparked primarily by numerous land claims settlements. As herds decline, the groups responsible have been asking tough questions about causes of declines and whether with increased development, human activity, climate change and more efficient hunting methods, the herds will recover. Moreover, they seek assistance in knowing what can be done to halt the declines and facilitate recovery. For the few herds that have not declined or have only begun to decline, experiences gained will be an invaluable tool should these herds begin a serious decline. Much of that collective experience therefore needs to be formally "housed," a task that has been the primary objective of the CARMA (CircumArctic Rangifer Monitoring and Assessment) Network.

THE PROJECT IN BRIEF

CARMA

An international network monitoring caribou and reindeer across the circumpolar North and targeting better *Rangifer*/human interrelationships

1) Tracking ecological indicators: through monitoring and comparing results among herds, the CARMA network is addressing health factors that affect individual animals.
2) CARMA's synthesis: assessing broad habitat/population trends by exploring relationships between such factors as climate, habitat, lichen depletion and infectious diseases.
3) Creating monitoring and decision-support tools: field protocols for hunters, training videos, and cumulative effects assessment tools to assist caribou management agencies.

Photo: Anne Gunn

Bathurst caribou herd July aggregation near McKay Lake, Northwest Territories, 2003.

Tracking ecological indicators

CARMA organizers recognized that reindeer and caribou across the circumpolar world were under increasing threat from climate change and industrial development. Principal investigator Don Russell says CARMA's basic objective was simply to "get people together to talk about what's happening with the herds." Particularly in Canada, caribou management responsibilities were changing with the increasing importance of wildlife management boards established through settlement of land claims. This increased the demand for better information and understanding of *Rangifer* – human interrelationships.

To get the most out of their IPY funding, the CARMA network capitalizes on making use of existing data and has standardized techniques for collecting new information. CARMA members focus on herds having good baseline information and partner with institutes, agencies, councils and boards committed to cooperation through future monitoring.

CARMA's synthesis approach

CARMA's overall objective is to assess the ongoing vulnerability of Rangifer herds across the north to global changes. This will be accomplished by conducting comparisons among a number of herds which have active CARMA partners and a relatively rich retrospective database. To that end, CARMA has developed a few key synthesis questions:

1. **How important are seasonal ranges to caribou and reindeer?**

   What are the relative contributions of different seasonal ranges to fecundity, pathogens (parasites and diseases), body condition and survival of Arctic calving *Rangifer*?

2. **What is different about the herds?**

   How consistent or variable are these relationships among herds?

3. **What causes herds to grow or decline?**

   Is there any common suite of input (habitat) or output (demography) variables that indicate the direction of herd growth?

4. **How important are pathogens and predators?**

   In what way do pathogens and predators affect productivity, habitat use and distribution of *Rangifer* (top-down)?

5. **How important is human harvest to caribou and reindeer herd growth or decline?**

   Are human effects on population abundance additive or compensatory?

6. **How are people responding to change now and how might they respond in the future?**

   What are the patterns of human community response (mitigation, adaptation, transformation) to change in caribou abundance, distribution, fecundity, health, and body condition?

Creating practical tools

CARMA's website now has monitoring protocols for assessing animal body condition and health and population factors. Field techniques are presented at two levels: simple methods that hunters can perform after minimal training, and more intensive monitoring techniques for trained staff who will document the health and condition of individual caribou. A hunter training video with additional information on caribou health has also been produced. By sharing experiences and monitoring herds in the same way, the CARMA network aims to identify vulnerabilities of individual herds.

CARMA experts have also been creating decision-support tools for co-management boards and management agencies. One such tool, which addresses cumulative effects assessment, will help caribou management agencies assess how caribou react to multiple stressors, including mining and other regional development activities.

ACHIEVEMENTS OF THE CARMA NETWORK

- Establishment of an international *Rangifer* network
- Annual network meetings to discuss key product development
- Establishment of a data-management strategy and central database of herd characteristics
- Establishment of standardized monitoring protocols that are being implemented across the Arctic
- Development of population models based on intensively studied herds and testing of the models on less intensively studied herds
- Development of decision-support tools for managing individual herds
- Beginning development of a *synthesis book* describing the current state of knowledge of *Rangifer* populations, their population dynamics and the role and approach of management systems

4.5 OTHER PROJECTS RECEIVING ENVIRONMENT CANADA IN-KIND SUPPORT

Environment Canada provided in-kind support to the following projects (also listed in the appendix).

- Inuit Sea Ice Use and Occupancy Project – Carleton University;
- Impacts of Severe Arctic Storms and Climate Change on Arctic Oceanographic Processes – Fisheries and Oceans Canada;
- Ocean Currents of Arctic Canada – Fisheries and Oceans Canada;
- Thermal State of Permafrost: A Canadian Contribution to the International Permafrost Association's International Polar Year Project – University of Ottawa;
- Determining the Diet of the Greenland Shark in a Changing Arctic – University of Windsor

Further information can be found at the Canadian IPY website:
www.ipy-api.gc.ca/pg_IPYAPI_050-eng.html

5 CONCLUSION

Environment Canada scientists are contributing significant skills and expertise to the projects described in *Environment Canada's International Polar Year Achievements* report. It has also provided infrastructure and support, including Canadian ice, aviation, marine and public forecasts. Through the research opportunities and funding provided by the IPY, Environment Canada has strengthened its northern research capabilities, addressing significant knowledge gaps and expanding into new areas that will be vital in a dynamic, rapidly changing environment. Projects led by IPY investigators have created a multi-layered legacy.

- **Building our Research and Monitoring Capability:** The IPY has helped Environment Canada and its research partners establish and expand environmental monitoring networks across the North. The Arctic Freshwater Systems project and the Cryosphere project, for example, have expanded Environment Canada's environmental monitoring networks, filling major gaps in Canada's baseline data on streams, rivers, lakes, glaciers and seas. INCATPA has developed and linked pollutant monitoring internationally, adding significantly to our understanding of the long-range transport of pollutants to the western Canadian Arctic.

- **Strengthened Research Networks:** A significant legacy of IPY has been the building and strengthening of ties among researchers across the country and internationally. The scale and depth of Arctic environmental challenges called for cooperation and information sharing. Many of Environment Canada's IPY projects are part of larger international networks.

- **Innovation:** With Polar-GEM, the TAWEPI project provided a new computer model for improved weather and environmental forecasting in the Canadian Arctic. Its launch in May 2009 was well ahead of the intended schedule. The self-contained, highly mobile OOTI (out-on-the-ice) sled used in the OASIS project allows scientists to gather a wide range of atmospheric data in the remotest locations. Many new applications for OOTI are likely in the years ahead. The automated monitoring buoys developed in the Arctic Freshwater Systems and OASIS projects will also continue to provide vital data into the future.

- **Tools for Northern Adaptation:** Climate change is a reality and the North is particularly vulnerable. Environment Canada's IPY research has therefore targeted better environmental information for Northerners, from enhancing weather-prediction capabilities to providing new information on pollutants and on the dynamics of ice, snow and surface waters. The Cryosphere project is helping Northerners understand the rapidly changing ice conditions so that they can navigate safely in their local environment. Results from the INCATPA project on air contaminants are being communicated to Northerners to help them understand the possible impacts on their communities.

Each project has provided new discoveries and opened further questions for northern science. Canada's approach of combining scientific activity with the expertise and traditional knowledge of Aboriginal peoples and northern communities has revealed new insights and a more comprehensive understanding. Thought the official observation period of IPY 2007–2008 has ended, it's just the beginning of a new era of awareness and knowledge of the Arctic.

Photo: Francis St-Pierre, Environment Canada

Aerial view of Ellesmere Island 2009.

APPENDIX CANADIAN IPY PROJECTS

There were 45 projects funded by the Government of Canada IPY program and 11 projects funded by the Natural Science and Engineering Research Council (NSERC). Projects with Environment Canada involvement are highlighted in boldface.

Link to map showing the locations of IPY projects with a brief project description:
www.ipy-api.gc.ca/pg_IPYAPI_006-eng.html

Link to project description for the NSERC IPY grants:
www.nserc-crsng.gc.ca/NorthernResearch-RechercheNordique/IPYProj-APIProj_eng.asp

Government of Canada IPY Program

Project title	Principal investigator	Affiliation
Sea Ice and Oceans		
The Circumpolar Flaw Lead System Study	David Barber	University of Manitoba
Ocean Production of Trace Gases in the Arctic and their Impact on Climate	Maurice Levasseur	Laval University
The Carbon Cycle in the Canadian Arctic and Sub-Arctic Continental Margin	Charles Gobeil	University of Quebec
Impacts of Severe Arctic Storms and Climate Change on Coastal Areas	William Perrie	Fisheries and Oceans
Investigation of the Effect of Climate Change on Nutrient and Carbon Cycles in the Arctic Ocean	Roger Francois	University of British Columbia
Ocean Currents of Arctic Canada	Humfrey Melling	Fisheries and Oceans
C3O – Canada's Three Oceans	Eddy Carmack	Fisheries and Oceans
Hydrology/Cryosphere		
Measuring the Impact of Climate Change on Landscape and Water Systems in the High Arctic	Scott Lamoureux	Queen's University
Variability and Change in the Canadian Cryosphere (Snow and Ice)	Anne Walker	Environment Canada
Arctic Freshwater Systems	Frederick Wrona	Environment Canada
Environmental Change in the High Arctic from Snow and Ice Cores	Jocelyne Bourgeois	Natural Resources Canada
Permafrost Conditions and Climate Change	Antoni Lewkowicz	University of Ottawa

Project title	Principal investigator	Affiliation
Atmosphere		
Arctic Weather and Environmental Prediction Initiative	Ayrton Zadra	Environment Canada
The PEARL near the Pole: Atmospheric Research in the High Arctic	James Drummond	University of Toronto
OASIS-CANADA: Understanding Ozone and Mercury in the Air Over the Arctic Ocean	Jan Bottenheim	Environment Canada
INCATPA: Pollutants Travelling in the Air to the Arctic	Hayley Hung	Environment Canada
Ecosystems		
Impacts of a Changing Arctic Tree Line	Karen Harper	Dalhousie University
Climate Change Impacts on Canadian Arctic Tundra	Greg Henry	University of British Columbia
The Impact of Climate Change on Tundra Wildlife	Gilles Gauthier	Laval University
Carbon Cycle		
Carbon, Microbial and Plant Community Dynamics in Low-Arctic Tundra	Suzanne Simard	University of British Columbia
Changing Forests and Peatlands along the Mackenzie Valley	Jagtar Bhatti	Natural Resources Canada
Wildlife		
Polar Ecosystems in Transition: An Interdisciplinary Investigation into the Impacts of Climate Change on Polar Bears	Elizabeth Peacock	Government of Nunavut
How Seabirds Can Help Detect Ecosystem Change in the Arctic	William Montevecchi	Memorial University
Beluga Tagging in the Arctic	Mike Hammill	Fisheries and Oceans
Climate Variability and Change Effects on Chars in the Arctic	James Reist	Fisheries and Oceans
Determining the Diet of the Greenland Shark in a Changing Arctic	Aaron Fisk	University of Windsor
Effects of Global Warming on Polar Bears, Seals and Whales	Steve Ferguson	Fisheries and Oceans
Monitoring the Impacts of Global Change on Caribou and Wild Reindeer and their Link to Human Communities	Don Russell	Yukon College
Environmental Change and Traditional Use in the Old Crow Flats in Northern Canada	Shel Graupe	Vuntut Gwitch'in First Nation

Project title	Principal investigator	Affiliation
Community Well-being		
Northwest Territories Ice Patch Study	Thomas Andrews	Prince of Wales Northern Heritage Centre, GNWT
Inuit Sea Ice Use and Occupancy Project	Claudio Aporta	Carleton University
Inuit History: Climatic Change and Historical Connections in Arctic Canada	Patricia Sutherland	Canadian Museum of Civilization
Constructed Wetlands for Treatment of Wastewater in Arctic Communities	Brent Wootton	Fleming College
Dynamic Inuit Societies in Arctic History	Trevor Friesen	University of Toronto
Engaging Communities in the Monitoring of Country Food Safety	Manon Simard	Makivik Corporation
Communities in the Changing Arctic	Barry Smit	University of Guelph
The Impacts of Oil and Gas Activity on Peoples in the Arctic	Dawn Bazely	York University
Kwaday Dan Ts'inchi Discovery: Expanding our Understanding through Linked Scientific and Community Studies Project	Sheila Greer	Champagne and Aishihik First Nations
Arctic Peoples, Culture, Resilience and Caribou	Cindy Dickson	Council of Yukon First Nations
Documenting Traditional Knowledge in Relation to Climate Change and its Effects in Tr'ondëk Hwëch'in Traditional Territory	Allie Winton	Tr'ondëk Hwëch'in
Human Health		
Evaluating the Effectiveness of Vaccination against Respiratory Infections for Young Children of the Nunavik Region	Philippe DeWals	Laval University
Coordinated Effort to Clear Hepatitis Viruses from the Canadian North	Gerald Minuk	University of Manitoba
Human Papillomavirus and Cervical Disease in the Northwest Territories	Yang Mao	Public Health Agency of Canada
An Integrated Research Program on Arctic Marine Fat and Lipids	Eric Dewailly	Centre Hospitalier de l'Université Laval
Inuit Health Survey: Inuit Health in Transition and Resiliency	Grace Egeland	McGill University

Natural Sciences and Engineering Research Council IPY Grant Recipients

David Barber	University of Manitoba	The IPY Circumpolar Flaw Lead (CFL) system study
Jean-Pierre Blanchet	University of Quebec in Montréal	Detection and assessment of the dehydration-greenhouse feedback in the Arctic: A contribution to the HIAA's project
Gilles Gauthier	Laval University	ArcticWOLVES (Wildlife Observatories Linking Vulnerable EcoSystems)
Paul Hebert	University of Guelph	Polar Research Observatories for Biodiversity and the Environment (PROBE)
Gregory Henry	University of British Columbia	The state of Arctic tundra using the International Tundra Experiment (ITEX) network
David Hik	University of Alberta	Climate forcing of alpine tundra ecosystems in southwest Yukon
Susan Kutz	University of Calgary	Resilience of caribou and reindeer populations: Validation and application of the filter paper technique to access exposure to pathogens during International Polar Years
André Rochon	University of Quebec in Rimouski	Natural climate variability and forcings in the Canadian Arctic and Arctic Ocean
Martin Sharp	University of Alberta	The dynamic response of Arctic glaciers to global warming
Theodore Shepherd	University of Toronto	Structure and evolution of the polar stratosphere and mesosphere and links to the troposhere
Warwick Vincent	Laval University	Microbial biodiversity of High Arctic ecosystems: Canadian partnership in the International Polar Year program MERGE

Photo: Martin Fortier, ArcticNet

Coast Guard personnel prepare the CCGS *Amundsen's* helicopter for a flight in Gibbs Fjord, Baffin Island, Nunavut.