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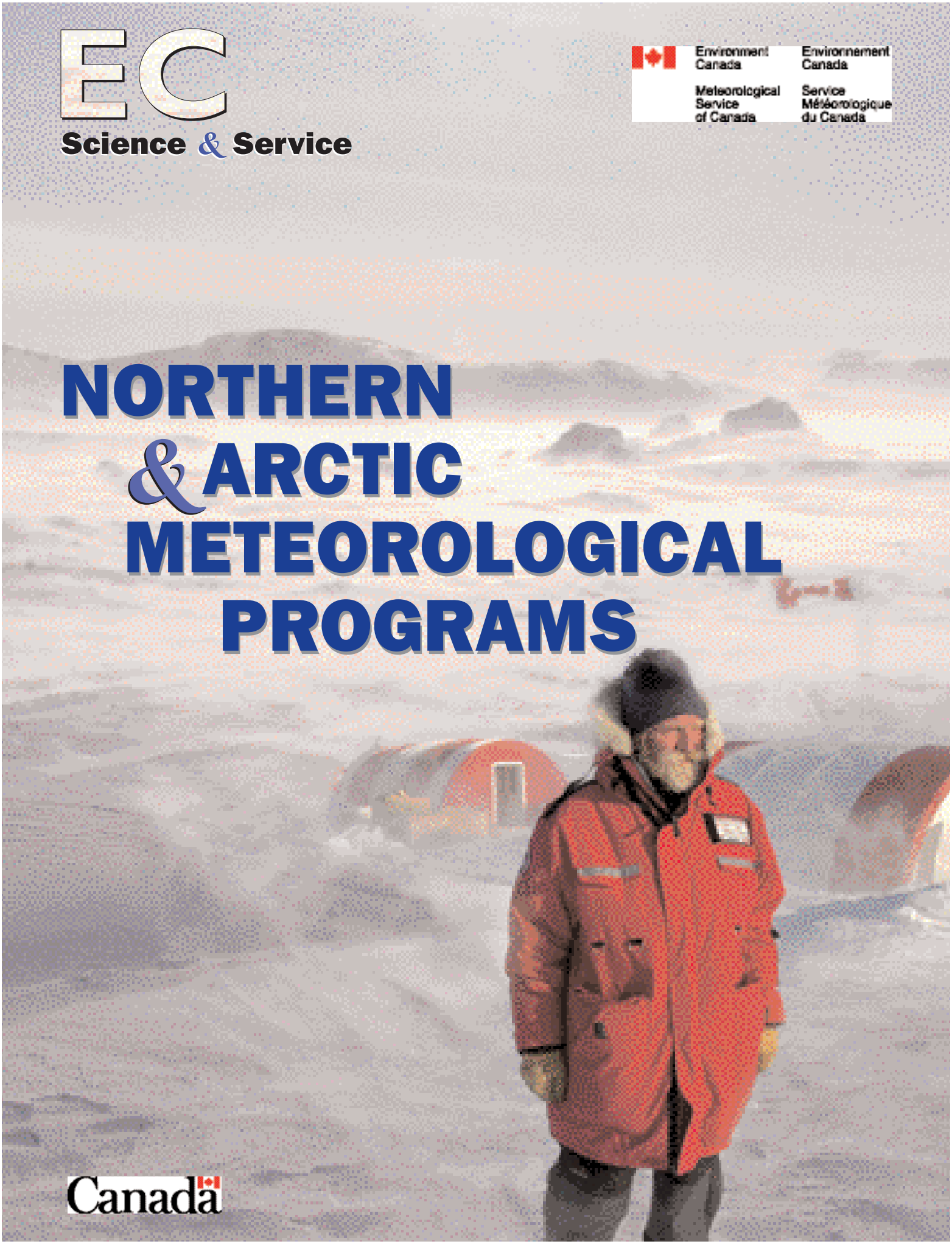

Canada

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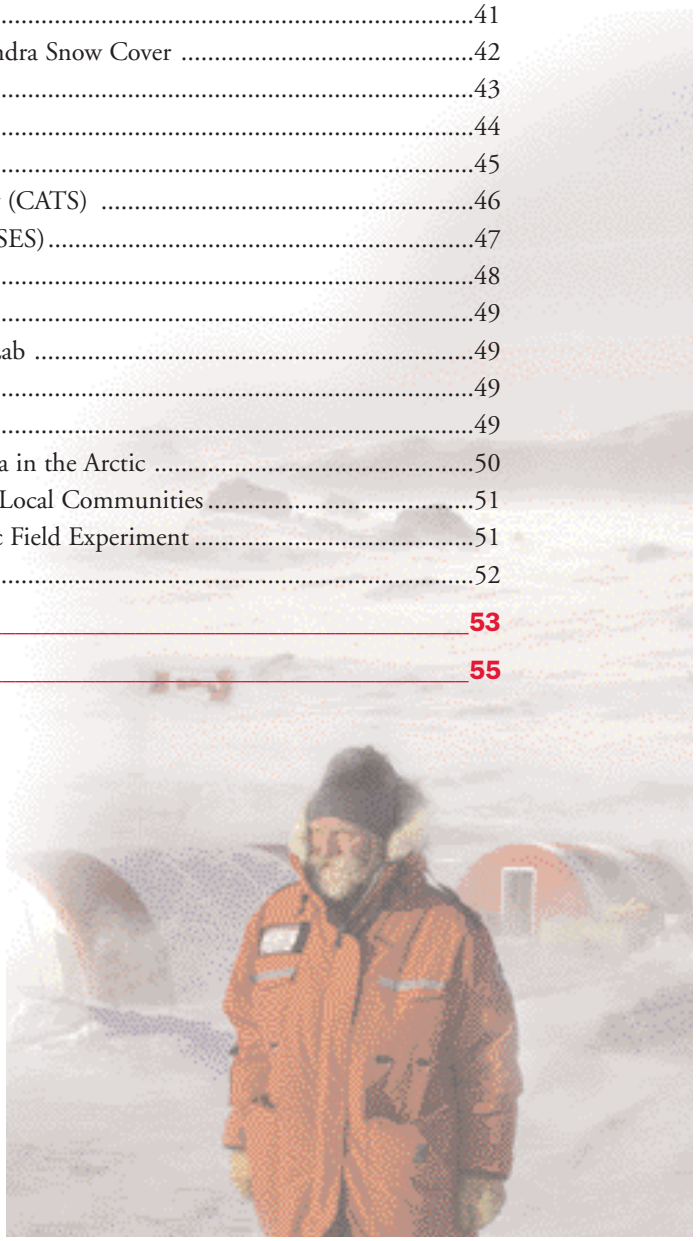

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In addition, we would like to thank the **MSC staff in the Regions, the Canadian Ice Service and the Atmospheric and Climate Science Directorate** for their detailed review of the material in this report. Special appreciation goes to **Deborah Brown, Lorne Baker, Jeff Sowiak, Ross Brown** and **Janice Lang**.

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Message from the Assistant Deputy Minister

It is with great pride that I make this report available to you on the Meteorological Service of Canada's (MSC) activities in the North and the Arctic. In less than one hundred years, we have gone from simply making meteorological observations in the North to providing timely and accurate meteorological, climate, hydrological, and ice services to Canadians in the North, as well as conducting and participating in research in support of national and international programs.

All four functions of the MSC, namely: monitoring, prediction, service and science, support our northern and arctic programs. Despite the harsh environment of the North and the Arctic, MSC has risen to the formidable challenge of serving the sparse population living in this immense region. MSC also contributes significantly to national and international research initiatives. For example, the Alert Global Atmospheric Watch Program and research facilities have attracted many scientists from around the World. MSC is also modernizing the administration and the accommodation facility at Eureka to better address the needs of the staff and visiting scientists who use Eureka as a stopover during their long journeys to the higher Arctic.

Our research scientists, in collaboration with universities and international scientists, continue to increase our understanding of the northern and arctic atmosphere and the cryosphere. Our quest to understand the atmospheric and climate processes in the North has led us, for example, to an understanding of how the climate is changing, how arctic ice, snow and atmospheric processes work, and how to model the northern and arctic atmosphere. With this increased knowledge, we can make reliable predictions of future states of the atmosphere and climate due to climate change.

I would like to take the opportunity to thank all the staff who have contributed to the success of MSC's northern and the arctic programs. I would also like to invite you to discover, through this report, how MSC's science and service in this region benefit Canadians and the world.

Marc Denis Everell

Introduction

MSC's Northern Services and Science

Canada's northern region is a vast area covering the land and ocean-based territory that lies above the line of discontinuous permafrost. Environment Canada's definition of Canada's North includes the Yukon, the Northwest Territories, Nunavut, the Hudson Bay Lowlands, northern Quebec and Labrador, and encompasses eight different ecological zones. The area north of the Arctic Circle is defined as Canada's Arctic Region.

Within this huge northern region, characterized by harsh climates and sparse populations, the Meteorological Service of Canada (MSC) provides science-based services and conducts research and development to ensure human safety and well-being, to protect the environment, to foster economic development, and to further our understanding of the northern atmosphere and environment.

The best known of these science-based services are the public, aviation and marine advisory and warning programs. These programs generate advisories and warnings based on meteorological and ice observations. They include public weather forecasts, aviation information and forecasts, and sea and ice conditions and forecasts for the marine community. The scope is huge. Every community in the North has the benefit of public weather information and forecasts; every aviation flight throughout the North is provided with current weather information and a forecast for the flight path; and every marine voyage, through northern or arctic waters, has at its disposal the latest sea, ice and weather conditions. The hydrometric network in the North (in partnership with Indian and Northern Affairs Canada) supports transportation on major rivers, hydro operations, and forecasting of floods, rain events and ice jams. MSC's data and forecasts help northern industries to operate effectively and efficiently, leading to economic prosperity for the North and Canada.

Photo by Doug Heard, RWED GNWT

These science-based services are available because of the sound and excellent research that has taken place at MSC over many decades. The backbone of the Meteorological Service of Canada is the data that is collected through its weather, climate, marine, atmospheric and water monitoring networks. Based on these observations, MSC has developed some of the finest numerical weather and climate prediction models in the world. These tools enable meteorologists to produce weather forecasts for northern communities in the same manner as they do for other Canadian cities such as Toronto or Vancouver.

MSC scientists, working with partners, investigate key northern issues such as air quality, the distribution of toxic substances, how the climate is changing, and the current and future state of the arctic ozone layer and ultraviolet radiation. Measurements and observations for research come from ground-based, airborne and satellite instruments that are located at various northern field sites, including MSC's Alert and Eureka observatories located in the High Arctic. Much of the research associated with these measurements and observations is conducted by MSC's Atmospheric and Climate Science Directorate (ACSD). MSC scientists collaborate with colleagues from Canadian universities and international government institutions and universities to carry out northern research. This collaborative effort has resulted in a much greater understanding of global issues involving contaminants and toxic substances, climate change and ozone depletion.

Canada's obligations under international protocols and agreements also help determine MSC's northern research agenda. The Montreal Protocol for the Protection of the Ozone Layer and the Kyoto Protocol on Climate Change require Canada to further its understanding of these issues and to contribute to the international body of knowledge. MSC scientists participate in many key international forums and advisory groups such as the International Panel on Climate Change (IPCC), and contribute to international policy relevant assessments. Through Canada's membership in the Arctic Council, MSC scientists have contributed to the Arctic Climate Impacts Assessment. This assessment will lead to a better understanding of arctic science and will identify areas for future research.

Under the Montreal Protocol, MSC scientists continue to monitor the thickness of the northern and arctic ozone layer, especially in the springtime. This will ensure the effectiveness of global control measures and help to identify further required actions. MSC scientists have also been involved in tracking the long-range transport of heavy metals and pesticides over the Arctic from source regions across the world. Through MSC's climate network, scientists have determined that the western arctic climate has warmed by 3 to 5 Celsius over the past 40 years. MSC research has documented a number of important impacts of this warming, which include melting of glaciers, thawing of permafrost, a reduction in the thickness and extent of ice cover, earlier melt of snow in the spring period, and changing precipitation patterns. Information on the magnitude and rate of change in the climate system is essential to help Canadians and citizens of other countries to adapt to climate change.

Environment Canada's boundary for North

Global Climate Models are the only tools available to look into the future and predict how climate patterns and ocean circulation will respond to changes in greenhouse gases and related pollutants in the atmosphere. The Meteorological Service of Canada's scientists are pioneers and world leaders in building and using global climate models. Scientists at MSC's Canadian Centre for Climate Modelling and Analysis (CCCma) developed a coupled atmosphere/ocean/sea-ice model, which is considered to be among the best in the world. Beyond coupling the atmosphere, ocean and ice systems, MSC climate scientists have taken on the bold challenge of developing the next generation of climate models that will include the key biological and chemical processes that regulate the global carbon cycle – and thus, our climate. Understanding how the biosphere will respond to higher atmospheric concentrations of greenhouse gases, and in turn, what feedbacks this will have on the atmosphere, is essential for formulating policy to respond to our Kyoto commitments.

In addition to informing policy in Canada, Canadian climate models have been used extensively internationally. The 2001 *Third Assessment Report* of the Intergovernmental Panel on Climate Change (IPCC) used the Canadian model along with three others in its key studies to determine whether the human effect on climate was detectable in global climate data. The Canadian climate model was also one of two used (the British Hadley Centre model was the other) in the recent *National Assessment of the Potential Impacts of Climate Variability and Change* in the U.S.

Over the next ten years, MSC's research and development (R&D) objectives for the North are to:

1. Support risk-based decision making involving high impact atmospheric and related environmental events (weather, air quality, hydrology etc.) affecting Canadians' safety and security, their economy and the environment on the scale of minutes, days and weeks.
2. Support risk-based decision making involving atmospheric and related environmental change and variability affecting Canadians' security and health, economy and the environment on the scale of weeks, years and centuries.
3. Provide a coherent and consistent picture of the present and past states of the atmosphere and related environment.

The demand for MSC's northern services and research will continue to be pressing as economic development in southern Canada and in the North puts further stress on the northern atmospheric environment. Over the next five years, exploratory drilling will return to the Beaufort Sea and a proposed gas pipeline will be built through the Mackenzie Valley. These big ventures and others will lead to more people in the North working in an ever-changing environment. It will result in a need for additional services and further atmospheric and environmental research.

There are many challenges inherent in providing theses services. Communications challenges are significant, including language; for example, Inuktitut is the first language of approximately 85% of the population in Nunavut. Media coverage is mainly centralized in the three large communities of Yellowknife, Rankin Inlet and Iqaluit. Automated broadcasts, automated telephone answering devices (ATADs) and Weatheradio service the other areas. The MSC has numerous networks and stations in the North, but given the vast size of the North, the data density is sparse. MSC's challenge is to provide these needed services in a cost effective manner while insuring it meets the needs of northerners and Canadians.

METEOROLOGICAL SERVICE OF CANADA'S ORGANIZATION FOR THE NORTH

The Meteorological Service of Canada is Environment Canada's lead service for northern science and technology and provides leadership in service delivery in the North.

The components of the Meteorological Service of Canada (MSC) that contribute to northern services and research are located in MSC's Regions across Canada, in MSC's Headquarters in Downsview, Ontario, and at the Canadian Ice Service in Ottawa, Ontario. In the North, MSC owns and operates observation facilities at Eureka and Alert, upper air facilities at 17 locations in the North, and has climate, weather, and hydrometric observing stations throughout the North.

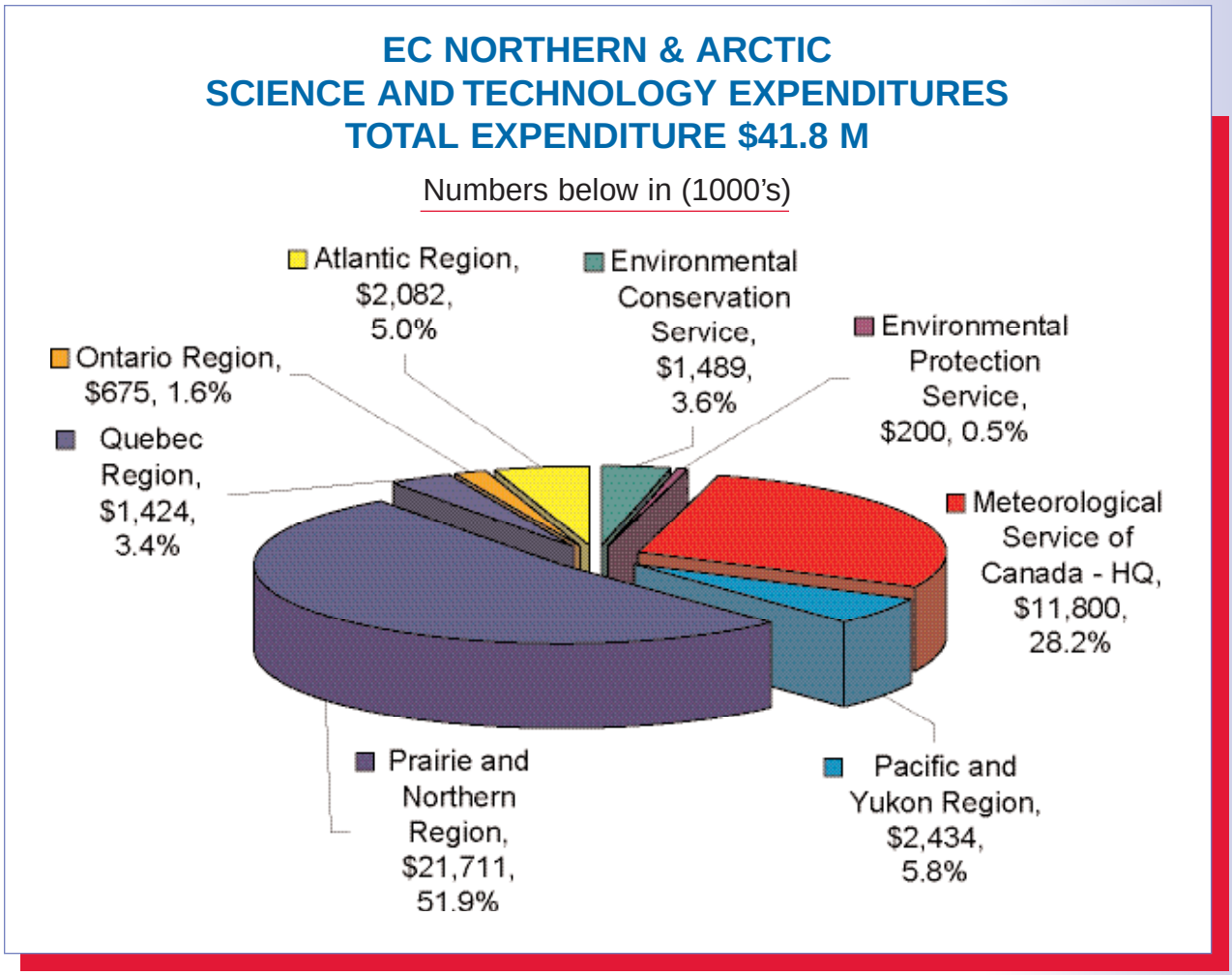
Since 2002, MSC has been transformed from 15 weather centres into five new Storm Prediction Centres (SPCs). Forecasting responsibility for Canada's northern regions will be shared among the Centres:

- Pacific SPC (Vancouver) - for Yukon Territory
- Prairie and Arctic Storm Prediction Centre (Edmonton) - for Nunavut and the Northwest Territories
- Ontario SPC (Toronto) - for northern Ontario
- Quebec SPC (Montreal) - for northern Quebec
- Atlantic SPC (Halifax) - for Labrador

The new Canadian Meteorological Aviation Centres (CMACs) in the east (Montréal) and in the west (Edmonton) became operational in the spring of 2004. The CMAC in Montreal handles aviation forecasts for northern Ontario, northern Quebec and Labrador. The CMAC in Edmonton produces aviation forecasts for Nunavut, the Northwest Territories and the Yukon Territory.

Observation facilities at Eureka, NU

The MSC has established a national lab in Edmonton, co-located with the storm prediction centre (SPC), which will focus on applied science dealing with hydrometeorology and arctic weather. Special positions in warning preparedness and outreach have been created to address high impact weather issues in Nunavut and the Northwest Territories by identifying opportunities to improve Environment Canada's program effectiveness, and by working with communities to reduce risks.



This chart provides an estimate of Environment Canada's northern expenditures. These expenditures are difficult to determine accurately because in many cases, northern services or programs are not classified specific to the North - they are considered extensions of national services or programs.

MSC NORTHERN SERVICES AND NETWORKS

The Meteorological Service of Canada (MSC) provides vital science-based services to northern communities that include weather forecasts, warnings and advisories, ice and floe edge information, water surveys, climate monitoring, and information dissemination.

These northern services are based on ground-based observational and monitoring networks, state-of-the-art environmental monitoring technologies, forecaster workstation technology using sophisticated weather prediction models, and satellite data. MSC delivers these services in the North through the effective use of technology by MSC meteorologists, and through partnerships and coordinated efforts between MSC and provincial, territorial, and municipal governments, as well as other federal government services, departments and agencies, and private industry.

The services that MSC provides also support MSC's research and development initiatives for the North. This includes logistics requirements for northern observatories, the establishment of environmental monitoring sites, and support for northern research aircraft.

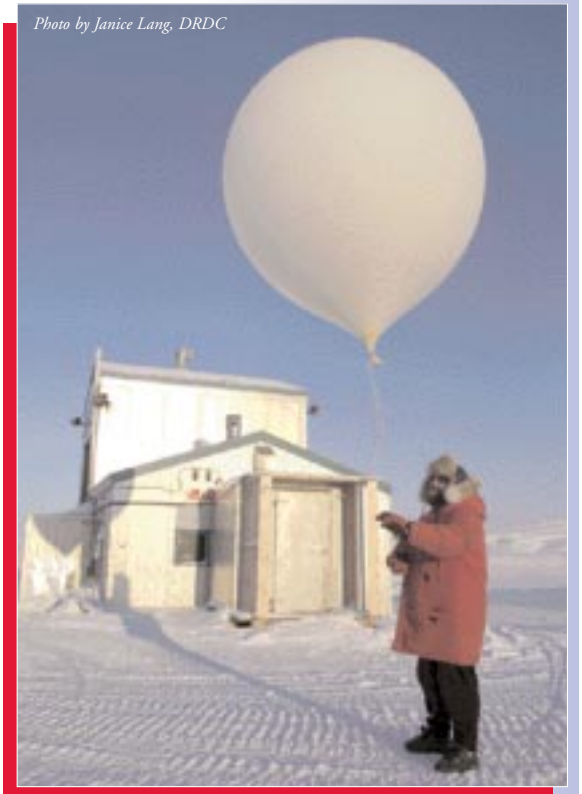
MSC also makes important contributions to the international community through data exchange and other agreements with the World Meteorological Organization. For example, data from MSC upper air stations, arctic buoys and solar radiation and stratospheric ozone monitoring instruments are essential for weather and environmental monitoring over high latitudes of the Northern Hemisphere.

AWOS instruments at MSC's High Arctic Observatory at Alert, NU

High Arctic Weather Observatories

MSC operates two weather observing stations in the High Arctic, one at Eureka and the other at Alert, both located on Ellesmere Island in Nunavut. These observatories are operated in partnership with the Department of National Defence (DND). The eight staff at Eureka and the three staff at Alert carry out upper air soundings twice daily and are responsible for routine data collection. The High Arctic Weather Station (HAWS) staff provide basic weather data, and are critical for arctic weather and atmospheric observations that feed into scientific research on issues such as global warming and the depletion of the ozone layer. The HAWS also provide support to a wide variety of partners and clients such as Energy, Mines and Resources (EM&R) and the Polar Continental Shelf Project (PCSP). Many northern expeditions undertaken by groups from around the world rely on these stations for support.

During the summer of 2004, MSC started construction of a new two-storey administration and accommodation facility in Eureka. The building is tentatively scheduled for completion by late 2005. The new complex will replace the current building, which dates from the 1960s. This new facility will enhance the capacity for a wide variety of research, and other operations in Canada's High Arctic.



Ozonesonde launch at Alert, NU

Weather Forecasts and Outreach

Sparse populations, communication challenges and the need for services in Inuktitut and other languages make providing weather services in the North especially challenging. MSC ensures that northerners receive timely weather information in order to make informed decisions for their health and safety, security and economic prosperity. With the difficulties inherent in providing weather information in the Arctic, MSC has and is developing working relationships with the media, other governments, non-government organizations, and industry to deliver this service. It is an on-going process that is continually changing to meet the needs of Canadians in the North, and the aviation and shipping industries.

Public Weather forecasts and information is disseminated in the North through automated telephone answering devices (ATADs), Weatheradio, the media (newspapers, and radio and television broadcasts including the CBC and TVNC), and through MSC's *'WeatherOffice'* website (**http://weatheroffice.ec.gc.ca/canada_e.html**). This website provides Canadians with on-line access to the following regional meteorological services:

- Short-term and long-term weather forecasts (including current weather, 5 day weather forecasts and long-range seasonal forecasts)
- Weather warnings, advisories and special weather statements
- Past weather / climate data

The public forecast regions for Canada's North incorporate both community names and well-recognized geographic or traditional names to reflect smaller traditional divisions. MSC provides computer generated voice messages of

current weather conditions, in Inuktitut, on the Nunavut Weatheradio and ATADs. Upon request, MSC spokespeople also give radio broadcast interviews to explain unusual weather events, as well as provide monthly climate reviews to the media. Storm Prediction Centres disseminate this information across the country. Environment Canada also has a number of subscription services available for weather radar and satellite images.

Wind Chill Hazards

Wind Chill	Description	Hazard
0 to -9	Low	• Slight increase in discomfort.
-10 to -24	Moderate	• Uncomfortable. • Exposed skin feels cold. • Risk of hypothermia if outside for long periods.
-25 to -44	Cold	• Risk of skin freezing (frostbite). • Check face, fingers, toes, ears and nose for numbness or whiteness. • Risk of hypothermia if outside for long periods.
-45 to -59	Extreme	• Exposed skin may freeze in minutes. • Check face, fingers, toes, ears and nose for numbness or whiteness. • Serious risk of hypothermia if outside for long periods. • Be ready to cut short or cancel outdoor activities.
-60 and colder	Extreme	DANGER! • Outdoor conditions are hazardous. • Exposed skin may freeze in less than 2 minutes.

MSC's wind chill card.

MSC is improving weather services in the North by introducing a new winter storm watch program that will provide Northerners with better advance notification of severe weather. In spring 2005, MSC will reorganize the existing public forecast regions to improve the accuracy of the day-to-day forecasts in a number of communities in the Northwest Territories and Nunavut.

MSC also produces aviation and marine forecasts for the North and Arctic Regions. Aviation weather forecasts are issued from MSC's two Meteorological Aviation Centres for Nav Canada. This information and current weather information for Northern and arctic airports is available on NAV Canada's website at http://www.flightplanning.navcanada.ca.

MSC also uses the marine communication system of the Canadian Coast Guard to broadcast weather and ice forecasts to mariners at sea in the North. In addition, MSC provides the Canadian Coast Guard with specialized ice and weather forecasts for their icebreakers' operations.

To ensure the safety and well-being of Northerners and to help northern industry and public aviation operate effectively and efficiently, the MSC has special warning preparedness and outreach programs in place in the North. MSC Regions are also active in distributing outreach material. For example, in cooperation with the Department of Education, MSC Pacific and Yukon distributed the new pocket-sized wind chill chart to every school age child in the Yukon with the hope that the occurrence of frostbite among the young will decrease. The internet-based school weather program "Sky Watchers" is now available to all teachers in the North, and in the coming years, plans are in place to highlight special northern weather related issues.

Quebec Region's weather forecast office for northern Quebec.

Weather Observing Networks

Critical weather elements such as temperature, precipitation and wind speed are observed in real time to provide timely, accurate forecasts and warnings to the public. In Canada's northern regions, this is a very big challenge since the distances between observing sites are very large. The use of satellite data can only partially compensate for sparse surface data.

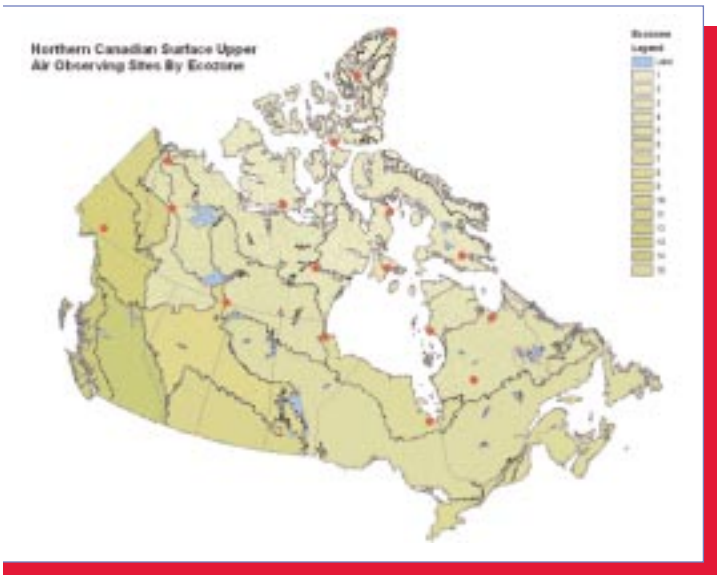
In the North, the MSC manages the **Upper Air Network, the Public Surface Weather Network, the Canadian Lightning Detection Network and the Marine Network**. MSC is also an integral part of the operation of NAV CANADA's **Aviation Weather Network**. Together, these networks support public weather forecasts and severe weather warnings, marine weather forecasts and aviation forecasts. They also provide data for climate studies and a wide range of environmental applications.

These national networks are managed by the Atmospheric Monitoring and Water Survey Directorate (AMWSD). The Atmospheric Monitoring Divisions in Canada's five regions manage the installation, inspection, maintenance and operation of these networks.

The automated radiosonde launcher at Whitehorse Upper Air Station, Yukon Territory.

UPPER AIR NETWORK

The Upper Air Network operates 31 stations across Canada, 17 of which are in the North. The MSC owns the facilities at each of the upper air sites, but contracts are in place at many of the sites for the soundings. Data from the Upper Air Network are critical input for numerical weather, climate and air quality forecasting, and are useful for validating satellite retrievals.



MSC's Upper Air Network for Canada's North.

Upper air data includes measurements of barometric pressure, temperature, humidity, and wind speed and direction (and may include radiation, ozone, and pollutants).

Upper air data sources include radiosondes, satellites, ground-based weather radars and wind profilers. Currently, the main source of upper air data is the radiosonde. A radiosonde contains data sensors and is launched into the atmosphere using a hydrogen/helium-filled balloon. The Network launches radiosondes twice daily at 0000 UTC and 1200 UTC from each of its sites. The MSC shares its data nationally and internationally through initiatives such as the Global Climate Observing System (GCOS).

The Upper Air Network also provides support to a wide variety of partners and clients such as the Department of National Defence (DND), Energy, Mines and Resources (EM&R), and the Polar Continental Shelf Project (PCSP).

Canadian Aircraft Meterorological Data Relay (AMDAR)

Since April 2000, the Meteorological Service of Canada has been developing the Canadian Aircraft Meteorological Data Relay (AMDAR) Program to augment MSC's core Upper Air Network. MSC is creating partnerships with Canadian air carriers. The goal of the program is to equip commercial aircrafts with instrumentation for the automated observation, collection and communication of upper air meteorological data to improve weather forecasts and warnings in the North.

The development of AMDAR for Canadian northern and arctic areas has been a formidable challenge since the airlines servicing these areas operate with mixed fleets of older aircraft and avionics systems. This makes real-time communications difficult. Despite these challenges, the Meteorological Service of Canada has developed two proof-of-concept systems based on satellite communications and the Internet - one each for First Air and Canadian North - the two most important airlines servicing northern communities.

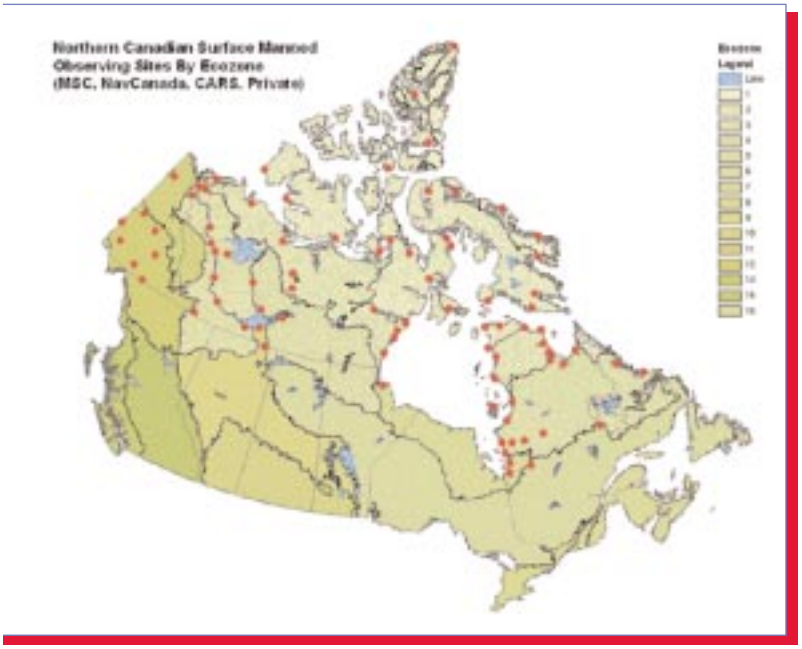
System testing will begin in January 2005. Scientists will be fine-tuning the AMDAR systems to ensure that the data quality meets the standards of the existing upper air network. If the testing proceeds as expected, MSC will outfit the fleet of five Boeing 737s from Canadian North Airlines with AMDAR systems by March 2005, and the 15 aircraft from the First Air fleet by March 2006.

The AMDAR systems will automatically report (over all phases of flight, i.e. ascent, en-route and descent phases), the latitude and longitude of the aircraft, the date and time of the observation, pressure, temperature, wind direction and wind speed. In addition, the First Air systems will have the capability to measure and report relative humidity, turbulence and icing.

AMDAR flight paths

PUBLIC SURFACE WEATHER NETWORK

The Canadian Public Surface Weather Network supports weather forecasts and severe weather warnings. This network includes observations from the aviation and upper air networks, buoys, and ships.



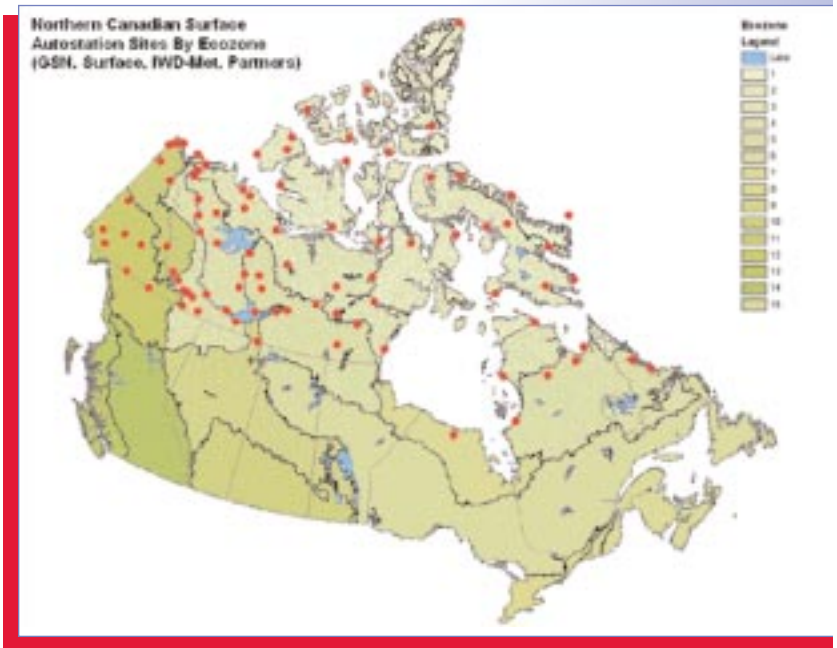
To produce public weather forecasts, meteorologists require hourly measurements of the air temperature, dew-point, pressure, precipitation occurrence, type and amount, visibility, cloud type and amount, cumuliform cloud, wind speed and direction, precipitation rate and tendency. Meteorologists also require measurements of the following at least every three hours: cloud amount, snow depth, snow cover, ice cover, grass minimum temperature and water temperature (where appropriate). To generate forecasts in the North, forecasters use computer model outputs, and satellite data and polar orbiting satellite photos.

MSC's manned Public Surface Weather Network stations for Canada's North.

AVIATION SURFACE WEATHER NETWORK

Under contract to NAV CANADA, the MSC provides direct support for aviation weather observations. This includes the installation, calibration and maintenance of meteorological equipment, and support for the meteorological communications infrastructure.

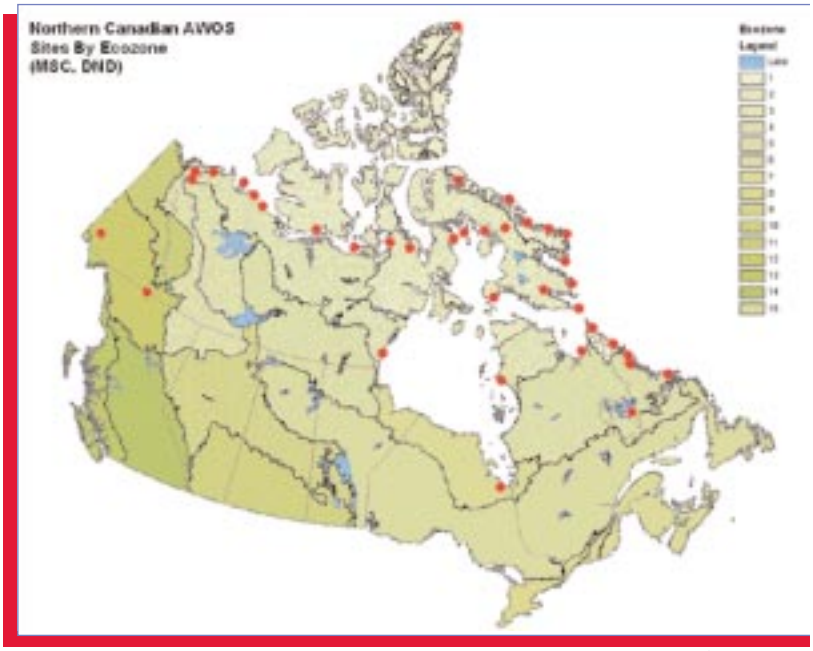
Aviation data includes routine observations of wind velocity and direction, air and dew-point temperatures, visibility, cloud amount, type and height of base, present weather including icing and freezing conditions, altimeter and mean sea level pressure, and at selected sites runway visual range. The data are essential for aviation forecasting and briefing purposes.



MSC's automated Public Surface Weather Network stations for Canada's North.

Automatic Weather Observing Stations

Under contract to NAV CANADA, MSC owns and operates AWOS (Automatic Weather Observing Stations) in Canada's North. These automated stations measure data that are essential for aviation forecasting. Automated systems in the North are cost effective and practical due to harsh environmental conditions and limited facilities and staff in the North. At sites with manned observations, AWOS data assists the observer in assessing and reporting current meteorological observations, and provides observations when the station is not manned.



MSC's Automatic Weather Observing Stations for Canada's North.

An AWOS measures wind velocity, air and dew-point temperatures, visibility, precipitation occurrence, cloud amount, type and height of base, current weather including icing and freezing conditions, altimeter and mean sea level pressure. In addition to the full capability AWOS, MSC owns and operates two LWIS (Limited capability AWOS) for aviation use. These stations provide only wind, temperature, dew-point and pressure (altimeter setting).

MSC's Canadian Meteorological Centre (CMC) in Dorval, Quebec, formats all aviation data according to the international and national standards. The CMC disseminates this data globally for use by pilots, flight service specialists, aviation briefers, and aviation forecasters.

Weather instrumentation at MSC's High Arctic Observatory in Eureka, NU.

MSC Arctic Surface Weather Instrumentation and Systems Test Site

The Atmospheric Monitoring and Water Survey Directorate (AMWSD) is in the process of establishing a national test facility in Iqaluit (Nunavut). The primary objective of the national test facility will be to evaluate the performance of surface weather instruments and systems, and related processing algorithms in 'rugged' arctic conditions. Performance evaluation is critical to the effective management of all ground-based observational and monitoring weather networks: Public Weather Networks, Aviation Surface Weather Network, Canadian Climate Reference Network, and Global Climate Observing Network.

MSC weather instruments operating in Canada's rugged northern environment.

The World Meteorological Organization recommends evaluating instruments and systems in conditions that are representative of their operational environment, and throughout their life cycle. This ensures the quality of the data provided to user communities. Evaluations at this test facility will contribute to improved quality control of weather data and more efficient management of life cycle costs (for example, select instruments with lower failure rates in arctic environments). The test facility will also provide staff with the opportunity to test new technology before deploying it network-wide. This will minimize or eliminate introducing biases into existing data sets.

Overall, this test facility will create the conditions for effective use of monitoring technologies in support of MSC's services in the North. This will improve services to northern communities, and will increase the capacity to accurately predict climate variability and climate change. The international meteorological community will also benefit from access to the Iqaluit test site. The U.S. National Weather Service (NWS) and National Centre for Climate Data have expressed an interest in using the facility to test their monitoring technologies.

The first cooperative project will begin in January 2005, when NWS plans to test their ice resistant wind sensors.

THE CANADIAN LIGHTNING DETECTION NETWORK

Lightning information is critical to a wide range of operations that are vulnerable to electric power fluctuations or direct hits by lightning. It is particularly important for forestry management, especially in regards to forest fires. The MSC operates 23 lightning detection stations in Canada's North. The Canadian Lightning Detection Network (CLDN) supports weather forecasting, severe weather research and aviation operations. Its clients include electric power utilities, conservation authorities, major infrastructure planners, the communications industry, and hosts of outdoor public events.

In the North, the CLDN services a smaller fraction of the landscape compared to latitudes that are more southern. The network adequately covers most of the Yukon Territory, Labrador and the southern half of the Mackenzie Valley. However, the northern-forested half of the Mackenzie Valley, the barrens of Kitikmeot (Hudson Bay Coast) and northern Quebec lack coverage. These areas are at risk from occasional lightning and thunderstorms.

The CLDN detects and reports cloud-to-cloud lightning discharges and cloud-to-ground strokes. Flashes are detected and reported in real-time data and are stored in data archives. The data are beamed via satellite to the control centre where it is processed to determine the location and strength of the lightning events. This information is transmitted to Environment Canada's Storm Prediction Centres. The complete process takes about 30 to 40 seconds from the time lightning is detected by sensors to the display on the forecaster's workstation screen.

MSC's Canadian Lightning Detection Network stations for Canada's North.

A Canadian Lightning Detection Network site. Shown are an IMPACT sensor and VSAT dish used for the detection of lightning strokes.

MARINE MONITORING NETWORKS

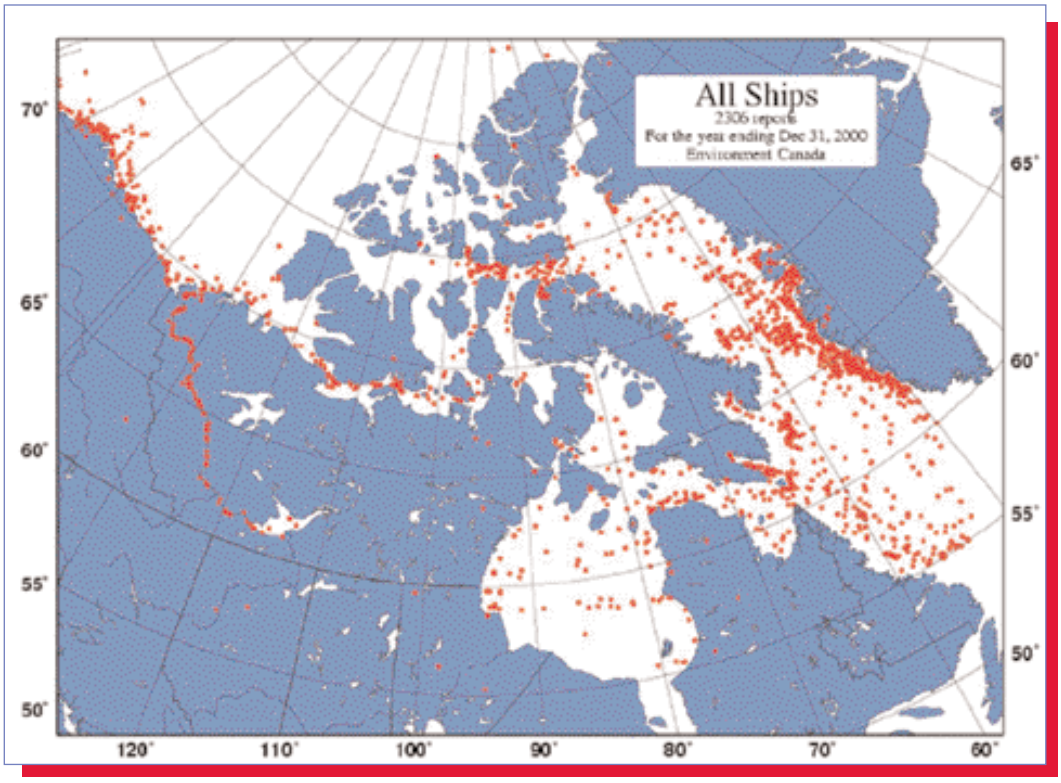
Voluntary Observing Ships and Automated Voluntary Observing Ships

MSC's Regions support the Ocean Data Acquisition System (ODAS) buoy program, the Voluntary Observing Ships (VOS) program, and the Automated Voluntary Observing Ships (AVOS) program. These programs provide essential marine observations on Great Slave Lake, the Mackenzie River, the Beaufort Sea, and in Arctic waters such as Baffin Bay and Hudson Bay.

Meteorological observations from VOS contribute to marine safety, and the efficiency of marine operations. They also provide essential input to numerical weather prediction models, operational weather forecasts, and the development of historical databases. Observations also provide knowledge about ocean climates and the linkages between the oceans and global and regional climatic patterns.

VOS observations include historical and current weather, wind direction and speed, amount of cloud, type of cloud, height of cloud base, visibility, temperature, humidity, atmospheric pressure, ship's course and speed, sea temperature, direction of movement of waves, period of waves, height of waves, sea ice and/or icing of ship superstructure.

MSC's voluntary observing ships are recruited from the Canadian Coast Guard (CCG) and from the Northern Transportation Co Ltd. (NTCL). In Prairie and Northern Region, MSC currently has three coast guard vessels, and four NTCL tugs providing information.



All Voluntary Observing Ships' reports for the year 2000.

EC's ODAS Buoy Program for the North

Environment Canada's Ocean Data Acquisition System (ODAS) buoy program is the second largest national buoy program in the world. The ODAS program has 46 automated moored buoy stations (three of which are in the Arctic) and up to 20 drifting buoys.

With the assistance of the Canadian Coast Guard, the MSC deploys two buoys on Great Slave Lake each summer to be in place through the open water marine season. MSC also has a buoy in Hudson Bay off Churchill during the open water marine season.

Standard observations from a buoy include wind speed, wind direction, peak wind speed, atmospheric pressure, air temperature, sea surface temperature, ocean wave period, significant wave height, maximum wave height and non-directional wave spectra, housekeeping functions, and sensor diagnostics. The buoy stations report hourly data via the GOES (Geostationary Operational Environmental Satellite) and/or the Argos system. The data are posted on the global transmission system.

Data Buoys on Ice in the Arctic Basin

The MSC contributes to the acquisition of weather data for the Arctic Basin by participating in the International Arctic Buoy Programme (IABP). Annually, the MSC provides one buoy for the international White Trident deployment exercise. In total, the White Trident exercise airdrops 7 buoys on the ice of the Arctic Basin. These buoys are contributed to the exercise by governments with northern interests (i.e. Canada, U.S., Germany, Norway etc.). MSC (with the support of Polar Continental Shelf Project) in an annual spring deployment operation out of Eureka also deploys 1 to 2 data buoys for U.S, IABP participants via Twin Otter landings on ice.

The MSC deploys data buoys on the Arctic Basin to support other institutions such as the Institute of Ocean Sciences. MSC also retrieves, processes and makes this data accessible globally. Standard data from a buoy on ice includes, position, air temperature and pressure.

A CES Zeno Buoy deployed for the U.S. National Ice Service on March 23, 2000.

CIS Data Buoys on Ice

The Canadian Ice Service (CIS) routinely deploys at least one buoy on northern Baffin Bay each fall on a multi-year floe. The last icebreaker to depart the Canadian Arctic for the season usually deploys this buoy. Position and, in some cases, pressure information are retrieved from this buoy.

The CIS often provides support to research activities in the North. For example, the CIS provided several position-only buoys to CASES (Canadian Arctic Shelf Exchange Study) for the ice break up period, early in the summer of 2004. This information was used for the deployment of the Amundsen Gulf to validate an ice motion algorithm being developed by the University of Manitoba and the Canadian Ice Service.

Ice

Sea ice plays a central role in the traditional lifestyle of those in coastal arctic communities. It is also a significant barrier and hazard to arctic marine shipping. To facilitate the safe use of sea ice for hunting, transportation, tourism and recreational activities, timely sea ice information is vital for northern activities. The MSC's Canadian Ice Service (CIS) has had a presence in Canada's North for over forty years. Its mandate is to monitor and report on ice conditions in Canadian coastal waters year-round. The CIS uses satellite and aircraft to monitor ice conditions on a systematic basis.

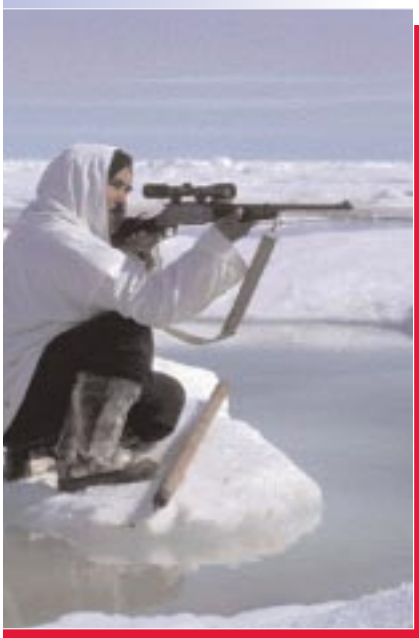
ARCTIC SHIPPING

Efficient and safe marine transportation is of high importance to the sustainability and development of northern communities. Since sea ice is a significant hazard to shipping, information regarding its state and distribution is critical for arctic marine operators. The CIS provides ice information service to the public and marine communities to help ensure safe and sustainable use of arctic waterways. In addition, through an agreement with the Canadian Coast Guard, the CIS provides additional ice information to support icebreaker operations and detailed ship routing through ice. This integrated service provides regular ice charts, ice hazard warnings, 30-day forecasts of ice conditions and seasonal ice breakup / freeze-up forecasts.

A Canadian Coast Guard ice breaker in Canada's North - Courtesy of the Canadian Coast Guard.

ICE DATA ACQUISITION

Annually, the Canadian Ice Service collects vast amounts of ice and iceberg data - mostly from remote sources (satellites, reconnaissance aircraft and ships). Remote sensing data forms the core of the data used to generate daily ice information products. RADARSAT SAR data is the primary remote sensing data source used in the analysis and preparation of ice chart and other ice information products. The CIS acquires about 4000 RADARSAT scenes annually. Supplementary data and information include meteorological data (temperature, wind, etc.), oceanographic information (currents, bathymetry, etc.), fields from numerical ice models (drift/trajectories, concentration, ocean currents/temps, winds and air temp., etc.), climatological data, and previous ice charts.



FLOE EDGE ADVISORY

The most popular spring destination in many Arctic communities is the floe edge, where the landfast ice meets the ocean. Arctic marine wildlife converges on floe edges in the spring, luring tourists, hunters and weekend campers. Springtime weather and ice conditions combine to make floe edges one of the most dangerous places in the icescape. People have found themselves floating away on pieces of ice that have unexpectedly fractured, often resulting in dangerous and costly search and rescue operations.

The MSC's Canadian Ice Service (CIS), with the support of the National Search and Rescue Secretariat, developed a prototype floe edge advisory that provides daily on-line ice information to two communities in Nunavut, Arctic Bay and Pond Inlet. These two communities are active users of spring ice floe edges.

With ice models and satellite imagery, the CIS provides year-round internet information customized for floe edge activities. The CIS places current satellite images and information on ice strength, temperatures, tides and winds on-line for northerners to access. This information, combined with traditional knowledge, provides communities with an increased sense of security and minimizes their risk.

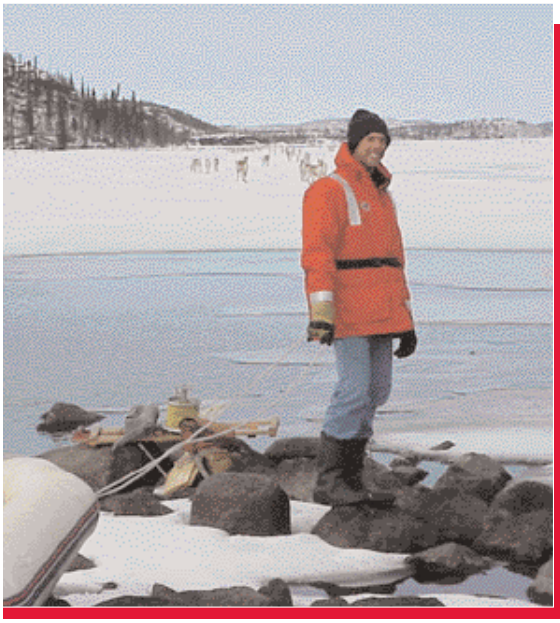
A sample of a floe edge update product that is distributed to northern communities that are very active users of spring ice floe edges.

SEA ICE PRODUCTS AND CLIMATE DATA ARCHIVE

During the summer months, the Canadian Ice Service produces daily ice hazard bulletins and charts for the Canadian Arctic, including Hudson Bay. Regional ice charts are produced weekly in the summer and monthly during the winter. This information is available on the CIS web site at **http://ice-glaces.ec.gc.ca**. The CIS also delivers data automatically to various clients by e-mail, fax and ftp. From April 2002 to March 2003, CIS made over 1.3 million automatic deliveries of ice products as well as other related products.

The CIS archives historical sea ice information for Canadian researchers and industry. A primary goal of this archive is to support studies of past, present and future sea ice conditions in Canada's North. The CIS also produces various publications including an "Annual Arctic Atlas" and a "Sea Ice Climatic Atlas – Northern Canadian Waters – 1971-2000" based on the CIS Digital Charts Database.

A chart produced by MSC's Canadian Ice Service that shows the minimum ice coverage (in percent) for the Eastern Arctic for 1969 - 2003.



Water

WATER SURVEY

The Water Survey Division (WSD) operates a network of 94 hydrometric stations across the Yukon, the NWT and Nunavut. The goal of the Water Survey Division is to improve the availability and dissemination of water data and to ensure the efficiency and effectiveness of water monitoring systems. This enables wise decision-making in areas that impact security of life and property, efficiency of the economy, and protection of environmental quality. Information on stream flow supports river transportation, and contributes to effective flood response.

A technician from MSC's Water Survey Division at work in the North West Territories.

In Canada's North, the WSD works in partnership with the Territories, other government departments (OGDs) and agencies, and the private sector. Seventeen percent of northern hydrometric stations support the needs of Indian and Northern Affairs Canada (INAC) and another 17 percent support the requirements of OGDs and the private sector. The remaining 66 percent of the network is required to meet Environment Canada's science and policy requirements regionally, nationally, and internationally. The Water Survey operates hydrometric stations in the North in all five Regions, including the Yukon Territory, the Northwest Territories, Nunavut, northern Ontario, northern Quebec, and Labrador.

Data collected at hydrometric sites include water flows and levels, water quality, water temperature, data to support sediment transport studies, limited capacity automated weather data, isotope samples, and snow and ice thickness data. The information from the network is important to aid in understanding fresh-water flow into the sea, which is critical to understanding current and future changes to arctic sea ice conditions.

Currently, the hydrometric network operating in the NWT and Nunavut is primarily in place to monitor climate change, which is a high national priority. The hydrometric network is part of the long-term national Reference Hydrometric Basin Network (RHBN), the Mackenzie GEWEX (Global Energy and Water Cycle Experiment) study (MAGS), and the Arctic Climate Systems Studies (ACSYS).

Tide levels are monitored on a regular basis in the Arctic.

The data collected at hydrometric sites provide valuable information for studies on climate change impacts on:

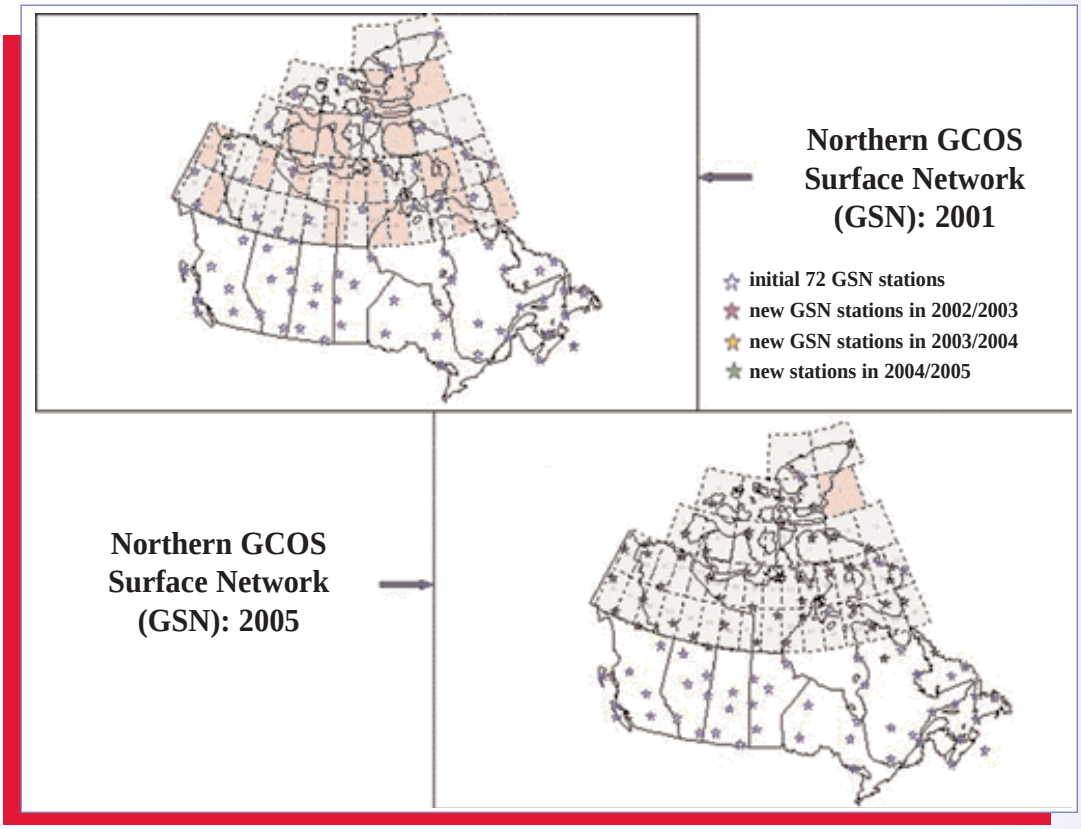
- northern hydrology
- northern ecosystems
- international/transboundary water management
- fisheries management
- flood forecasting and warnings
- flood plain management
- hydro-power production
- water supply
- pollution
- navigation
- recreation

Climate

GLOBAL CLIMATE OBSERVING SYSTEM SURFACE NETWORK (GSN)

The World Meteorological Organization (WMO) has established a collaborative international climate-monitoring program called the Global Climate Observing System (GCOS). The objective of the program is to establish climate observing stations within a 5-degree by 5-degree grid globally. The Meteorological Service of Canada's commitment to WMO is to establish a long-term climate observing system within this spatial coverage throughout the country. With significant financial funding from the Climate Change Action Fund, the MSC will establish new stations where none exists within this grid by 2006.

In the Arctic, the Canadian Global Surface Network (GSN) consists of 57 Automatic Weather Observing Stations (AWOS) including stations in Labrador and Quebec. There will be 47 upgraded, new or modernized stations across the North within the next few years. These GSN stations are, for the most part, a subset of the Canadian Reference Climatological Station Network. The MSC uses data from reference climatological stations for determining climate trends.



MSC is upgrading its current Global Climate Observing System Surface Network from it current size of 57 stations to 104 stations by 2006. Stations will be situated within a 5 degree x 5 degree grid globally.

RESEARCH

The Fourth International Polar Year (2007 – 2008)

The International Polar Year (IPY) 2007-2008 is an intensive internationally coordinated effort that includes interdisciplinary scientific research and observations focused on the Earth's Polar Regions.

The official observing period of the IPY will be from March 2007 until March 2009. The main geographic focus will be the Earth's high latitudes, but studies in any region relevant to the understanding of polar processes or phenomena will be encouraged. Canada has established a Canadian National IPY Steering Committee to stimulate and co-ordinate the Canadian IPY contribution. The National IPY Secretariat is located at the University of Alberta. A federal government department working group co-ordinates the Department's activities, and is co-chaired by the Meteorological Service of Canada (MSC). MSC will also co-ordinate Environment Canada's involvement in IPY initiatives. A MSC Canadian expert will serve as co-chair of the new IPY Joint Planning Committee.

The International Council for Science (ICSU) Joint Planning Committee has defined six research themes for IPY:

1. **Status:** Determine the present environmental status of the Polar Regions.
2. **Change:** Quantify and understand past and present natural environmental and social change in the Polar Regions, and improve projections of future change.
3. **Global Linkages:** Advance our understanding on all scales of the links and interactions between Polar Regions and the rest of the globe, and of the processes controlling these.
4. **New Frontiers:** Investigate the frontiers of science in the Polar Regions.
5. **Vantage Point:** Use the unique vantage point of the Polar Regions to develop and enhance observatories from the interior of the Earth to the Sun and the cosmos beyond.
6. **Human Dimension:** Investigate the cultural, historical, and social processes that shape the sustainability of circumpolar human societies, and identify their unique contributions to global cultural diversity and citizenship.

The IPY will seek to exploit new technological and logistical capabilities, and to make major advances in knowledge and understanding. It aims to leave a legacy of new or enhanced observational systems, facilities and infrastructure, numerical earth simulators, research networks, and an unprecedented degree of access to data and information.

MSC is preparing projects that will contribute to the national and international effort and address both the scientific themes and observational needs. These initiatives address IPY and Canada's science needs, and issues identified by the 2004 Arctic Climate Impact Assessment.

Atmosphere

ATMOSPHERIC MONITORING AT MSC'S HIGH ARCTIC OBSERVATORY AT ALERT, NU

Global Atmospheric Watch Program

Alert is the most northerly site in the World Meteorological Organization's (WMO) Global Atmospheric Watch Network (GAW). It is located on the northeastern tip of Ellesmere Island in Nunavut, far removed from major industrial regions. Alert is ideally situated to determine representative background concentrations of air pollutants in the Northern Hemisphere.

MSC's High Arctic Observatory in Alert, NU during polar sunrise.

At Alert, the Meteorological Service of Canada (MSC) measures interannual and long-term changes in the concentrations of greenhouse gases, toxic air pollutants and aerosols. These measurements are indicators of changes in global atmospheric chemistry that are associated with climate change, stratospheric ozone depletion, photochemical smog, and the bioaccumulation of toxics in arctic ecosystems. Scientists use this information to understand the complex physical processes occurring in the atmosphere to advise decision-makers on emerging atmospheric and climate issues.

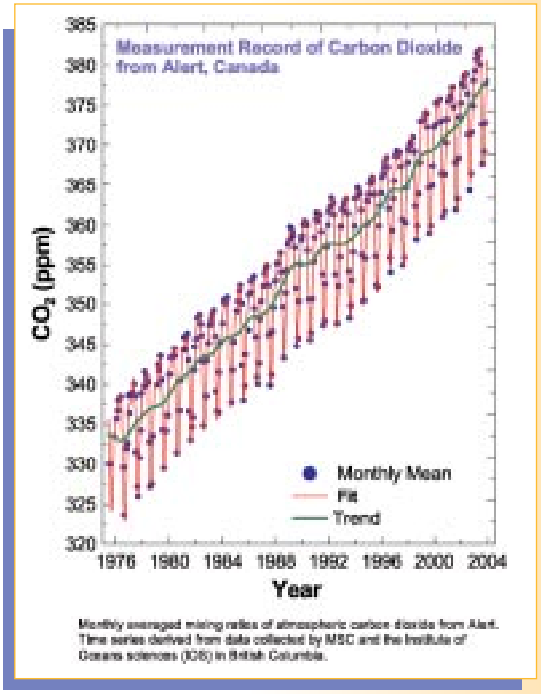
The high quality of Alert's measurement program and research facilities has attracted many international research scientists to Alert. MSC's leading research, coupled with the complimentary nature of the international measurement programs at Alert, has earned it a worldwide reputation for excellence in science.

Measurements at Alert also help to track the effects of policy decisions such as the phasing out of ozone depleting substances (ODS) under the Montreal Protocol or progress towards meeting commitments to reduce greenhouse gases under the Kyoto Protocol. Many international archive centres such as the WMO World Data Centre for Greenhouse Gases (WDCGG) in Japan, and the Carbon Dioxide Analysis Centre at Oak Ridge National Laboratory in the U.S. archive and disseminate Alert data to the international scientific community.

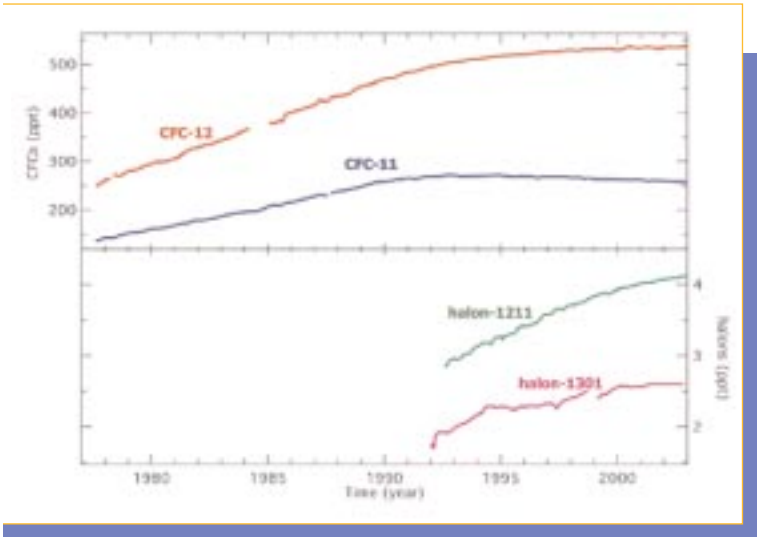
Atmospheric Measurements at MSC's High Arctic Observatory at Alert, NU.

Measurements	Co-operative countries	Atmospheric issue	Concentration Trend	Record length (yrs)
GREENHOUSE & OTHER TRACE GASES				
Determine the trends and variability in global background concentrations				
Carbon Dioxide (CO_2)	Canada, US, Australia, Japan	Climate change	Increasing	29
Methane (CH_4)	Canada, US, Germany, Australia	Climate change	Increasing - during the last decade the growth rate has dropped and is presently near zero	17
Nitrous oxide (N_2O)	Canada, Australia, Germany, US	Climate change	Increasing	4
Peroxyacetyl nitrate (PAN)	Canada	Smog	Decreasing up to 1997, currently increasing	18
Carbon Monoxide (CO)	Canada, US, Australia, Germany	Climate change	Decreasing	6
Ozone (O_3) ground level	Canada	Climate change & smog	Increasing	12
Sulphahexafluoride (SF_6)	Canada, US, Australia, Germany	Climate change	Increasing	4
STRATOSPHERIC OZONE & SOLAR RADIATION				
Study the behaviour of the ozone layer in the Arctic to determine if significant losses of ozone are occurring over the Polar Region during spring				
Stratospheric ozone (O_3)	Canada	Ozone depletion	Decreasing	40
Solar Radiation-UVB	Canada	Ozone depletion	Increasing	18
HAZARDOUS AIR POLLUTANTS				
Study the transport of toxic pollutants from source regions into the Arctic and the cycling and behaviour of these substances in arctic ecosystems				
Mercury (Hg)	Canada	Bioaccumulation & Health risks	Increasing in arctic ecosystems	9
PCBs and Persistent Organic Pollutants (POPs)	Canada	Bioaccumulation & Health risks	Decreasing except 'current use pesticides'	2
AEROSOLS				
Study the trends of the anthropogenic and natural components of aerosols in the Arctic				
Aerosols - (anthropogenic (components such as heavy metals, and inorganic species)	Canada	Arctic Haze, Climate change, Health risks	No obvious increasing trend, but a very slight decreasing trend	24
Aerosols - (anthropogenic carbonaceous particles)	Canada	Arctic Haze, Climate change, Health risks	Decreasing	15
ISOTOPES				
Use isotopic signatures of trace gases to determine various anthropogenic and natural sources and sinks				
^{13}C, ^{14}C, ^{18}O, in CO_2	Canada, US, Australia, Germany	Climate change	NA	6
^{13}C, ^{2}H, in CH_4	US	Climate change	NA	6

The first figure below illustrates the increasing trend in carbon dioxide concentrations at Alert from 1988 to 2004. The concentration of this greenhouse gas continues to increase at a rate of about 1.5 parts per million per year. The second figure below shows the trends for two common chlorofluorocarbons (CFC- 11 and 12 and Halon 1211 and 1301). Some CFC's are decreasing in concentration because of the actions taken under the Montreal Protocol to reduce ozone-depleting substances; others are still increasing.



Weekly measurements of carbon dioxide from Alert, NU from 1976 – 2004.



Global monthly means of the major CFCs and halons as parts per trillion (ppt) in the atmosphere versus time from the NOAA climate monitoring and Diagnostics Laboratory (CMDL). The means include measurements from Alert, NU; Point Barrow, Alaska; Niwot Ridge, Colorado; Mauna Loa, Hawaii; American Samoa; Cape Grim, Tasmania, and the South Pole.

ALERT 2000 – Polar Sunrise Experiments

Studies of the persistent and historical presence of 'arctic haze' in the 1980s led serendipitously to the discovery of the phenomenon of ozone depletion in the Arctic at polar sunrise. Since that time, MSC scientists have organized a series of studies focused on understanding the chemical activity that is triggered by the 'polar sunrise' in the Arctic.

In the Arctic between late October and late February, the sun does not rise above the horizon. This allows scientists to study chemical and physical processes in the absence of sunlight, and then determine the difference when the sun first appears above the horizon in the spring. Alert 2000 was the culmination of several **Polar Sunrise Experiments** at Alert since 1988. MSC scientists spearheaded the 2000 intensive field investigation to explore the chemical behaviour of the arctic snow surface, and to examine tropospheric (surface level) ozone and mercury depletion phenomena.

The Alert 2000 study revealed that snow is a highly reactive medium especially when irradiated by sunlight. Significant photochemical reactions occur on the snow pack that affect the levels of ambient trace gases, including toxics. The discovery that the snow pack is much more chemically reactive than previously thought has led scientists to believe that the snow pack is a cauldron for the production of highly reactive chemicals. This could have a substantial impact on the fate of pollutants transported in the air to the Arctic, including toxic chemicals that may accumulate in arctic ecosystems. Prior to this campaign, the photochemical relationship between the air and the snow was unrecognized.

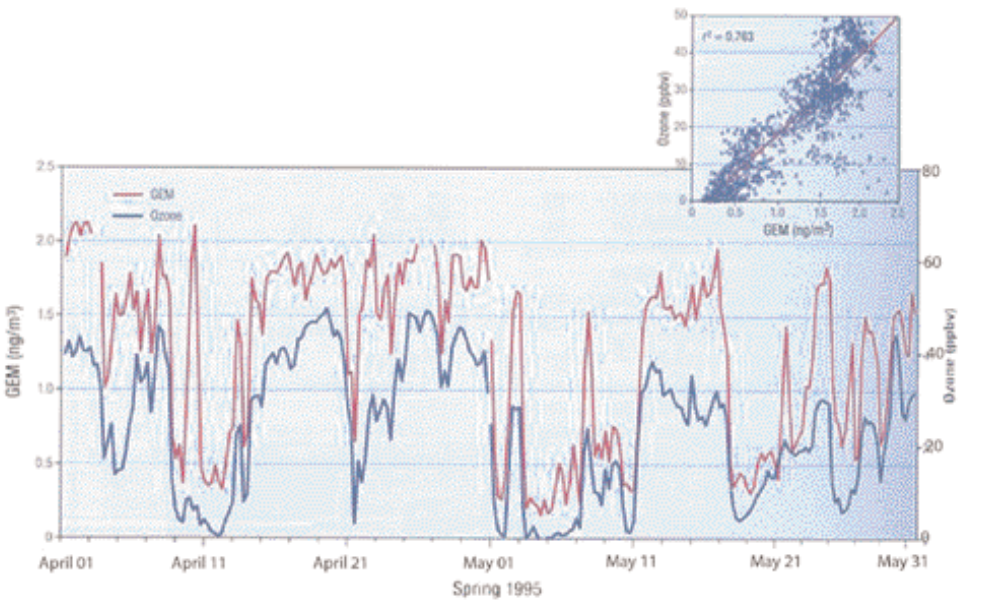
The DRDC and Environment Canada ice camp set up at Alert in 2002.

Over the long, dark winter, pollutants transported over long distances from southern latitudes accumulate in the Arctic. With the appearance of the first rays of sunlight in the spring, chemical processing of such pollutants accelerates. MSC scientists discovered that during polar sunrise at Alert, solar radiation initiates processes that lead to the dramatic destruction of ground-level ozone. Although ozone is both a toxic substance and a greenhouse gas, it plays a key role as a producer of chemicals that remove other atmospheric contaminants from the atmosphere.

Concurrent with the depletion of ground-level ozone, MSC scientists discovered at Alert that gaseous elemental mercury concentrations also dropped markedly after polar sunrise. This was a surprising discovery since such a decrease in mercury levels had not been observed anywhere else in the world. The mercury depletion events are highly correlated to the tropospheric ozone depletions, and there is a close link between the chemical reactions that are responsible.

The Polar Sunrise Experiments studied the details of these processes. Scientists established the pivotal role played by highly reactive bromine atoms in these processes. These atoms originate from the photochemical processing of sea salt. The reactions between bromine atoms and ozone result in a multiplication of bromine atoms that have an accelerating effect on the ozone (and mercury) destruction. When mercury reacts with bromine it becomes a more 'reactive' form of mercury and potentially leads to the production of a much more toxic form of mercury that could enter the food chain and bioaccumulate in higher order species.

MSC scientists continue to study these and other chemical processes at Alert. The goal is to develop a comprehensive understanding of the chemical processes and interactions that occur during polar sunrise, and gain insight into the fate of chemical species in cold climates.



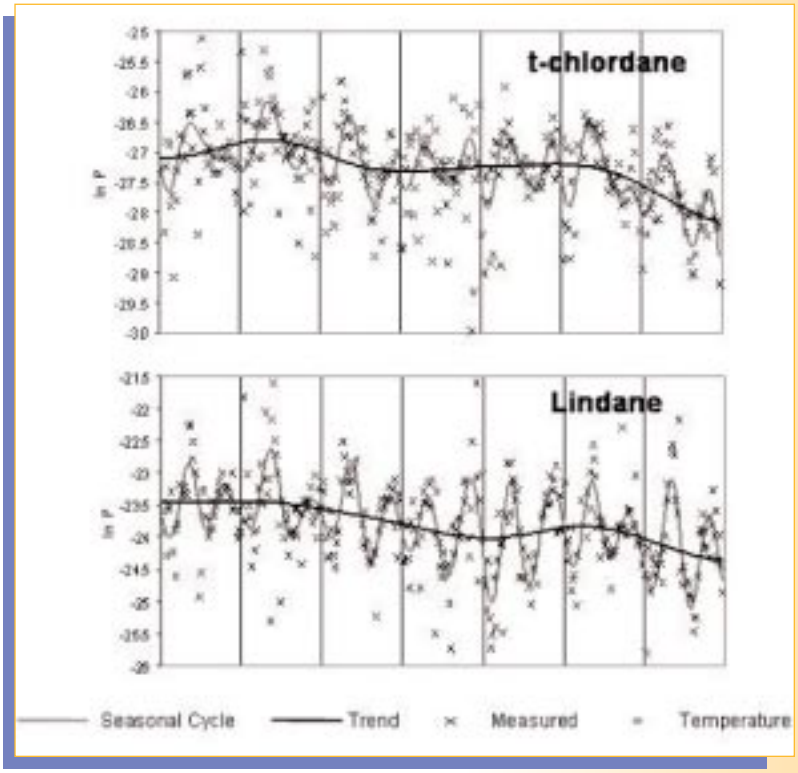
Gaseous elemental mercury (GEM) and ozone concentration measurements between April 1 and May 31, 1995 at Alert, NU.

TOXIC CONTAMINANTS

Northern Contaminants Program

The Northern Contaminants Program (NCP) was established by Indian and Northern Affairs Canada (INAC) in 1991. In developing the program, INAC consulted with scientists, northern aboriginal organizations and communities, and various levels of government. The mandate of the program is to "*work to reduce and, wherever possible, eliminate contaminants in traditionally harvested foods, while providing information that assists informed decision making by individuals and communities in their food use.*"

Through funding from the Northern Contaminants Program, MSC's Atmospheric and Climate Science Directorate has monitored concentrations of persistent organic pollutants (POPs) in Canada's Arctic since 1992. At Alert, these measurements include currently used and banned pesticides. In addition to the on-going measurements at Alert, MSC scientists also carried out short-term measurement campaigns at five other arctic sites (see map). MSC's measurements of POPs in the Arctic will help to determine whether atmospheric concentrations and deposition of POPs into arctic ecosystems are changing in response to national and international control strategies.

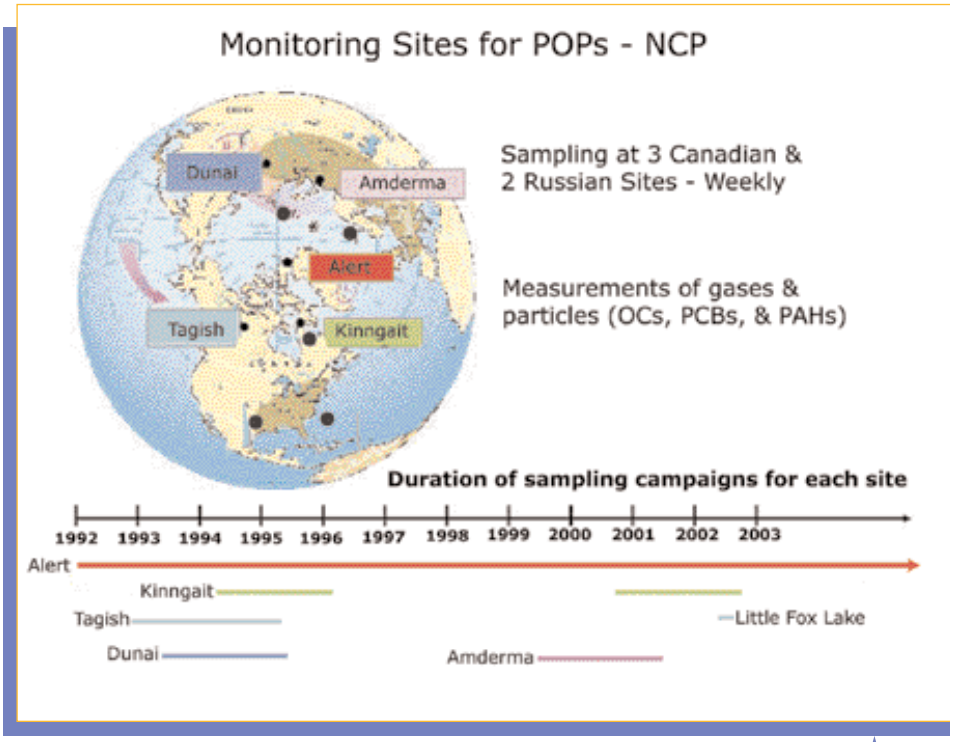


Trends of trans-chlordane and lindane (γ-HCH) measured in air at Alert (Air concentrations expressed as natural log of partial pressure in air, P)

Pesticides banned from use in Western and industrialized countries (e.g. chlordanes) are generally decreasing in air concentrations in the Arctic. This trend is seen in the Alert 1993 -1999 data series for *trans*-chlordane and Lindane. Occasionally, some elevated concentrations of chlordane-based pesticides, such as heptachlor and *trans-/cis*-chlordane, are observed at Alert. This is an indication of fresh input of these pesticides into the Arctic. MSC scientists found that air concentration trends for currently used pesticides (such as endosulfan) were decreasing very slowly or remaining relatively constant at Alert.

At the other arctic sites, the concentrations of POPs in the air were similar to those measured at Alert. However, the relative concentrations of the different compounds and seasonal variations of each differed from site to site. This indicates that the sites have different source regions. For instance, Tagish receives air transported over the Pacific from Asia, while Alert is affected by transport from Eurasia and North America. Since sampling at these other locations was short-term (up to 2 years), long term trends cannot be determined for sites other than Alert.

Given that our northern climate is changing, long-term measurement programs will help scientists investigate how global climate variations are affecting the transport and distribution of POPs in arctic air. MSC scientists found evidence that climate fluctuation patterns are influencing POPs concentrations. As temperatures change in the day and from season to season, POPs behave differently. They evaporate into the atmosphere at high temperatures, and condense out of the atmosphere at low temperatures, depositing onto land surfaces, lakes and forests. Over time, these pollutants repeatedly evaporate and condense and make their way northward from source regions.



A map showing the sites and duration of sampling for the Northern Contaminants Program measurement campaign of persistent organic pollutants in the High Arctic.

Air sampling at Alert will continue in order to monitor the changing levels of different POPs in arctic air. The NCP POPs air concentration dataset, together with other MSC datasets - IADN from the Great Lakes Region - and datasets from other circumpolar countries (AMAP), will provide policy makers with vital information. The data will help Canadian negotiators to prepare reasonable and practical control strategies for POPs that are consistent with how contaminants move through the North. Canada has played a pioneering role in defining the issue of toxics in the North, and is pursuing solutions internationally.

Sources of Organochlorine Pesticides

In Canada and other developed countries, the use of many organochlorine pesticides (OCPs) is banned in industrial and agricultural practices. Examples of banned pesticides include toxaphene, dichloro-diphenyl-trichloroethane (DDT), chlordane, dieldrin, and hexachlorocyclohexanes (HCH - also referred to as technical HCH). Traces of these substances, however, are still cycling through ecosystems - especially in vulnerable regions like the Canadian Arctic.

MSC scientists are studying the sources of these compounds in order to determine whether they come from countries where they are still used, or if they are 'ghosts of the past' that are recycled into the air from previously contaminated soil and water. The Northern Contaminants Program (NCP) supports MSC's Atmospheric and Climate Science Directorate's research initiatives in tracing the sources of OCPs.

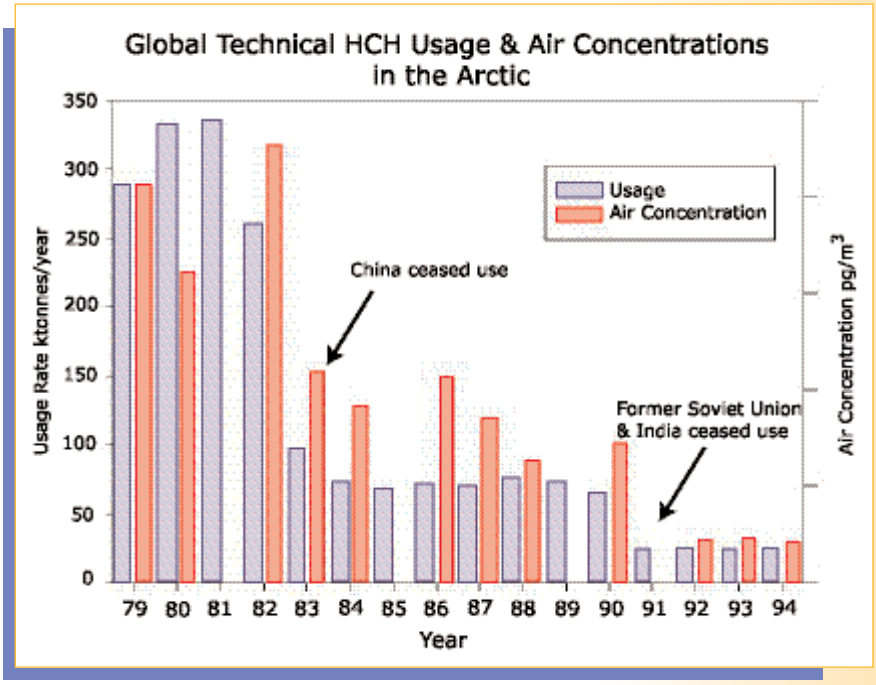
MSC's scientists studied air concentration data of α-HCH (a component of technical HCH) collected from different northern locations between 1979 and 1996 (by various groups). These concentrations were compared with global usage of technical HCH and emissions of α-HCH for the corresponding years. Two significant decreases were seen in the data. The first corresponds to China's abandonment of technical HCH (1982-1983), and the second corresponds to the reduction in technical HCH use by the former Soviet Union and India (1990-1992). This indicates that atmospheric long-range transport rapidly disperses HCH from its source regions to the Arctic.

MSC scientists have found that the physical properties of pesticides at the molecular level are tremendously important to their transport pathways. Organochlorine pesticides, like many other organic molecules, can have the same chemical formula, but vary from one another in their molecular configuration and shape (referred to as isomers). Ultimately, these subtle differences can have profound affects on the behaviour of these molecules in the atmosphere and water.

The story for α-HCH and β-HCH, two isomers of technical HCH, is a good example. MSC scientists identified that the dominant pathway for the transport of β-HCH is oceanic. In contrast, the dominant pathway for α-HCH is atmospheric. A comparison of HCH isomer pathways has suggested that most of the β-HCH originating in Asia is deposited in the North Pacific Ocean and then delivered to the Arctic Ocean through the Bering Strait. This implies that water-soluble chemicals removed from the air by precipitation or air-to-sea gas exchange may reach the Arctic primarily via ocean currents. These findings have led scientists to believe that the role of ocean currents in the transport of toxics to the Arctic is more important than was previously thought.

Another way to establish the source of a pesticide is to determine the ratios of enantiomers (optical isomers - mirror images of a molecule) in the contaminant. Enantiomer ratios are initially exactly 1:1, but as pesticides biologically degrade, their ratio of enantiomers changes. A change in the ratio indicates to scientists that the compound has undergone partial biological degradation. It also provides scientists with an idea of how long the compound has been cycling in the environment. For example, an emissions inventory for toxaphene in the United States suggests that, even though the pesticide was deregistered two decades ago, volatilization of soil residues contributed 360 tonnes of toxaphene to the atmosphere in 2000.

MSC scientists will continue to use the distinctive physical properties of organochlorine pesticides to differentiate between old and new sources of pesticides, and to help them determine the transport pathways of these chemicals into the Canadian Arctic. MSC's findings help to fulfill Canada's POPs Protocol obligations under the Convention on Long-range Trans-boundary Air Pollution (LRTAP) and the Stockholm Convention on POPs.

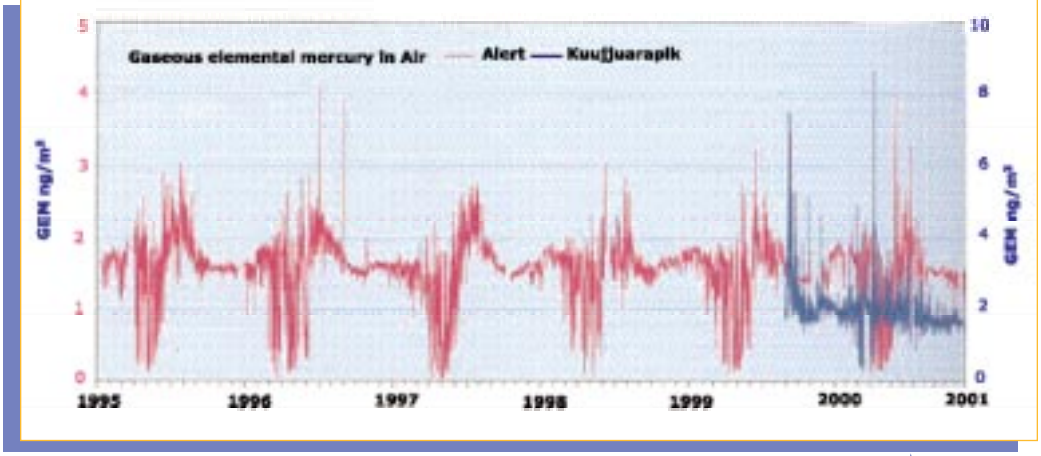


Mercury

Similar to other toxics, certain forms of mercury can bioaccumulate in the tissues of aquatic and terrestrial animals. Mercury in the gaseous form can remain in the atmosphere for 6-24 months, allowing it to travel to the remote Arctic via atmospheric and hydrologic processes. This can make northern communities susceptible to mercury producing activities such as fossil fuel burning, metal smelting and waste incineration from distant industrial areas.

Through the Northern Contaminants Program (NCP), MSC's Atmospheric and Climate Science Directorate and MSC's Quebec Region measure mercury at two locations in Canada's North. These measurements began at Alert, Nunavut in 1995 and at Kuujjuarapik, Quebec in 1999.

There is an annual reoccurring pattern of a sharp drop in gaseous elemental mercury concentrations at Alert annually in late February (during Polar Sunrise - see story on page 25). This depletion of mercury in springtime in the arctic air signaled to scientists the existence of a unique chemical process. A similar pattern emerged in the data from Kuujjuarapik, Quebec and for other locations throughout the Arctic and in the Antarctic. This suggests that these mercury depletion events (MDE) occur over large regions and are not restricted to the High Arctic. The MDEs at Kuujjuarapik, however, are less frequent and less intense than at Alert. The source regions of the two sites are distinct. Kuujjuarapik's airshed is mainly from southern areas, whereas Alert's airshed is mostly from Eurasia and North America.



Gaseous elemental mercury (GEM) measurements at Alert, Nunavut and Kuujjuarapik, Quebec.

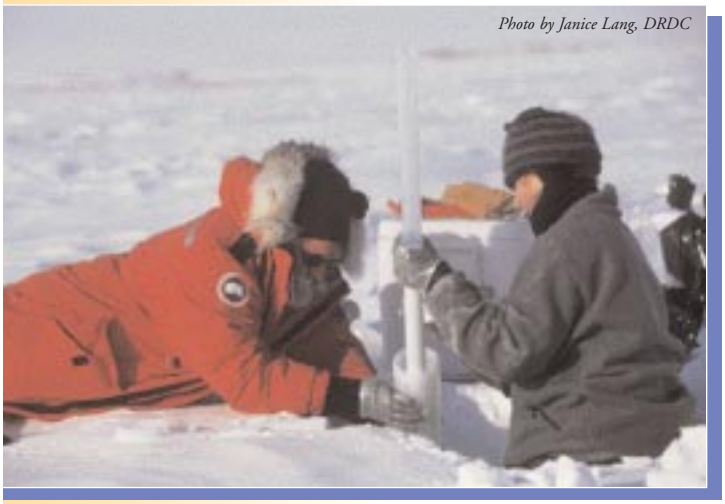


Photo by Janice Lang, DRDC

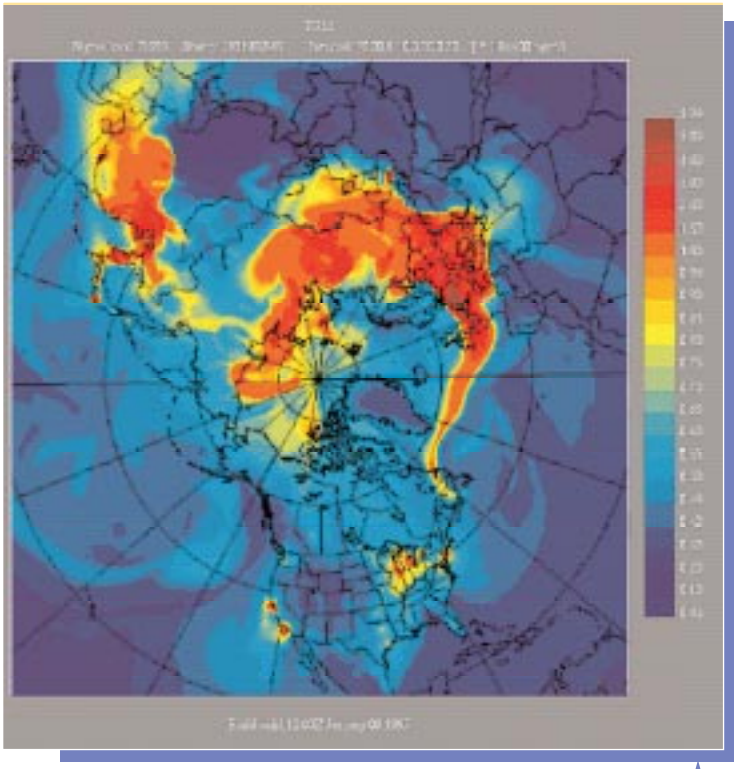
Scientists from MSC's Quebec Region have been studying gaseous mercury concentrations and atmospheric processes at Kuujjuarapik. The main purpose of this research is to study atmospheric mercury transport and fallout in northern Quebec in connection with mercury oxidation processes. Scientists believe that these oxidation processes are an important contamination route to the northern environment.

Scientists are measuring total mercury concentrations in precipitation, surface-air fluxes, and in soil, water, snow, and over characteristic landscapes in Nunavik. For comparison

Snow sampling during the Alert 2002 Polar Sunrise Experiments for determination of total mercury concentrations in snow.

purposes, similar measurements will be made over different landscapes - a southern terrestrial area (St. Anicet) and maritime area of the St. Lawrence Gulf (Mingan). This will provide scientists with valuable insights into the geographical extent of mercury oxidation processes and will help them to identify the mechanisms involved.

MSC's mercury measurement programs in Nunavut and Nunavik will enable scientists to gain further insight into how mercury transfers from the atmosphere into the arctic food chain. Continuous annual measurements are necessary for policy makers to assess the effectiveness of mercury emission control strategies and for the development of adaptation strategies for Northerners in traditional food consumption.



GRAHM model output for January 9, 1997, showing the surface air concentrations of total gaseous mercury (in nanograms/m3) in the Northern Hemisphere. The figure gives an indication of the pathway for the transport of mercury into the Canadian Arctic.

Atmospheric Heavy Metals

MSC's Atmospheric and Climate Science Directorate is tracing the life cycle of mercury to develop a comprehensive model that will simulate the transport pathway of mercury into the Canadian Arctic. Mercury has both anthropogenic and natural sources. Anthropogenic mercury comes primarily from coal-fired power plants, metal smelting operations and waste incinerators. Natural sources include weathering of bedrock and gaseous emissions from soils. MSC scientists are developing an accurate inventory of mercury emissions (both natural and anthropogenic) to use as input into MSC's **Global and Regional Atmospheric Heavy Metals** model (GRAHM).

The GRAHM model is a transport and transformation model for the global distribution of mercury. Used in conjunction with MSC's Global Environmental Multi-Scale (GEM) meteorological model, it will simulate the pathways traveled by mercury and other heavy metals. This project is still in its infancy, but there is a strong scientific focus worldwide on defining mercury transport because of its high toxicity.

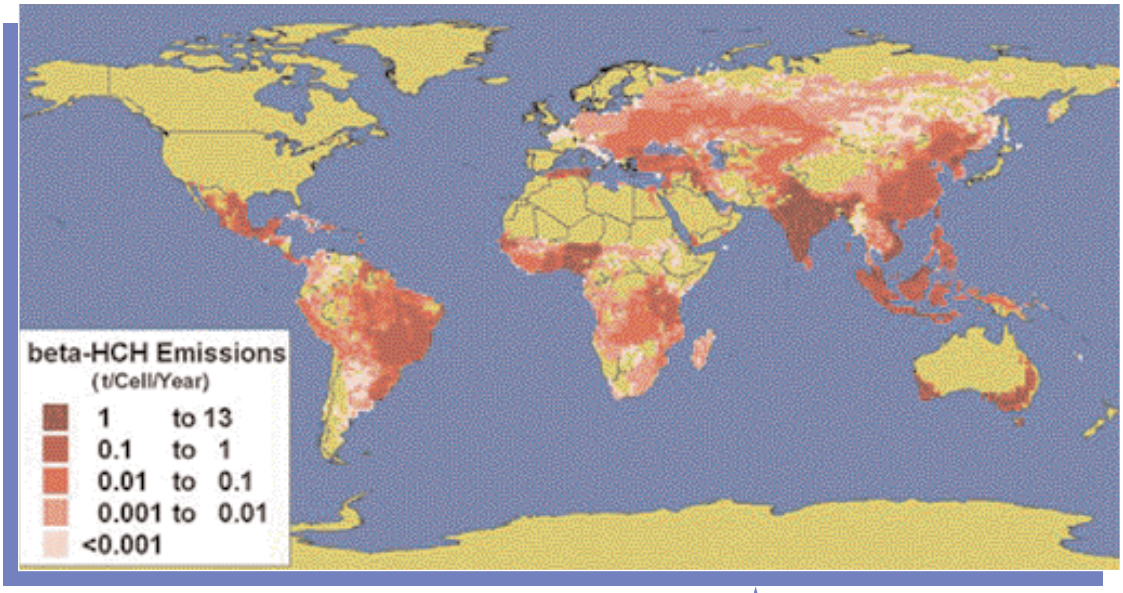
Once mercury transport pathways are understood, effective emission control strategies can be put into place to prevent the dangerous accumulation of mercury in arctic ecosystems.

Using Pesticide Emissions Inventories to Determine Sources and Pathways of Pollutants

Organochlorine pesticides (OCP) such as hexachlorocyclohexanes (HCH), dichloro-diphenyl-trichloroethane (DDT), toxaphene, and endosulfan have been detected in the air, snow, seawater, polar bears and marine mammals in the Arctic. The sources and pathways are known for some of these OCPs, but are not very clear for others. MSC scientists are creating global emission inventories for all OCPs in order to study the sources and pathways of these pollutants.

MSC's Atmospheric and Climate Science Directorate started developing an OCP emission inventory in the early 1990s. The inventory is comprised of global production and usage information for pesticides and commercial chemicals. MSC inputs this information into the **Simplified Gridded Pesticide Emission and Residue Model** (SGPERM) to generate gridded global emission inventories for specific OCPs. MSC is one of only a few organizations in the world to have created such an inventory on both regional and global scales.

MSC distributes the output from this model worldwide through the internet-based **Global Pesticide Release Database** (GloPeRD, http://www.msc.ec.gc.ca/data/gloperd). As data continues to become available, the inventory will expand to enable the scientific community to investigate OCP transport and transformation processes. This data sharing contributes to international efforts such as the Arctic Monitoring and Assessment Programme (AMAP), and the United Nations Economic Council of Europe's (UNECE) Task Force on Persistent Organic Pollutants and the UNECE Expert Panel on Emission Inventories. Such information is essential for developing global pesticide use policies to ensure the future health of Canadians in the North and northern ecosystems.



Gridded global annual emissions for β-HCH in 1990 (Li et al. 2003).

REGIONAL AIR QUALITY PROGRAMS TO ASSESS THE IMPACTS OF CURRENT AND FUTURE NORTHERN DEVELOPMENT

The North is experiencing a boom in mining, oil and gas development. There is concern that atmospheric emissions from these developments may adversely affect human, wildlife and ecosystem health through degradation of regional air quality and increased acid deposition.

The majority of the mining development is occurring in a region spanning across central Northwest Territories to western Nunavut. There are two diamond mines and one gold mine in operation, another two diamond mines and one gold mine are in the environmental assessment regulatory process or construction phase, and two more diamond and gold mines are being proposed for future development. The mines are sources of nitrogen, sulphur, ammonia and particulate matter emissions.

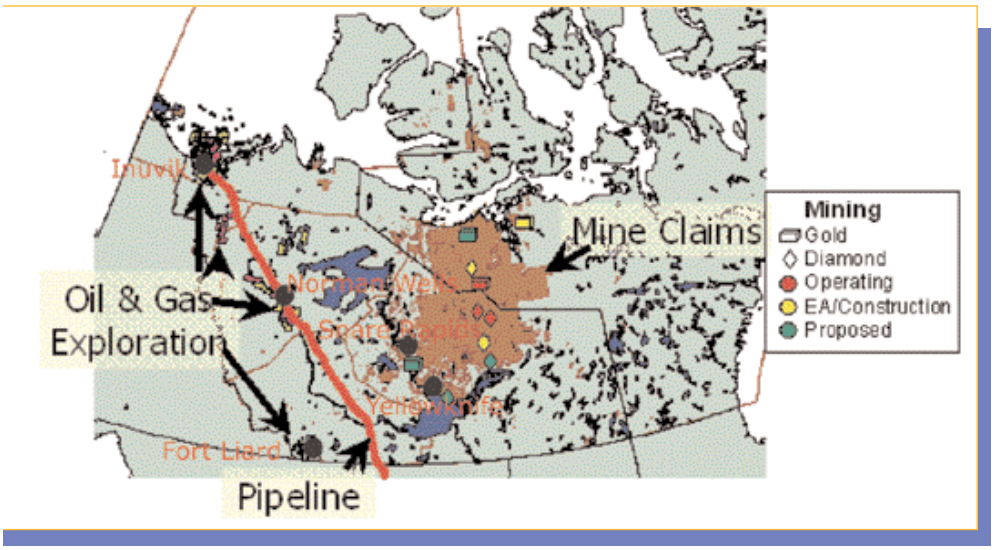
Oil and gas exploration and development is occurring along the Mackenzie Valley and Delta regions. Currently there are small developments in operation in Inuvik, Norman Wells, Fort Liard and Cameron Hills. The Mackenzie Gas Project (including three anchor gas fields in the Mackenzie Delta and a gas pipeline from the Mackenzie Delta to Alberta) is going through the environmental assessment regulatory process. If the pipeline is constructed, oil and gas exploration and development will increase dramatically.

The Prairie and Northern Regional Air Quality Modelling Program has implemented the Community Multiscale Air Quality (CMAQ) modelling system to investigate potential cumulative impacts to regional air quality from current and future northern developments. Over a 1-year modelling episode, scientists will predict ambient concentrations of criteria pollutants (nitrogen oxides, sulphur dioxide, carbon monoxide, particulate matter and ammonia), acid deposition and regional haze.

Through Northern Energy Program funding, MSC's PNR has contributed equipment to the existing Government of the Northwest Territories' (GNWT) air quality monitoring network. Specifically, PNR has provided continuous NO_x and ozone analyzers to the Inuvik station in an effort to determine baseline levels of these gases before oil and gas development ramps up. This will enable scientists to track changes and trends in ambient levels as development occurs. The GNWT also has air quality monitoring sites at Norman Wells and Fort Liard (see map). Each site, including Inuvik, has a program that measures meteorological parameters, and concentrations of hydrogen sulphide, sulphur dioxide and fine particulate matter ($PM_{2.5}$).

MSC's Canadian Air and Precipitation Monitoring Network (CAPMoN) in Downsview is involved in remote deposition-monitoring at Snare Rapids, about 100km northwest of Yellowknife. This site has provided valuable background information from developed regions with diamonds mines. The information will be useful to compare to measurements along the Mackenzie Valley. There are plans to expand this site to include measurements of ground-level ozone and potentially fine particulate matter to assist with the national air quality prediction modelling program. CAPMoN also has additional northern monitoring sites at Goose Bay (Labrador) and LGIV (James Bay).

Up until now, global influences on Canada's northern air quality has been the dominant northern air quality issue. However, as the exploitation of northern resources expands, local and regional issues will become increasingly important to the air quality in the North. MSC's monitoring and air quality modelling activities will be vital to ensuring that increased development in the North does not negatively affect the well-being of Northerners and vulnerable arctic ecosystems.



Current and future northern oil, gas and mining developments.

THE OCEAN-ATMOSPHERE-SEA ICE-SNOWPACK STUDY (OASIS)

OASIS is new international multi-disciplinary initiative to study Ocean-Atmosphere-Sea Ice-Snowpack interactions in Polar Regions. The mission of OASIS will be to determine the importance of ocean-atmosphere-sea ice-snowpack chemical, physical and biological exchange processes on tropospheric chemistry, the cryosphere, and the marine environment, and their feedback mechanisms in the context of a changing climate.

OASIS plans to address how these processes affect atmospheric chemical composition, and control the input of toxic chemicals to polar environments. The nature and extent of snow and ice cover is changing in the Arctic. OASIS will assess the feedback mechanisms of this in the context of climate change. On the one hand, it is likely to be due to a change in the climate, but at the same time, it will also have an impact on the climate. Furthermore, OASIS will address the human and ecosystem impact of air-surface exchange of chemical species. OASIS is endorsed by many international programs including IGAC (International Global Atmospheric Chemistry) Program, AICI (Air Ice Chemical Interactions) activity, and by SOLAS (Surface Ocean Lower Atmosphere Study). An important part of OASIS is expected to take place during the upcoming International Polar Year activities 2007/09. MSC's Atmospheric and Climate Science Directorate is the lead for the OASIS initiative.

CANADIAN SYSTEMATIC MEASUREMENTS OF STRATOSPHERIC OZONE AND UV

The ozone layer is vital to human health and safety because it screens out harmful ultraviolet (UV) radiation. Increased UV at the earth's surface, due to ozone depletion, can be highly damaging to sensitive arctic life forms and to people living in the Circumpolar Regions.

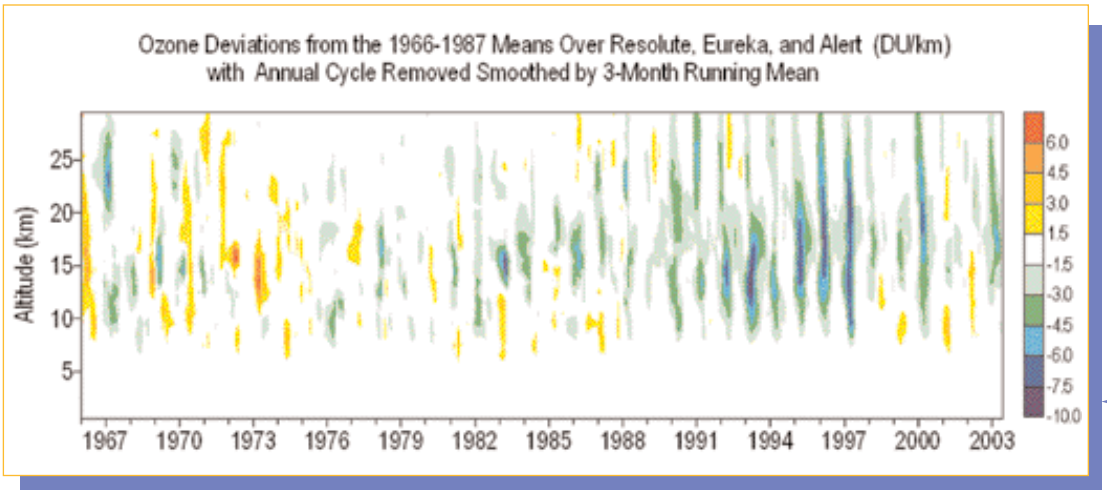
In the winter months over the Polar Regions, the stratospheric winds isolate the polar air mass and result in very cold temperatures, and the formation of polar stratospheric clouds. These clouds support chemical reactions that deplete the ozone layer. Scientific studies suggest that further cooling of the stratosphere due to climate change will increase the formation of these clouds and potentially accelerate the depletion of the ozone layer. The MSC has a network of 12 ozone and UV Brewer monitoring stations across Canada. MSC scientists developed the Brewer instrument, and it has since become the international standard for ground-based measurements. There are currently over 160 Brewers used in 40 countries worldwide. Brewer stations are located in Canada's North at Churchill in Manitoba, Goose Bay in Labrador, and at Alert, Eureka and Resolute Bay in Nunavut. The stations conduct long-term monitoring of stratospheric ozone and UV.

The MSC also operates the Ozonesonde Network with observation stations in Canada's North. Ozonesondes are released into the atmosphere at each network site, and transmit measurements of pressure, wind speed, temperature and humidity as the instruments rise through the ozone layer. As part of its international commitments, MSC has participated in the Match Ozonesonde Program since 1991. This program coordinates the launch of ozonesondes in Europe and Canada to probe common air masses, at different points, as they travel around the Arctic vortex. In 2005, MSC will collaborate with European meteorological services during the next Match campaign.

The Eureka Stratospheric Ozone Laboratory, located on Ellesmere Island in the High Arctic, was the site of a measurement campaign in February and March 2004. It was a collaborative effort between scientists from the

MSC, University of Toronto and the University of Waterloo. The project was funded by the Canadian Space Agency. The objective of the campaign was to validate satellite measurements from the ACE/Scisat-1. This Canadian satellite, launched in August 2003, is equipped with MSC instrumentation to gather data that will increase our understanding of ozone depletion - especially over arctic regions.

Brewer and the Ozonesonde Network data are archived at the World Ozone and UV Data Centre in Downsview, Ontario, and are made available to scientists internationally. These data are essential to MSC and the international science community to help them monitor current and future states of the ozone layer.



Long-term vertical ozone distributions over the Canadian Arctic from 1966-2000 with the annual average for 1966 – 1997 subtracted from the data to show concentration deviations from normal. The green and blue indicate lower than normal ozone concentrations, and are evident in the recent years (1993, 1995, 1996, 1997, 2000 and 2003). (Data are in Dobson units (DU) per km.)

Climate and Climate Change

GLOBAL CLIMATE OBSERVING SYSTEM (GCOS)

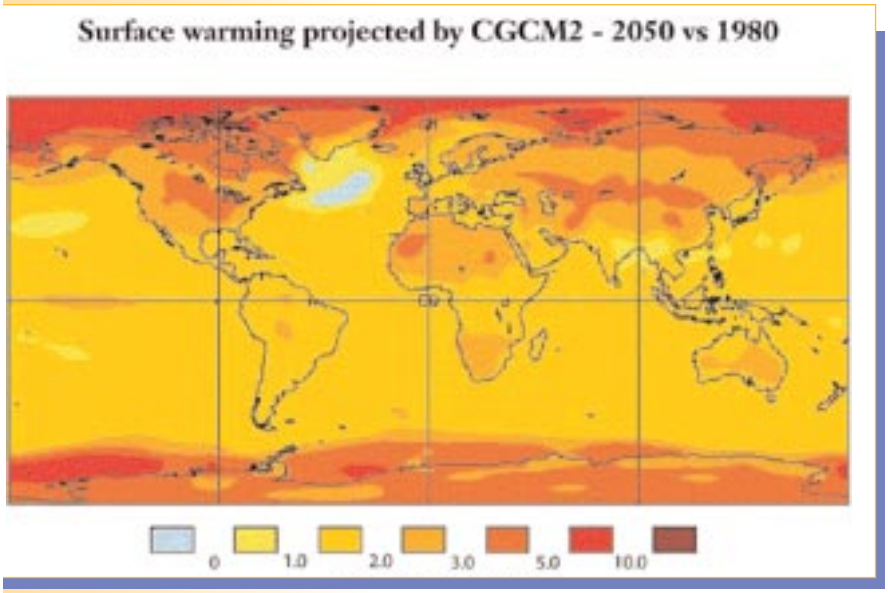
The Arctic is particularly sensitive to climate change impacts. It will become increasingly important to develop adaptation strategies for northerners as their traditional lifestyles are challenged. This will require an increased capacity to predict climate variability and climate change. Long-term and comprehensive global observations of the Earth's climate will lead to improvements in these areas.

With significant financial funding from the Climate Change Action Fund, the MSC has taken the national lead for this program and has made an international commitment to the World Meteorological Organization (WMO) to provide long-term climate data across Canada. MSC collects climate data from the Global Climate Observing System Surface Network (see GCOS story on page 21). The MSC is committed to the sustainability and longevity of these sites. These stations represent long-term, high quality, complete, homogeneous data across all the major climate regions of Canada.

The MSC integrates observations from this network into models of the climate system. Model outputs will provide scientists with improved insight into the patterns of climate change and will be vital in helping Northern communities adapt to changing environmental conditions.

CANADIAN CENTRE FOR CLIMATE MODELLING AND ANALYSIS (CCCma)

The Canadian Centre for Climate Modelling and Analysis (CCCma) develops and applies global climate models to improve understanding of past climate change and to make projections of future climate change, inclusive of Canada's northern region. The MSC widely distributes model results within Canada and internationally for impact and adaptation studies.

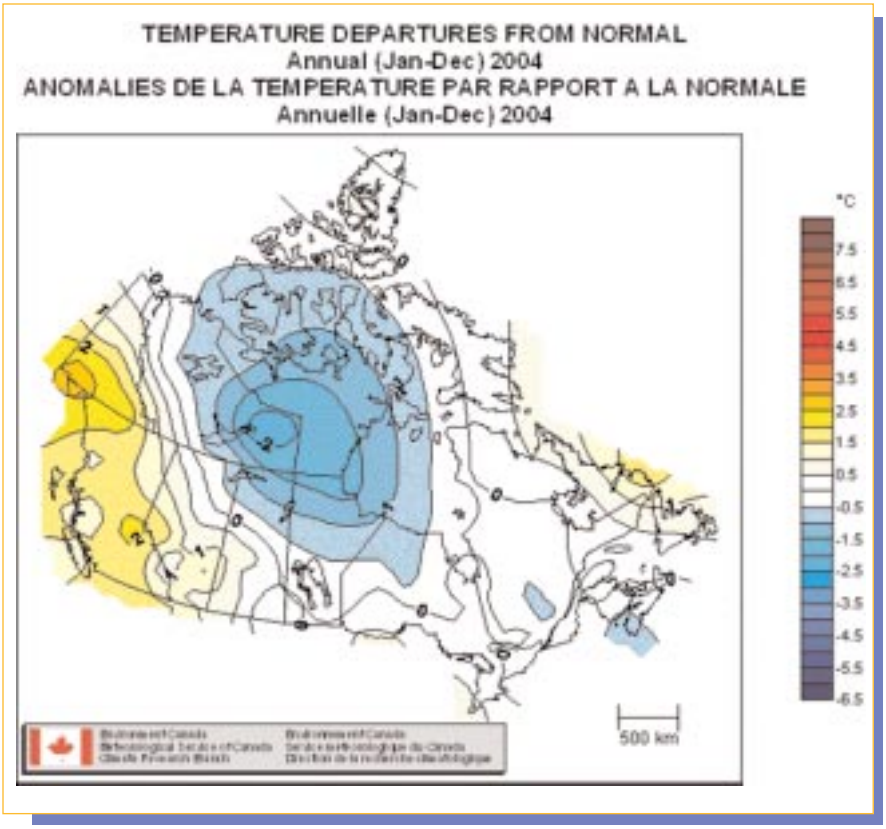


The CCCma is also involved in areas of sea-ice process research with the aim of representing sea-ice processes in global and regional climate models, and in operational sea-ice forecast models. Results of this work contributed to the Intergovernmental Panel on Climate Change's (IPCC) Third Assessment Report, and the 2004 Arctic Climate Impact Assessment (ACIA).

Surface warming projected by CGCM2 for 2050 vs. 1980.

THE CANADIAN CLIMATE

With increased global attention to the climate change issue, Canada has an international responsibility to document climate trends and variations in all regions of the country. Through the internet-based Canadian Climate Trends and Variations Bulletin (**http://www.msc-smc.ec.gc.ca/ccrm/bulletin**), Canadians can educate themselves on the current state of the Canadian climate. On this website, the Arctic is sub-divided into four regions, and information on the trends and variability in temperature and precipitation is given for each region.



Current and future variability in the climate system are better understood in the context of historical changes in climate. The MSC has been involved in research that extends the world's climate record back 1000 to 2000 years. This work was conducted in collaboration with a number of paleo-data researchers. For example, pre-instrumental climate information was derived using temperature data from 140 boreholes in Canada. This has made it possible for researchers to reconstruct critical climate periods for the past several centuries, demonstrating cooling events in the 18th and 19th centuries, and warming events in the 16th, 17th and 20th centuries.

Annual precipitation extremes and current season ranking, 1948 - 2004 (57 Years)

	Extreme years				Annual 2004	
Region	Driest	Dep. %	Wettest	Dep. %	Rank*	Dep. %
Atlantic Canada	2001	-19.8	1990	19.2	51	-9.0
Great Lakes/St. Lawrence Lowlands	1963	-16.0	1990	19.1	24	4.0
Northeastern Forest	1997	-11.0	1979	13.2	6	7.3
Northwestern Forest	1998	-23.1	1973	16.5	23	-0.9
Prairies	2001	-32.4	1951	26.8	21	3.2
South British Columbia Mountains	2001	-24.7	1996	32.2	20	3.7
Pacific Coast	1985	-24.6	1980	17.4	53	-17.3
North British Columbia Mountains/Yukon	1998	-35.8	1974	22.7	48	-9.2
Mackenzie District	**2004**	**-28.3**	1974	27.6	57	-28.3
Arctic Tundra	1954	-19.8	1996	25.8	32	4.2
Arctic Mountains and Fiords	1948	-46.4	1953	44.2	14	15.4
Canada	1956	-7.3	1996	9.1	33	0.4

The rank for the most recent value in the series (the 2004 Annual value for each region in this case) is calculated on series data arranged in descending order, from wettest to driest values. Note: the 2004 data are preliminary.

2004 was the driest year on record for the Mackenzie District, 28.3% below normal, 4.1% drier than 1995, the 2nd driest year.

PERMAFROST

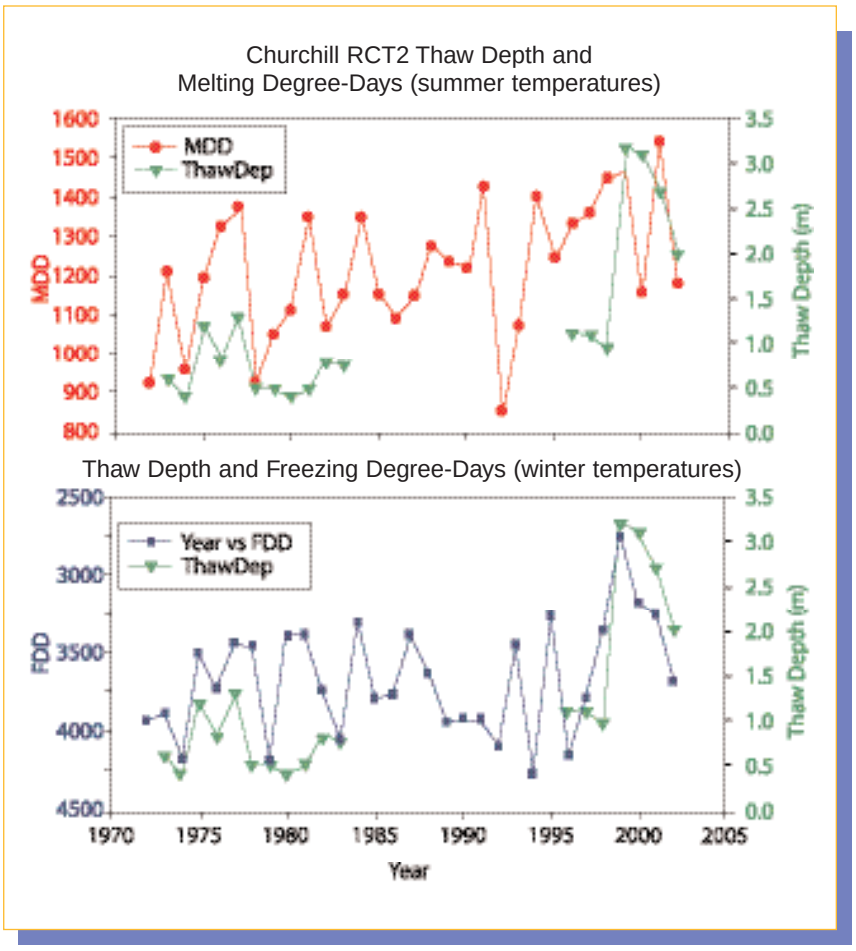
MSC established a series of climate-permafrost weather stations from the mid-1980s to the early 1990s as part of investigations of permafrost response to climate change. This work is collaborative with the permafrost experts in the Geological Survey of Canada (GSC), a component of Natural Resources Canada. Experts examine the relationship between ground temperature and the atmosphere.

Construction issues are the main concern for Canadians in regards to permafrost. Thawing of frozen ground means that ice in the ground will not support roads, pipelines or other structures, leading to damage. Prediction of the fate of permafrost or designing structures to slow its degradation can improve our ability to respond to climate change. A secondary component of climate/permafrost science is using permafrost changes as an indicator of climate change. This project focuses on the southern margin of the permafrost zone, and looks at changes in the state of permafrost with interannual and long-term climate variations.

Ground ice permafrost.

The charts below of winter and summer thaw depth for the Churchill area show permafrost response to climate variability. A large change in thaw depths occurred in the Churchill area in 1999. For previous years, the summer and winter thaw depths were less than 0.8m for most years, and then suddenly increased to over 3m in 1999. The melting and freezing degree-days data shows that this large increase in thaw depth was triggered by preceding mild summers and a change to milder winters.

This network will continue to monitor permafrost changes as an indicator of climate change and to support built infrastructure in Canada's North to ensure the socioeconomic well-being of northerners.



Winter and summer thaw depth measurements for Churchill, Manitoba form 1970 - 2003.

MACKENZIE GEWEX STUDY (MAGS)

Canada's freshwater resources are amongst the largest in the world. The Mackenzie River is the largest North American source of freshwater entering the Arctic Ocean, and has an important influence on global ocean circulation and long-term climate.

The Mackenzie Basin extends from the mountainous cordillera to the Canadian Shield, and from grasslands to tundra. A strong warming trend is occurring in this area. In addition, MAGS research has shown that extreme winter warming events occurred over the Mackenzie Basin more frequently in recent years than ever. Changing climate can alter the nature of our water resources in this region. Since northern rivers and lakes are major transportation arteries, changes in water levels can also have dramatic impacts on the socioeconomic activities in the basin.

When the WMO World Climate Research Program initiated the Global Energy and Water Cycle Experiment (GEWEX) in 1988, Canada's contribution was to study a northern watershed in order to expand knowledge

of cold climate regions. The Canadian research community of over thirty government and university research groups coalesced to measure and model the atmospheric and hydrologic cycles of the Mackenzie Basin. This collaborative effort, called the Mackenzie GEWEX Study, or MAGS, has documented the energy and water cycles of the basin for the first time.

The overall goals of MAGS are to understand and model the high-latitude water and energy cycles that play roles in the climate system, and to improve our ability to assess the climate related changes to Canada's water resources. MAGS is a long-term (1996-2005), multi-phased study with both monitoring and modelling components. MSC's Atmospheric and Climate Science Directorate and Prairie and Northern Region have made significant contributions to the study. Research results include the following:

- MSC's Climate Research Branch, along with scientists at the NWRI and the University of Waterloo have developed a fully coupled atmosphere/land-surface/hydrologic model for water resource and other research applications in northern and temperate environments.

- MAGS research has significantly improved our knowledge of important but previously poorly understood northern climate processes such as evaporation from surface snow and northern lakes. Scientists from both Canadian and international weather centres currently use this new knowledge, along with the field data collected in MAGS, to improve climate and weather prediction models.

- MSC's Prairie and Northern Region scientists are studying the energy budgets and heat regimes of several subarctic Canadian Shield lakes, including lakes of many different sizes - from small ponds to Great Slave Lake.

- McMaster University and the Northwest Territories Power Corporation have formed a partnership and in conjunction with MAGS are carrying out field studies on processes of runoff generation in the subarctic Canadian Shield. Scientists will incorporate the results of these studies into hydrological models, which will improve short and long-term streamflow forecasting on many Canadian Shield Rivers. This is important for hydropower generation and water supply.

- A team of scientists from MSC's Prairie and Northern Region, the Canadian Forest Service, and McGill University is focusing on the role that thunderstorms

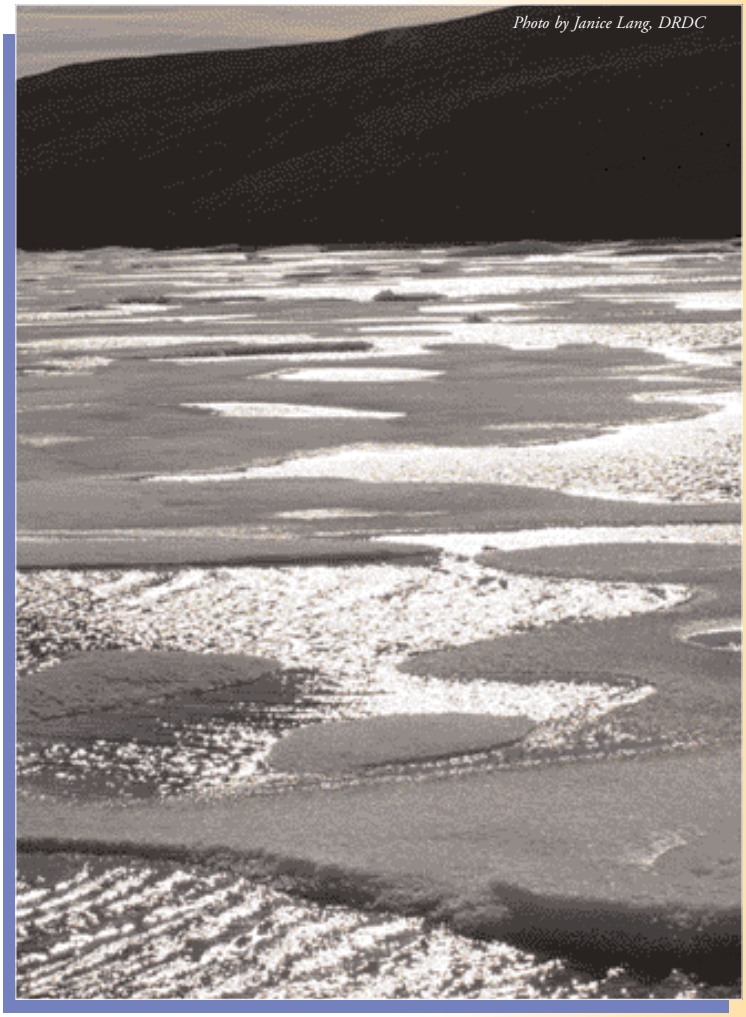


Photo by Janice Lang, DRDC

play in the cycling of water and energy over the boreal ecosystem of the Mackenzie Basin. Thunderstorms are common during the summer months, and the associated lightning triggers the majority of forest fires. Findings from this study, used in combination with projected climate scenarios, will be helpful in estimating future fire activity in the region.

There is no doubt that MAGS will be a key contributor to climate impacts knowledge for many years to come. In the remaining years, MAGS scientists will interact with stakeholders to apply the learned knowledge and developed tools to address water resources and other climate-related issues in Northern Canada. The research methods and tools developed by MAGS apply to other watersheds in both Canada and other northern countries.

Field scientists work at the Snare River Meteorological Site during the MAGs Study.

IMPACTS AND ADAPTATION

Mackenzie Basin Impacts Study

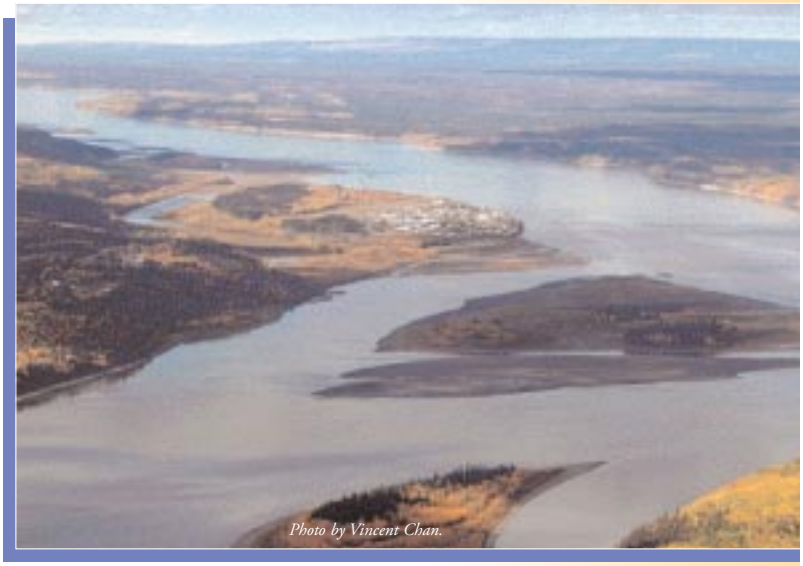
In addition to living in a harsh and isolated environment, Northerners must also face high vulnerability to chemical contamination and the effects of temperature and precipitation extremes associated with climate change. Impact and adaptation research is therefore essential to the health and safety of Canada's northern communities.

The MSC participated in the Mackenzie Basin Impacts Study (MBIS), which was a six-year collaborative research effort that began in 1990 and culminated with the publication of the Mackenzie Basin Impact Study in 1997. The purpose of the study was to look at the impacts of climate change on the lands, waters and communities in Canada's North. The Mackenzie Basin was selected because it is an area that is expected to experience some of the largest climate change related impacts in the world, and because the lifestyles of the residents are closely linked to the natural resources and the land. The people of this area have already seen a significant rise in temperature over the past 50 years.

The MBIS was unique in that it brought scientists from many disciplines together with stakeholders ranging from industry to aboriginal organizations to participate in a comprehensive review of research. Participants focused on the significance of the various research findings to the people and the communities of Northern Canada. As the project unfolded, the level of participation increased, as did the mutual understanding between scientists, the decision-makers and the public. Study results indicate that the most likely impacts of climate change on the lands, waters and communities in Canada's North will be:

- Lower minimum lake levels
- Increased erosion from thawing permafrost including more landslides
- Increased risks to forests from pests and fires
- Risks to aboriginal lifestyles
- Mixed impacts on access to wildlife
- Potential benefits to agriculture from a longer growing period if irrigation services are expanded

An integrated assessment of climate change impacts and adaptation requires a long-term partnership between scientists and stakeholders at all stages of the research process. The results of the study raised awareness of climate change among policy and decision-makers around the world.



Picturesque Fort Simpson in the Mackenzie Basin.

Cryosphere

TRACKING SNOW AND ICE

The cryosphere is defined as the portion of the climate system consisting of the world's ice masses and snow deposits, including ice sheets, ice caps and glaciers, sea ice, snow cover, lake and river ice, and seasonally frozen ground and permafrost.

The cryosphere is among the most important features of the physical and biological environment in Canada with most of the country experiencing several months of snow cover each winter, more than half covered by the permafrost zone, and many of our navigable waters affected by ice. Furthermore, our terrestrial ice masses constitute the most extensive permanent ice cover in the Northern Hemisphere outside of Greenland. In the western cordillera, glaciers are a significant component of the mountain hydrological system.

Monitoring and understanding the cryosphere is required to address key science questions such as the contribution of glacier and ice sheet melt to sea level rise, and for improved representation of cryospheric processes and feedbacks in climate and hydrological models. There are also ongoing domestic requirements for monitoring the cryosphere in Canada for operational decision-making, and for understanding its response to warming and the impacts that it will

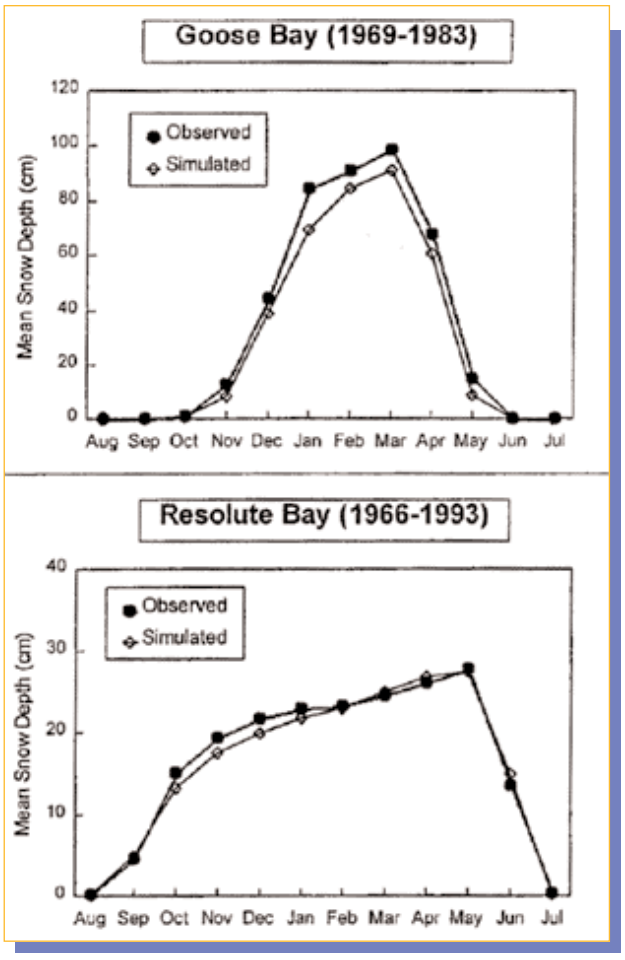
have on our ecosystems and economy. The latter is particularly important since a wide range of Canadian activities are sensitive to changes in cryospheric elements (e.g. agriculture, transportation, construction, mining, offshore are oil exploration, recreation).

Field measurements of snow cover.

The MSC plays a significant role in monitoring the Canadian cryosphere through surface and satellite observations of snow cover, sea and lake ice, and through improved representation of the cryosphere in weather prediction and climate models. In addition, MSC is the lead for the CRYSYS network (see below) which supports R&D in monitoring and understanding variability and change in the Canadian cryosphere.

Satellite Derived Measurements of Canadian Tundra Snow Cover

The depth and extent of snow cover are highly variable and depend on factors such as the frequency and intensity of snowfall events, weather conditions between these events, wind redistribution, surface topography and vegetation cover. Undertaking snow cover measurements using conventional methods is costly and labour intensive because of the extensive and spatially variable nature of snow cover across Canada's North. Accurate estimates of tundra snow cover are necessary to aid operational forecasts of blowing snow events, to quantify winter season water storage, and to investigate climatological trends. This information is especially important with the rapid expansion of mineral exploration activities in the North. Because regular daily snow depth measurements are concentrated in areas below 55° N, scientists are developing remote sensing techniques to improve the spatial representativeness of snow cover measurements at higher latitudes.



Comparison of observed and simulated mean monthly snow depths for 2 sites with different snow climate zones – Goose Bay (taiga –open) and Resolute Bay (tundra) R. Brown

Spaceborne passive microwave sensors have demonstrated an all-weather ability to map **snow water equivalent** over selected types of land cover, although developing retrieval algorithms requires validation by comparing results to actual field measurements.

MSC's Climate Research Branch recently completed a major snow surveying campaign with investigators from Wilfrid Laurier University. A helicopter and snowmobile based campaign took place between April 27 - May 10, 2004, and included snow cover and lake ice measurements at approximately 225 sites in the vicinity of the Tundra Ecosystem Research Station at Daring Lake, located 300 km north of Yellowknife. The data from this campaign will aid scientists in developing and evaluating satellite passive microwave methods for monitoring snow cover over tundra environments.

MSC scientists have planned a follow-up campaign for April 2005, and will include data acquisition from airborne and ground-based microwave radiometers. A number of private and public organizations are collaborating and contributing to this project, including the Canadian Water Network, INAC the Government of the Northwest Territories, Polar Continental Shelf Project, NWT Power, and BHP Billiton.

CRYOSPHERE SYSTEM IN CANADA (CRYSYS)

CRYSYS (CRYosphere SYStem in Canada) is a Canadian-led Interdisciplinary Science Investigation in the NASA Earth Observing System (EOS) Program. The main goals of CRYSYS are to develop capabilities for monitoring and understanding regional and larger scale variations in Canada's cryosphere (sea ice, snow cover, freshwater ice, glaciers and ice caps, frozen ground/permafrost), and to improve our understanding of the role of the cryosphere in the climate system.

Through the CRYSYS project, MSC assembles and analyses key historical cryospheric data sets in support of climate monitoring and the validation of climate models. CRYSYS is a collaborative research project, and currently involves over 30 researchers from 14 universities, 6 federal research groups, and the private sector. The MSC has hosted and funded CRYSYS since 1993. The Canadian Space Agency (CSA) became a major funding partner of CRYSYS in 2000 through its Government Related Initiatives Program. The CRYSYS project has developed and strengthened scientific partnerships between government departments, the CSA and universities. It has also allowed Canadian scientists and agencies to maintain a leadership role, expertise and visibility in the development of applications of space-based systems for studying the cryosphere and its response to climate change.

MSC's major research contributions to CRYSYS have been through the Atmospheric and Climate Science Directorate and the Canadian Ice Service. Recent examples of MSC research contributions to CRYSYS in the areas of climate monitoring, applications of space-based systems, and the development of climate data sets are shown on the next page.

CRYSYS researchers drilling an ice core in Chruchill, Manitoba.

Climate monitoring:

- Execution of aircraft/field campaigns in northern regions (e.g. northern boreal forest/tundra transition zones in Manitoba and the Northwest Territories) to verify passive microwave satellite-derived retrievals of snow water equivalent (collaboration with Manitoba Hydro and NWT Power in support of hydroelectric power applications); and
- Operating several climate stations at permafrost monitoring sites in northern Canada (Norman Wells, Churchill, Iqaluit) to evaluate the effects of climate variability on permafrost.

Applications of space-based systems:

- Development of techniques to derive sea ice motion velocities in the Arctic Basin and the flux of sea ice into the North Atlantic from advanced microwave scanning radiometry (AMSR-E imagery);
- Development of improved methods for seasonal sea ice forecasting in Hudson Bay in support of commercial shipping; and
- Documenting the variability in lake ice freeze-up and break-up processes over large lakes in northern Canada using passive microwave satellite data.

Development of climate data sets:

- Merging of satellite-derived and surface-derived information on snow water equivalent over central North America to provide continuous information from 1915;
- Development of a gridded snow dataset over North America for evaluation of MSC's Global Circulation Model (GCM) in collaboration with the Canadian Meteorological Centre; and
- Analysis and correction of inhomgeneities from historical sea ice charts;

CRYSYS is providing timely and consistent information on the cryosphere in Canada to the public and decision-makers through the Canadian Cryospheric Information Network (CCIN **http://www.ccin.ca**), which was established in partnership with the University of Waterloo, and through the "State of the Canadian Cryosphere" (**http://www.socc.ca**) website that is maintained by the CCIN. Additional information on CRYSYS is available at **http://www.crysys.ca**.

THE ARCTIC CLIMATE SYSTEM STUDY (ACSYS)

The Arctic Climate System Study (ACSYS) was a 10-year World Climate Research Program (WCRP) that began on January 1, 1994 to study the role of the Arctic in the global climate system.

While ACSYS officially ended in December 2003, a number of ACSYS initiatives have transitioned into the WCRP's Climate and Cryosphere (CliC) program that started in 2000. ACSYS involved over 241

A northern waterway in Canada.

participants from 20 different countries with MSC scientists playing key roles in research and in the organization of the study.

The goal of ACSYS was to develop and co-ordinate national and international Arctic science activities aimed at the following three main objectives:

- Understanding the interactions between the Arctic Ocean circulation, ice cover and the hydrological cycle;
- Initiating long-term climate research and monitoring programs for the Arctic; and
- Providing a scientific basis for an accurate representation of Arctic processes in global climate models.

MSC made substantial leadership contributions to the ACSYS Numerical Experimentation Group, the Data Management and Information Panel, the Science Steering Group, and to the organizing committee for the final ACSYS conference. MSC also provided expertise and leadership to ACSYS science activities such as the Sea Ice Model Intercomparison Project (SIMIP), the PILPS 2e Arctic Model Intercomparison Project and to animation software to help understand sea ice dynamics and ice transport in Polar Regions. MSC also contributes extensively to the International Arctic Buoy Program (IABP). MSC's involvement in SIMIP is continuing under the CliC Project. For additional information, visit the ACSYS website at **http://acsys.npolar.no**.

CLIMATE AND CRYOSPHERE PROJECT (CLIC)

The World Climate Research Program (WCRP) established the Climate and Cryosphere (CliC) project in March 2000. CliC is a 15-year program that builds on the initiatives of ACSYS (ended in 2003) but covers a much broader scope.

CliC research addresses the entire cryosphere (i.e., snow cover, sea-, lake- and river- ice, glaciers, ice sheets, ice caps and ice shelves, and frozen ground including permafrost) and its relation to climate. The principal goal of CliC is to assess and quantify the impacts of climatic variability and change on components of the cryosphere, and to determine the stability of the global cryosphere.

Over the last two decades, Canadians have seen dramatic changes in snow, ice and permafrost conditions in Canada. There is less snow on the ground, snow and ice are melting earlier in the spring, arctic sea ice extent has decreased significantly, mountain glaciers are experiencing rapid retreat, extensive areas of permafrost are melting, and major ice features are disintegrating. These changes not only have significant impacts for Canada (e.g. threats to water quantity and quality); they influence the global climate system through linkages and feedbacks such as enhanced freshwater export to the Arctic Ocean.

Photo by Janice Lang, DRDC

CliC is mobilizing the Canadian research community to take an integrated, multidisciplinary approach to cryospheric science in Canada. This approach is critical to understanding and modelling what is happening in regions such as Hudson Bay, where the climate is influenced by complex interactions between fresh water runoff, ocean circulation and atmospheric circulation. An ad hoc CliC Canada committee was formed in 2003 to promote CliC in Canada, and to develop a national plan for the study. MSC provides secretariat support for the committee and organized the first CliC Canada workshop in December 2003.

MSC is also playing an important leadership role in the international CliC program by providing the Chair of the Science Steering Group as well as project leadership for Phase II of the Sea Ice Model Intercomparison Project and Phase II of the Snow Model Intercomparison Project. MSC scientists will also be contributing to CliC through:

- Validation of satellite-derived estimates of snow water equivalent over tundra
- Estimates of the export of ice and fresh water through the Canadian Arctic Archipelago
- Snow data sets for climate monitoring and model evaluation
- Sea ice data sets for climate monitoring and model evaluation
- Observation and modelling of cold surface processes and carbon fluxes in the boreal forest at the MSC-supported BERMS (Boreal Ecosystem Research and Monitoring Sites) super-site.

Canadian Archipelago Through-Flow Study (CATS)

The Canadian Archipelago Through-flow Study (CATS) is a five-year international study bringing together Canadian and American scientists to study the first-ever simultaneous tracking of sea ice and freshwater out of the Arctic Ocean through Canadian Arctic Islands and into the North Atlantic. The outflow of freshwater from the Arctic Ocean constitutes a key process that influences the circulation of the global ocean system, and thus global climate.

This study will combine moored ocean instruments, remote sensing satellite data, chemical analyses, and atmospheric modelling to determine the amount and origin of this freshwater. Much of the instrumentation for the study was installed during the 2003 expedition to Nares Strait (between northern Ellesmere Island and Greenland) aboard the US Coast Guard Healy.

MSC scientists are developing a method to use satellite microwave data to estimate the transport of sea ice. Satellites give a more accurate spatial

Water sampling being carried out by the Canadian Coast Guard and crew aboard the Zodiac2 – courtesy of the Canadian Coast Guard.

representation of how the sea ice moves through the main channels of the Arctic Islands than can be derived from in-situ ocean moorings. Once fully developed, this approach will provide the most reliable estimates of sea ice moving from the Arctic Ocean into the North Atlantic.

The US National Science Foundation (NSF) and the Canadian Government, through MSC and the Department of Fisheries and Oceans, are funding this study. The information gained from the study will contribute to the Canadian and US Global Climate Change Programs and the Climate and Cryosphere Program (CliC).

THE CANADIAN ARCTIC SHELF EXCHANGE STUDY (CASES)

The Canadian Arctic Shelf Exchange Study (CASES) Network brings together over 70 leading experts in polar science from 10 Canadian universities, four Federal Departments (Fisheries & Oceans, Environment Canada, Natural Resources Canada, Department of National Defence), and nine foreign countries (USA, Japan, UK, Denmark, Russia, Poland, Norway, Belgium, Spain).

A Canadian Coast Guard Helicopter and ice breaker during a CASES sampling exercise of the Mackenzie Shelf ecosystem in the Beaufort Sea.

The main objective of the study is year-round sampling of the Mackenzie Shelf ecosystem in the Beaufort Sea. The study has two phases that included a preliminary 5-week expedition in August to September 2002 for the mooring of instruments at key locations, followed by the over-wintering of an icebreaker on the Mackenzie Shelf from September 2003 to August 2004. The Canadian Coast Guard provided the administrative, logistic and navigational expertise to operate the research icebreakers for the duration of the project.

To assist in the preparation of the initial proposal for the study, MSC's Canadian Ice Service (CIS) provided the CASES project with climatological ice information for the proposed study area. The CIS also provided the team with crucial information on the feasibility of a vessel freezing in the study area, and whether ice conditions would permit over winter transects throughout the flaw polynya (a non-linear shaped opening enclosed by ice and limited on one side by fast ice). The CIS also played a critical role in determining the optimal location for deployment of the icebreaker, and provided information to the team on the spring break-up of ice.

When the Amundsen departed Quebec City on September 13, 2003, a CIS ice specialist was onboard providing operational ice information support to the vessel using Radarsat imagery and ice charts - produced daily by the CIS. The ice specialist remained aboard until Nov 2, 2003 when the ship froze in. Throughout the winter, monthly ice charts were sent to the ship to monitor the solidifying pack ice.

MSC's CIS also participated in the CASES Sea Ice sub-group. The science group focused on validating microwave signatures of sea ice in the CASES study area. Together with the University of Calgary and University of Manitoba, a CIS technical specialist assisted CASES scientists in developing, testing and deploying two state-of-the-art surface scatterometers. These instruments served to improve mapping of sea ice with RADARSAT-2 data. The CIS technical specialist worked aboard the icebreaker.

In conjunction with CASES, MSC's Prairie and Northern Region Science Division provided researchers with a variety of climate data for the field study area and contributed to the upper air program by donating radiosondes and balloons to the experiment. The Science Division also provided specialized satellite imagery for the field site and worked co-operatively with the University of Alberta during a six-week field experiment.

The Natural Sciences and Engineering Research Council of Canada (NSERC) and the Canada Foundation for Innovation (CFI) largely fund the CASES study. Scientists participating in the study are interested in all aspects of the Mackenzie Shelf ecosystem - from carbon dioxide in the atmosphere to polar bears. In particular, CASES focuses on the impacts of climate warming on the biological and physical processes of the Mackenzie Shelf system.

ARCTICNET

ArcticNet is a project of the Canada Network of Centres of Excellence (NCE). Cooperative partners will conduct integrated regional impact studies in coastal marine regions of the Canadian Arctic from 2003 to 2008. ArcticNet will contribute to the knowledge required to formulate policies and adaptation strategies for arctic coastal communities. The Network is centred around a newly retrofitted research icebreaker, the Amundsen, which provides a unique platform for carrying out multi-disciplinary research in the Canadian Arctic. ArcticNet researchers are collaborating with research teams in the USA, Japan, Denmark, Sweden, Norway, Poland, the United Kingdom, Spain, Russia, Greenland and France.

MSC provides leadership to the ArcticNet project by having a presence on the Board of Directors. The Network has more than 20 current projects, organized into the following four research themes:

- Climate change impacts in the Canadian High Arctic: A comparative study along the East-West gradient in physical and societal conditions.
- Food, water and resources in the shifting North-South thermal gradient of the terrestrial Eastern Canadian Arctic.
- Managing the largest Canadian watershed in a new climate: Land-ocean interactions in Sub-Arctic Hudson Bay.
- Adapting to change in the Canadian Arctic: Knowledge transfer, policies & strategies. MSC's Canadian Ice Service also supports this study by providing operational ice information support to the Amundsen vessel; including an onboard CIS ice specialist and daily ice information (satellite imagery and ice charts).

Meteorology & Hydrology

MSC'S NATIONAL HYDROMETEOROLOGY AND ARCTIC LAB

The Meteorological Service of Canada is in the process of establishing the Hydrometeorology and Arctic Lab (HAL) in Edmonton, collocated with MSC's Prairie and Arctic Storm Prediction Centre. This national lab will focus on applied science dealing with hydrometeorological events and high-impact arctic weather, and transferring this applied research into operations. This lab will address these types of high-impact weather events throughout the country. The co-location of the HAL with operations in the storm prediction centre will provide science and operations staff with opportunities to discuss and seek advice on operational science issues.

Hydrometeorology Lab

Recognizing and collaborating with the hydrological expertise within the National Water Research Institute (NWRI) in Saskatoon, the Water Survey of Canada and meteorological expertise within MSC, the HAL will address the following two themes:

1. Meteorological applications in support of hydrology
   - Radar-quantitative precipitation estimation (QPE) validation
   - Precipitation studies
   - Coupled modelling
   - Significant precipitation studies

2. Client feedback to NWRI (Saskatoon), and other MSC national labs
   - Hydrological applications to address water resource management issues
   - Operationalizing research developed at NWRI (Saskatoon), universities, etc.
   - Hydrologic modelling

Arctic Lab

The Arctic lab will focus on improved understanding and prediction of high-impact weather that affects people in Canada's northern latitudes. Some research themes identified by the client community include:

- Blizzard and blowing snow studies
- Wind forecasting
- Remote sensing
- Mesoscale modelling

An example of a new, regional mesoscale modelling initiative at HAL is described on the next page.

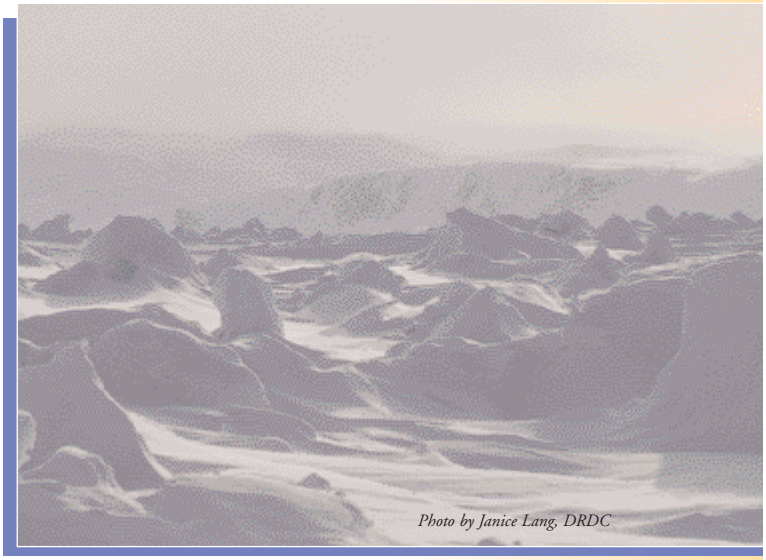


Photo by Janice Lang, DRDC

MESOSCALE MODELLING OF ATMOSPHERIC PHENOMENA IN THE ARCTIC

For many Arctic communities, proper forecasting of the wind is crucial for predicting many other weather elements. For example, temperature and fog formation are both very sensitive to wind direction in coastal communities, and blowing snow and blizzards depend critically on wind speed. In the North, many communities are located in regions of complex topography with nearby mountains and deep fjords. Due to sparse observations in the North, (sites in the Arctic are 100s of km apart) the affect of topography on the surface wind is often unknown. As well, many stations exhibit wind behaviour that is poorly understood or predicted by operational models. For example, at Resolute Bay in Nunavut, winds may vary between light northerlies to moderate or strong northeasterlies in a matter of minutes.

High-resolution mesoscale models can provide the forecaster with a representative view of the wind flow at the surface and aloft for a small area. These models allow the forecaster to visualize the flow patterns in regions with complex topography. Running these high-resolution models, however, requires many, many hours of CPU intensive processing, making them impractical and too costly to use on an operational basis. When used in case studies, these models can provide valuable information to the forecaster.

Researchers in MSC's Hydrometeorology and Arctic Lab (HAL), in conjunction with researches at RPN, have planned case studies over various Arctic communities to study a variety of weather patterns. Scientists will use a high-resolution version of the GEM (Global Environment Multiscale numerical weather prediction model) with a grid-resolution of 2.5 km. Results from the model will form the basis of training notes that will graphically show the flow patterns induced at the surface from prevailing weather patterns and surface features. Forecasters will be able to use this conceptual knowledge to recognize, and better forecast winds on an operational basis to provide more accurate weather warnings to protect residents in the North. The use of satellite data in the North has also lead to improved weather forecasts. Meteorologists use satellite data to track high amplitude weather systems that impact the North. The integration of model output, satellite, and in-situ data enables forecasters to understand storm behavior more fully.

Photo by Janice Lang, DRDC

Studying Impacts of Meteorological Hazards on Local Communities

Researchers in MSC's Hydrometeorological and Arctic Lab will collaborate with McGill University and other MSC Branches (the Meteorological Research Branch and the Canadian Ice Service) on an upcoming ArcticNet project. The project aims to increase prediction capabilities for meteorological and related hazards in the Arctic. The study will assess the impacts of these meteorological hazards on local communities, and predict how the occurrence of these hazardous events will change with climate.

To make progress on these critical issues, the proposed project will focus on extreme weather events in Nunavut. Permanent settlements in the Canadian Arctic are mainly located on coastal areas, which, for the most part, have steep cliffs, hills, and mountains. The goal of this project is to determine the general nature of winter storms in Nunavut and the way in which they are affected by local topography and land-sea transitions. This study will focus on the communities of Iqaluit on Baffin Island and Baker Lake.

MSC's Prairie and Northern Region has submitted a number of research proposals for the upcoming International Polar Year that include a convective and fire occurrence model that will help to expand existing lightning prediction capabilities, and arctic snow density evaluation and monitoring programs.

The small community of Cape Dorset.

High-Impact Weather Forecasts - Thorpex Arctic Field Experiment

The aim of the Hemispheric Observing System Research and Predictability Experiment (THORPEX) is to accelerate improvements in the accuracy of high-impact 1-14 day weather forecasts for those parts of the world influenced by the Polar Regions. Improvements in global forecasting will be a benefit to society and economy worldwide. Thorpex is an initiative of the World Meteorological Organization's Global Atmospheric Research Program.

For the upcoming International Polar Year (IPY), THORPEX will be the meteorological component for the IPY activities. The project will address specific weather phenomena, such as the impact of Arctic perturbations on European weather and the effect of extreme Artic outflows on Asian and North American weather. In addition, THORPEX will contribute to improving the use of satellite and in-situ data from high latitudes through its various data assimilation programs and will participate in regional field campaigns associated with IPY activities.

For MSC, the project lead is the Meteorological Research Branch of the Atmospheric and Climate Science Directorate with collaborators from the Atmospheric Environmental Prediction Directorate, the Atmospheric Monitoring and Water Survey Directorate and Pacific and Yukon Region.

Streamflow Prediction

Streamflow monitoring in northern Canada is sparse relative to its area. Sound methods are needed to accurately extrapolate measured streamflows from gauged basins to ungauged areas. In response to growing and future industrial development, MSC scientists in the Prairie and Northern Region are currently working on a project to predict streamflow characteristics in ungauged basins in the Mackenzie Valley. This project supports MSC's Water Survey of Canada's ongoing network planning activities, and environmental assessments of current and proposed industrial and transportation developments in the North.

Related Internet Sites

MSC Weather Services and Products

Canada	www.weatheroffice.ec.gc.ca
Nunavut	www.weatheroffice.ec.gc.ca/forecast/canada/index_e.html?id=NU
Northwest Territories	www.weatheroffice.ec.gc.ca/forecast/canada/index_e.html?id=NT
Yukon	www.weatheroffice.ec.gc.ca/forecast/canada/index_e.html?id=YK
Ontario	www.weatheroffice.ec.gc.ca/forecast/canada/index_e.html?id=ON
Quebec	www.meteo.ec.gc.ca/forecast/canada/index_e.html?id=QC
Labrador	www.weatheroffice.ec.gc.ca/forecast/canada/index_e.html?id=NF

Lightning – Canadian Lightning Detection Network
www.weatheroffice.ec.gc.ca/lightning/index_e.html

Marine Monitoring Networks
www.weatheroffice.ec.gc.ca/marine/index_e.html

Sea Ice Information – Canadian Ice Service
www.ice-glaces.ec.gc.ca

Water Survey of Canada
www.climate.weatheroffice.ec.gc.ca/rel_arch/index_e.html

Climate Data and Information Archive
www.climate.weatheroffice.ec.gc.ca/Welcome_e.html

Atmosphere, Climate, Ice and Hydrology Research

Fourth International Polar Year
www.dfait-maeci.gc.ca/circumpolar/int_polar_year-en.asp

▼ Atmospheric Research

Alert 2000 – Polar Sunrise Experiments
www.msc-smc.ec.gc.ca/projects/alert2000/index_e.html

Northern Contaminants Program
www.ainc-inac.gc.ca/ncp/index_e.html

Global Pesticides Release Database (GloPeRD)
www.msc.ec.gc.ca/data/gloperd

▼ Climate and Climate Change

Global Climate Observing System
www.wmo.ch/web/gcos/gcoshome.html

Canadian Centre for Climate Modelling and Analysis
www.cccma.bc.ec.gc.ca

The Canadian Climate Trends and Variations Bulletin
www.msc-smc.ec.gc.ca/ccrm/bulletin

Mackenzie GEWEX Study (MAGS)
www.usask.ca/geography/MAGS

Mackenzie Basin Impacts Study
www.msc-smc.ec.gc.ca/airg/research_projects/mack_basinstudy/sum_results_e.cfm

Canadian Cryospheric Information Network (CCIN)
www.ccin.ca

State of the Canadian Cryosphere
www.socc.ca

CRYSYS - CRYosphere SYStem in Canada
www.msc-smc.ec.gc.ca/crysys

The Arctic Climate System Study (ACSYS)
www.acsys.npolar.no

The Climate and Cryosphere Project (CliC)
www.clic.npolar.no

ArcticNet
www.arcticnet-ulaval.ca

▼ Meteorology & Hydrology

Thorpex
www.wmo.int/thorpex/mission.html

▼ Assessment

Arctic Climate Impacts Assessment
www.acia.uaf.edu

Arctic Ozone
www.msc-smc.ec.gc.ca/education/arcticozone/index_e.cfm

Climate change and ozone depletion: Understanding the Linkages
www.msc-smc.ec.gc.ca/saib/ozone/docs/ozone_depletion/index_e.html

Glossary

ACRONYM	EXPANSION
ACIA	Arctic Climate Impact Assessment
ACSD	Atmospheric and Climate Science Directorate
ACSYS	Arctic Climate Systems Studies
AMAP	Arctic Monitoring and Assessment Programme
AMDAR	Aircraft Meteorological Data Rely Program
AMWSD	Atmospheric Monitoring and Water Survey Directorate
AR	Atlantic Region
ATADs	Automated telephone answering devices
AWOS	Automatic Weather Observing Stations
CAPMoN	Canadian Air and Precipitation Monitoring Network
CASES	Canadian Arctic Shelf Exchange Study
CATS	Canadian Archipelago Through-Flow Study
CCCma	Canadian Centre for Climate Modelling and Analysis
CCG	Canadian Coast Guard
CFI	Canada Foundation for Innovation
CIS	Canadian Ice Service
CLDN	Canadian Lightning Detection Network
CliC	Climate and Cryosphere Project
CMAC	Canadian Meteorological Aviation Centre
CMAQ	Community Multiscale Air Quality modelling system
CMC	Canadian Meteorological Centre
CRYSYS	Cryosphere System in Canada
CSA	Canadian Space Agency
DFO	Department of Fisheries and Oceans
DND	Department of National Defence
EC	Environment Canada
EM&R	Energy, Mines and Resources
GAW	Global Atmospheric Watch Program
GCM	Global Circulation Model – sometimes referred to as Global Climate Model
GCOS	Global Climate Observing System
GEM	Gaseous elemental mercury
GEM	Global Environmental Multi-Scale meteorological model
GEWEX	Global Energy and Water Cycle Experiment
GloPeRD	Global Pesticide Release Database
GNWT	Government of the Northwest Territories

GRAHM	Global and Regional Atmospheric Heavy Metals Model
GSC	Geological Survey of Canada
GSN	Global Surface Network
HAL	Hydrometeorology and Arctic Lab
HAWS	High Arctic Weather Station
IABP	International Arctic Buoy Programme
INAC	Indian and Northern Affairs Canada
IPCC	International Panel on Climate Change
IPY	International Polar Year
LWIS	Limited capability AWOS
MAGS	Mackenzie GEWEX Study
MBIS	Mackenzie Basin Impacts Study
MDEs	Mercury depletion events
MSC	Meteorological Service of Canada
NAV CANADA	Not-for-profit private company delegated by the Canadian government to provide civil aviation services (including weather services) in Canada.
NCE	Network of Centres of Excellence
NCP	Northern Contaminants Program
NSF	National Science Foundation
NWS	National Weather Service
OASIS	International multi-disciplinary initiative to study Ocean-Atmosphere-Sea-ice-Snowpack interactions in Polar Regions
OCP	Organochlorine pesticides
ODAS	Ocean Data Acquisition System
ODS	Ozone depleting substances
OGD	Other Government Departments
OR	Ontario Region
P&Y	Pacific & Yukon Region
PCSP	Polar Continental Shelf
PNR	Prairie and Northern Region
POPs	Persistent organic pollutants
QR	Quebec Region
RHBN	Reference Hydrometric Basin Network
SGPERM	Simplified Gridded Pesticide Emission and Residue Model
SPC	Storm Prediction Centre
SWE	Snow water equivalent
UTC	Universal Time Constant
UV	Ultraviolet
VOS	Voluntary Observing Ships Program
WCRP	World Climate Research Program
WDCGG	WMO World Data Centre for Greenhouse Gases
WMO	World Meteorological Organization
WSD	Water Survey Division