MSC

Atmospheric and Climate Science

Research Making a Difference

Environment Canada / Environnement Canada

Meteorological Service of Canada / Service Météorologique du Canada

Canada

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“Providing Knowledge IN THE Service of Canadians”

Dedication

This report is dedicated to the Meteorological Service of Canada (MSC) research scientists who have committed so much of their lives to expanding the frontiers of science through their visionary thinking and approaches.

We would especially like to acknowledge the late Dr. Neil Bruce Trivett for his lifelong efforts in atmospheric research, and for establishing a world-class Arctic measurement program at Alert, Nunavut. The story on page 3 illustrates the value of the work that Dr. Trivett started in the Arctic, and the value of the many international partnerships that he fostered.

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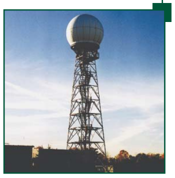


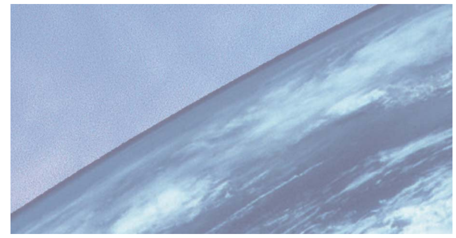
Atmospheric and Climate Science

Atmospheric and climate science within the Meteorological Service of Canada (MSC) focuses on advancing the state of ***knowledge*** for the public good and on developing ***new products and services*** to help Canadians avoid or adapt to severe weather and other atmospheric hazards.

Research and development activities at MSC provide the scientific foundation for weather forecasts, air quality advisories, climate change projections, and flood and ice forecasts. They also provide the scientific underpinning for a wide range of government policy initiatives, such as national air quality standards for air pollutants, the Montreal Protocol on Substances that Deplete the Ozone Layer, and the Kyoto Protocol on climate change.

This report showcases how the new scientific knowledge produced by MSC is being used in support of policies and services to Canadians and the international community.

Because of the excellence of its science, MSC is a significant contributor in many international arenas. Canadian General Circulation Models (GCMs) are among the best in the world and were used extensively in the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) – an international panel of climate experts. Many of MSC's air quality monitoring stations are part of World Meteorological Organization



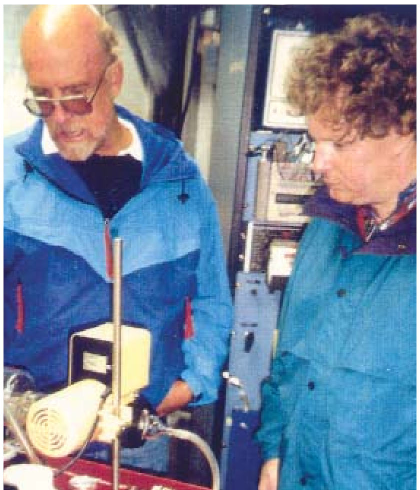
networks, helping the scientific community to maintain a watch over global environmental issues such as greenhouse gases, stratospheric ozone depletion, acid rain, and hazardous air pollutants.

The most visible results of the MSC's atmospheric science are the daily weather forecasts and the storm warnings provided to Canadians. MSC's weather, climate and air quality services have evolved by drawing on uniquely Canadian approaches to solving scientific problems and meeting the public's needs.

Whether it is nationally or internationally, the MSC strives to reflect the latest scientific understanding in all of its products, services and advice. This ensures that Canadian citizens and policy makers are able to understand and act effectively to protect themselves from atmospheric threats and to safeguard the atmosphere.

Collaboration with scientists from government, academia and the private sector, both nationally and internationally, has been an essential element in making the achievements in this report possible.

Watching the World from Canada's High Arctic
The Alert Monitoring & Research Station



Dr. Neil Trivett (on left), who founded the Alert Observatory in 1986, is shown here with former Environment Minister, Jean Charest (on right), briefing him on the various measurement programs at Alert.

At the extreme northern tip of Canada is the Canadian Forces Station, ***Alert*** – where the Meteorological Service of Canada (MSC) has a scientific research station of world-wide importance.

Alert is the northern-most observatory in the World Meteorological Organization's Global Atmosphere Watch Network of stations that have been tracking the chemistry of the atmosphere on a global basis for several decades. Alert's location (far away from industrial pollution sources, with no settlements within hundreds of kilometres) makes it the perfect place from which to monitor long-term changes in the chemistry of the Earth's atmosphere.

At Alert, research scientists continuously measure the trends and variability of the atmospheric chemicals that are key to understanding how human activities are affecting the world's atmosphere. These measurements include greenhouse gases, toxic air pollutants such as mercury, organic pesticides and fine particles, and others such as stratospheric ozone. Changes in these atmospheric constituents over time are indicators of phenomena such as global warming, ozone depletion and the insidious spread of persistent organic pollutants into remote regions.

During polar sunrise, Alert becomes a photochemical laboratory. Since it is located very near the geographic North Pole, Alert sees extended periods of darkness in winter and continuous sunlight in summer. This prolonged day-night cycle makes it a valuable place to carry out photochemistry experiments.

The pollutants, transported over long distances from southern

The ice camp at Alert, Nunavut during the 2000 Polar Sunrise Study focused on mercury processes and snow surface chemistry.

Photo by Janet Lang

latitudes, accumulate in the Arctic atmosphere during winter and then react in the first rays of sunlight in spring.

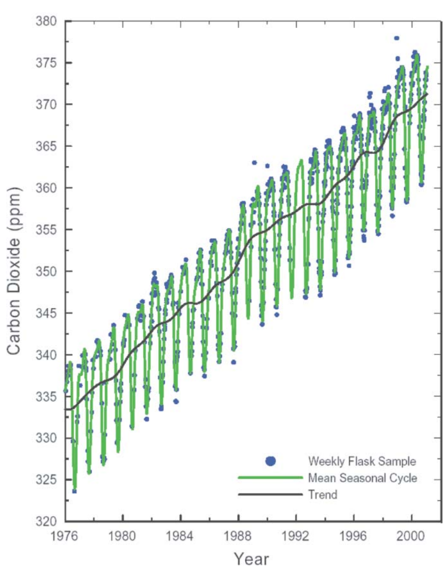
The Polar Sunrise Experiments, designed to study this phenomenon, have attracted researchers from around the world and have resulted in significant scientific discoveries that have changed our understanding of chemical and physical processes in the atmosphere.

At Alert, scientists have discovered that:

- Arctic haze in late winter and spring is due largely to sulphate aerosols arising from the long range transport of sulphur oxides from the former Soviet Union and Eastern Europe.
- Tropospheric (surface level) ozone disappears at polar sunrise because oxides of bromine cause ozone depletion at the Earth's surface.
- Bromine compounds are also linked to mercury deposition from the atmosphere.
- The snow surface is much more chemically reactive than previously assumed, making snow part of the pathway for toxic chemicals such as polychlorinated biphenyls (PCBs) and pesticides to accumulate in Arctic ecosystems.

"Alert is the most northerly station in the Global Atmosphere Watch network of the WMO, and is critical in detecting global change. Monitoring efforts at Alert have anchored numerous international collaborative research studies of stratospheric ozone depletion, Arctic haze and the depletion of elemental mercury and tropospheric ozone at Polar Sunrise."

Leonard A. Barrie
Chief, Environment Div.
World Meteorological Organization, Switzerland

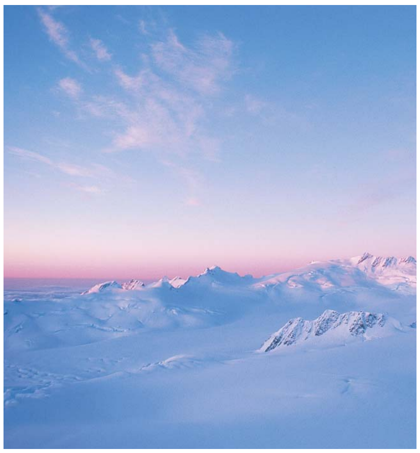


The increasing trend of carbon dioxide concentrations at Alert, Nunavut from 1975 to present (based on weekly flask samples).

Conducting research in the High Arctic is a very expensive endeavour that has its challenges. Nevertheless, Canadian researchers have made valuable discoveries here that have furthered our understanding of atmospheric processes that impact on human and ecosystem health.

Pathways to the Arctic – The Grasshopper Effect

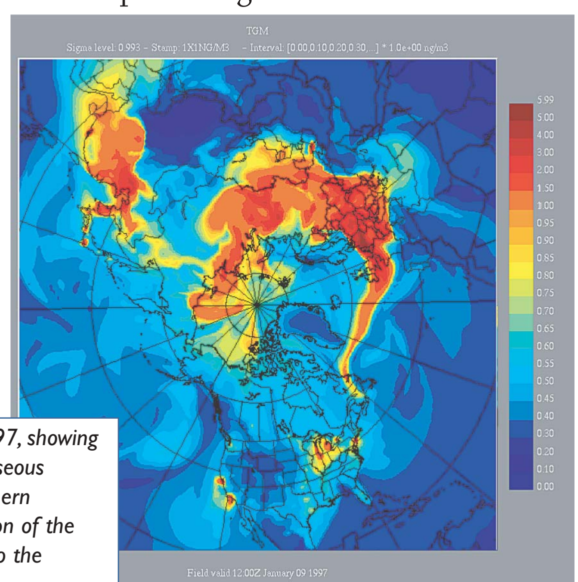
The Atmospheric Heavy Metals (GRAHM) Model



How can pesticides and other pollutants that are used in far off places like India or Africa end up in the Canadian Arctic, and in concentrations high enough to be harmful to plants, animals and people so far away from the source regions? Canadian scientists have been working to solve this puzzle for many years and have made great progress in understanding the overall picture of how toxic substances end up in Arctic ecosystems.

Two major processes are at work here. First, is the atmospheric transport of pollutants from source regions to the Arctic. Although this has been accepted on a theoretical basis, scientists at the Meteorological Service of Canada (MSC) have developed a model to simulate these transport processes. This global numerical model simulates emissions of specific pollutants, such as pesticides and mercury, and shows how they move around the globe, and are influenced by daily variations of weather patterns.

This powerful model, called the ***Global/Regional Atmospheric Heavy Metals model (GRAHM)*** showed that a major pathway for these pollutants on their journey to Canada passes right over the Canadian Arctic. This starts to explain why atmospheric levels of these toxic pollutants in the Arctic are similar to those in southern Canada.



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.

The second process influencing pollutant transport to the Arctic is global distillation due to temperature differences in the atmosphere that cause evaporation and condensation of pollutants. This global distillation process is also known as the ***"grasshopper effect"***.

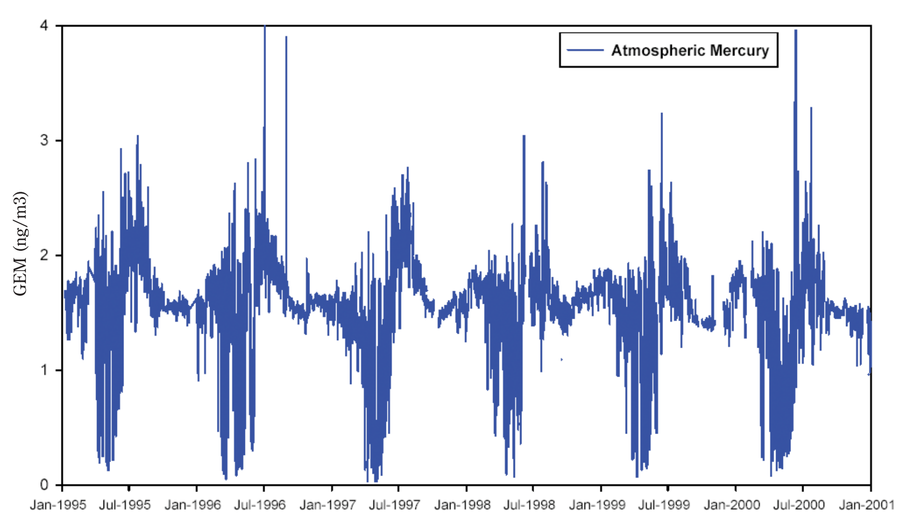
Mercury and many pesticides behave differently at different temperatures. At high temperatures, they evaporate into the atmosphere, but at low temperatures they condense out of the atmosphere and are deposited onto land surfaces, lakes and forests. As temperatures change from day to night and from winter to summer, these pollutants are repeatedly evaporated and condensed. Slowly but surely, the pollutants make their way northward.

Once in the northern ecosystems, these pollutants bio-accumulate in plant and animal tissues where their toxic effects are magnified up through the food chain, reaching harmful levels in both humans and animals.

Scientists now have a better understanding of how pesticides that are meant to improve productivity in one part of the world can have an unintended and adverse consequence on the other side of the globe in the Canadian Arctic.

"The GRAHM model is proving to be a valuable tool in tracking the long range transport of mercury, particularly over the Arctic. The model is contributing to the Arctic Monitoring and Assessment Program (AMAP) Assessment of Heavy Metals, which is underway."

Lars-Otto Reiersen
Executive Secretary
Arctic Monitoring and Assessment Program



Gaseous atmospheric mercury concentrations at Alert, Nunavut (1995-2001). Mercury concentrations tend to be fairly uniform across rural Canada, but fall dramatically at polar sunrise in the high Arctic as shown in this figure.

Understanding the Chemical Processes that Affect the Ozone Layer

Space-based Measurements using Balloons and Satellites

Large-payload balloon flights were conducted as part of the Middle Atmosphere Nitrogen Trend Assessment (MANTRA). The MSC, the Canadian Space Agency, and several universities were jointly involved in this project.

For over 30 years, scientists within the Meteorological Service of Canada (MSC) have been sending probes into the stratosphere to gain an understanding of the chemistry related to the formation and destruction of the ozone layer - a problem that still has not been fully solved. The first experiments, in the 1970's and 1980's, used high-altitude balloons and rockets. Since then, MSC researchers have flown experiments aboard NASA space shuttles and on high-altitude NASA research aircraft.

In 1998, 2000 and 2002, these same scientists teamed up with the Canadian Space Agency, several universities, and industry to launch large-payload balloons to continue studying the stratosphere to determine what changes have taken place over the last 25 years.

MSC's next step in understanding ozone depletion chemistry is the recently launched SCISAT I, Canada's first scientific satellite in over 30 years. MSC scientists, with the help of the Canadian Space

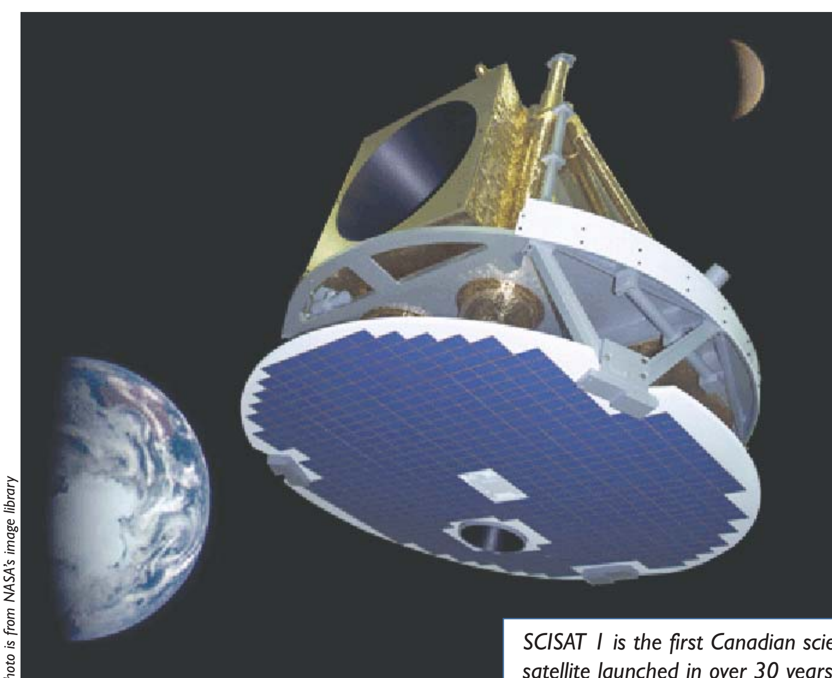


Photo is from NASA's image library

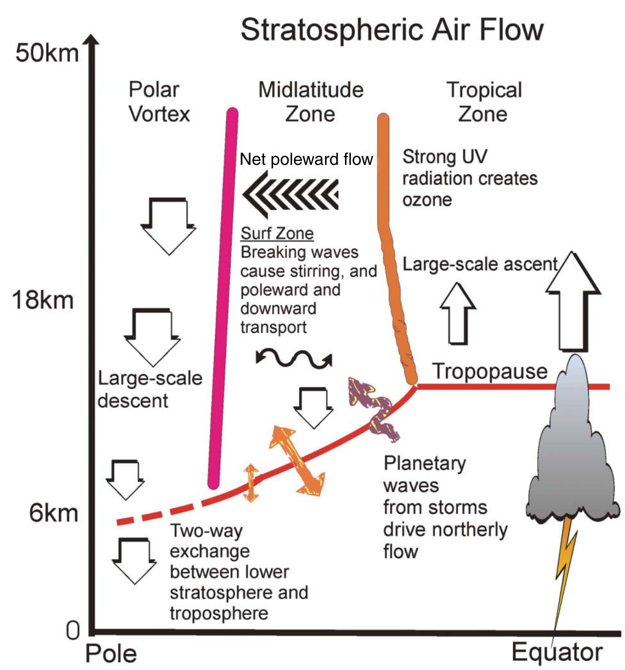
SCISAT I is the first Canadian scientific satellite launched in over 30 years.

Agency, universities and industry, designed one of the two Canadian instruments selected to be part of this historic flight. This instrument, called MAESTRO (Measurements of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation), measures stratospheric and tropospheric ozone, aerosols and other trace species. It will provide important new information on aerosols and chemistry in the stratosphere and upper troposphere by looking through the Earth's atmosphere at the sun as it rises and sets.

The information provided by this experiment will give scientists a greater understanding of why the stratospheric ozone layer is not rebounding as quickly as expected following the implementation of the Montreal Protocol and the Vienna Convention on Substances that Deplete the Ozone Layer. Such space-based science is an important tool in ensuring that Canadian environmental policy is founded on the most up-to-date scientific findings.

"MSC's expertise in making highly accurate and precise spectral measurements has contributed greatly to the development of both ground-based and space-based instruments, providing critical information on the accuracy of ozone measurements around the world."

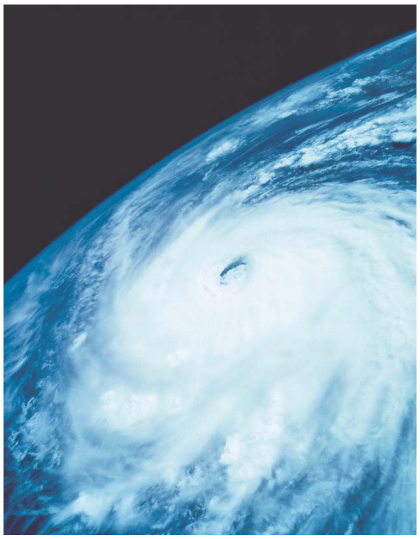
Jim Drummond
Associate Chair,
Graduate Studies
Department of Physics
University of Toronto



The chemistry related to the formation and destruction of the ozone layer is affected by the air flow in the stratosphere. Air enters the stratosphere at the equator. The hot surface generates strong upward currents and thunderstorms. The air then moves northward towards the poles where it subsides.

A Community Approach to Building a Better Meteorological Model

The Meso-scale Compressible Model (MC2):



In 1994, researchers at the Meteorological Service of Canada (MSC) undertook the development of a new type of meteorological model, the ***Meso-scale Compressible Community model (MC2)***. "Community" in this context reflects the collaboration of MSC scientists with others in Canada and internationally to develop the world's fastest, most efficient meso-scale to local scale numerical model. Applications for this model include improving wind forecasts in mountainous terrains, driving wind power models, and generating air quality forecasts.

Because the source code for MC2 was made available to other researchers (known as "open source code"), MSC scientists have effectively leveraged their intellectual investment. Over 50 researchers around the world, in universities and national labs, have adopted MC2 and developed enhancements for it.

This model has been designed to take full advantage of the power of parallel processors - meaning that the calculations of atmospheric dynamics that form the basis for all subsequent calculations can be run, in parallel, on any number of processors. There are plans to run MC2 on Earth Simulator, a massively parallel computer system in Japan, which is 64 times more powerful than the supercomputer currently used for Canada's daily weather forecasts. The goal of the exercise is to produce an unprecedented high-resolution simulation of one of nature's most powerful weather phenomena – a hurricane.

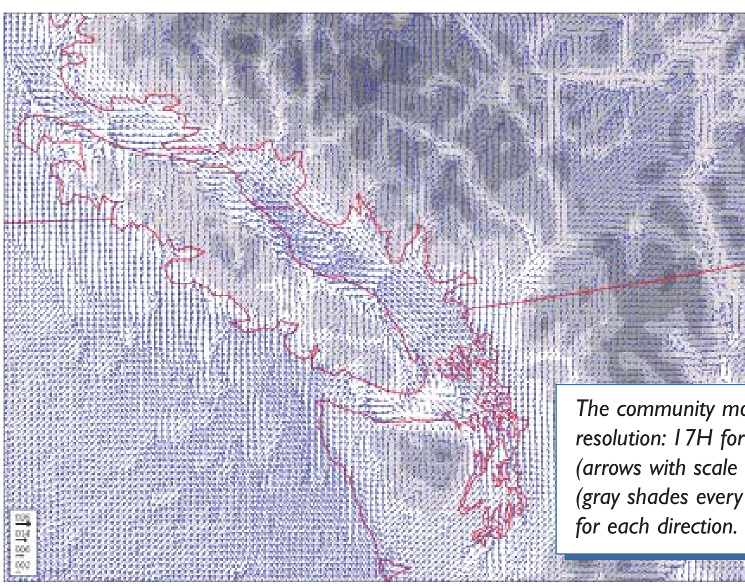
Norway uses MC2 to forecast winds at airports – an extremely challenging task because of the wide variations in wind speed and direction in their mountainous terrain. The biggest challenge for

MC2 was the head-to-head competition with several European models in one of the most challenging places to forecast weather on the globe – the Alps. The combination of mountainous terrain and the moisture of the Mediterranean Sea, make this area too difficult for the current global and regional weather forecasting models to handle well, and an exciting challenge even to meso-scale models. Sophisticated airborne and ground measurements were used to evaluate the performance of the models. In this competition, MC2 produced unprecedented realism, especially for intricate low-level wind flow patterns.

MC2 is also used to generate air quality forecasts. Researchers in Canada and elsewhere begin with MC2, and then add atmospheric chemistry calculations to predict the transport of smog.

All the experience gained in developing and applying MC2 worldwide is now being applied in Canada to improve wind forecasts in mountainous terrains, to drive wind power models, and to generate the air quality forecasts delivered jointly by Environment Canada and the provinces. This "community" approach led by MSC is a very effective way to access the scientific knowledge of the entire atmospheric science community.

> *"The MC2 model is one of the few models available that allows conducting real-time high-resolution numerical weather prediction in a cloud-resolving mode."*
>
> *Christoph Schär*
> *Institute of Atmospheric and Climate Science ETH*
> *Zürich, Switzerland*



The community model MC2 run over Vancouver Island at 2km horizontal resolution: 17H forecast valid 26 June 1997 2000 UTC. Near surface flow (arrows with scale in knots in lower left corner) superimposed over topography (gray shades every 500m). Only one arrow for every other grid point is displayed for each direction.

Water Resources in a Northern Environment

The MacKenzie GEWEX Study

A portable meteorological tower at the Inuvik, NT. upper air site.

Canada's freshwater resources are among the largest in the world. The Mackenzie River is the largest North American source of freshwater entering the Arctic Ocean and this has an important influence on the 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 has been observed for this area and this changing climate can alter the nature of the water resources in the region. Since northern rivers and lakes are major transportation arteries, changes in water levels could also have dramatic impacts on the socio-economic activities in the basin.

When the World Meteorological Organization's 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)***, is documenting the energy and water cycles of the basin for the first time.

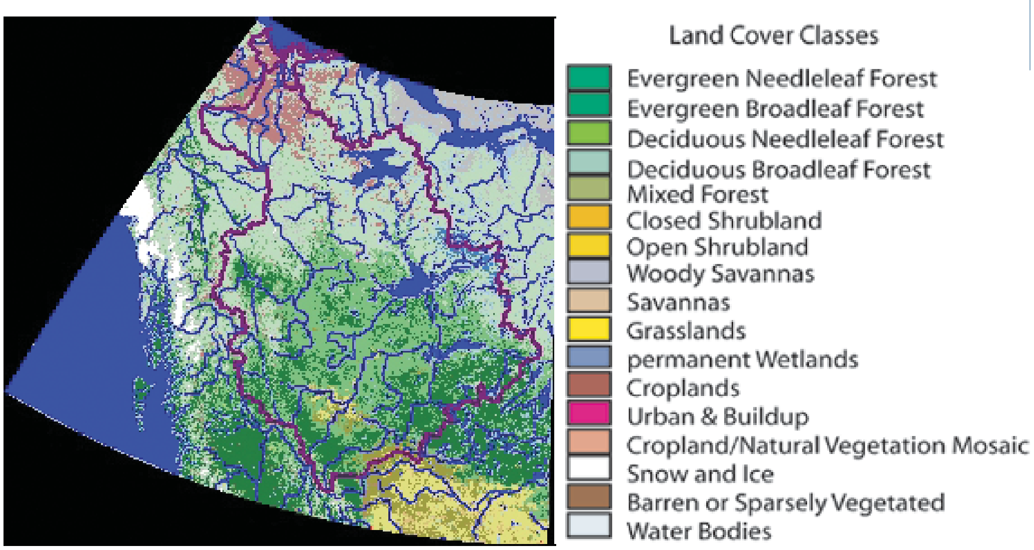
MAGS is a long-term (1996-2005), multi-phased study, focused on understanding and modelling the impacts that climate variability and climate change could have on the meteorology and hydrology of the area. The project has already produced many new and exciting findings since its inception. For example, scientists found that up to half of the summer precipitation that falls over the basin comes from land surface evaporation within the basin. This means that the hydrologic cycle is very sensitive to changes in characteristics of the land surface. This discovery is particularly important since we know that land surfaces are likely to change and permafrost is likely to melt as a result of global warming.

MAGS research has also significantly improved our knowledge of important but poorly understood northern climate processes. These include the quantification of water and energy fluxes from surface snow and northern lakes, the discovery of new runoff processes in frozen soils and bedrocks, and the elucidation of some cold-region cloud and precipitation processes. This new knowledge, along with the field data collected in MAGS, is currently used by scientists from the Meteorological Service of Canada (MSC) and international weather centres to improve climate and weather prediction models. The improved models will be essential in assessing the impacts of climate change for a northern country like Canada.

MAGS will be a key contributor to climate impacts knowledge for many years to come. The research methods and tools developed by MAGS are now being applied to other watersheds in Canada and other northern countries.

"MAGS has made significant contributions to GEWEX. The project has provided better representations of land surface and snow cover impacts that are improving climate, water and energy cycle predictions at high latitudes."

Paul D. Try
Director
International GEWEX Project Office



The Global Land Cover Characteristics database is based on a classification of 1-km Advanced Very High Resolution Radiometer (AVHRR) data spanning a 12-month period. This database has been prepared for the GEWEX Hydrometeorology community through a joint GCIP,NOAA,UNEP/GRID and USGS EROS Data Center project and can be found on their website at http://na.unep.net/gewex

Monitoring Acid Rain Control Strategies

The National Atmospheric Chemistry Database and Analysis Facility (NAtChem)

Photo courtesy of Tom Brydges

Forest dieback as a result of acid rain.

In the 1970s and 1980s lakes and rivers in eastern Canada and the U.S. were becoming more and more acidic. Sensitive fish species and other aquatic plants and animals were disappearing and forests were starting to die back. Acid rain was the cause and sulphuric acid from sulphur dioxide (emitted into the air from coal fired power plants and metal smelters) was the main culprit.

Extensive networks were set up by different agencies and have been operating over 2 decades in both Canada and the U.S. to monitor acid forming chemicals in both air and precipitation. The data from all these networks have been pulled together to map the extent of the acid rain problem, and to determine the effectiveness of pollution control strategies in reducing the impact of acid rain on ecosystems.

However, merging datasets from many networks using different measurement techniques, sampling frequencies and calibration standards is extremely difficult and presents a serious obstacle to the international management of air quality issues. Turning these disparate data into useful information required a mechanism to improve data exchange standards, data analysis procedures and visualization tools.

To address these problems, scientists at the Meteorological Service of Canada (MSC) created the National Atmospheric Chemistry Database and Analysis Facility (NAtChem). NAtChem archives and analyses precipitation chemistry, particulate matter and toxic chemical data from major North American monitoring networks. The results have been so successful that the United States and other countries are turning to NAtChem for analysis of air chemistry data.

The NAtChem program includes a new Data Exchange Standard (DES) and a new Research Data Management and Quality Control Software System (RDMQ™). The scientific community recognizes DES as a major breakthrough in preserving the value of atmospheric data for long-term use, and the RDMQ™ as a powerful system for quality controlling and managing environmental datasets.

NAtChem, with its supporting analytical tools of DES and RDMQ™, has enabled Canada to retain a leading-edge understanding of acid rain and other air quality issues. It has shown that despite reductions in SO_2 emissions over the past decade, over 500,000 square kilometres of eastern Canada still exceeds the critical load for sulphate – meaning that lakes and forests are still at risk of further damage. Additional emission reductions are needed to protect these sensitive ecosystems from acid rain.

By pulling data together from diverse air quality monitoring networks, the NAtChem program is able to examine the link between pollution control strategies and their impact on health and ecosystems.

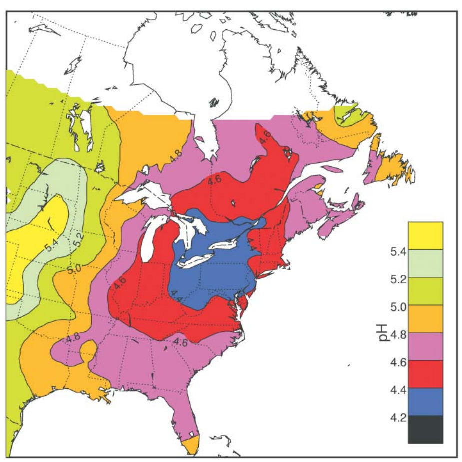
"RDMQ™ is an enormous time saver and invaluable for quality controlling global precipitation chemistry data sets. Without it we would be lost."

Volker Mohnen
Head,
Qualiy Assurance
Science Activity Center
of the Americas

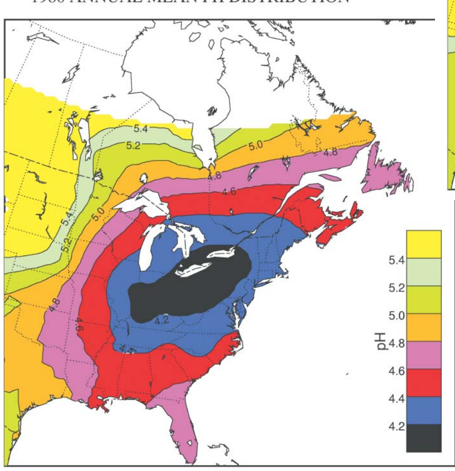
"NAtChem is invaluable in understanding the chemical climatology of North America."

Richard Artz
Deputy Director,
Air Resources Laboratory
National Oceanic and
Atmospheric Administration
USA

1998 ANNUAL MEAN PH DISTRIBUTION



1980 ANNUAL MEAN PH DISTRIBUTION



These two maps generated by NAtChem show how the extent of acidic rainfall has decreased over eastern North America as a result of the implementation of sulphur dioxide control strategies in Canada and the United States between 1980 and 1998.

The Effectiveness of the Montreal Protocol on Ozone Depleting Substances

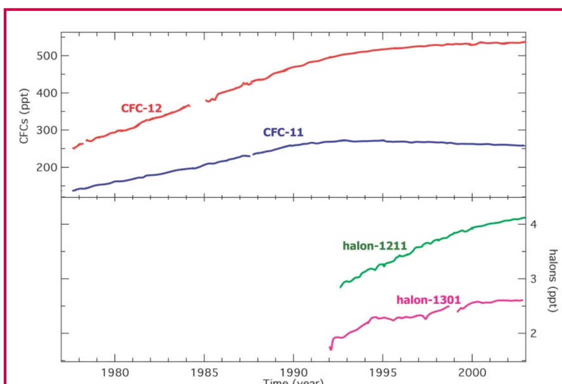
Systematic Measurements of Stratospheric Ozone & UV

The Canadian ozonesonde network consists of six stations that launch ozonesonde carrying balloons weekly to determine long-term trends of ozone concentrations at all levels of the atmosphere.

Since 1987, 183 countries have ratified the United Nations Montreal Protocol that limits the emissions of ozone-depleting substances. To determine the effectiveness of the Protocol, the World Meteorological Organization (WMO) established a global network to monitor solar UV radiation and changes in the ozone layer. The Meteorological Service of Canada (MSC) has a network of 12 stations across Canada that measure column ozone and UV-B.

MSC scientists have been leaders in this field for nearly 50 years. In the mid-1970's, they directed their expertise in high precision measurements of the sun's energy into the development of the Brewer spectrophotometer, an instrument that measures column ozone and UV-B. This instrument has become the standard for ground-based measurements around the world. It is now manufactured under licence, and over 160 instruments are used in more than 40 countries worldwide, plus Antarctica. MSC maintains the world standard calibration group of instruments at its headquarters in Toronto, and operates the World Ozone and UV Radiation Data Centre as part of Canada's commitment to the WMO. Examples of ozone and UV data include forecast maps used to predict the UV index for Canadians, and near-real time ozone measurements and maps from ground-based instruments and satellites.

Ozone depletion is most severe at the Earth's poles. The Antarctic ozone hole is well documented, and a significant thinning of the ozone layer over the Arctic was first detected



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, NT; Pt. Barrow, Alaska; Niwot Ridge, Colorado; Mauna Loa, Hawaii; American Samoa; Cape Grim, Tasmania, and the South Pole.

in the measurements from Eureka, Alert and Resolute in Canada's high Arctic. This ozone depletion over the Arctic has been linked to climate change. Climate models predict that as the surface warms, the stratosphere cools and ozone destruction is accelerated.

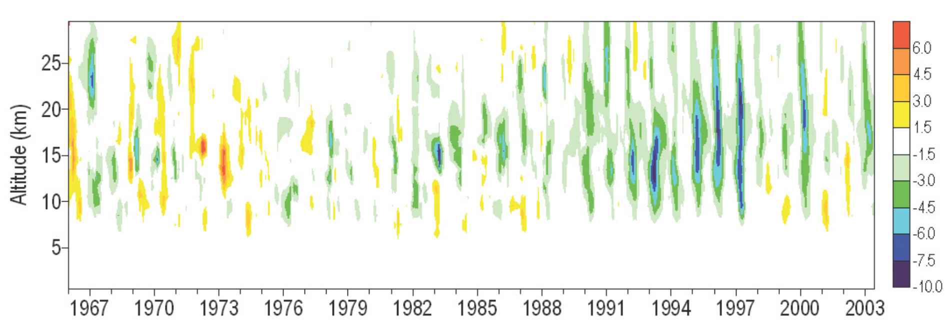
In 1993, MSC researchers were the first to definitively link an increase in ***mid-latitude*** UV-B at the Earth's surface to depletions of ozone in the stratosphere. This was particularly significant in that it showed that ozone depletion was not only a problem in Polar Regions.

Canada also measures the vertical distribution of ozone using a small instrument package called an ozonesonde that is carried aloft by weather balloons. This information is important in understanding ozone depletion chemistry and global ozone transport. Three of the six Canadian stations involved in this program are in the high Arctic. The knowledge gained from this program, along with that from the other monitoring networks, is critical to our ability to monitor the recovery of the ozone layer.

The expertise of MSC researchers and the location of Canadian monitoring stations have enabled Canada to make a unique contribution in this area of science, and to work together with the international community in tracking the effectiveness of international environmental management policy.

"MSC's research & development is making a strong contribution to international efforts to elucidate the coupling between stratospheric ozone depletion/recovery and climate change."

International Independent Peer Review 2001



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 areas indicate lower than normal ozone concentrations, and are evident in the recent years (1993, 1995, 1996, 1997, 2000, 2003). These major losses occur in the late winter - early spring. (The data are in Dobsin Units (DU) per km which is equivalent to 0.01 mm thickness at standard temperature and pressure.)

The Scientific Basis for Clean Air Policy in the Lower Fraser Valley

Pacific 2001

Meteorological Service of Canada staff launch a tethersonde during Pacific 2001 to obtain detailed profiles of temperature, winds and humidity in the atmospheric boundary layer.

The Lower Fraser Valley in British Columbia is often blanketed with smog in summer and autumn. Ground-level ozone and small airborne particles become trapped in the valley between the ocean and the mountains. Elevated levels of these pollutants can reduce visibility, adversely affect respiratory health, and damage vegetation and ecosystems.

The chemistry associated with the formation of smog is very complex. By 2001, advancements in the science of measuring airborne particles and understanding their composition and atmospheric transport, enabled Meteorological Service of Canada (MSC) scientists to launch the largest intensive field campaign ever to take place in Canada – Pacific 2001. This field study involved 22 agencies, including Canadian federal, provincial, regional and U.S. governments, and 13 universities. The goal was to further the understanding of the physical and chemical processes that lead to particle formation in the Lower Fraser Valley airshed.

There are many air pollution sources in the Valley - emissions come from vehicles and industries in the Greater Vancouver area; from ships in the basin; from agriculture; and from industries in Washington State that are carried across the border. In addition, there are emissions from natural sources such as trees, vegetation, and the ocean. Emissions from all of these sources can react with sunlight to produce smog that can persist for several days.

During the study, measurements were made at five sites across the valley from Eagle

An instrument deck used in the Pacific 2001 experiment equipped to measure various components of particulate matter.

Ridge to the Cassiar Tunnel, and from Langley to Golden Ears Park. Research balloons and aircraft were flown above the valley carrying instruments designed to help identify the nature and sources of urban smog.

Datasets collected during intensive field studies such as Pacific 2001 take 5 to 10 years to fully analyze and integrate into the knowledge of the science and policy communities. Analyses of the results will shed light on the complex chemical and physical processes of particle formation. To date, analyses have revealed that:

- The complex interaction of pollution with sea salt particles contributes to the impairment of visibility in the valley.
- Biogenic particles are prevalent, even in urban areas.
- Ammonia from agricultural and traffic emissions contributes to the formation of fine particles.
- Motor vehicle emissions contribute fine carbonaceous particles to urban air.

A previous study, led by MSC in the Valley in 1993 on ground-level ozone, contributed to the development of various emission control strategies, including vehicle tail-pipe emission testing. The 2001 study has produced an unparalleled database which will provide a strong foundation for air quality management policies in the Lower Fraser Valley well into the 21st century.

"The Pacific 2001 study will provide the scientific underpinning we need to support policy development to protect this sensitive airshed."

Hugh Sloan
Director, Planning
Fraser Valley Regional District

The Lower Fraser Valley in British Columbia blanketed in smog.

Predicting Climate Change
Canada's Climate Models

Photo by Diana Nethercott

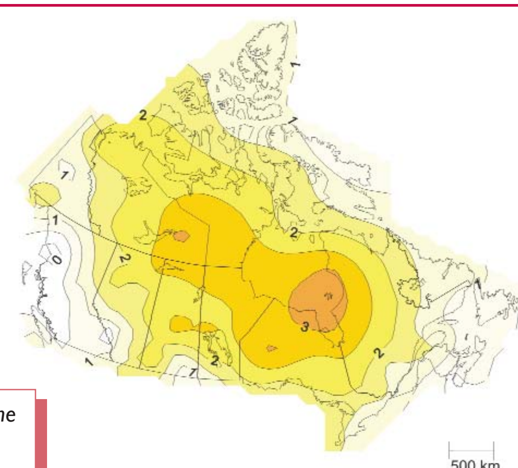
Developers of the Canadian General Circulation Models (GCMs) Norman McFarlane (left), Francis Zwiers and George Boer, with the Pacific Ocean in the background.

The average global concentration of carbon dioxide, the best-known greenhouse gas, has increased by approximately 30% during the industrial era. Methane, another of the greenhouse gases that contributes to global warming, has more than doubled. The weight of scientific evidence indicates that the global temperature will increase significantly over the 21st century, and increase at a pace that has not been seen for at least 10,000 years. Knowing how fast, where, and in which ways climate change will occur has become a preoccupation of citizens, scientists and governments alike.

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. Meteorological Service of Canada (MSC) scientists are pioneers and world leaders in building and using global climate models.

The first climate models developed in MSC focussed on the atmospheric physics that determined global climate patterns. In the late 1980s and early 1990s atmospheric processes and ocean circulation were combined in the models to make them more realistic. Subsequently, MSC scientists developed a coupled atmosphere/ocean/sea-ice model, which is considered to be among the best in the world.

The 2001 *Third Assessment Report* of the Intergovernmental Panel on



In 2001, Canada, as a whole, experienced its third warmest year, with the warmth spread fairly evenly over the whole country, as shown in this annual temperature anomaly map. Each isoline represents a half a degree Celsius in warming.

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. It was also one of two models 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.

MSC climate scientists are now 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.

Most climate models project that the change in climate is likely to be more pronounced in Polar Regions and to be greater in winter than in summer. Hence, Canada's fragile northern environment will be the most vulnerable to the impacts of climate change.

The strength of Canada's climate science, the leadership provided by MSC, and the potential for significant impacts in this country, played a significant role in the decision to ratify the Kyoto Protocol.

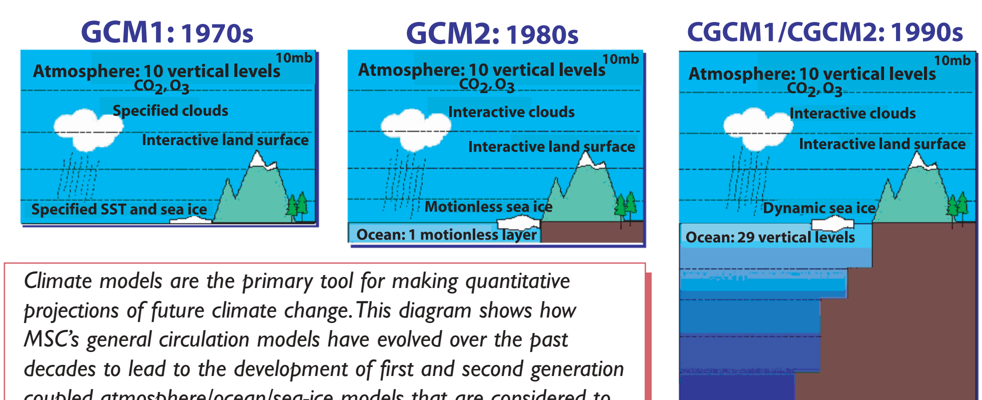
The MSC climate science team continues to advance the science of global climate modelling by tracking change in the climate system and helping to prepare Canadians and citizens of other countries to adapt to climate change.

"They (the MSC climate modelling team) do a stunning job and somehow they stay at the cutting edge."

Bob Corell
past Administrator
National Science Foundation
USA

"The susceptibility of Canadian ecosystems, like the Arctic, to significant impacts from climatic change underscores the importance of maintaining excellence in Canadian climate science."

Gordon McBean
Chair
Canadian Foundation for Climate and Atmospheric Sciences



Climate models are the primary tool for making quantitative projections of future climate change. This diagram shows how MSC's general circulation models have evolved over the past decades to lead to the development of first and second generation coupled atmosphere/ocean/sea-ice models that are considered to be among the best in the world.

Climate Change & Canada's National Parks
Assessing the Impacts

Photo by Malek

How will climate change affect our national parks system and its representation of Canada's natural heritage? That is the question that scientists at the Meteorological Service of Canada (MSC) undertook to answer in the ***Climate Change and Canada's National Park System*** study. The study was a first assessment conducted jointly with the University of Waterloo to look at this issue for Parks Canada, in 2000.

Assessing the impacts of climate change on a national system of parks – 38 in total – in a country the size of Canada is a daunting task. MSC scientists developed seasonal climate change scenarios for each of the 38 national parks using the outputs of four general circulation models (GCMs), including the MSC's GCM. Researchers also conducted an assessment of potential climate change impacts and examined each national park individually. The parks were grouped into six broad geographic regions (Atlantic, Great Lakes - St. Lawrence, Prairie, Western Cordillera, Pacific, and Arctic) for which the range of climate change impacts was similar. The results

indicated that the biophysical character of most of the parks would change under the predicted climate scenarios, with the parks located in central and northern Canada at the greatest risk of major change.

A subsequent study for Parks Canada by an MSC scientist, working with faculty at the University of Waterloo and the University of Toronto, used two global vegetation models together with four GCMs to examine how vegetation changes could impact the national parks. This modelling exercise revealed that new biome types would emerge in more than half of the parks and that there would be a loss of representative northern biomes (tundra, tundra/taiga, and boreal forest) in the park system.

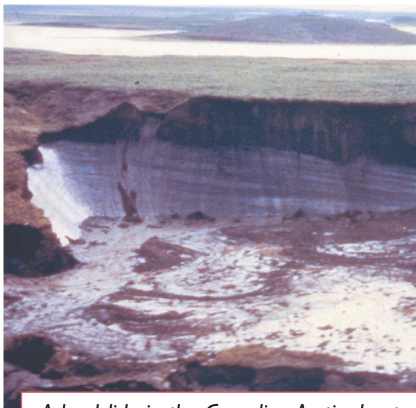
This assessment of the impacts of climate change on our national parks suggests that Canada's National Park System may not be adequate to protect the ecosystems for which they were originally established. This underscores the need for Canada to develop and implement adaptation strategies for biome conservation. These results are currently influencing how parks managers plan for the future and how they see the role of our national parks in preserving Canada's natural heritage.

"The assessment brings impacts and adaptation understanding to the park level. Park scientists can use locally relevant information in ecosystem planning."

David Welch
Ecological Integrity Branch
Parks Canada

Climate Change and Canada's Northern Communities

The MacKenzie Basin Impacts Study



A landslide in the Canadian Arctic due to decaying permafrost.

It's a big challenge to understand the impacts of climate change on weather and water resources. It's an even bigger challenge to integrate that scientific knowledge with anticipated social, economic and cultural impacts to support wise policy decisions. The Mackenzie Basin Impacts Study (MBIS), led by the Meteorological Service of Canada (MSC), serves as a model for integrating all the complex aspects of geophysical and socio-economic knowledge to strengthen policy and development decisions at the local level.

The MBIS began in 1990, and culminated with the publication of the Mackenzie Basin Impact Study by MSC 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 residents are closely linked to 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 and stakeholders ranging from industry to aboriginal organizations together to participate in a comprehensive review of research. Participants focused on the significance of the various research findings to the people and communities of northern Canada. As the project unfolded, the level of local participation increased, as did the mutual understanding between scientists, the decision-makers and the local 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 water levels in lakes and rivers.
- Increased erosion from thawing permafrost, including more landslides.

- Increased risks to forests from fires and pests.
- Risks to aboriginal lifestyles.
- Mixed impacts on access to wildlife.
- Potential benefits to agriculture from a longer growing season if irrigation services were to be expanded.

Adaptation measures to reduce vulnerability may include:

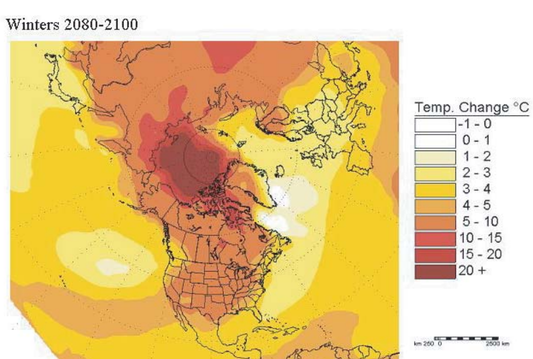
- Increased community-based monitoring.
- Expanded use of co-management strategies.
- Regional and local control of climate-sensitive resources.
- Adoption of flexible strategies such as adjustable harvest quotas.

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, specifically the need for enhanced institutional capacity on climate change. For example, the Northern Climate Exchange at Yukon College was established in 2000 to provide a regionally based structure to serve as an information source and to facilitate research collaboration in Northern Canada.

The results of the study raised awareness of climate change among policy and decision-makers around the world. The MBIS has been used as a model for subsequent integrated impacts studies in other countries, including the United States (Bering Sea Impact Study) and the European North (Barents Sea Impact Study). It is clear that potential effects on aboriginal lifestyles will be determined by development choices made by northern residents over the next few decades, as well as by the rate and magnitude of climate change effects.

"MBIS has been of significant help in the design and execution of the Barents Sea Impacts Study. In particular, we learned from MBIS the importance of direct contact with stakeholders and integration of study results, right from the start."

Manfred A. Lange
Project Manager
Barents Sea Impacts Study



By 2080, winter temperatures in most of Canada could rise by 5 to 10 degrees or more.

Improving the Accuracy of Canada's Weather Forecasts

The Global Environmental Multi-scale (GEM) Model

The front end of Environment Canada's 'supercomputer' which is housed at the Canadian Meteorological Centre (CMC) in Dorval, PQ. The CMC is the main location for the Numerical Prediction Research Division and other components of the Meteorological Research Branch, and other Meteorological Service of Canada employees.

Forecasting the weather always stands as one of the most challenging tasks for any computer system. Meteorological researchers and computer scientists are always anticipating the next, more powerful supercomputer in order to expand their calculations – attempting to simulate more accurately one of the most complex processes on Earth.

It was in the 1950s that the first electronic computers enabled the operational use of Numerical Weather Prediction (NWP) on a systematic basis. Since that time, standard measures of the quality of weather forecasting from the Meteorological Service of Canada's (MSC) Canadian Meteorological Centre in Dorval show dramatic progress. For example, a 5-day forecast in the year 2003 is as accurate as a 36-hour (1.5 day) forecast was in 1963. As the accuracy and range of forecasts increases, so does their value to the general public and to the 1/7th of Canada's GDP (Gross Domestic Product) that is weather sensitive.

There is also another way to increase computing capacity. That is through the software that is used. The more efficient the programming is, the more calculations can be done within the time limits imposed by meteorologists and clients.

Researchers at the MSC made a large intellectual investment in the early 1990s to develop the Global Environmental Multi-scale model ***(GEM)*** which became operational in 1997. The heart of this numerical model is the dynamical core, which provides the computational foundation for describing the conservation of energy and momentum. All the other aspects of the model, such as predicting radiation, cloud formation, land/surface exchange etc., plug into this flexible core. The GEM is unique in the world in its ability to run with fixed or variable spatial and temporal resolution from the global to local scales - all with the same dynamical core.

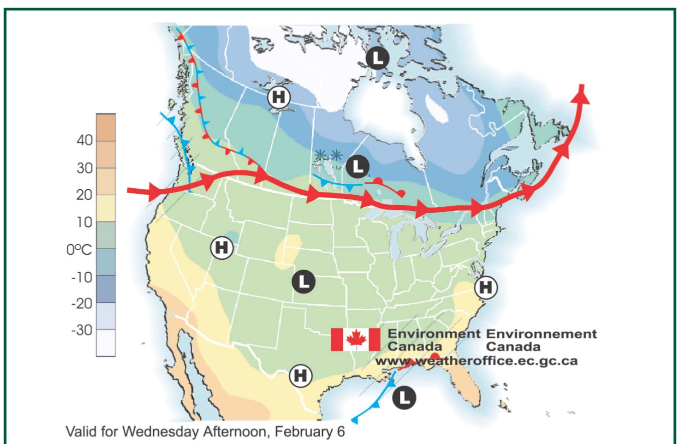
The GEM dynamical core is so efficient and flexible that it now also powers several different forecast programs. The model is run twice daily at 24km horizontal resolution, with sophisticated data assimilation techniques that take advantage of real-time surface and satellite meteorological data from around the world, producing 48-hour forecasts for all of Canada. GEM is run at a coarser resolution of 100km to produce daily forecasts out to ten days for the entire globe. In somewhat of a scientific tour-de-force, GEM is also used for local and convective scale modelling out to 30 hours to simulate hurricane, severe squall line, and heavy precipitation weather.

"The GEM dynamical core represents the best in the world"

International Independent Peer Review 2001

The next test for GEM will be to extend its time horizon to produce seasonal forecasts that will be more accurate than those from our existing multi-model ensemble prediction system. Replacing the current multi-model system with a single GEM-based system will result in significant cost savings.

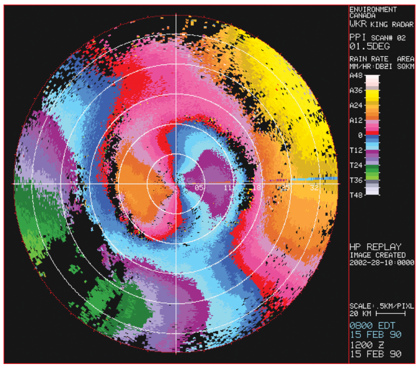
One of the biggest challenges facing meteorological services around the world is merging weather, ocean, climate, hydrology and air quality models into integrated environmental prediction models. Such integrated models can link atmospheric change to ecosystems, human health and the economy. This is another area where GEM holds great promise. Research is currently underway to develop these GEM-based unified modelling platforms for environmental prediction of the impact of human activity on the environment and the environment's impact on the health, safety, security and businesses of Canadians. GEM is an excellent example of doing more with less.



An example of the next day forecast of the major weather systems over North America produced daily by Environment Canada.

Detecting Severe Weather

Canada's Doppler Weather Radar and Lightning Networks

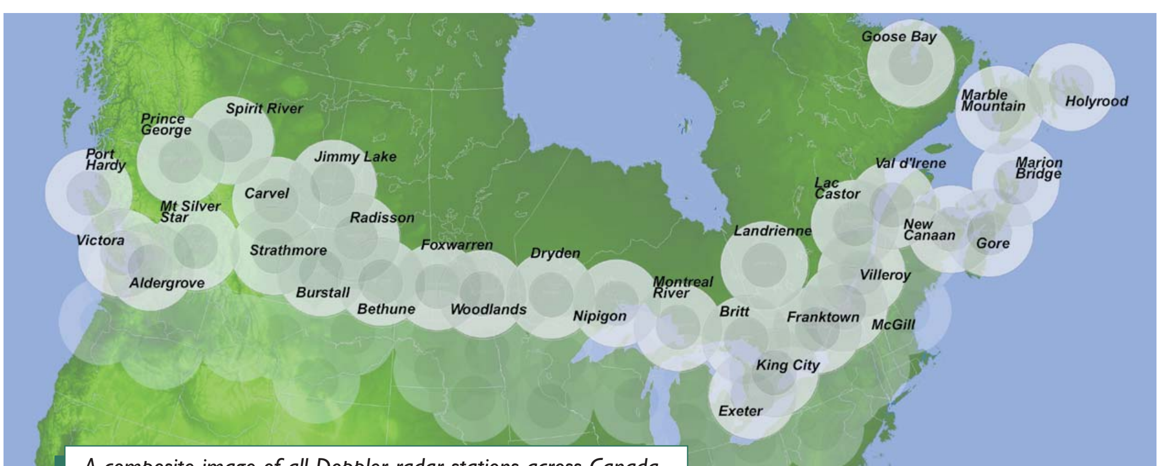


A radar image from Environment Canada's King City Doppler radar for a freezing rain event that occurred on February 15, 1990.

Severe weather such as thunderstorms, lightning, tornadoes, hail, heavy rain, and blizzards frequently lead to loss of life and damage to property. In the 1980s, tornadoes in Ontario and Alberta killed 35 people. On average, lightning kills about 7 and injures 60 or 70 people in Canada each year. In 1998, the ice storm in eastern Canada resulted in damages over 4.2 billion dollars.

The ability of operational forecasters to provide sufficient warning of these and other weather related hazards is highly dependent on the Meteorological Service of Canada's (MSC) ability to process and interpret a large quantity of observational measurements from radars, satellites and surface meteorological stations.

Over the past several years, MSC has invested heavily in two operational networks, the Doppler Radar Network and the Canadian Lightning Detection Network. The Doppler Radar Network consists of a string of 30 Doppler radars, each with a detection area of 250 km in radius, in total covering 90 to 95 percent of Canada's population. The Lightning Detection Network covers most of Canada. It enables meteorologists to detect and



A composite image of all Doppler radar stations across Canada.

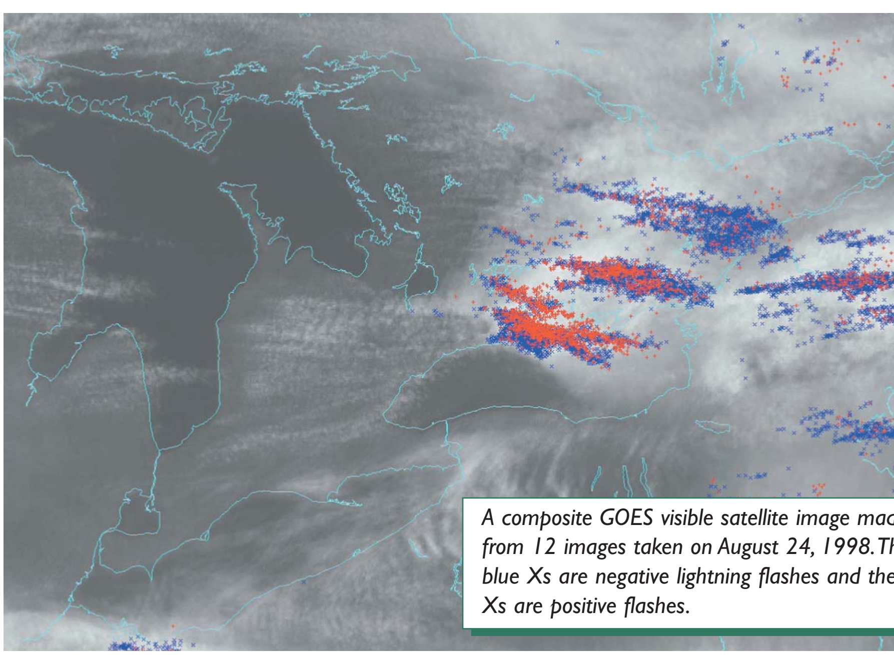
monitor thunderstorms at an early stage of their development, and provides invaluable support for the identification of areas with high forest fire potential. Both networks are integrated with similar U.S. networks, and together they provide an unprecedented ability for forecasters to identify severe weather and provide public warnings.

In the past decade, MSC scientists, meteorologists and computer programmers have made considerable progress in developing forecasting applications of radar measurements and have become world leaders in radar meteorology. Their achievements include doubling the range and substantially increasing the sensitivity of radar measurements, as well as halving the cost of radar hardware.

In the regional forecast offices, a single forecaster must keep watch over two million square kilometres, while at the same time delving into the details of a single thunderstorm that is only about 100 square kilometres in area. The Doppler Radar Network now provides the surveillance capability required to meet these forecasting needs. As a result, Canada has one of the leading severe weather forecasting systems in the world.

"The MSC radar group is unquestionably one of the world's leaders in nowcasting convective storms."

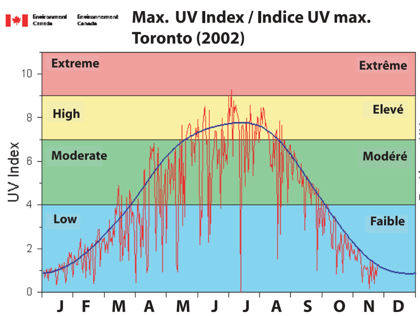
Jim Wilson
Senior Scientist
National Centre for Atmospheric Research
USA



A composite GOES visible satellite image made from 12 images taken on August 24, 1998. The blue Xs are negative lightning flashes and the red Xs are positive flashes.

Alerting Canadians of Atmospheric Risks

UV, Air Quality, Wind Chill and Heat Indexes



A chart of the annual UV (ultra violet) index maximums for Toronto, Ontario for the year 2002.

Canada operates networks that measure atmospheric conditions across the country. Scientists at the Meteorological Service of Canada (MSC), working with health scientists and others, have used the data from these networks to develop indexes that alert Canadians to atmospheric conditions that pose a risk to their health and wellbeing.

UV Index

Ultraviolet (UV) radiation from the sun can harm a person's skin, eyes and immune system. It is estimated that over 800 Canadians will die from malignant melanoma and that some 72,000 will develop other sun induced skin cancers each year.

Based on a decade of UV data collected at the 12 Canadian monitoring sites, MSC scientists developed the UV Index, which provides a measure of the intensity of the sun's ultraviolet radiation. In 1992, the MSC started using the UV Index in its weather models to forecast the next day's UV levels. Canada was the first country in the world to introduce these forecasts, which have raised public awareness of the health hazards associated with prolonged exposure to UV. People are now more likely to take preventitive actions to reduce the likelihood of developing skin cancer or cataracts.

Air Quality Index

Poor air quality, especially fine particles and ground-level ozone, affects respiratory health and contributes to hundreds of premature deaths each year in Canada. It also impairs visibility and adversely affects materials and the natural environment.

Smog can occur in the summer or winter, though more often on hot still days. People can take action to reduce their exposure to poor air quality if they know about it. Health Canada and MSC scientists are working with provincial and other experts to develop a health risk based air quality index that can be used to provide consistent information to the public across Canada.

Heat-Health Alert System

The elderly and individuals with pre-existing medical conditions are particularly vulnerable to heat-stress. MSC scientists collaborated with health scientists to develop a heat alert system that links mortality rates with weather data. During its first summer of operation in Toronto in 2002, 4 heat alerts and 1 heat emergency were issued. The alerts triggered the city to respond by distributing water to vulnerable sectors of the population, and to open air-conditioned facilities to the public for relief from the heat.

Wind Chill Index

Each year, more than 80 Canadians die from over-exposure to the cold, and many more suffer injuries from frostbite and hypothermia. The combination of cold temperatures and strong wind speeds up the rate at which the body loses heat resulting in "wind chill". MSC worked with scientists in the U.S. and human physiologists to develop a new ***Wind Chill Index***. This new index was implemented in October 2001 throughout North America, and expresses wind chill as an equivalent temperature.

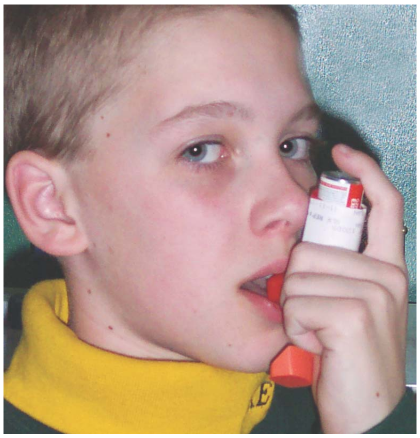
MSC scientists working in conjunction with health scientists, and across governments, have brought the science of solar radiation, air quality, and temperature extremes to the Canadian public in a relevant, credible and understandable way - enabling Canadians to make informed choices to protect themselves from the risks of atmospheric threats.

"The UV Index has been a great help in raising the awareness of Canadians to the risks of UV exposure."

Michelle Albagli
Executive Director
Canadian Dermatology Association

Providing Air Quality Forecasts and Advisories for Canadians

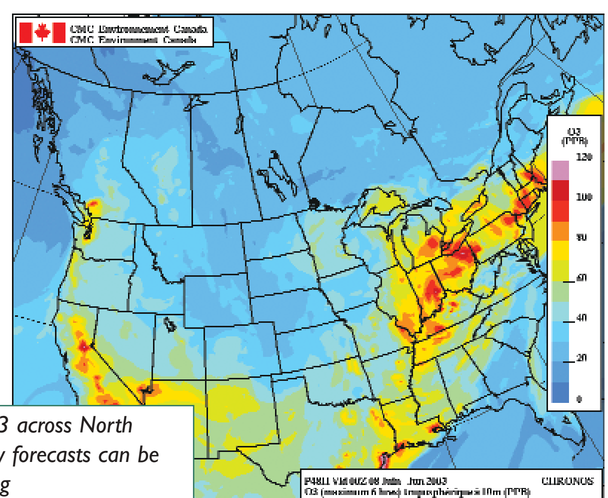
The CHRONOS Chemical Transport Model



One of the challenges of any research program is the transfer of knowledge and technology from a research environment to an operational environment where the investment in research and development is paid back through improved products and services to the public. The challenge is even greater when the final product must be delivered in real-time, in a collaborative manner, and involving multiple levels of government.

Air quality forecasts and advisories are important and complement the Air Quality Index Program. A few thousand premature deaths are attributed to air pollution in Canada each year. Anyone with respiratory or cardiovascular conditions can benefit from taking special precautions during an air quality advisory, issued when pollution levels are expected to be high. Others can make informed decisions on a range of actions that either reduce their exposure or contribute to reducing air pollution emissions.

At the centre of the Meteorological Service of Canada's (MSC) capability to produce and support air quality forecasts and advisories is a state-of-the-art computer model – CHRONOS (Canadian Hemispheric and Regional Ozone and NO_X System). It is a comprehensive air quality model containing a full description of atmospheric chemistry and meteorological processes. CHRONOS uses a North American emission



The distribution of ground-level ozone for June 8, 2003 across North America as forecast by the CHRONOS model. The daily forecasts can be viewed on-line at http://www.msc-smc.ec.gc.ca/aq_smog inventory for atmospheric chemistry, and MSC's weather forecast model for transport processes.

The development of CHRONOS started in the early 1990s and it has emerged as MSC's model of choice for smog-related forecasts. It has recently made the transition from a research environment into operations. These model outputs feed into air quality forecasts and advisories. The national smog forecasting program builds on and complements existing regional, provincial and municipal capabilities and measurements to deliver air quality forecasts and advisories.

CHRONOS can also be used to answer questions in support of policy development such as, "How much will air quality improve with the implementation of a given set of management actions or control strategies to reduce air pollution emissions?". This provides valuable insights for air quality policy makers, notably in support of the development and implementation of Canada-Wide Standards for Particulate Matter and Ozone. Canada-U.S. negotiations over cross-border transport of smog and related pollutants have also benefited from insights provided by CHRONOS.

The use of CHRONOS is a good example of bringing a research model into an operational environment and using it as a tool to support air quality forecast services to Canadians. It's an excellent example of research making a difference.

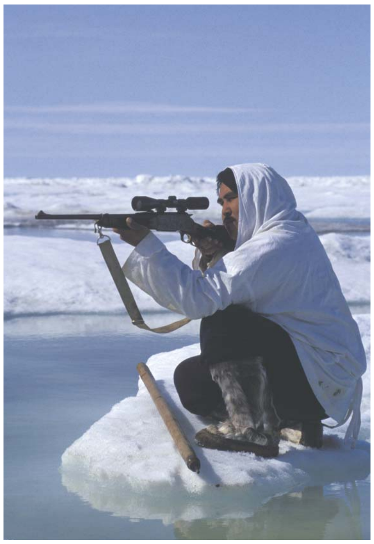
"A few thousand people die prematurely each year in Canada due to poor air quality. High quality and accurate air quality forecasts are essential to helping protect the health of Canadians. MSC's CHRONOS model assists regional, provincial and municipal agencies to deliver air quality advisories, which in turn enable Canadians to take action to protect themselves from poor air quality."

Dr. Quentin Chiotti
Air Programme Director
Pollution Probe

These images show the contrast between a clean air day and a 'smog' day in downtown Toronto, Ontario.

Reducing the Risk of Hunting & Fishing at the Ice Edge

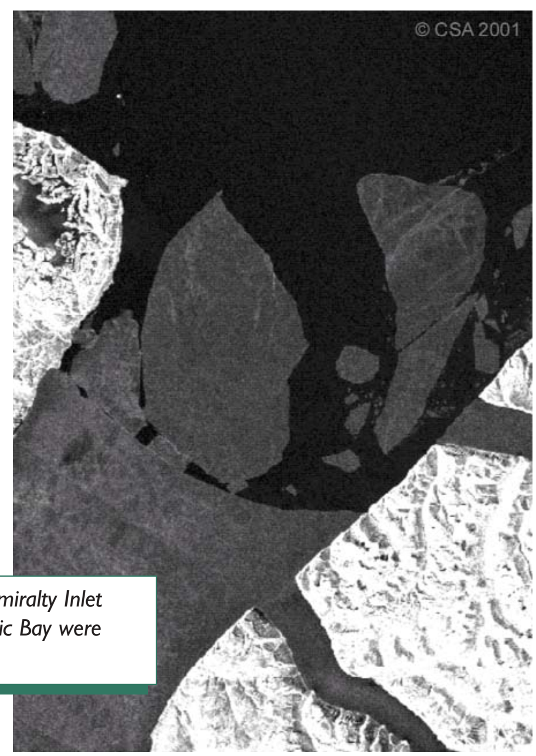
The Canadian Ice Service's Floe Edge Advisory



Each year in Canada's north, as winter's grip gives way to longer days and rising temperatures, native communities like to venture out onto the ice, which has grown outward from the land during winter, until they reach the edge where the ice meets open water. The ice or floe edge is the best location for hunting and fishing. It is also the most dynamic and dangerous place in the spring "icescape". Each year, unsuspecting people are set adrift as the ice edge fractures and large ice floes float out to sea, often in weather conditions that make airborne search and rescue efforts impossible.

It was just such an occurrence on June 2, 1997 that stirred sea ice experts at the Meteorological Service of Canada (MSC) to find some way to turn their scientific understanding into a service that would benefit northern settlements. On that day, 15 people from the community of Pond Inlet on Baffin Island were stranded on a 60x60 metre ice floe that drifted out into Baffin Bay in poor weather conditions. Search and Rescue had to wait for the weather to clear and were elated when they were able to pick up everyone without incident – three days later!

MSC's Canadian Ice Service (CIS), with the support of the National Search and Rescue



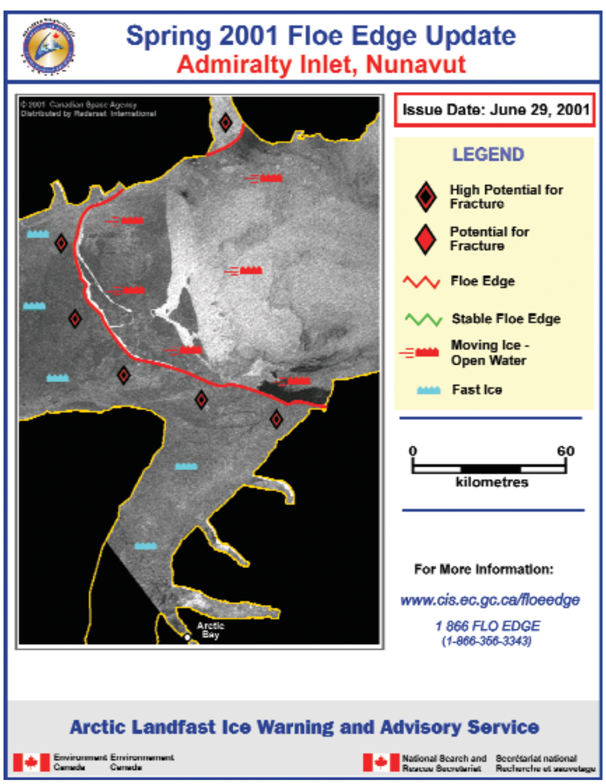
RADARSAT-1 image of the fracture of the Admiralty Inlet floe edge in July 2001. Fifty residents of Arctic Bay were caught on this large pan of drifting ice.

Secretariat, developed a prototype ***Floe Edge Advisory.*** Local input identified two locations for the trial, Pond Inlet and Arctic Bay – two communities that are very active users of spring ice floe edges. Community involvement was critical to the development of a service that would be meaningful and useful.

In 2001, the advisory program consisted of a seasonal outlook and a weekly update. In 2002, service delivery took a big step forward with the increased use of the Internet in the communities. The CIS places current satellite images along with vital information on ice strength, temperatures, tides and winds on their website for northerners to access. This information combined with traditional understanding enables communities to hunt and fish at the ice edge with an increased sense of security and less risk. Given the climatic changes expected in the Arctic, northerners will have to pay close attention to the shifting ice edge, as will Canadian Ice Service researchers - to help northern communities maintain their traditional lifestyle, but with enhanced safety.

"By providing communities with up-to-date ice information, the Floe Edge Information Service has increased the safety of those working around the floe edge."

Brian Koonoo
Park Warden
Sirmilik National Park



A sample of a floe edge update product that is distributed to the study communities by the Canadian Ice Service.

Ensuring Safe Flights in Northern Climates
Aircraft Icing Research

Icing that occurred on probes of the Convair-580 during a flight on February 19, 2003 at Mirabel airport in Quebec. The probes measure the size, shape and concentration of particles.

Aircraft icing is one of the biggest hazards to aviation in North America, particularly in the northeast. Aircraft that operate in winter conditions can encounter rapid ice accumulation that is so severe that they cannot maintain level flight. Ice accumulates on the leading edges of the aircraft – reducing lift, while at the same time increasing drag dramatically. The combination of decreased lift and increased drag can lead to disaster. Several major aircraft accidents in recent years have been attributed to aircraft icing.

Scientists at the Meteorological Service of Canada (MSC) are international experts when it comes to understanding and measuring aircraft icing. They have conducted studies in Canada's most ice-prone maritime and continental locations - near St. John's, Newfoundland, and the Great Lakes. MSC's researchers have logged hundreds of hours flying through freezing drizzle, freezing rain and ice-laden clouds, in order to improve scientific understanding of the meteorological conditions under which icing occurs.

In 1998, when the U.S. - Canadian Aircraft Icing Research Alliance (AIRA) was formed, MSC researchers were at the centre of a research plan that included NASA, the Canadian National Research Council, Transport Canada and the U.S. Federal Aviation Administration. The goal was to develop and implement an integrated aircraft icing research plan. The role of MSC on this team was to conduct in-cloud measurements of icing environments, develop techniques to remotely detect icing conditions, and to

The windshield of the NRC Convair-580 after returning from an experimental flight during which measurements of in-flight icing rates were made.

improve methods of forecasting in-flight icing. The first major study under AIRA, the Alliance Icing Research Study (AIRS), took place in the winter of 1999-2000. MSC scientists, using a variety of direct and remote sensing instruments, made an extensive array of ground and in-flight measurements of icing rates.

This research has resulted in a large, comprehensive data set that characterizes aircraft icing conditions, and in particular, supercooled large droplet conditions that are outside the current aircraft certification requirements. A follow-up study, AIRS II, is planned and attracting interest from a wider range of participants extending beyond North America.

Using MSC's numerical weather prediction models, scientists have developed new algorithms, and quantitatively evaluated them for predicting icing. An Airport Vicinity Icing and Snow Advisor (AVISA) currently under development, showed promising results during initial testing in the winter of 2002-2003.

MSC scientists are applying their research to new design criteria for commercial aircraft, and innovative products that will ultimately result in safer flights for us all.

"MSC's accomplishments in icing and cloud microphysics are world-class and have been critical to the Aviation Rulemaking Advisory Committee's drafting of proposed airworthiness requirements for safe aircraft operations in freezing drizzle and freezing rain conditions."

Eugene G. Hill
Chief Scientific and Technical Advisor
Environmental Icing
Federal Aviation Administration
USA

The National Research Council's (NRC) Convair-580 is the best-instrumented aircraft in the world for in-cloud microphysics measurements.

Making Wind Energy an Attractive Option for the Future

The Wind Energy Simulation Toolkit

If you've ever stood out on the prairies, or in the foothills, or on an ocean-side beach, you have felt the potential power of wind energy for generating electricity. The contribution of wind energy to electricity production in Canada is steadily increasing.

Technology to generate electricity from wind has improved significantly over the past 30 years to the point that several electricity companies in Canada, both large and small, have begun to add "wind farms" to their electrical generation capabilities. Large utilities, like Alberta's TransAlta Corporation, foresee up to 10% of their electricity generated by wind turbines in the future. The federal government's Wind Power Production Incentive Program has received proposals far exceeding the initial scope of the program.

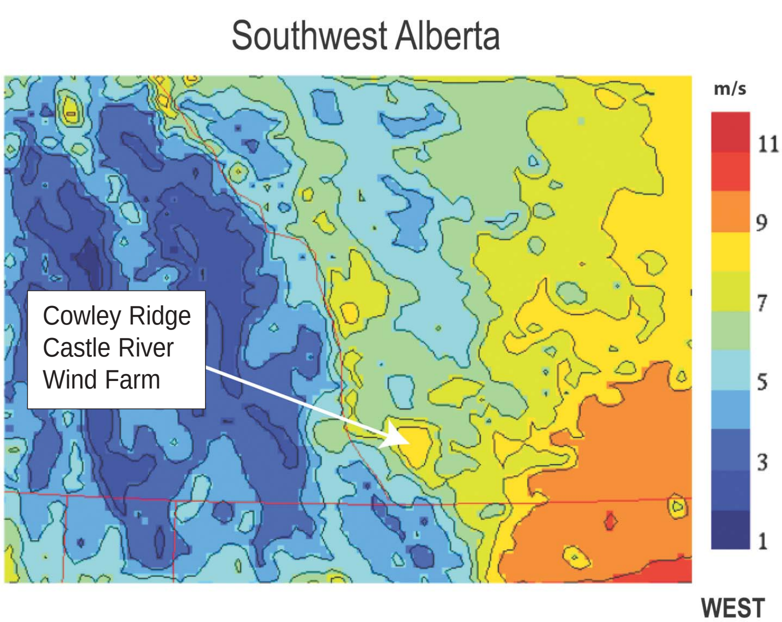
Wind may be free, but the technology to convert it to electricity certainly is not. The capital investment required for wind turbines and electricity generators is significant. In addition, short-term operational decisions on buying or selling, generating or importing electricity are key to the economic sustainability of power generation companies. The very nature of electricity demand and generation is very sensitive to weather conditions. It is critical for electric power companies to know when, where and how much they can count on wind energy to provide electricity.

This is where the Meteorological Service of Canada's (MSC) expertise comes to the fore. MSC scientists have developed a complex modelling system called ***WEST – the Wind Energy Simulation Toolkit.*** WEST can look backward and forward in time to generate a wind atlas for any location in Canada with unparalleled detail. A wind atlas can be used to site wind farms in appropriately windy locations, dramatically reducing the need for field observations to verify the wind energy potential of a given area. WEST can also be run in predictive mode using the meso-scale model MC2 (Meso-scale Compressible Community Model) to forecast wind power up to two to three days in advance, enabling better operational decisions to be made by electricity generators.

Sophisticated software like WEST, coupled with the newest wind turbine technology will continue to make wind energy an even more attractive option for the future. WEST will help Canada achieve an environmentally responsible and cost-effective approach to electricity generation that will result in a reduction in the use of fossil fuels for cleaner electricity generation.

"WEST enabled us to model wind power potential for the entire African continent, from our offices in Montreal, using existing data. The results far exceeded anything we could have done using other models."

Richard Legault
CEO
Helimax Energy



A forecast of wind power for the Cowley Ridge Castle River wind farm in southwest Alberta, produced using MSC's WEST (Wind Energy Simulation Toolkit) and the Canadian Meteorological Centre's MC2 Community Model.

Providing Reliable Estimates of Snow Melt

Measuring Snow Water Equivalence

Snow melt in a Canadian prairie field.

Spring snowmelt is an annual event that is watched very closely throughout Canada. Even before the weather warms, farmers, electricity companies, water management authorities, forecasters, and others have an intense interest in knowing just how much water will be produced when the winter snow cover melts. The Meteorological Service of Canada (MSC) works to provide them with the answer. Providing reliable estimates of snow cover and its ***Snow Water Equivalent*** is a challenge that MSC continues to address. Satellites in space can be an important source of information.

Since the early 1980's researchers at the MSC have developed the capability to measure snow cover and its water equivalent using passive microwave sensors on satellites. The snow water equivalent (SWE) gives a direct estimate of how much water hydrologists and farmers can expect when the snow melts.

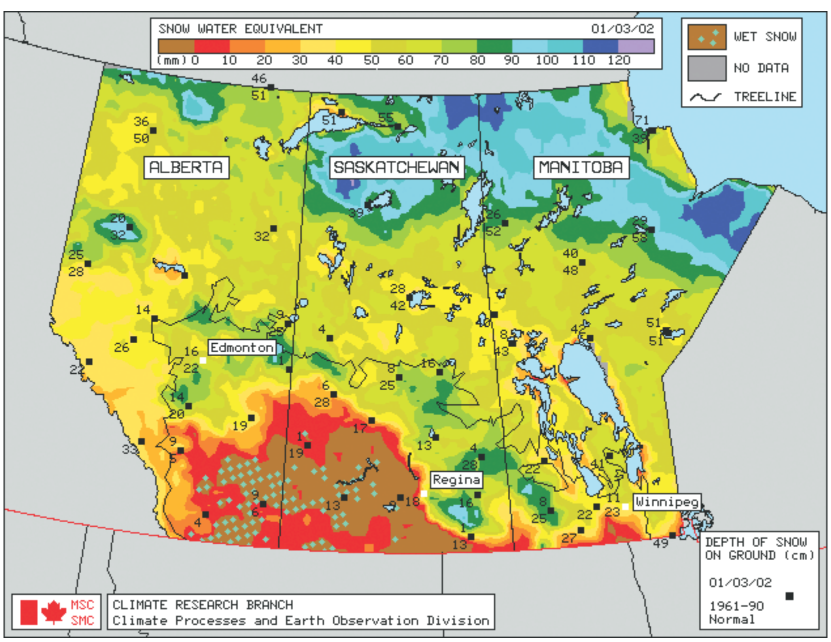
In-situ snow sampling to determine water content for the ground truthing of satellite measurements.

MSC scientists have developed algorithms that convert passive microwave data from satellites into estimates of SWE, which have been carefully evaluated by scientists and users such as the National Snow and Ice Data Centre. Focusing on the prairie and boreal forest environments in western Canada, scientists from MSC and collaborating universities have conducted extensive, on-ground verification of the SWE outputs – an essential step in building confidence in the numbers. Comparisons have also been conducted with airborne sensors to provide additional corroboration of the methods.

Each week during the snow season, electricity companies, water management and agricultural agencies, and MSC regional offices are sent SWE maps that they use to make operational decisions. Measuring snow from space has turned out to be a reliable and cost-effective way for MSC to provide mission-critical information to the agencies that rely on it.

"The passive microwave snow water equivalent maps have definitely improved real time flood forecasting and reservoir operations."

Alf Warkentin
Senior Hydrologic Forecaster
Water Branch
Manitoba Conservation



Satellite derived snow water equivalent (SWE) over the Canadian Prairie Provinces for March 1, 2002. The lack of snow cover in southern Alberta and southwestern Saskatchewan is a significant feature on the map, which contributed to the drought conditions that affected this area during the 2002 summer.

Providing Remote Communities with Safe Drinking Water

Fog Collectors

When scientists at the Meteorological Service of Canada (MSC) began collecting fog samples on the slopes of Mount Sutton, Quebec in the mid-1980s, all they really intended was to shed some light on the chemical composition of the fog. This was part of understanding acid rain and its impacts on forests. Little did they know that years later their work would be helping people around the world find safe drinking water.

It all came about when Chilean scientists approached Canada to examine ***fog collection*** technology for possible use in Northern Chile. This established a scientific collaboration that has lasted 17 years and is still going strong.

The Chilean fishing village of Chungungo has become synonymous with fog collection. The first operational fog collectors were built on the mountain ridge high above this coastal desert village. Consisting of simple wooden poles and plastic mesh, the collectors catch fog droplets as they are blown

Beads of water from passing clouds run down the fog collectors into a water collection system that provides the village of Chungungo, Chile with fresh drinking water.

through the mesh by the wind. Fresh, clean water from the clouds over the Pacific Ocean is caught by these mountainside collectors and flows downhill through a pipeline to the village.

The project couldn't have been more successful. The collectors provide an astounding average of 15,000 litres of safe drinking water each day of the year. Some days produce 100,000 litres of potable water! Perhaps the best indication of the suitability of the method is that the array is still functioning in 2003, eleven years after fog water first flowed to the village.

Chungungo has attracted worldwide attention. Many similar projects have already been launched, with plans for many more. Fog collectors are providing safe water in South Africa, Nepal, Haiti, Chile and Hawaii. The water is used for human and livestock consumption and for irrigation. Arid regions are being planted and sustained with fog water. Once the resulting vegetation gets established, it sustains itself by catching the fog droplets directly. This technique allows for arid, fog-impacted deserts, to become valuable forests or agricultural lands.

From a fishing village in Chile to a schoolhouse on a seaside cliff in South Africa, and even to the Himalayas in Nepal, MSC scientists have made a vital difference in many communities around the world.

"The work in Chile was pivotal and has lead to numerous other fog collection projects around the world."

Robert S. Schemenauer
Executive Director
FogQuest

The Chilean residents of Chungungo give thanks for a Canadian-led program that has brought fresh water to their village.

Canada's First Operational Storm Surge Prediction System

The Atlantic Environmental Prediction Research Initiative

A cottage near Savage Harbour in Prince Edward Island after being flooded by the storm surge of January 2000.

On January 21, 2000, the most severe storm in 35 years struck Atlantic Canada near Charlottetown, Prince Edward Island. The low atmospheric pressure in the heart of the storm pulled the surface of the ocean upward, while gale-force winds pushed the water towards shore – raising sea level to 1.5 metres over what was already an unusually high tide. The phenomenon, called storm surge, flooded coastal areas of P.E.I. and eastern New Brunswick, causing widespread damage to unprotected docks and other shoreline structures.

The impact of this storm surge resulted in the Atlantic Environmental Prediction Research Initiative which includes scientists from the Meteorological Service of Canada (MSC), Dalhousie University and other agencies such as the Department of Fisheries and Oceans, to focus on improving the prediction of ***ocean storm surge*** in the Maritimes.

Scientists from MSC and the University of Dalhousie's Oceanography Department coupled their independent weather and ocean models, so that the effects of weather systems and ocean dynamics could be combined to predict storm surges. The challenge was to provide forecasts and warnings with enough lead time that people could make decisions and take precautions when appropriate. Their initiative

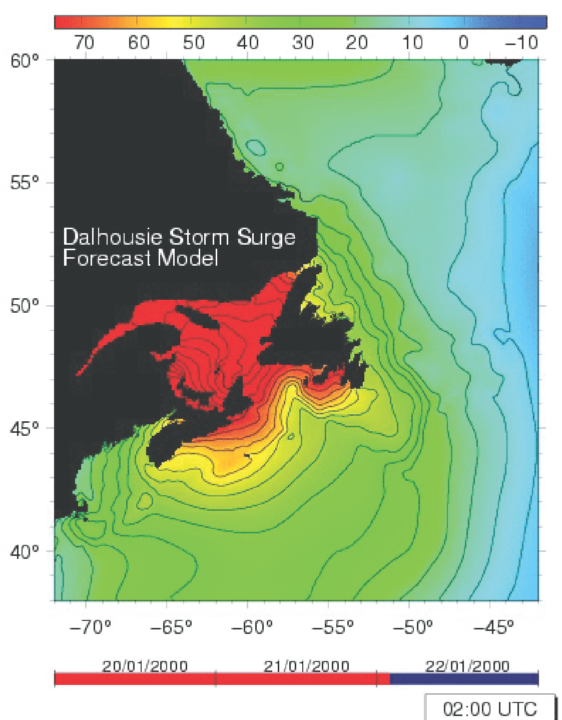
and expertise produced a new capability to forecast storm surges up to 48 hours in advance.

The storm surge prediction model was tested on February 6, 2001, when forecasters alerted P.E.I. Emergency Measures officials that storm surge conditions could be hazardous in an approaching winter storm. The storm was not nearly as severe as in January 2000, but it served as a good test of the improved forecast and warning methods. Officials monitored the strengthening winds and rising seas and warned those that might be at risk. The P.E.I. Department of Highways took precautionary measures to reinforce bridge embankments and the Rustico fire department kept residents informed of developments. The advance notice allowed local merchants to remove merchandise from their shops – avoiding water damage.

The Maritimes Weather Centre has since implemented the nation's first fully operational system for predicting storm surges and potential flood risks. Forecasters will now be able to give the public and local authorities the advance warning that they require to protect against wide-spread damage and to ensure personal safety.

"Environment Canada's Storm Surge Model and the information received were extremely critical in enabling P.E.I. EMO to notify the affected areas of the province and to monitor the situation as it unfolded."

David E. Campbell
Acting Manager
P.E.I. Emergency
Measures Organization



While running in experimental mode at the MSC's Atlantic Region, the Atlantic Storm Surge System produced very accurate forecasts for the January 21, 2000 severe storm surge. (Storm surge forecast in cm)

Transferring Knowledge for Service and Policy

Building the Bridge

The Meteorological Service of Canada (MSC) carries out mission-oriented research that focuses on improving weather forecasting, and predicting the impacts of climate change and air pollution on people and the environment. The MSC also investigates how Canadians can better adapt to changing atmospheric conditions. To be relevant to policy-makers and the public, MSC's research must be placed in the context of the issues that require service and policy solutions.

Each of the major projects presented in this report has made a difference because the scientific results have been accurately interpreted and effectively communicated to policy-makers and the general public. This process of bridging knowledge to service and policy is essential for the development of effective policy solutions and service needs.

Canadian Environmental Protection Act, 1999

Statutes of Canada 1999
Chapter 33
Act assented to 14 September 1999

Loi canadienne sur la protection de l'environnement, 1999

Loi du Canada (1999)
Chapitre 33
Loi sanctionnée le 14 septembre 1999

Individuals who accomplish this are the "bridgers". They may be scientists, advisors, or communicators. They maintain the integrity of the science and at the same time communicate it in a manner that is understandable to the non-scientific community - be it decision-makers, service providers or the general public.

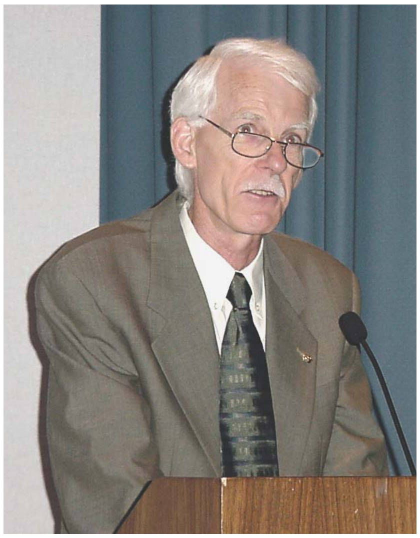
Bridgers keep current on all the relevant science and must often integrate knowledge over many disciplines in order to address complex issues. Acid rain, for example, required, and continues to require, meteorological, atmospheric, chemical, and ecosystem specialists to provide the scientific basis for the policy that addresses this issue.

New scientific knowledge typically takes 5-10 years to be integrated into service and policy products. MSC's long-term commitment to quality scientific research as illustrated by the projects presented in this report (many of which started a decade ago) has paid off in providing tangible products and services for Canadians.

"The science assessment and integration activities of MSC provide another impressive linkage to the national and international policy development process."

International Independent Peer Review, 2001

About our Scientists...



The scientists at the Meteorological Service of Canada (MSC) who study atmospheric phenomena come from Canada and elsewhere in the world, bringing with them the broad expertise and experience of the national and international science community. The scientists from the Atmospheric and Climate Science Directorate prepare approximately 200 scientific papers per year for publication in peer-reviewed journals. As well, they participate in national and international scientific bodies that review the state of knowledge for a given issue, such as climate change or stratospheric ozone, and provide leadership and input to the development of research programs and major field experiments. All of this is to further the collective global understanding of the atmosphere, and to lay the foundation for the development of effective environmental policy and services for the Canadian public.

Descriptions of current research activities within the Atmospheric and Climate Science Directorate can be found at *http://www.msc-smc.ec.gc.ca/acsd*.

Study and work opportunities for ***undergraduate students and graduate students, and post-doctoral fellows*** are available through government-university work-study programs, such as Science Horizons, through partnerships between MSC and the National Science and Engineering Research Council (NSERC) for:

- Summer student supplements;
- Graduate scholarship supplements; and the
- Visiting Fellows in Government Laboratories Program.

"The panel was impressed with the quality and the productivity of the research personnel of the MSC research & development program. Many of the individual scientists are recognized both nationally and internationally for their scientific contributions."

International Independent Peer Review, 2001

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A detailed description of specific scientific accomplishments over the period 1996-2001 is available in the document *Atmospheric and Climate Science Directorate - Report to 2002,* from the Meteorological Service of Canada, at the address below:

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