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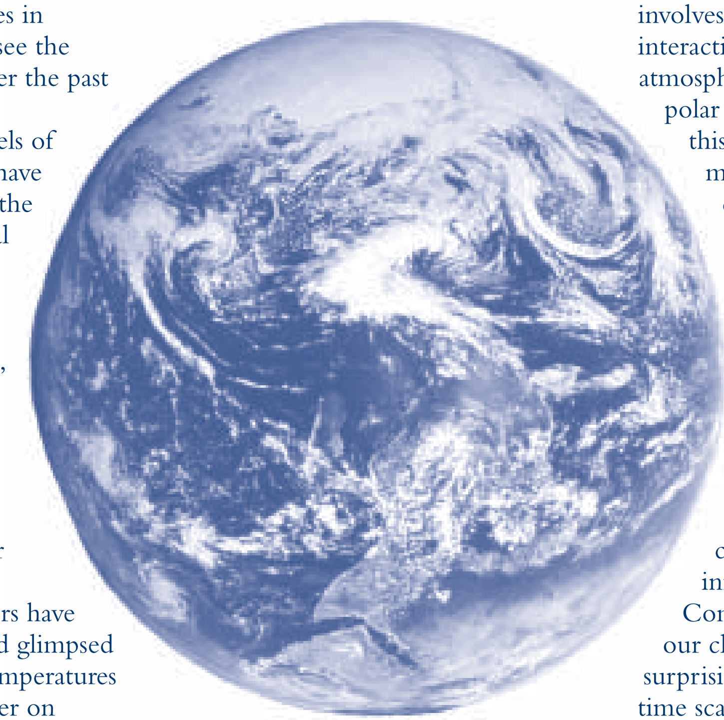
MODELS PUT SPIN ON FUTURE CLIMATE

Once only the territory of prophets and fortune tellers, forecasting the future has become more a matter of science than soothsaying over the past half century. Today, supercomputers capable of performing billions of arithmetic operations per second make it possible to predict the behaviour of many natural systems using mathematical models of the processes that make them tick.

Such models are particularly important when it comes to studying the impact of human activities on the environment, because they allow scientists to plug-in changes in certain variables and then see the possible consequences. Over the past four decades, results from increasingly complex models of our global climate system have raised awareness of one of the most serious environmental issues facing the world today: the dramatic warming effects of increases in carbon dioxide, methane and other heat-trapping "greenhouse gases" on the earth's atmosphere.

Using various scenarios for future emissions of air pollutants, climate modellers have looked ahead 100 years and glimpsed a world in which global temperatures may be nearly 4.5 °C higher on average than they were in 1985. Warming is expected to be even greater in Canada, and some parts of the Arctic could see average increases three times that magnitude. These warmer temperatures could have devastating implications—including a drastic reduction in sea ice and snow cover, changes to our water cycle and supply, and the enhanced survival of pests. Ecosystems and animals, such as polar bears, that can't adapt to their new surroundings could disappear forever.

Just how accurate is this picture of the future? Understanding how *well* climate models work means first understanding *how* they work. Simply put, climate models are very large computer programs that simulate the functioning of our global climate system in three spatial dimensions and in time. Climate models are based on the laws of physics, which govern the ways in which matter and energy interact. Woven into this framework are equations describing the different processes within the climate system, and how they respond to internal and external changes.



The earth from space. Photo: NASA

While early climate models represented only atmospheric processes, today's "coupled" models recognize that our climate system involves a myriad of complex interactions connecting the atmosphere, oceans, land surfaces and polar ice masses. Scientists simulate this system by linking individual models of each of these different components with the various processes by which they exchange energy and mass.

Climate models divide the air, land and oceans into a three-dimensional grid made up of thousands of interacting cells. As conditions in one cell change, they also have an influence on their neighbours. Computer-simulated versions of our climate have shown surprisingly realistic variability on time scales from hours to centuries. If

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you could step inside one of these models, you would experience weather and year-to-year changes in climate similar to those in the real world.

Involved in climate modelling since the 1970s, Environment Canada's work is based out of its Canadian Centre for Climate Modelling and Analysis (CCCma) in Victoria, British Columbia. The CCCma is one of a dozen centres around the globe currently developing coupled climate models, and one of only four whose models have been used by the Intergovernmental Panel on Climate Change to assess evidence of human effects on climate.

Environment Canada created its first coupled model in the mid-1990s, and is currently testing a third-generation version. These models run on a mammoth supercomputer at the Department's weather centre in Dorval, Quebec. The system's mind-boggling capacity to perform 128 billion arithmetic operations per second lets the climate model simulate three years of weather in a single day.

Canada's global climate model is made up of two main components: a general circulation model of the atmosphere and one of the ocean. The atmospheric component divides the atmosphere into a three-dimensional grid with 10 vertical layers extending a total of 30 kilometres above the earth's surface. Each cell in the grid has a horizontal resolution or "width" of about 300 kilometres. The atmospheric component simulates day-to-day weather—that is, the movement, temperature, pressure and density of air, clouds, the transfer of radiative energy through the atmosphere, and the hydrological cycle.

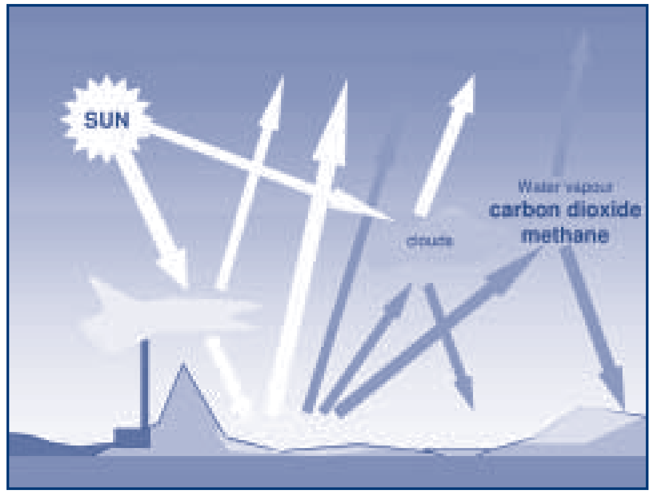

Illustration showing how anthropogenic (human-caused) influences, such as emissions of the greenhouse gases carbon dioxide and methane, affect climate by trapping heat in the atmosphere.

The ocean component, which simulates the ocean's circulation and water properties, has 29 vertical layers and a horizontal resolution of 150 kilometres. It reproduces the large-scale features of the ocean's circulation, as well as important water properties such as temperature, density and salinity. The model also has a sea-ice component that allows ice to form and melt as it exchanges heat with the ocean and atmosphere, and to move naturally with the currents and winds. Finally, there is a land-surface component that calculates variations in soil moisture and surface temperature, evaporation, and reflectivity.

Coupling these components is no easy task. The ocean and atmospheric models must first be individually "spun up" to a state representative of the present climate—a process that takes only a few decades of simulated time for the atmospheric component, but several thousand years of simulated time for the ocean

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TOMORROW'S CLIMATE

What does the Canadian Global Coupled Model (CGCM1) predict for the future?

- *Average global surface temperatures increase by about 1.7°C above 1985 levels by 2050 and nearly 4.5°C by 2100. Increases over land are higher than over the ocean, with the former warming by 6°C and the latter by 3.5°C by 2100.*
- *In Canada, cold extremes become less severe and less frequent with time, while extreme maximum temperatures become hotter and more frequent.*
- *Average global precipitation increases by about 1 per cent by 2050 and 4.5 per cent by 2100. By 2090, precipitation over most of Canada increases by 10-20 per cent, and damaging precipitation could double in frequency.*
- *Combined with warmer temperatures, North America experiences a notable decrease in available soil moisture.*
- *Major changes occur in sea ice coverage in the Northern Hemisphere, with the annual mean coverage decreasing by about 40 per cent by 2050 and virtually disappearing by 2100.*
- *Average global sea-level rises about 40 centimetres by the last two decades of the 21st century, mainly as the result of the thermal expansion of ocean waters.*

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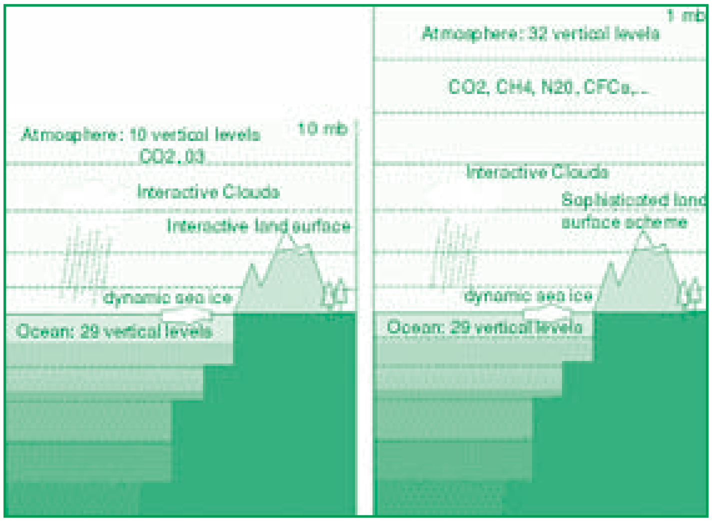


Schematic comparing some of the differences between the structures of the second-generation Canadian Global Coupled Model (left) and the third-generation version of the Model (right).

component, which evolves much more slowly. Once they have been coupled, inaccuracies in the modelled flow of heat and moisture between the ocean and atmosphere are difficult to avoid, and would eventually cause the simulated climate to drift if not corrected using a "flux adjustment". This adjustment has become smaller with each successive generation of the climate model.

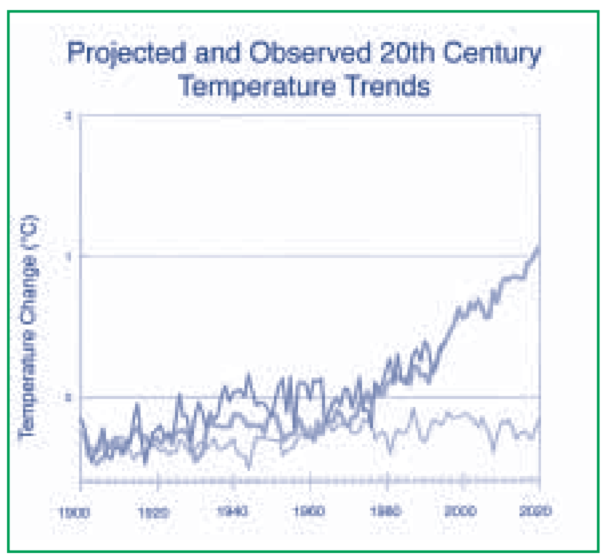
An important test of a climate model is whether it can reproduce the changes in global mean temperature observed during the past 150 years when it is run with known changes in greenhouse-gas and aerosol concentrations. Although current models pass this test, scientists point out that there is room for improvement. For example, the influences of many surface features, such as mountains and vegetation, can only be estimated because the resolution of the model does not allow it to "see" features smaller than 300 kilometres across.

Two other areas of the model that require improvement are those dealing with clouds and aerosols. Clouds, which can both reflect and trap solar rays, are difficult to represent not only because their basic physics isn't well known, but also because they occur on a small scale and are highly chaotic. Aerosols are tiny particles in the atmosphere that are a product of fossil fuel combustion. Although they have a direct cooling effect on climate by reflecting the sun's energy back into space, they also have an uncertain indirect impact resulting from their effect on the reflectivity and longevity of clouds.

In an effort to address these and other shortcomings, Environment Canada is actively developing new models with collaborators in Canada's universities. A third-generation coupled model is now running in test mode. Its atmospheric component has many improved physical processes and 32 vertical layers extending 50 kilometres above the earth's surface. It also has a multi-layer land-surface model that includes a vegetative canopy, flowing rivers that carry runoff to the ocean and a representation of ice sheet processes that operate in Greenland and Antarctica. While tests on the third-generation model continue, further work is under way to incorporate the carbon cycle—the continuous transfer of carbon back and forth between the atmosphere and living organisms—into the model.

In the meantime, researchers at the Université du Québec à Montréal are refining a regional climate model that is nested in Environment Canada's global model and operates at a finer horizontal scale of 45 kilometres. This regional model uses data from the larger-scale model in much the same way that regional weather forecasts use data from global forecasts. Already tested in a series of simulations of the current and future climate in western Canada, the model will soon be used to create the first high-resolution assessment with a dynamical model of how global climate change will affect the different regions of Canada.

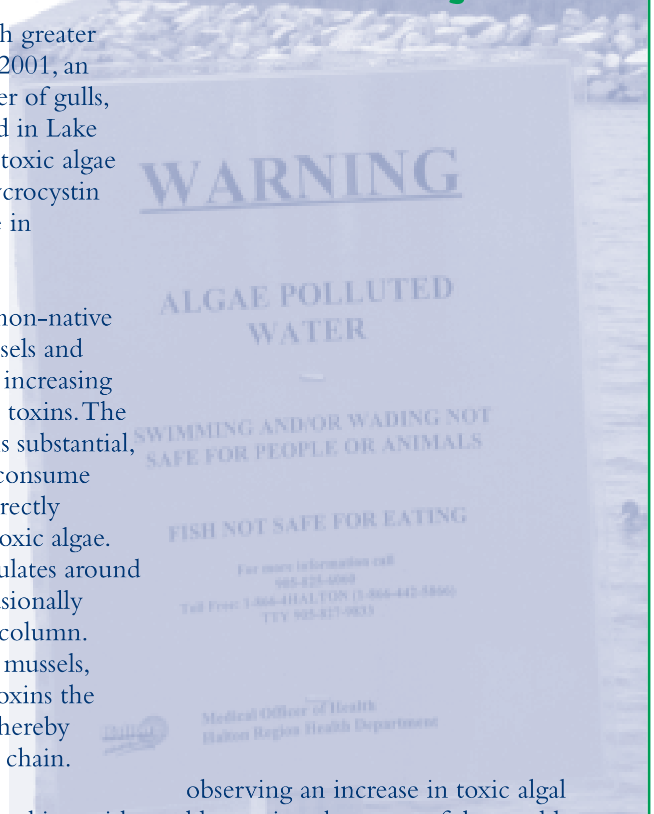
While there will always be room for improvement, today's models provide us with remarkably realistic forecasts of the future state of our environment. Such forecasts are not only useful in the formulation and implementation of policies to reduce environmentally harmful human activities—they also allow us to develop strategies for adapting to the impacts of droughts, floods and other related risks of climate change. S&E



Trends and variations in average global surface temperatures as simulated by the Canadian Global Coupled Model 1. The thin, lower line is the model's control run; the thickest line the model's greenhouse-gas and aerosol runs; and the other line (which ends in the year 2000) shows observed climate trends.

TOXIC ALGAE THREATEN WATER QUALITY

"Swimming not safe for people or animals." "Fish not safe for eating." These messages posted around Hamilton Harbour in southern Ontario last summer were grim warnings of a growing threat to water quality in Canada and around the world: toxic algae.



Scientists from Environment Canada's National Water Research Institute became aware of the problem when they discovered high levels of the toxin "microcystin" in algae samples taken from the Harbour. Coupled with these dangerous toxin levels was a suspected minor outbreak of avian botulism—a deadly form of food poisoning that affects birds and is caused by the bacterium *Clostridium botulinum*.

The situation seemed paradoxical: Hamilton Harbour has been slowly recovering over the years from the impact of vast quantities of industrial and other pollution. Yet, even as levels of nutrients and toxic sediments were decreasing and water chemistry was improving, a new environmental threat was emerging.

In 1996, departmental researchers worked with Ducks Unlimited to investigate an outbreak of avian botulism that had killed over 200 000 ducks at Whitewater Lake, Manitoba. At the time, they had detected the presence of algal toxins at the lake but had not been able to determine the precise link between the toxins and the disease. Although the researchers speculated that small animals killed by the toxins may have served as a breeding ground for the bacteria—which then spread to the birds—further study is required to support this hypothesis. They did, however, determine why certain areas of the lake were more toxic than others. Nutrients released by the lake sediment were being carried by the wind and deposited in these areas, creating hotspots conducive to toxic algae production.

These same researchers are now focusing their attention on the Great Lakes region, where toxic algal blooms are occurring with greater frequency. From 1999 to 2001, an exceptionally large number of gulls, loons and mergansers died in Lake Erie, despite the fact that toxic algae in the lake have lower mycrocystin concentrations than those in Hamilton Harbour.

Researchers suspect that non-native species, such as zebra mussels and gobies, may play a role in increasing the bioavailability of such toxins. The biomass of zebra mussels is substantial, so when they selectively consume non-toxic algae, they indirectly enhance the presence of toxic algae. The rejected food accumulates around their colonies, and is occasionally resuspended in the water column. When gobies feed on the mussels, they bioaccumulate any toxins the mussels have consumed, thereby passing them up the food chain.

Environment Canada is working with the State University of New York to address this complex problem. Through field and laboratory experiments and computer models, researchers hope to gain a better understanding of the environmental conditions that trigger the growth of the algal blooms and the interactions between the blooms and the surrounding ecosystem—particularly the food web. They want to know how a warmer climate and greater penetration of ultraviolet light are affecting Lake Erie, and the impact these are having on the growth of toxic algae. They also plan to test the effectiveness of treatments to control the blooms, such as applying clay and iron. The iron-enriched clay is sprayed from a boat to precipitate algae and lock them in the sediments.

This problem is not unique to North America. Scientists are not only observing an increase in toxic algal blooms in other parts of the world, but also discovering species of algae in northerly locations that were once found only in tropical lakes. In Japan, toxic *Heterocapsa* algae have almost destroyed the oyster industry.

Environment Canada is collaborating in international research efforts to confront this global phenomenon. For example, the Department is working with Japanese scientists to explore how sulphur loading may have contributed to the recent appearance of blue-green algal blooms in Lake Biwa, the largest freshwater lake in Japan.

Many factors—from local nutrient discharges to global air pollution and climate change—may be involved in this emerging threat to global water quality. Researchers are now beginning to grasp the scope of the problem and to develop strategies to resolve it. S&E

HEDGEROWS A FINAL FRONTIER ON FARMS

The intensification of agriculture over the past 50 years has spurred the creation of larger and more productive farms in many regions of North America. To maximize the use of cultivable land, hedgerows, woodlots and riparian (riverside) habitats in these regions are becoming progressively smaller, narrower and more isolated.

Compounding the pressure on these uncultivated areas is the fact that many farmers view them as homes to species of plants and animals that are harmful to nearby crops. As a result, vegetation on any such remaining habitat is often removed or controlled using mechanical or chemical methods—making it less useful to wildlife and more vulnerable to invasion by weeds and non-native plant species.

In highly fragmented rural landscapes, uncultivated strips serve not only as vital breeding and foraging areas for many species, but also as green wildlife corridors linking isolated islands of natural habitat. Riparian strips also prevent riverbank erosion and help to maintain water quality, while hedgerows decrease wind erosion and pollution.

Environment Canada biologists have been working with scientists at the Société de la faune et des parcs du Québec to assess the importance of these shrinking habitats to biodiversity in the St. Lawrence Plain ecoregion of southern Quebec. Inventories of plant and animal species in riparian habitats on the Boyer River watershed and in rural hedgerows in the Saint-Hyacinthe region have yielded interesting results.

The Boyer River studies covered various types of riparian habitat, ranging from those grazed by livestock to those containing a mix of trees, shrubs and other vegetation. Overall, findings indicated that habitats with more complex vegetative structures contained a greater diversity of species but a lesser number of pest species. This is likely because the more complex the vegetative structure of the habitat, the better it is able to provide nesting sites, cover from predators, and food in the form of fruit, seeds, foliage and invertebrates.

For example, the wooded habitats contained more plant species but fewer weeds than other riparian habitats. They also had the greatest diversity and abundance of birds, including insect-eating species such as Black-capped Chickadees, flycatchers, warblers, woodpeckers and vireos, which serve as important non-chemical forms of pest control for the surrounding fields. The abundance of Red-winged Blackbirds—a potentially crop-damaging species—was higher in wooded habitats, but nonetheless low in adjacent cropfields.

Other studies showed that the diversity and abundance of small mammals also increased with vegetative complexity, while the abundance of small rodent pest species actually decreased. For amphibians and reptiles, number and species richness was highest in shrubby habitats—illustrating the importance of protecting a variety of types of land within the watersheds. Of particular relevance to farmers, however, is the fact that nearly two-and-a-half times as many insect-eating mammals and amphibians were found in wooded riparian habitats than in herbaceous ones—once again, indicating the value of such habitats in controlling insect pests.

These findings were echoed in studies of plant and bird diversity in unused strips of land bordering farm fields in Saint-Hyacinthe. Three types of field margins were inventoried—natural hedgerows containing a mix of trees and shrubs; planted windbreaks made primarily of coniferous trees; and herbaceous fencerows without any trees (the most abundant type).

A riparian (riverside) ecosystem in rural Quebec.

Plant diversity was highest in the natural hedgerows, which also contained more species of conservation value (such as native perennials) than the others. More introduced species and weeds were found in planted windbreaks and in fencerows than in natural hedgerows, as such plants grow more easily in disturbed habitats. In fact, weeds made up approximately half the vegetation growing in planted windbreaks.

Underlining the theory that plant diversity supports larger insect communities, birds used natural hedgerows and planted windbreaks more than fencerows—and most species were insect-eaters using these habitats as nesting and foraging sites. As in riparian habitats, large and structurally complex hedgerows harboured a greater diversity of bird species. Very few bird species considered potentially harmful to crops were observed in the hedgerows and in adjacent cropfields.

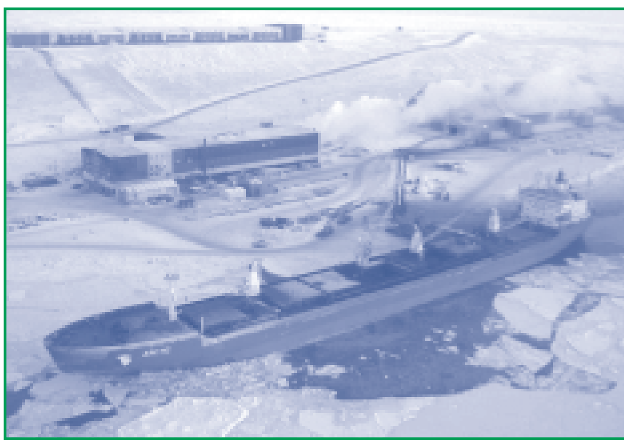
Sustainable development is of prime concern to the future of both Canada's environment and its agriculture. These studies offer strong evidence that the preservation of natural hedgerows and riparian habitats—particularly those with a complex vegetative structure—is an efficient conservation strategy that can benefit farmers as well as wildlife. S&E

KEEPING AN EYE ON CANADA'S ICE

Ice conditions on Canada's shipping routes can be fickle and dangerous. In a matter of hours, a shift in wind or tide can suddenly close an open path and trap ships between massive, hull-crushing floes. In early summer, the waters off the coast of Labrador become a minefield of giant icebergs, which threaten ships and oil-rig operations in the area.

Environment Canada helps ships find a safe route through Canada's frozen waters through the work of its Canadian Ice Service (CIS). The CIS combines data from satellite images, airborne radar and visual observations with weather and oceanographic information to create charts and forecasts of ice and iceberg conditions for the Canadian Coast Guard, the shipping and fishing industries, offshore oil and gas companies, and environmental researchers.

Since it was formed in the 1960s, the Ottawa-based service has evolved from half a dozen to more than 80 employees—a third of whom spend nine months of the year in the field. These ice specialists carry out six-week tours of duty aboard Coast Guard icebreakers, advising the captain about local ice conditions that might affect the ship. In addition to receiving satellite images and other large-scale data by Internet, they gauge ice concentration, thickness and type from ship and helicopter observations, and by flying reconnaissance missions on aircraft equipped with radar mapping systems.



The M.V. Arctic *loading cargo at the Polaris Mine on Little Cornwallis Island, in the Arctic.*

Photo: Graham Campbell

Generally speaking, ice looks lighter in colour the thicker it gets, so that new ice (under 10 cm thick) appears dark, while first-year ice (30+ cm) appears white. Thermodynamic models based on air temperature help to estimate thicknesses greater than this when the ice is often covered by snow. Ice also evolves as it ages. When it first freezes, it contains air bubbles, salt and other impurities that make it less dense. If it survives the summer melt, however, these impurities drain out and the air holes fill with water that refreezes, making this "multi-year" ice clear blue and as hard as steel.

Knowing the concentration, thickness and age of ice is of utmost importance to ships, because of differences in hull strength and power. Most foreign cargo ships plying the waters of the St. Lawrence River start to have difficulty in 15 cm of concentrated ice, while larger ships with more power and stronger hulls can navigate in much thicker ice. With 20 000 horsepower, the *Louis St. Laurent*—Canada's largest icebreaker—can cut a swath through ice up to two metres thick, while Russian nuclear icebreakers equipped with 75 000 horsepower roam the Arctic Ocean at will.

To put all this information into a usable format, ice analysts and forecasters in Ottawa produce large-scale (1:2 000 000) maps known as ice charts. These charts show the location and extent of the ice coverage in an area roughly the size of the Gulf of St. Lawrence at a specific date and time, and describe the various qualities of the ice in numerical terms inside an oval-shaped "key" called the egg code. Several charts are produced each day to span all areas where ships are operating in the vicinity of ice.

Since satellite, radar and observational data are collected at different times, a sophisticated coupled ice-ocean model helps forecasters integrate them to create a snapshot of the ice conditions at 1 p.m. Eastern Standard Time each day. The model, which simulates ice movement and development, is able to forecast conditions to about 48 hours in the future, and is very dependent on numerical weather forecasts from the Canadian Meteorological Centre in Dorval, Quebec. It also tells forecasters about how the ice is changing—melting, breaking up, or freezing—and whether the pressure in the ice is increasing or decreasing.

A text bulletin of the daily chart is broadcast over marine radio to provide information on significant ice factors, along with a short-term

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forecast of any hazardous ice situations. Larger-scale (1:4 000 000) charts are also produced as weekly and monthly overviews of conditions for longer-term planning and climatological purposes. Seasonal and monthly forecasts are created from past records and current conditions to give users a sense of longer-term prospects for shipping. A collection of over half a million charts, radar and satellite images and other data are kept in the Canadian Ice Data Archive for climate and environmental impact studies, legal purposes, planning the re-supply of northern communities, tourism, fishing and other activities.

Two main seasons keep Environment Canada's ice experts busy almost all year round. The winter shipping season in the Great Lakes, the Gulf of St. Lawrence, the St. Lawrence River and off the east coast of Newfoundland runs from mid-December to mid-May. Home to three of the five largest ports in

Ice Service specialists using a gas auger to measure the thickness of sea ice.

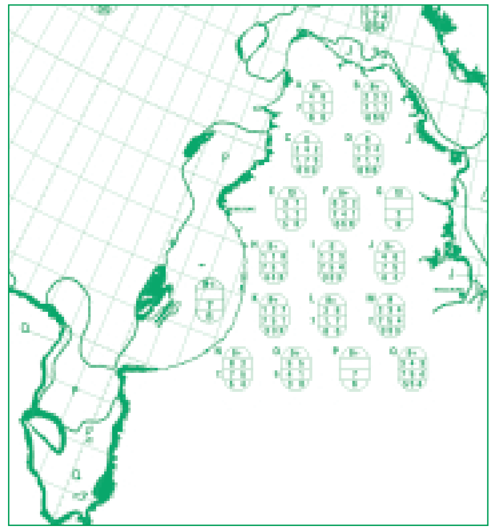
Canada—including Montréal and Sept-Îles—the St. Lawrence is kept open year-round, and sees about 1500 ships through each winter. Although there is less activity on the Great Lakes because the locks at Sault Ste. Marie and Welland are closed from late December on, a fair bit of shipping still takes place on lakes Huron, Erie and Michigan.

Arctic waters are frozen over during winter, but open up in the summer, allowing ships to pass from around mid-May to early November. With decreasing ice in recent years, improved technologies, and greater economic incentives, ships are heading into the Arctic earlier and staying later each year—making accurate, up-to-date forecasts of ice conditions more important than ever.

During the summer shipping season in the Arctic, ships travel to northern communities to re-stock them with supplies for the coming year, as well as to export ore concentrates from mines that have been active all winter. The port at Churchill, Manitoba, on Hudson Bay, receives some 30 ships during the summer that pick up Prairie grain bound for South America. Recent years have also seen a surge in eco-tourism, with some half a dozen cruise ships regularly exploring the Arctic waterways.

Monitoring icebergs is a small but integral part of Environment Canada's ice-related responsibilities. Each year, as many as 3000 icebergs—most of them originating from Greenland glaciers—make their way south along the Labrador coast and the Grand Banks of Newfoundland. Although they melt rapidly upon reaching the Gulf Stream, they pass through the transatlantic shipping lane on the fog-shrouded Grand Banks, posing a collision hazard to both ships and offshore oil rigs.

Although the Hibernia oil-production platform was built to withstand the impact of a one-



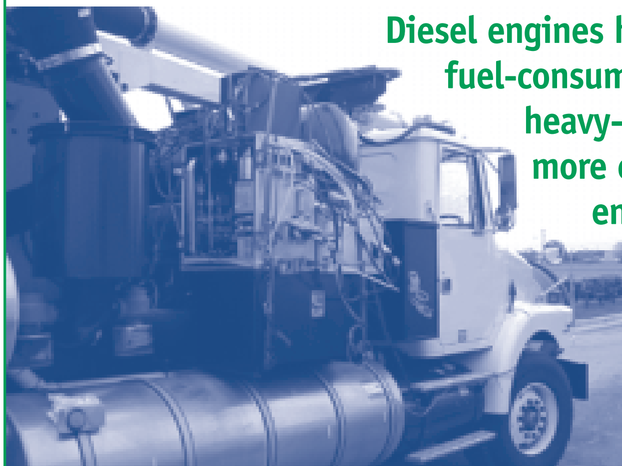
Close-up of an ice chart showing the "egg codes" used to convey information about the thickness, type and distribution of ice in frozen waters.

million-tonne iceberg, its operators still use tugboats to tow or deflect any bergs that come within range of the rig. Other oil rigs are simply stationary ships not equipped to withstand any collision, so they require at least 12 hours' notice to deflect potentially hazardous icebergs, or to detach their fitting and move out of harm's way.

Environment Canada provides daily iceberg maps and forecasts to these and other clients that indicate the concentration of icebergs found within the "Limit of All Known Ice" delineated by the International Ice Patrol. These maps are created by combining radar and visual data with models that simulate the erratic and speedy movement of the icebergs and their disintegration over time.

From mid-November to mid-December, when the southern shipping lanes are clear and the Arctic is frozen up, the Department continues to monitor ice conditions in both regions for historical purposes. Records dating back to the 1940s have been helpful not only in raising awareness of the changes our climate has undergone in recent years, but also in improving our understanding of the important role that sea ice plays in our global climate system. S&E

TECHNOLOGIES MAKE DIESELS LESS DIRTY



Diesel engines have long been the technology of choice for high fuel-consuming vehicles such as buses, transport trucks and heavy-duty construction equipment. Although they are more efficient and longer lasting than gas-powered engines, diesels have a dark side when it comes to creating urban smog and particulate matter.

Emissions sampling equipment mounted on a truck to determine the effectiveness of various diesel emission-control technologies.

A typical diesel-powered vehicle emits one-and-a-half to two times as much nitrogen oxide into the air as a comparable gas vehicle. When nitrogen oxide and volatile organic compounds react in sunlight and stagnant air, they form ground-level ozone—the main component of smog. Diesels are also major contributors to urban particulate matter, which can carry carcinogens and cause respiratory health problems in people.

Canada's federal Ministers of Health and the Environment have declared particulate matter smaller than 10 microns in diameter (PM_{10}) as toxic to human health and the environment under the *Canadian Environmental Protection Act*. Such tiny particles are a health risk because they can be inhaled deep into the lungs.

As part of its clean air agenda the federal government has proposed regulations to mandate low-sulphur diesel for on-road vehicles by mid-2006, and will soon propose stringent new emission regulations for on-road diesel vehicles and engines. Combined, the low-sulphur fuel and the emission regulations will reduce particulate matter emissions from new diesel vehicles by 90 per cent over current regulated levels.

Environment Canada also works closely with manufacturers, fleet operators and others across North America to develop and verify after-market technologies using chassis dynamometers and other advanced sampling and analysis equipment at its Environmental Technology Centre in Ottawa.

Recent technology development work has included cooperating with consortia in Ontario, Quebec and New York State to examine emissions from diesel-electric hybrid buses. Such hybrids have been proven to produce lower emissions of all types because they are equipped with advanced controls that allow them to recapture wasted energy, and to operate in the most fuel-efficient and least polluting mode. The Department has also been involved in emissions testing on New York City buses using ultra-low-sulphur fuel and equipped with a particulate filter system. Over the first eight months of operation, the buses showed a greater than 90-per-cent reduction in emissions of particulate matter, carbon monoxide and hydrocarbons.

Since construction equipment is a significant contributor to total nitrogen oxide emissions, many tests have also been carried out on heavy-duty non-road equipment, such as bulldozers, dump trucks and backhoes. Trials carried out in New England on equipment retrofitted with various exhaust-emission control technologies showed that they can achieve substantial in-use emission reductions.

For example, diesel oxidation catalysts—which use the temperature of the exhaust to convert carbon monoxide and hydrocarbons to carbon dioxide and water and to oxidize the organic fraction of the particles—reduced particulate matter by an average of 23 per cent. Other engines equipped with catalyzed particle filters showed reductions of up to 97 per cent for particles and 66 per cent for carbon monoxide and hydrocarbons.

Emissions tests carried out on diesel construction equipment in Houston, Texas, confirmed that vehicles using a new blend composed of diesel fuel, purified water and an additive package exhibited nitrogen oxide reductions of up to 41 per cent and particulate matter reductions of up to 69 per cent—all without requiring any changes to their existing engines. Particle filters and catalyst systems also fared well when added to in-use vehicles, cutting nitrogen oxide emissions by up to 81 per cent, total particulate matter by up to 83 per cent, and carbon monoxide emissions by up to 95 per cent.

The results of these and other tests offer strong proof that many after-market technologies may be added to in-use diesel engines to significantly reduce their production of harmful emissions. If such technologies were applied to even a small portion of the diesel vehicles in Canada and the United States today, they would help to reduce the risk of smog-related health problems. S&E

S&E Bulletin

This bi-monthly newsletter provides information on Environment Canada's leading-edge science and technology.

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Scientific contacts may be obtained from the *Bulletin*'s editor at Paul.Hempel@ec.gc.ca, or (819) 994-7796. Comments and suggestions are also welcome.

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