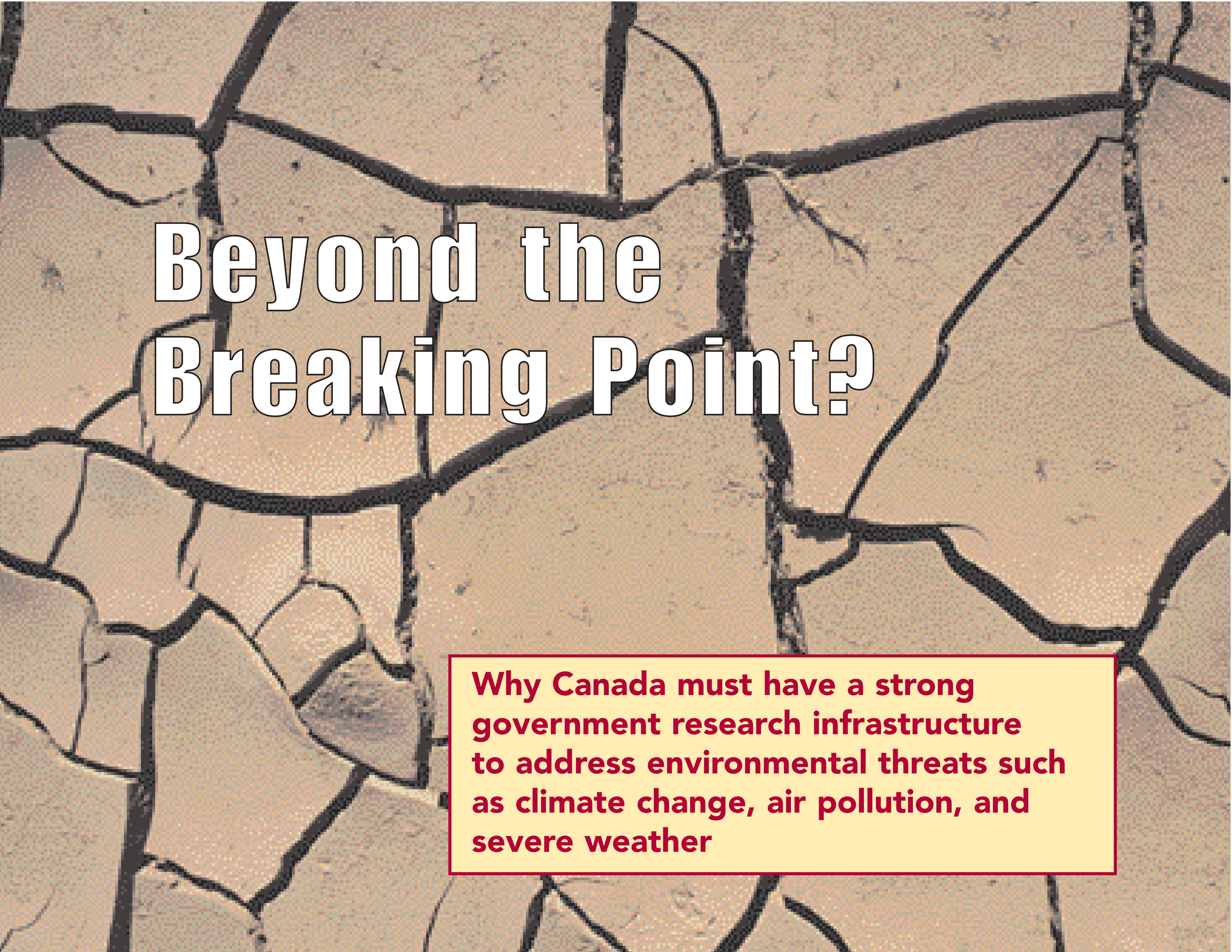

Beyond the Breaking Point?

Why Canada must have a strong government research infrastructure to address environmental threats such as climate change, air pollution, and severe weather

BEYOND THE BREAKING POINT?

WHY CANADA MUST HAVE A STRONG GOVERNMENT RESEARCH INFRASTRUCTURE TO ADDRESS ENVIRONMENTAL THREATS SUCH AS CLIMATE CHANGE, AIR POLLUTION, AND SEVERE WEATHER

"The role of government is to represent the future to the present."

▼▼▼

Lester Thurow
Massachusetts Institute of Technology

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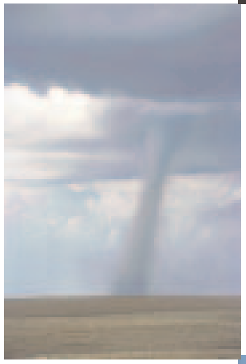


AN OPEN LETTER TO CANADIANS AND THEIR ELECTED REPRESENTATIVES

Atmospheric research is hardly a common topic of conversation among Canadians, but it is nevertheless a matter of vital importance to all of us. It is important because atmospheric research underlies our capacity to provide reliable weather forecasts and climate information as well as our ability to respond to pressing environmental issues. Without continuing research in atmospheric and climate science, our ability to improve weather forecasts and give earlier warnings of tornadoes, blizzards, and other dangerous events is diminished. So too is our capacity to develop policies and programs to minimize the impacts of climate change, acid rain, ozone depletion, smog, and other environmental problems.

Over the years, Canadians have developed an expertise in the atmospheric sciences that is recognized worldwide for its excellence. Much of that expertise has been based in government, for the most part in the Meteorological Service of Canada (MSC), an organization whose research programs have been described by international experts as "representative of the best the global science community has to offer." The universities are the other major source of expertise in this country, and a good deal of what has been achieved in Canadian atmospheric science has been the result of a close collaboration between MSC scientists and their academic counterparts.

As a result of cost-cutting pressures, however, MSC's ability to sustain leading-edge research is deteriorating. After peaking in the first half of the 1990s, funding for government research in atmospheric and climate science has declined steadily. In 2002 lack of funds forced the closure of one of MSC's most important research assets, the Eureka observatory in the High Arctic. Temporary funding from a university consortium brought Eureka back into service in 2004, but the long-term future of this vital facility remains in doubt. In addition, cuts to important data collection networks, already thin by international standards, loom on the horizon. Faced with an increasingly frustrating research environment, MSC's top scientists are departing for more rewarding research opportunities elsewhere and replacements are becoming harder to recruit. According to international reviewers who audited MSC's research program in 2001, "even a doubling of [its climate] research budget over, say, a five-year period would still be regarded internationally as a comparatively low commitment to its stated interests in climate understanding and services."

As the downgrading of its research capabilities continues, there are concerns that MSC's research role may eventually be phased out altogether, and the leadership and excellence that it provided in the past may no longer be available to the Canadian scientific community.

These funding cuts may have been made in the belief that government does not need to be in the business of research, that any reduction in research now done by government agencies can be compensated simply by supporting more research in the universities. While we applaud recent increases in university research funding, we must also stress that MSC plays a critical and indispensable role in atmospheric and climate science research in this country. That role cannot easily be assumed by another organization. MSC is, in fact, the backbone for virtually all major long-term atmospheric and climate research in this country, providing the extensive resources, long-term commitment, and administrative and technical support that only a large government organization can offer.

Universities cannot provide many of these resources, nor can they guarantee the sustained commitment needed for long-term research programs of the kind needed to address issues such as climate change or smog. Consequently, many university scientists depend heavily on MSC support and collaboration to further their research goals. Without the involvement of MSC, some very significant research in which Canada is now a world leader would have to be pursued at a much lower level of sophistication.

Furthermore, universities alone cannot provide the full range of scientific advice that government needs. Their research, quite rightly, is driven by the interests of individual scientists, not by government policy needs. Those interests and the government's needs do not always coincide, especially in the case of mature issues such as acid rain or protection of the ozone layer. But government still needs research-based scientific advice to update regulations, negotiate international treaties, and do many of the other things needed to manage these issues effectively. Only a government agency, such as MSC, can be relied upon to provide fully up-to-date advice when it is needed.

In 2001, the federal government announced its intention to make Canada one of the top five countries in the world for research and development performance by 2010. In atmospheric and climate science, however, Canada reached that goal more than a decade ago. It could not have done so without the existence of MSC, whose approximately 300 research personnel account for nearly half of the atmospheric and climate research done in Canada, and it cannot continue to maintain its leading status without the continuing presence of a strong research arm within MSC.

There is no doubt in our minds that if the downgrading of MSC's scientific capacity continues over the longer term, it will seriously diminish both the quality and quantity of work being done in the atmospheric sciences in Canada. Government will then be less able to develop policy and services on the basis of sound science, academic scientists will have fewer opportunities to participate in major long-term research projects, and the Canadian public will be served less effectively by both their government and their universities.

As citizens we want our government to have the best available expertise to improve the quality of weather services and address difficult environmental issues such as climate change. As members of the Canadian atmospheric science community, we want to be able to deliver a level of expertise that meets the highest world standards. That will only be possible, however, if the federal government provides the stable long-term funding needed to maintain a high-quality advanced research organization within MSC.

The research arm of the Meteorological Service of Canada is one of this country's most valuable scientific assets. It should not be allowed to decline gradually into insignificance as a result of continued underfunding.

Terry Bidleman
Meteorological Service of Canada

George Boer
Meteorological Service of Canada

Jan Bottenheim
Meteorological Service of Canada

Jean Côté
Meteorological Service of Canada

Jacques Derome
McGill University

Miriam Diamond
University of Toronto

James Drummond
University of Toronto

George Isaac
Meteorological Service of Canada

James Kerr
Meteorological Service of Canada (retired)

Charles Lin
McGill University

John McConnell
York University

Gordon McBean
University of Western Ontario

Thomas McElroy
Meteorological Service of Canada

Norman McFarlane
Meteorological Service of Canada

Harold Ritchie
Meteorological Service of Canada

Ted Shepherd
University of Toronto

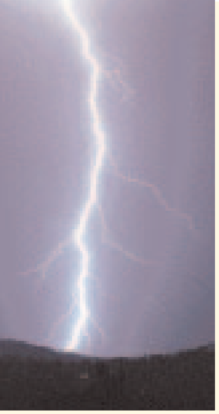
Ronald Stewart
McGill University

Peter Taylor
York University

David Wardle
Meteorological Service of Canada

Andrew Weaver
University of Victoria

Francis Zwiers
Meteorological Service of Canada



ATMOSPHERIC SCIENCE AND GOVERNMENT

Government is society's greatest consumer of atmospheric science information. That is because governments have major responsibilities for public safety, health, economic development, communications, and environmental protection – and all of these are affected in many ways by weather events and climate conditions. As a result, governments have been obliged to develop an extensive array of reporting and forecasting services to help citizens plan for routine changes in the weather and survive its harmful extremes. As society has become more aware of the human impact on the environment, governments have also been obliged to develop policies and controls to deal with major issues such as atmospheric pollution and climate change.

The information that government needs to meet these obligations takes a variety of forms. Some of it consists of atmospheric observations, which must flow continuously from all regions of the country to provide a basis for weather forecasting and climate analysis. Some of it is knowledge of atmospheric processes, which is needed to develop more reliable ways of predicting hazardous weather events such as tornadoes or storms, for example – or to increase understanding of issues like acid rain, climate change, or ozone depletion so that policies and strategies can be developed to deal with them.

To ensure that such information is available, governments have traditionally maintained an in-house establishment of atmospheric science specialists. Canada is no exception and depends on the Meteorological Service of Canada, a branch of Environment Canada, as a source of expertise. In addition to providing essential meteorological services, MSC also responds to other government needs – conducting detailed assessments of issues for decision makers, for example, or giving advice and background information to ministers, developing regulations, answering questions from MPs, the media, and the public, and providing support for intergovernmental negotiations.

But getting all of the knowledge needed to provide advanced weather services and develop responses to baffling environmental issues such as atmospheric pollution and climate change also demands a capacity for research. Improving the accuracy and range of weather forecasts, for example, requires better knowledge of atmospheric processes, more

> "It is imperative that the Canadian government provide a strong, ethical civil service to provide science for the public good. It is essential for protecting the health of Canadians and the environment."
>
> *Miriam Diamond*
> *University of Toronto*

... inflation continues to erode MSC's capacity to meet present research commitments and undertake future ones.

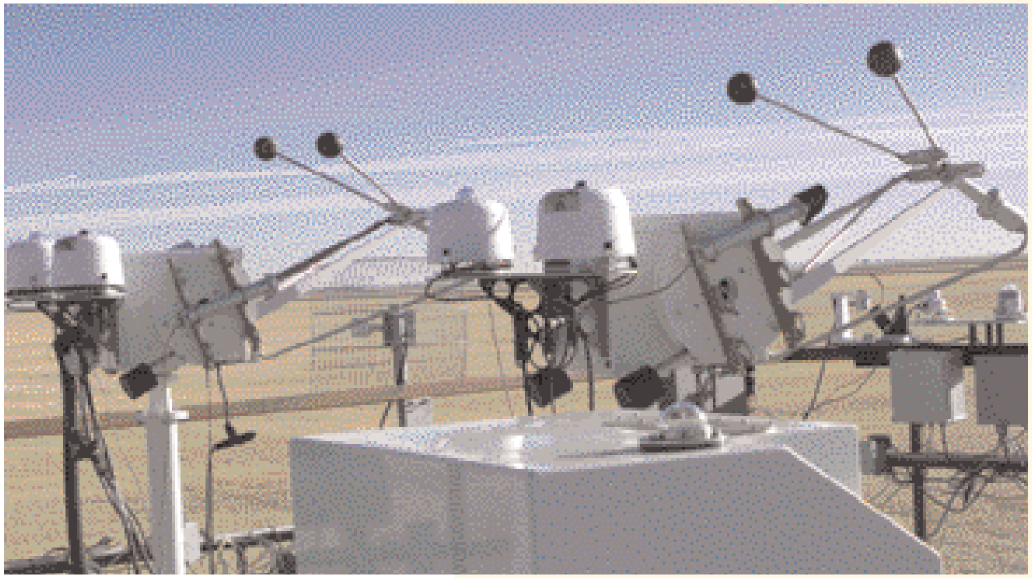
sophisticated computer modelling techniques, advanced technologies such as doppler weather radar, satellite instruments, and powerful supercomputers, and complex mathematical techniques such as data assimilation that improve the simulation of evolving weather systems. Advances in all of these areas require extensive basic and applied research before they can be put into operation.

In the case of environmental issues, research is necessary to anticipate emerging problems, determine causes, assess the severity and extent of present and future impacts, and identify measures to control these problems. Even after controls have been implemented, as in the case of acid rain and ozone depletion, continuing research, backed by long-term monitoring, is still necessary to assess the effectiveness of existing control measures and identify any need for further action.

Because atmospheric issues often cross political borders, science also plays an important part in negotiations to develop the bilateral or multilateral agreements needed to manage these issues. To be credible, national negotiating positions have to be buttressed by authoritative, leading-edge science. That kind of science can only be provided by scientists who are active and expert researchers in the areas in question and who are also fully cognizant of government policy issues.

To meet all of these obligations, MSC maintains a relatively large research organization that includes scientists with many different specialties and subspecialties and facilities in every region of the country. MSC also possesses extensive technical resources and infrastructure such as monitoring networks, laboratories, supercomputers, high-altitude research balloons, and access to research aircraft equipped to make detailed

An array of instruments measures solar radiation at Bratt's Lake Observatory in Saskatchewan. Observational networks that collect data on atmospheric and water quantity conditions in every part of the country are essential tools for daily reporting and forecasting. Over the long term, they are also important adjuncts to atmospheric and climate research and to the management of related issues. They are an indispensable tool for detecting changes in trends and provide the scientific basis for improving international agreements and domestic regulations to control environmental pollution. Only government, however, can provide the continuity and commitment needed to maintain these networks over the long term.



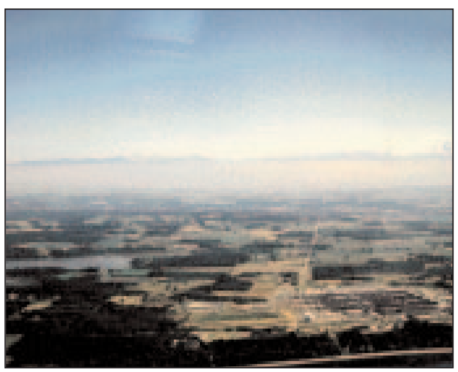
MSC: What it does...

REPORTS AND FORECASTS

MSC collects and analyzes atmospheric data to provide:

- Public weather forecasts
- Aviation forecasts
- Marine weather forecasts
- Warnings of severe weather events such as heavy thunderstorms, tornadoes, and hurricanes
- Ice hazard warnings
- UV Index forecasts
- Smog forecasts
- Ice and wave forecasts for ocean and inland shipping
- Special services to help defence and emergency services deal with situations such as forest fires, chemical spills, nuclear accidents, floods, acts of terrorism, and overseas military operations
- Water quantity reports for rivers and lakes

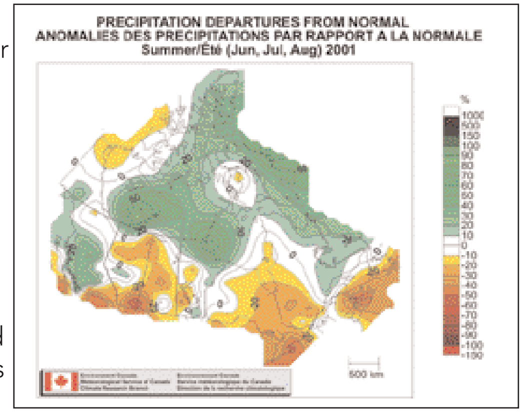
ENVIRONMENTAL AND HEALTH PROTECTION



MSC collects data and provides analyses and assessments to help society respond to environmental and health threats that involve the atmosphere, including

- climate change
- smog
- depletion of the ozone layer
- acid rain
- atmospherically transported toxic substances

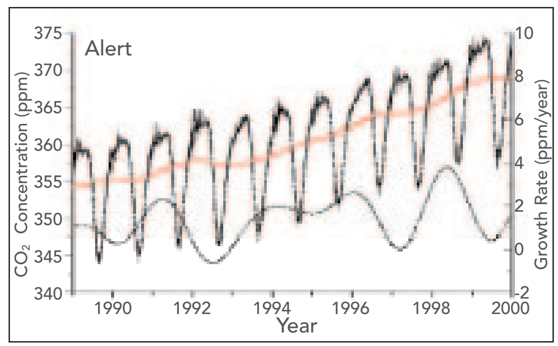
CLIMATE SERVICES



MSC archives weather data and provides climate analyses for use in an extensive array of applications, such as:

- agricultural planning
- developing building codes and materials standards
- determining the climate stresses that bridges, dams, offshore oil rigs, and other structures must be capable of withstanding
- estimating climate-related insurance risks
- managing water resources
- improving transportation safety and efficiency
- increasing resilience to weather hazards
- studying climate-related health problems

RESEARCH



MSC collects data and conducts basic and applied research relating to:

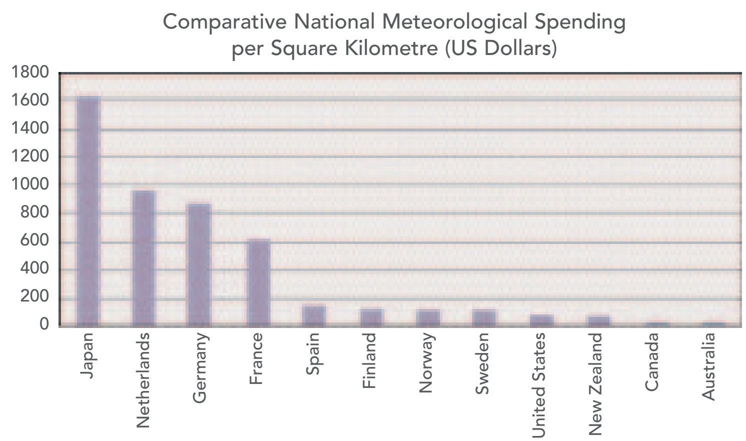
- weather prediction
- climate change
- climate impacts and adaptation
- air quality (including smog, hazardous pollutants, stratospheric ozone, acid rain, and greenhouse gases)

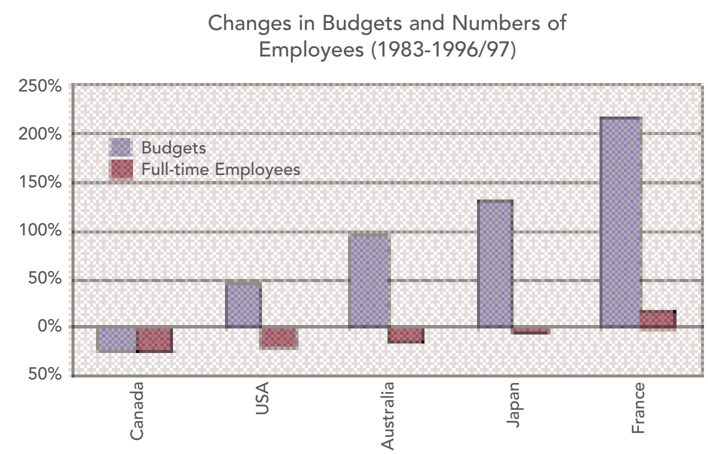
...And what it does it with

MSC provides these services on a budget of approximately $190 million per year and with some 1800 personnel. Of these, about 300 are engaged in research or related activities.

Because climate and weather can vary considerably from one locality to another, atmospheric data have to be collected from many different places to give an accurate picture of conditions in every part of the country. A country like Canada, with a large land area and a small population, must therefore invest more money per capita to run efficient weather and climate services than a country like the United Kingdom, which has a small land area but a large population, or even the United States, with both a large land area and a large population. Compared with other developed nations, Canada spends about as much per capita as densely populated France and considerably less than such lightly populated countries as Australia, Finland, and Norway. In terms of spending per square kilometre, Canada's investment in its weather and climate services is one of the lowest in the world.

Over the past 20 years several industrialized countries have substantially increased investments in their national meteorological services, recognizing the strategic contribution that high-quality weather and climate services make to national health and security, economic productivity and competitiveness, and environmental sustainability. Canada, in contrast, now spends about 20% less than it did in the mid-1980s.





atmospheric measurements. Such a concentration of atmospheric science assets is unique in Canada, and as a result MSC has often been an essential partner in large-scale research projects and the only organization capable of initiating such projects on its own. Until recently, MSC has been the only organization in Canada with the continuity, mandate, and stable funding necessary to carry out the kind of long-term research that is needed to resolve uncertainties in areas such as climate change or ozone depletion or to evaluate the effectiveness of control programs, such as those for acid rain.

The big advantage of such an organization from a public perspective is that it is dedicated to serving the atmospheric science needs of the government and to pursuing research that serves the public interest. Since the mid-1990s, however, budgetary restraints have made it increasingly difficult for MSC to carry out these roles effectively. Between 1994 and 1998, its research budget shrank by nearly 30% (in constant dollars). Although subsequent budgets have not seen further cuts of this magnitude, there have been no significant increases either, and inflation continues to erode MSC's capacity to meet present research commitments and undertake future ones.

Indeed, MSC has already been forced to cancel programs and close facilities that were contributing to important areas of research. When it closed in 2002, for example, the Eureka observatory was one of the world's best sources of information about ozone

GOVERNMENT SCIENCE: What is the payback?

"[Our] analysis indicates that R & D on stratospheric ozone depletion conducted by AES [now MSC] during the period 1975 to 1997 will result in the avoidance of over 57,000 cancers, 30,000 cases of cataracts, and 625 deaths….

For each dollar of research, Canadians received the following quantifiable benefits:

- $7.90 in health benefits
- $3.03 in environmental benefits
- $1.94 in economic benefits

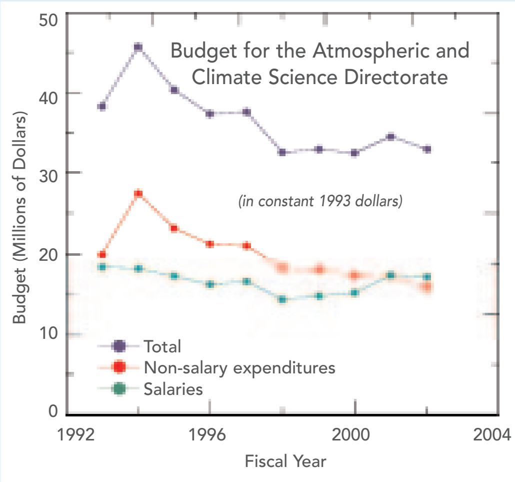
In addition, there were a large number of non-quantified impacts (overwhelmingly positive), including scientific capacity, benefits in other countries, effects on climate, and others."

Marbeck Resource Consultants
Measuring the Impacts of Environment Canada's R & D (May 1998)

A supply ship departs from an oil rig in stormy seas. Atmospheric and climate science contributes in a number of ways to the safety of offshore oil operations. Reports and forecasts of weather and ice conditions warn of impending dangers, while climate data about long-term wind and wave conditions help engineers design structures that can withstand the rigours of a harsh ocean environment.

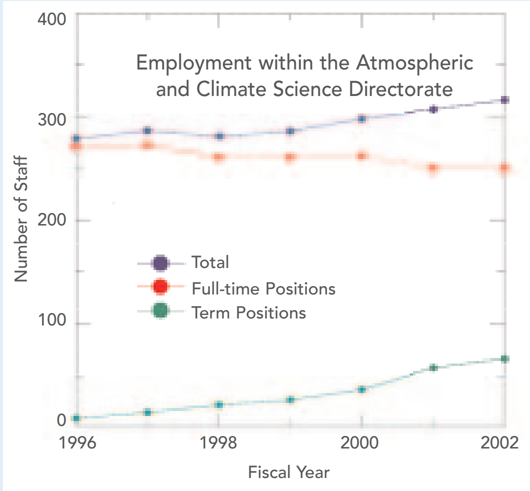
depletion in the Arctic and the effects of climate change on the recovery of the ozone layer. Thanks to the determined efforts of a group of university researchers, money has been found to restore Eureka to service at least temporarily, but nearly three years of important data have been lost and the longer-term future of the facility is still in doubt, even though important concerns remain about ozone depletion and other threats to the Arctic environment. MSC continues to run a number of extensive research programs on budgets that are remarkably small for the results produced, but its ability to do so is becoming increasingly precarious as key research staff are lost to retirement or opportunities outside the country and the hiring of replacements becomes more difficult.

BUDGET AND STAFFING TRENDS



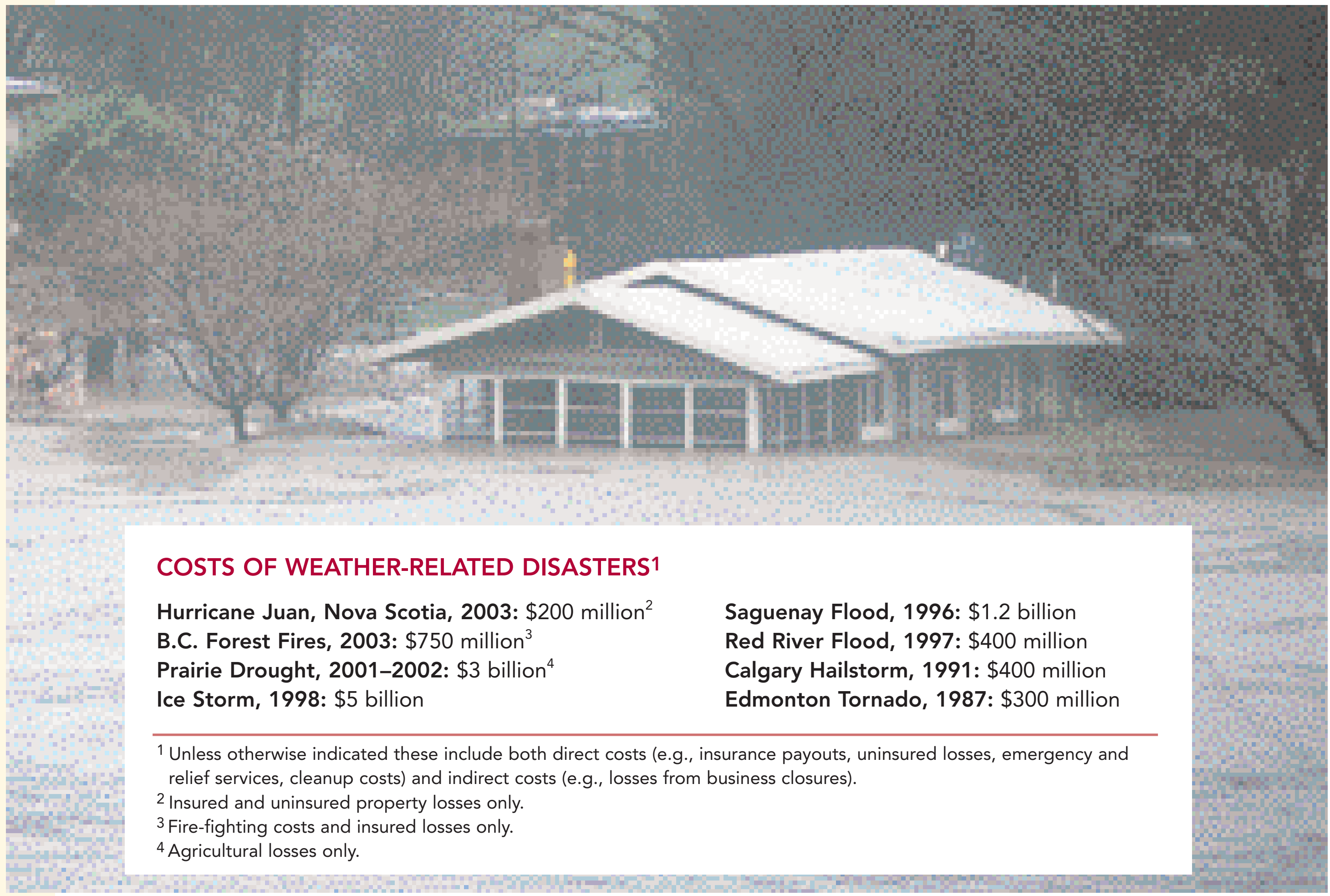
Support for MSC's atmospheric and climate research programs, as indicated by non-salary expenditures, peaked in the mid-1990s, thanks to an infusion of one-time funding from the now defunct Green Plan. Since then financial support for research activities has returned to earlier levels – about 19–20 million dollars per year since 1998 – but because of inflation those dollars buy much less research than they did in the early 1990s. In constant 1993 dollars, research funding was actually 20.6% lower in 2002 than it was in 1993, and 42.5% lower than in the peak year of 1994. Over the five fiscal years from 1998 to 2002, support for MSC research activities slipped by 13.6% in inflation-adjusted terms.

Spending on salaries, in comparison, has shown an increase since 1998, but that increase is the result of routine salary increases and a rise in the number of term employees. The number of full-time employees, however, has decreased. That means that fewer full-time career scientists are being recruited to replace the current generation of researchers. As a result, the ability of MSC to sustain current levels of research activity and to initiate new areas of study is diminishing.



Compared to many other areas of government expenditure, the MSC research budget is remarkably small. At $38 million dollars, a single CF-18 fighter aircraft and its on-board equipment cost about twice as much as MSC's current annual research budget. And yet MSC must support monitoring and advanced research relating to a multitude of different areas of public concern, including weather forecasting, climate change, acid rain, stratospheric ozone depletion, smog, and toxic air pollutants.

As of 2004, MSC may be facing further cutbacks to some of its most important data collection networks. These cuts would affect the Brewer network that monitors the ozone layer and measures incoming ultraviolet radiation, the upper air network that provides data for weather forecasting, and the climate station network that provides temperature and precipitation information for determining climate norms and tracking climate change. With reduced coverage, these networks would be less able to reflect local detail and variability and consequently less effective.



Weather-related hazards can exact a severe toll in human suffering and economic losses. The ice storm that struck Ontario, Quebec, and parts of the Maritime Provinces in 1998, for example, was responsible for 28 deaths and more than $5 billion in damage. More than 600,000 people in Quebec and eastern Ontario were forced out of their homes. Continuing research helps to identify the causes and future probabilities of such events and contributes to the development of better methods of forecasting their occurrence and adapting to their consequences.

COSTS OF WEATHER-RELATED DISASTERS[1]

Hurricane Juan, Nova Scotia, 2003: $200 million[2]
B.C. Forest Fires, 2003: $750 million[3]
Prairie Drought, 2001–2002: $3 billion[4]
Ice Storm, 1998: $5 billion
Saguenay Flood, 1996: $1.2 billion
Red River Flood, 1997: $400 million
Calgary Hailstorm, 1991: $400 million
Edmonton Tornado, 1987: $300 million

1 Unless otherwise indicated these include both direct costs (e.g., insurance payouts, uninsured losses, emergency and relief services, cleanup costs) and indirect costs (e.g., losses from business closures).
2 Insured and uninsured property losses only.
3 Fire-fighting costs and insured losses only.
4 Agricultural losses only.

THE ACADEMIC ALTERNATIVE – AND WHY IT IS NOT ENOUGH

The continuing erosion of MSC's research capabilities is usually justified, explicitly or implicitly, by the assumption that the federal government no longer needs to maintain an independent research capacity in the atmospheric sciences. Much of the necessary expertise also exists in the universities, and by harnessing it to government needs through a variety of short-term funding arrangements the federal government can reap the dual benefit of reducing its own direct operating costs while at the same time strengthening the research capacity of the universities. In reality, however, this idea does not work well for either the government or the universities.

For government, the primary disadvantage is that such an arrangement will inevitably be much less responsive to its needs. That is because neither the structure nor the culture of university research is suited to providing the kind of service that government requires. Responding to government information needs is simply a low priority for most academics. Their priorities are set instead by trends within the international research community.

In addition, the focus of university research depends largely on the interests and expertise of individual researchers rather than a continuing institutional commitment to specific research priorities. When leading researchers leave an institution, their research programs go with them. As a result, university research cannot provide the continuity that government needs for many of its activities.

University research, for the most part, is also small-scale – usually involving the collaboration of a professor and a few graduate students – and projects are typically pursued over short time frames, often no more than a few years. Moreover, atmospheric science departments within universities are too small individually to afford the high-altitude research balloons and other expensive equipment and infrastructure needed for many issue-oriented research activities. Consequently, universities are not well suited to carry out the large-scale projects, involving many researchers and spanning many years, that government often needs. The management of data collection networks that span large geographical areas

> "Although some research could be conducted equally well in either government laboratories or the universities, there are many activities that necessarily require the long-term stability or infrastructure support that is difficult to achieve and maintain in a university environment. Graduate students and research grants typically have a four-year lifetime."
>
> *Peter Taylor*
> *York University*

and must operate over long time periods, for example, is a task that universities are not usually capable of nor interested in handling. Yet these networks, which collect data on surface temperature and precipitation, water quantity and flow, upper air conditions, solar radiation, and a host of other variables, must be maintained, as they are an essential source of raw information for both forecasting and research.

As a case in point, the substantial contributions that Canada now makes to international research on climate change would not be possible without a government component. Individual university researchers, of course, can and do provide insights into important aspects of climate behaviour, but they lack the resources to produce the elaborate, leading-edge computer models that are at the core of climate change research. These models, which simulate the interaction of the numerous elements that comprise and affect the global climate system, are essential for assessing our current understanding of climate change and identifying further research needs. Their complexity is such that fewer than 20 exist in the world at the present time – and all of them, significantly, are the products of government-affiliated research centres.

Over time, an influx of government funding directed at government research priorities could enhance the universities' capacity for larger-scale, longer-term research, but not

University scientists such as Dalhousie's Eville Gorham and the University of Toronto's Harold Harvey played a leading role in identifying the threat of acid rain to Canadian lakes in the 1950s and 1960s. As acid rain evolved into a major environmental issue in the 1970s government scientists became increasingly involved in expanding scientific understanding of the problem and developing the knowledge needed to develop effective measures for controlling it. Although much progress has been made in managing acid rain, it remains a serious problem and continuing research and monitoring are needed to ensure the protection of sensitive ecosystems.

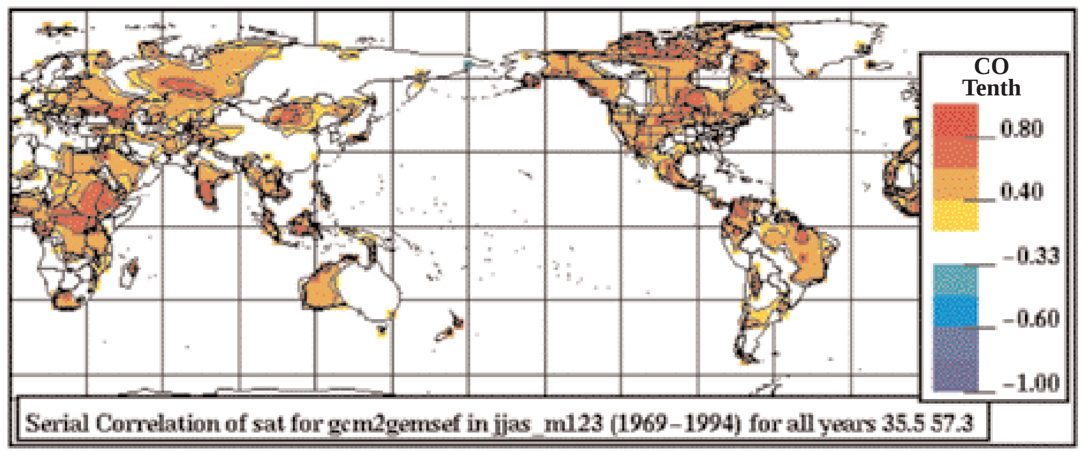
Without MSC providing the backbone for large research projects, the scope of university research in Canada would have to be much more limited.

enough to make them an adequate substitute for a government department already dedicated to that purpose. The universities will always have other and higher priorities than being a research service for government.

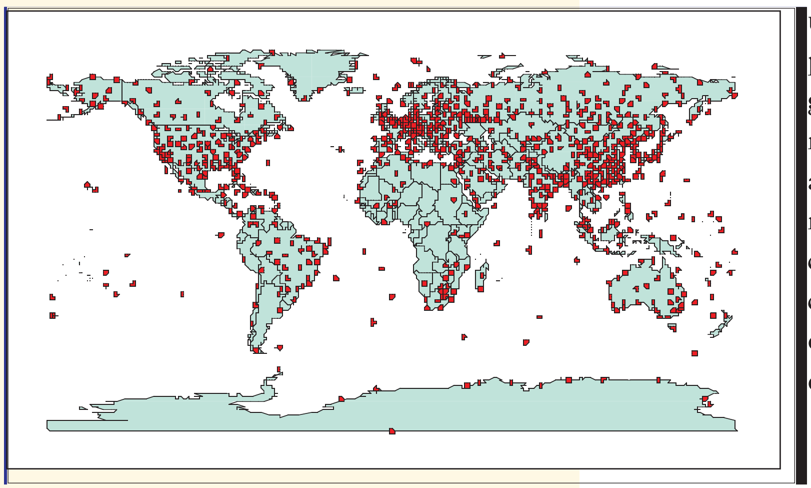
Without a research capability of its own, MSC's capacity for advising policy makers and managing research would lack the authoritative underpinning that a staff of first-rate researchers provides. Although it would still have some resident scientific expertise, this would come from scientists who were not actively involved in research. They would be individuals involved in operational tasks such as weather forecasting or issue specialists who would keep abreast of scientific developments, provide background information to policy makers, and make the funding decisions that would direct academic research towards government needs. While these specialists would undoubtedly be well informed, they would not be able to deliver as detailed and authoritative information on, for example, the role of clouds in climate change as someone actually involved in research on the properties and behaviour of clouds. Given the three- to five-year time lag that exists between the start of a research project and publication of its results, the information available to issue specialists would also inevitably be less current than that available to researchers. In addition, because scientists who are not directly engaged in a field of research do not have the same leading-edge knowledge as those who are, issue specialists would be less effective at identifying research requirements and building research programs to meet government needs.

Ironically, reducing MSC's research capabilities in order to increase those of the universities would be disadvantageous for the universities too and for the

One summer is never quite like another. Variations in average seasonal conditions from one year to another can have important economic consequences, especially in activities, such as agriculture, that depend on predictable climate conditions. MSC is working with a university-led research team in an attempt to understand the reasons for seasonal variability and develop methods for predicting them. The colours on the map show how closely the team's predictions correlate with observed summer temperatures in different parts of the world for the period 1969–1994. While the correlations are generally good, research in seasonal forecasting is still young and further improvements can be expected in the future.



Upper air monitoring sites around the world. Upper air data, obtained by balloons, are important for both forecasting and research. Canada's upper air network, in relation to its land area and in comparison to networks in other developed countries, is unusally small. While Britain operates six upper air sites for its small land area, Canada has only seven for the entire Arctic. Canada's networks for collecting data about climate and UV radiation are also less than optimal by international standards. Further reductions will only render these sites less effective for scientific purposes.



atmospheric science community generally in Canada. That is because the participation of the universities in large-scale research projects depends heavily on support from MSC. This includes not only access to expensive technical equipment but also skilled technical support, administrative support, research expertise, and the institutional and financial stability needed to see lengthy projects to their conclusion. MSC expertise in both climate modelling and numerical weather prediction, for example, supports a wide range of advanced research in universities across the country. Without MSC providing the backbone for large collaborative research projects, the scope of university research in Canada would have to be much more limited.

Even if major technical assets were transferred to selected universities, the universities – or more precisely their atmospheric science departments – would find it extremely difficult to afford the cost of maintaining and upgrading expensive technical facilities in the future without substantial government support. Allowing these resources to deteriorate or become obsolete, however, would soon limit the capabilities of the Canadian atmospheric science community and diminish the quality of the research being done in this country.

A continuing MSC research capability is also important to the universities because MSC researchers often have cross-appointments to university faculties and help to strengthen university programs in atmospheric science. In addition, MSC research departments are important employers of graduates with advanced qualifications in atmospheric science in Canada. Since there is no long-term career path for non-tenured researchers within the universities, the universities themselves cannot absorb the graduates they produce, nor could they, even with a much expanded research role on behalf of government. These graduates, however, represent a valuable intellectual resource that must be kept within the country if we are to be able to meet the atmospheric challenges of the future. As long as it maintains a significant research capacity, MSC can provide many of these scientists with appropriate careers that will enhance their talents and prepare them to meet these challenges on behalf of the Canadian public. Without such opportunities, many of our most talented young scientists will have no option but to join the brain drain to the south and elsewhere.

Turning universities into research contractors for the government could also undermine some of the strengths of university science. Unlike government research, which is constrained by policy needs, university research is largely curiosity driven. That indeed is one of its strengths, since university researchers are free to pursue interests that do not reflect government priorities. That freedom is one reason why early warnings of emerging issues, such as acid rain, stratospheric ozone depletion, and climate change, have tended to come from academic scientists. Making a large commitment to serving government information needs, however, would limit that freedom, and consequently it is an idea that does not have a strong appeal to many academics. Collaboration between government and university scientists can be enormously beneficial, but science loses if university research is unduly constrained by the government agenda.

WHY DOES GOVERNMENT NEED ITS OWN RESEARCH CAPACITY WHEN THERE IS SIMILAR EXPERTISE IN THE UNIVERSITIES?

"Big research projects involving issues that are long-term or are on a national or global scale are more appropriately carried out in the government environment. This is recognized and practised in all developed countries. Long-term scientific issues that last several decades require long-term commitments, which are difficult to maintain beyond the lifetime of a research grant or a particular university researcher. A broad-scale national or global issue requires planning and coordination at the national or international level and is more suited to being led by a government institute."

Jim Kerr
Meteorological Service of Canada

"The universities are not able to provide stable long-term funding to support career scientific research staff. Without these people, large-scale research projects spanning many years cannot be accomplished."

Jim Drummond
University of Toronto

"To keep operations abreast of a new technology, it is essential for government to have highly trained research scientists on staff who are in touch with current research around the world. The rapidly increasing knowledge base cannot be interpreted by policy people or by scientists who only track the published literature."

George Isaac
Meteorological Service of Canada

"A significant advantage to in-house research by government agencies such as MSC is the direct feed into operational requirements and the development of new operational tools for the delivery of environmental observations and predictions."

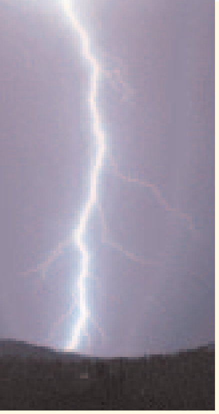
Peter Taylor
York University

"A lot of basic research needs to be done if we are to be able to predict tornadoes and other extreme events. This will only happen though if MSC is there to present these problems to the academic community in the first place and to ensure the technical follow-up needed to implement the research."

Pierre Gauthier
Meteorological Service of Canada

"Atmospheric research in Canada stands on two legs: MSC and the universities. It can't be made more effective by making one leg longer and amputating the other."

Thomas McElroy
Meteorological Service of Canada



RESEARCH PARTNERSHIPS – A UNION OF STRENGTHS

While the universities alone cannot sustain the burden of meeting government research needs, they are nevertheless a source of considerable expertise that can be of great benefit to government. Recognizing this, MSC began during the 1990s to involve the universities as major partners in a variety of important research projects. The resulting collaboration between government and university scientists has been highly productive, and almost all large-scale research activity in the atmospheric sciences in Canada is now organized around MSC-university partnerships.

These partnerships have been effective because they capitalize on the strengths of both partners, compensate for their weaknesses, and make efficient use of all the research resources available in the country. In particular, they take the extensive infrastructure and long-term continuity that only government can provide and place it at the disposal of the whole atmospheric science community to pursue projects that are of public interest. During the past decade such partnerships have helped to reinforce Canada's status as one of the world's leading centres for atmospheric science research, along with the United States, the United Kingdom, Germany, and Japan.

University-government partnerships take a variety of forms. A few involve full-time collaboration between MSC researchers and their university counterparts, with MSC personnel actually based on the university campuses. The Canadian Climate Centre for Modelling and Analysis (CCCma) at the University of Victoria uses this arrangement, as does MSC's Adaptation and Impacts Research Group (AIRG), which has researchers at the universities of British Columbia, Waterloo, Toronto, York, and New Brunswick. Most, however, are project-based collaborations, such as the Middle Atmosphere Nitrogen Trend Assessment (MANTRA) high-altitude balloon flights. Partnerships of this kind may link MSC with a few researchers from a single university or with a large number of researchers from several universities as well as other government agencies.

Any plan to improve the way that the federal government promotes atmospheric research should recognize the necessity of these partnerships. It should also recognize that

"Our research into climate variability involves, by necessity, the use of such extensive infrastructure resources that it would have been unthinkable in a purely academic environment. I am grateful for the opportunity that my MSC colleagues provided to collaborate with them and to share their resources. This has had a profound influence on my research trajectory over the last few years. Without the strong scientific cadre and the computer resources of the Meteorological Service, this research work on seasonal forecasting would not be done to this day in Canada."

Jacques Derome
McGill University

There is increasing doubt about MSC's capacity to sustain these partnerships.

the government component is the backbone of these arrangements, because it provides the facilities, the long-term monitoring programs, the archived data, the technical and administrative support, and a good share of the research expertise that make them viable and productive. Take away these resources, and there is neither the incentive for the universities to collaborate on government projects nor the framework to make such collaboration effective.

Although an active government role is essential to the success of such partnerships, the government partner does not necessarily have to be an in-house agency such as MSC. It could, for example, be an independent atmospheric research institute or national laboratory, operating at arm's length from government but receiving stable, long-term funding from it. Whether such an arrangement would offer significant advantages, however, is unclear, as there are few examples of successful organizations of this type in Canada.

What is clear though is that whatever the government component might be it must itself remain a viable research entity if these valuable partnerships are to continue. To enlist the collaboration of university scientists in a given area of research, government must have a credible in-house capacity in the same area, both in terms of technical resources and the involvement of expert researchers. That same logic applies also to collaborations with researchers in other countries whose expertise could benefit work being done in Canada.

There is increasing doubt, however, about MSC's capacity to sustain these partnerships, let alone engage in new ones. When an independent Review Panel of international experts evaluated MSC's research and development programs in 2001, it commended the overall

A major research project requires many people and extensive resources. The 14 scientists, 2 pilots, 3 students, and 8 technicians shown here in front of the National Research Council's flying laboratory are only part of the Canadian team that took part in a recent international study of clouds in the Arctic. Cloud research can yield a wide range of benefits, from better protection of aircraft from icing hazards to more accurate weather forecasts and more reliable projections of future changes in climate.

"For the past 10 years I have been leading the Canadian effort to develop, validate, and exploit a Regional Climate Model (CRCM). While this endeavour has been mainly a university-based effort, the collaboration with federal government labs has been very valuable. Operational model development, as opposed to the development of model prototypes or the exploitation of existing models, is a long and arduous process that is not in the tradition of university research. The collaboration of government scientists and access to their infrastructure has been an essential element in the success of the CRCM."

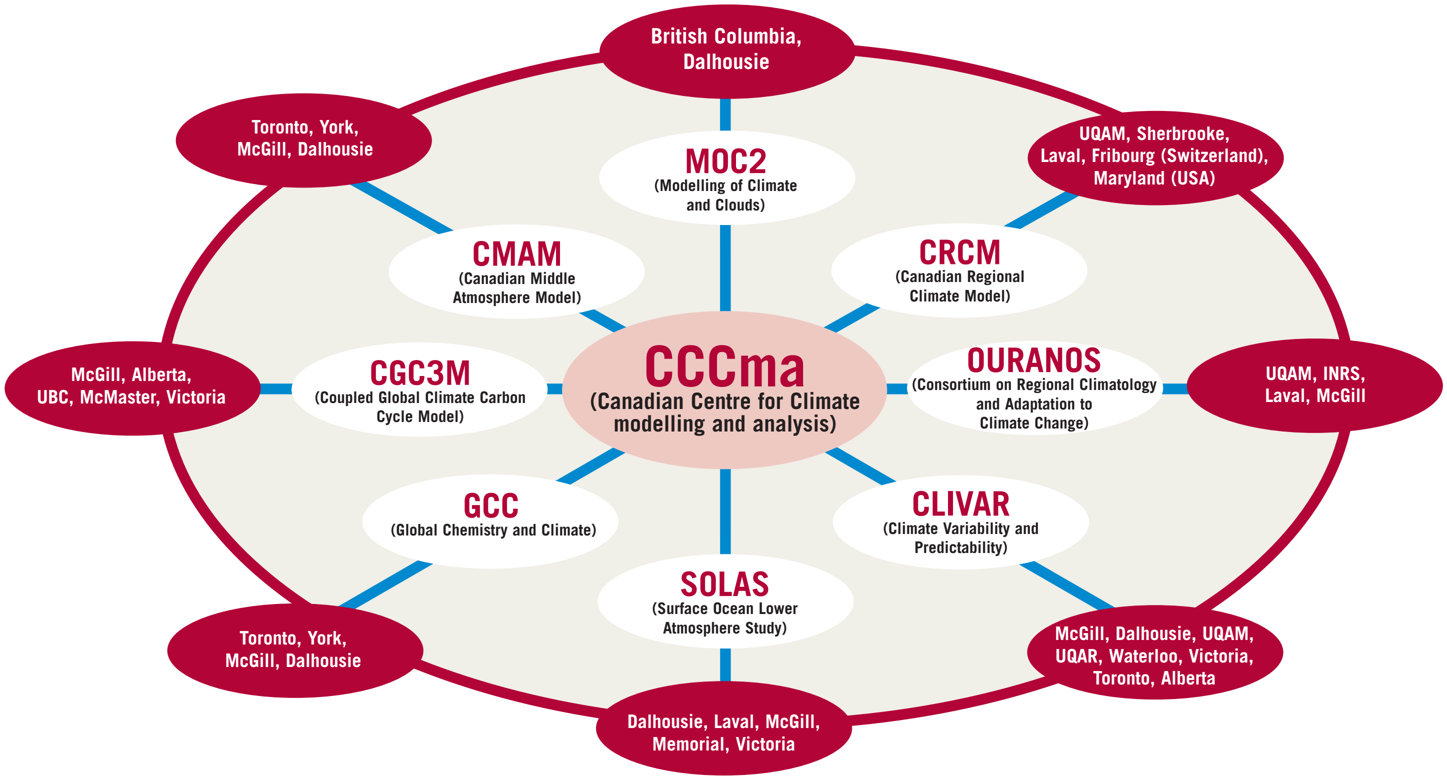
René Laprise
Université du Québec à Montréal

excellence of the work being done. "In several areas," it noted, "the MSC research and development program components are world class, representative of the best the global science community has to offer." But it also observed that MSC's resources are already deeply strained by current research commitments and that research staffing in many areas is remarkably thin for the results achieved. Many leading researchers are close to retirement and not enough younger scientists are being groomed to replace them. Moreover, research activities are becoming increasingly dependent on "soft money" – temporary funding – that makes it harder to ensure the continuation of the kind of stable, long-term data collection and research needed to understand many atmospheric trends and processes. Pure research is an uncertain activity, and research workers produce their best results when they are not preoccupied with their long-term future.

If MSC's ability to attract university partners declines, so will the ability of the federal government to involve the universities in research that is directly relevant to its policy needs. To be an effective partner with Canada's universities and with agencies in other countries, MSC needs stable funding at a level that will maintain the high standard of its own research capabilities. As the Review Panel concluded in its report, "the transfer of basic research to the university community does not negate the requirement to maintain a strong scientist cadre within the MSC."

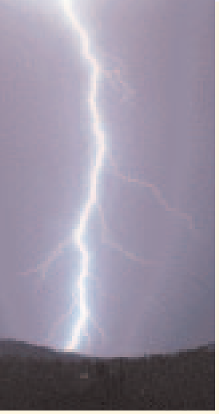
Volunteers carrying portable air samplers in backpacks measure air pollution levels typically encountered by pedestrians on a downtown Toronto street. By comparing air pollution data with records of the volunteers' activities and physiological responses, researchers are gaining more insight into how common pollutants affect the human body. This ongoing study unites the talents and resources of researchers from MSC, Health Canada, and the universities of Toronto and Michigan.

MSC RESEARCH: A nucleus for collaboration



The extensive resources and scientific expertise of MSC are central to many major research projects that Canadian universities participate in. Through MSC's Canadian Centre for Climate Modelling and Analysis, based at the University of Victoria, for example, university and other researchers have access to one of the world's most advanced global climate models and the detailed projections of climate change derived from it. As a result, CCCma is an essential hub for a large network of research connections.

The diagram shown here offers a snapshot of the major research projects and participating universities that were linked to CCCma in 2003. Many of these projects also involved the participation of other government departments. In addition, the Centre offers access to more than 2800 years of climate model output through its web site. Since 1998, over 14,000 datasets have been downloaded.



BUILDING ON A FOUNDATION OF EXCELLENCE

The increasing need for atmospheric science information is part of a growing need for scientific information generally by government. According to an article published in *Nature* in January 2000, references to scientific information in British parliamentary debates have increased sixfold during the 1990s. With a similar trend occurring here, the Canadian government is also attaching greater importance to the role of science in policy making. The SAGE, BEST, and STEPS reports, recently published by Industry Canada, are all concerned with the need for creating a better interface between science and policy and for developing the best possible science and technology base within the country.

At the opening of the 37th Parliament on January 30, 2001, the federal government set itself the goal of making Canada one of the top five countries in the world for R & D performance by 2010. We have, in fact, already attained this goal in the atmospheric sciences, but we must be careful not to undermine the strengths that allowed us to do so. Indeed, we must reinforce these strengths and build upon them or risk the rapid deterioration of our leading expertise in this field and all the benefits that derive from it.

What are these strengths? First, a high level of expertise both within MSC and the universities and, second, a productive interaction between them, one that is synergistic rather than antagonistic. Government, mostly through MSC, provides the institutional underpinning (and hence the continuity and extensive resources) that make complex, long-term research activities possible. The universities expand the pool of intellectual capital and extend the range of ideas and expertise, some of which may be policy relevant in the future.

There is an urgent need for the federal government to move decisively to restore funding to MSC research and maintain it at a level that will allow MSC to meet the many demands placed upon it. New arrangements for atmospheric research should continue to be based on a mixed approach that combines a strong government component with the resources available in the universities and other sectors. Such an approach provides the most effective and flexible way of capitalizing on the advantages of each source of expertise while minimizing its disadvantages.

"We must strive for Canada to become one of the top five countries for research and development performance by 2010.…As its contribution, the Government will at least double the current federal investment in research and development by 2010. In making new investments, the Government will:

- continue to pursue excellence in Canadian research by strengthening the research capacity of Canadian universities and government laboratories and institutions
- accelerate Canada's ability to commercialize research discoveries, turning them into new products and services; and
- pursue a global strategy for Canadian science and technology, supporting more collaborative international research at the frontiers of knowledge."

Speech from the Throne
January 30, 2001

There is an urgent need for the federal government to restore funding to MSC research.

An institutional core and its associated infrastructure are crucial to the survival and growth of a strong atmospheric science community within Canada. That core is now provided by MSC, although it could, in principle, be provided through other structures. Either way, however, the core institution has to be maintained by the federal government because of its cost, the need for long-term continuity, and the requirement for a mechanism that can provide close support to government decision making.

Government will have much better access to expertise in the atmospheric sciences and will be able to utilize research much more effectively in the public interest if it is itself a partner in that research.

By all means let us consider new ways of getting more and better information to government at less cost. Let us look for ways of enhancing the intellectual capital that is in our universities as well as in the private sector and nongovernmental organizations. But in doing so, let us be sure that we do not destroy the mechanisms that have worked so well for us in the past and that are essential to our success in the future.

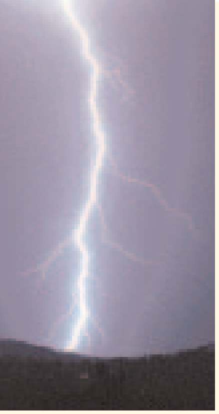
MSC climatologist David Phillips receives the Order of Canada from Governor-General Adrienne Clarkson. The award, which is not customarily given to serving civil servants, acknowledges Phillips's unique contribution as a commentator on weather events and climate issues. It also reflects the importance that Canadians attach to understanding the impact of weather and climate on their lives.

"The staffing of CRB [the Climate Research Branch of MSC] is remarkably thin relative to their current effectiveness and stature within Canada's...climate research and services program....The Panel is convinced that even a doubling of the CRB research budget over, say, a five-year period would still be regarded internationally as a comparatively low commitment to its stated interests in climate understanding and services."

Independent Review of the Research and Development Program of the Meteorological Service of Canada

"The Canadian Consortium for Research recommends that the Government of Canada recommit to supporting government science and national facilities that provide Canada with leading-edge research and open doors to international collaboration."

Canadian Consortium for Research Brief to the House of Commons Standing Committee on Finance, September 2002



APPENDIX I
HOW GOOD IS CANADIAN ATMOSPHERIC SCIENCE?

The short answer is very good. Canadians are among the most important contributors to atmospheric science at the international level. Canada, for example, is one of just a few countries involved in the development of global climate models (GCMs), the elaborate supercomputer-based programs that simulate the behaviour of the atmosphere and oceans and their interactions with other parts of the Earth system. Over the years Canadian models have ranked among the world's best, a fact that was acknowledged recently when the United States chose the current Canadian model as one of two to be used in its national climate impacts assessment.

Canada also ranks as a leader, along with the United States, the United Kingdom, Japan, and the European Union in the development of models and techniques for numerical weather prediction (NWP). Although Canadian researchers have had fewer resources at their disposal, the accuracy of their NWP forecasts compares well to those of other international centres.

The Brewer ozone spectrophotometer is another major Canadian achievement. Developed by a group of scientists based initially at the University of Toronto and later at the Atmospheric Environment Service (now the Meteorological Service of Canada), the Brewer is today's standard instrument for making ground-based observations of stratospheric ozone. About 180 Brewer instruments are now in use in some 45 countries around the world.

MSC scientists also developed the world's first UV Index, for informing the public about levels of harmful ultraviolet radiation at the Earth's surface. The Canadian index has been adopted as the international standard by both the World Health Organization and the World Meteorological Organization and is used in many other countries around the world.

Arctic issues are a special Canadian concern, and much of what is known about the atmospheric transport of mercury, pesticides, and other persistent toxic substances into the Arctic environment from the south has been the result of work by Canadian scientists.

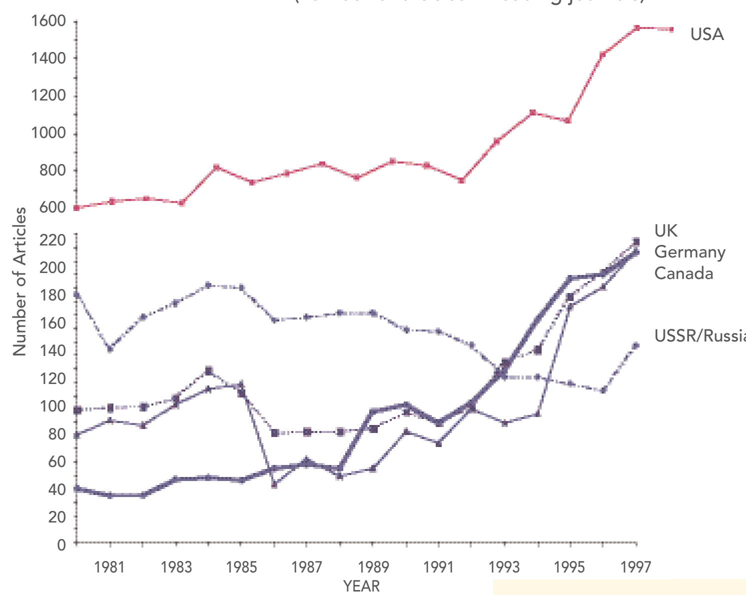
"…in several areas the MSC research and development program components are world class."

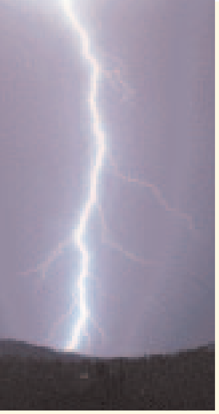
The number of articles published in leading scientific journals is often taken as a benchmark of scientific productivity, and by that standard the Canadian atmospheric science community has performed very well. For the past 20 years, Canada has been among the top five producers of articles in atmospheric science, along with the United States, the United Kingdom, Germany, and Russia. During the early 1990s, our output was second only to that of the United States.

In a recent review of MSC's research program, an international panel of scientific experts concluded that "in several areas the MSC research and development program components are world class" and that "in some cases the program components are the world leaders." More ominously, however, the reviewers noted that recent cuts to MSC resources had left the organization with "a program that was 'a mile wide and an inch deep,' in other words, a program that…is very limited in terms of the critical mass of…resources required to remain a strong, vibrant part of the research community."

Canada may be a country with a relatively small population, but in the atmospheric sciences Canadians cast a long shadow and our influence has been disproportionately large. Our globally recognized expertise provides a solid foundation on which future successes can be built. It is an asset that should be nurtured, not neglected.

Top Five Countries in Meteorology and Atmospheric Science
(number of articles in leading journals)





APPENDIX II

DIAL: THE FAILURE OF A SUCCESS

The promise of government-university partnerships and the perils of overreliance on the universities for critical research needs are clearly illustrated by the brief history of Environment Canada's DIAL operations and their role in the eventual demise of the Eureka observatory.

DIAL is the acronym for Differential Absorption Lidar – an instrument that uses a pair of laser beams to measure the concentrations of various atmospheric constituents at different altitudes above the Earth. With a DIAL, ground-based researchers can take measurements that formerly required the use of sondes carried aloft by balloons.

DIAL technology caught the interest of the Atmospheric Environment Service (as MSC was then known) in the mid-1980s. AES researchers had recently confirmed that ozone depletion was taking place over Canada, and it was becoming increasingly important to fill gaps in the ozone monitoring networks. One such gap was in the Toronto area, where information about the vertical distribution of ozone had been lacking since the late 1960s, when a regular program of ozonesonde flights had been abandoned because of aviation safety concerns.

DIAL technology, just recently developed, now offered a way of getting ozone profile information for the region again. Consequently, AES entered into a partnership with a team under Professor Al Carswell of York University to develop a DIAL capability for Toronto. Also participating were an Ontario government agency, the Institute of Space and Terrestrial Science (now CRESTech, the Centre for Research in Earth and Space Technology), and an industrial partner, OPTECH Inc.

In 1991, the Canadian government greatly increased its capacity to monitor crucial atmospheric parameters related to ozone depletion when it funded the building of the Eureka observatory on Ellesmere Island in the High Arctic. The ozone DIAL was a key part of the new observatory's instrumentation, along with the AES-developed Brewer Ozone Spectrophotometer and additional high-technology contributions from Japan and the United States. In addition to serving Canadian research needs, Eureka also became an important link in the Network for the Detection of Stratospheric Change – a global network set up under the auspices of the World Meteorological Organization to provide global-scale reference data and standards for ensuring the accuracy and compatibility of satellite and ground-based observing systems.

Both the ozone DIAL at Toronto and the one at Eureka were operated highly successfully by the founding organizations until 1999, when Professor Carswell retired from York University's Department of Physics. At that point the project began to unravel. First, the Department decided that Dr. Carswell's work did not match their priorities. It was not really physics, they concluded, but atmospheric science, and they would seek a replacement with expertise in a different area. Carswell's graduate students continued the research collaboration, but the university's involvement was effectively terminated. Then CRESTech decided that the project was essentially of federal interest and should not be supported by Ontario government funds.

Inevitably, the DIAL program lost momentum and over the next three years came slowly to a halt. Deprived of one of its key observational capabilites, Eureka was affected too. With its diminishing resources spread too thinly across too many priorities, MSC was looking for costs to trim. Eureka now became expendable. As a result, what had once been the jewel in the crown of Canadian ozone research was decommissioned in the summer of 2002.

The closure of Eureka affected not only Canadian research but major international projects as well. Eureka ozonesonde data had been used in the international MATCH project to provide what many researchers consider the best evidence available of chemical ozone depletion in the Arctic. Survival of the ozone DIAL operations at Eureka would have ensured a continuing flow of similar data that would have greatly improved the performance of the MATCH program.

The lessons to learn from this experience are numerous. The most important and most obvious one is the great success that government-university partnerships can have in providing innovative research opportunities and the chance to involve highly-qualified research personnel in projects of national importance.

A LIDAR beam pierces the Arctic night over Eureka.

UPDATE 2004

In the spring of 2004 a group of university researchers succeeded in rounding up enough financial support from various university granting agencies to return Eureka to service for a period of three to five years. While this support will allow the resumption of some very important research activities, there is no guarantee of further funding after these grants expire. As a result, adequate security is still lacking for long-term research and data collection at Eureka – the type of work that will do most to help scientists answer fundamental questions about ozone depletion, climate change, and other critical issues involving the Arctic atmosphere. Only stable government funding can ensure the continuation of such activities over indefinite time frames.

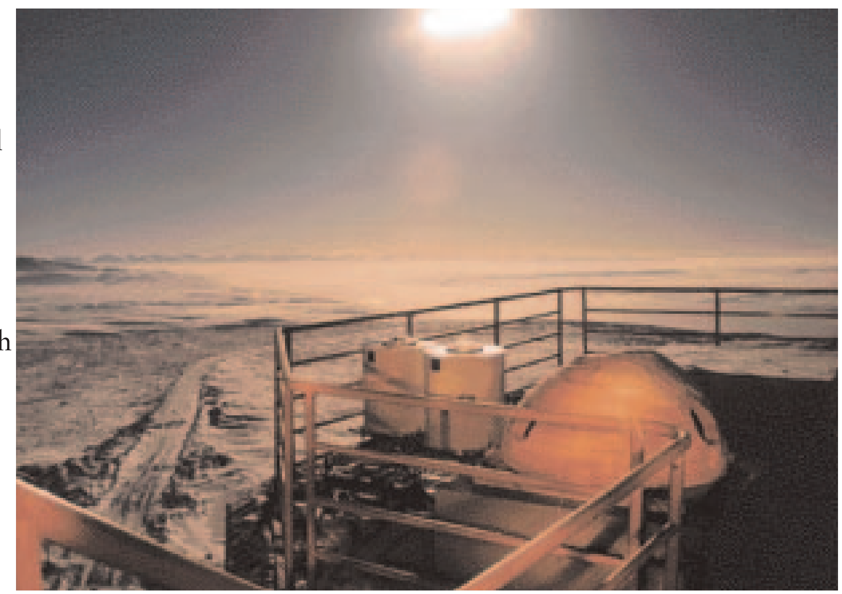
In the meantime, the U.S. National Science Foundation has given nearly $4 million to American researchers to establish an atmospheric science research station near the North Pole in Canadian territory. This research will take place within a few hundred kilometres of another Canadian research station, at Alert on Ellesmere Island, where proposed funding cuts further threaten MSC research activities.

Other lessons are not so positive, at least from a government perspective. One is that the goals of the university in carrying out research are not set by the needs of government nor the needs of the Canadian public. If government lacks the means to influence the research interests of its university partners, they will quite logically follow their own priorities. Those priorities may be perfectly justifiable in academic terms, but they cannot necessarily be expected to promote national objectives.

Another important lesson is that universities are not designed to support long-term research. Their preoccupation is interest-driven research, pursued competitively to the highest international standards of performance, and new faculty members are essentially required to start their own research programs from scratch. Such a focus provides little encouragement for pursuing the kind of continuous long-term activity needed to monitor and study persistent problems such as environmental pollution.

The ozone DIAL example shows many of the best and worst features of cross-sectoral collaboration. The close interaction between York University and OPTECH, which saw the rapid and almost seamless promotion of research ideas from the university laboratories to the industrial sector, was almost unique in the university–private sector landscape. At the same time the close interaction of government and university labs promoted both monitoring and experimental goals as well as educational activities.

However, when the winds changed on the university and the industrial research fronts, the government was left bereft of the infrastructure and personnel needed to maintain a watch on vital elements of the environment. In this case the impact was especially severe because MSC lacked both the financial resources and the expert personnel to fill the breach left by the departure of its university partner.



THE SIGNATORIES

TERRY BIDLEMAN is a senior research scientist with the Meteorological Service of Canada and an adjunct professor in the Department of Chemical Engineering and Applied Chemistry and the Department of Chemistry at the University of Toronto. A specialist in the study of persistent organic pollutants in the atmosphere, Dr. Bidleman has developed a number of methods for measuring the presence of PCBs and organochlorine pesticides in the atmosphere and their exchange between various surfaces such as water, soil, and airborne particles. He also provided the first measurements of these compounds in the air of the Canadian Arctic. He is involved in the Northern Contaminants Program of Indian and Northern Affairs Canada and was a co-editor of the physical environment chapter of the 2003 Canadian Arctic Contaminants Assessment Report. He has served on the editorial boards of the journals *Chemosphere* and *Estuaries* and was a co-recipient of theAmerican Chemical Society Award for Creative Advances in Environmental Science and Technology in 1999. Dr. Bidleman was listed among the 250 most frequently cited authors of papers in the environmental sciences in 2003 by the Science Citation Index.

GEORGE BOER is a senior research scientist with the Meteorological Service of Canada and an adjunct professor at the University of Victoria. Formerly Chief of the Canadian Centre for Climate Modelling and Analysis (CCCma) and its predecessor, the Numerical Modelling Division of the Canadian Climate Centre, he is one of the pioneers of modern climate modelling and analysis in Canada. He is currently attached to CCCma in Victoria, where he continues to work on climate modelling, climate diagnostics, and climate prediction. Dr. Boer has published numerous papers, co-authored two books, authored several book chapters, and has been a lead author and contributor to several chapters in the Second and Third Assessment Reports published by the Intergovernmental Panel on Climate Change (IPCC). He currently serves on a number of national and international committees and working groups of several scientific bodies, including the World Climate Research Programme, the Asian Pacific Climate Network, the Seasonal to Interannual Model Intercomparison Project, and the IPCC. He is a recipient of the Jim Bruce Award for outstanding contributions to the Atmospheric Environment Program and the Environment Canada Citation of Excellence for significant contributions to global climate science.

JAN BOTTENHEIM is a senior research scientist with the Meteorological Service of Canada and an adjunct professor in the Department of Chemistry at York University. His research is in the area of tropospheric gas-phase chemistry, with a particular interest in the formation of ozone and other oxidants. His responsibilities as lead scientist for several large field studies have taken him to almost every corner of the country in recent years. Dr. Bottenheim is particularly interested in the chemistry of the Arctic boundary layer. He discovered the spring ozone depletion in the surface air of the Arctic atmosphere, and was a co-principal investigator in the Polar Sunrise Experiments (PSE1998, ALERT2000), that revealed the surprisingly active photochemistry of the snow pack.

JEAN CÔTÉ is a senior research scientist with the Meteorological Service of Canada's Division de recherche en prévision numérique, where he heads the Numerical Methods Group. He also holds an adjunct professorship in the Department of Earth and Atmospheric Sciences in the Université du Québec à Montréal. Dr. Côté supervised the development of the unified Global Environmental Multiscale (GEM) model, which is widely recognized as one of the world's most advanced weather prediction models. His research interests include the development of numerical methods for describing environmental flows, parallel computation, and further applications of the GEM model. Dr. Côté is a recipient of the Canadian Meteorological and Oceanographic Society's Andrew Thompson Prize in applied meteorology.

JACQUES DEROME is a professor in the Department of Atmospheric and Oceanic Sciences at McGill University and principal investigator of the Canadian Climate Variability Research Network (CLIVAR). His research focuses on unravelling the physical mechanisms responsible for year-to-year variations in average seasonal atmospheric conditions and on determining the predictability of this variability. He is also engaged in studies of the connection between sea surface temperatures in the tropical Pacific and atmospheric conditions in other parts of the world. Dr. Derome has collaborated for a number of years with MSC researchers on the development of seasonal forecasting techniques, some of which are now used by the Canadian Meteorological Centre to produce operational seasonal forecasts. Dr. Derome is a recipient of the Patterson Medal of the Meteorological Service of Canada and the Oscar Villeneuve Prize of the Société de météorologie de Québec. He was elected a Fellow of the Canadian Meteorological and Oceanographic Society in 2000.

MIRIAM DIAMOND is a professor in the Department of Geography at the University of Toronto. Her research utilizes mathematical modelling, analytical chemistry, lab studies, field studies, and information management to study the movement of anthropogenic contaminants between different environmental media (e.g., air, water, and soils). Dr. Diamond also leads a multidisciplinary research group that applies a wide range of social and scientific perspectives to the development of strategies for improving environmental quality.

JAMES DRUMMOND is a professor of physics at the University of Toronto. His principal research interest is the measurement of atmospheric composition using a variety of remote sounding platforms, including satellites, balloons, and aircraft. He is the principal investigator of the Measurements of Pollution in the Troposphere (MOPITT) experiment, which was launched on NASA's Terra satellite in 1999 and provided the first satellite-based measurements of air quality in the troposphere. He is also a co-investigator on the balloon-based MANTRA program and the satellite-based MAESTRO and FTS instruments. He is currently developing proposals for instrumentation to measure the atmosphere of Mars. Dr. Drummond is an active member of several committees of the Canadian Space Agency and regularly reviews research proposals for both NASA and the European Space Agency. He was awarded the Patterson Medal of the Meteorological Service of Canada in 1996.

GEORGE ISAAC is a senior research scientist in the Cloud Physics Research Division of MSC and an adjunct professor in the Department of Physics and Atmospheric Science at Dalhousie University. His research interests include aircraft icing, the parameterization of clouds in numerical models, cloud chemistry, clouds and climate, and general cloud microphysics. Dr. Isaac has been a member of the World Meterological Organization's Committee on the World Weather Research Programme since 1988 and is president of the International Commission on Clouds and Precipitation of the International Association of Meteorology and Atmospheric Sciences. He is currently a member of the editorial board of *Atmospheric Research*.

JAMES KERR recently retired as a senior research scientist with the Meteorological Service of Canada and continues his research as a scientist emeritus of Environment Canada. His research interests centre on stratospheric ozone and ultraviolet radiation. He is a co-inventor of the Brewer ozone spectrophotometer, the standard, ground-based instrument for measuring atmospheric ozone and UV radiation, and co-developer of the Canadian UV Index. Both the Brewer instrument and the UV Index are in widespread use throughout the world. His other scientific achievements include demonstrating the critical link between ozone depletion and increased UV radiation (in collaboration with Thomas McElroy). Dr. Kerr has also made significant contributions as co-author and lead author of international scientific assessments on the ozone layer and climate change and is a member of the World Meteorological Organization's Scientific Advisory Group for atmospheric ozone.

CHARLES LIN is a professor in the Department of Atmospheric and Ocean Sciences at McGill University and chaired the department from 1998 to 2003. Dr. Lin's research has focused on high-resolution atmospheric modelling of severe precipitation events, the coupling of atmospheric and hydrological models for flood simulation, and climate science. From 1996 to 1999 he served on the Grant Selection Committee for Environmental Earth Sciences of the National Science and Engineering Research Council and is currently a director of the Computational Fluid Dynamics Society of Canada. He was awarded the President's Prize of the Canadian Meteorological and Oceanographic Society in 2002.

GORDON MCBEAN is a professor in the departments of Geography and Political Science and Policy Chair of the Institute for Catastrophic Loss Reduction at the University of Western Ontario. From 1994 to 2000 he served as an Assistant Deputy Minister in Environment Canada and headed the Meteorological Service of Canada. Dr. McBean's research interests range from the atmospheric and climate sciences to the development of government policies and public responses to these. From 1988 to 1994 he served as chair of the Joint Scientific Committee of the UN's World Climate Research Programme. He currently chairs the Board of Trustees of the Canadian Foundation for Climate and Atmospheric Sciences and is a member of the Advisory Committee on the Environment of the International Council for Science. He has received the Patterson Medal for distinguished contributions to meteorology and is a Fellow of the Royal Society of Canada, the Canadian Meteorological and Oceanographic Society, and the American Meteorological Society.

JOHN MCCONNELL is a professor in the Department of Earth and Atmospheric Science at York University, where his research encompasses the study of atmospheric transport, chemistry, radiative transfer, and other characteristics of the Earth's atmosphere and the atmospheres of other planets. He is currently principal investigator of the Multiscale Air Quality Network, funded by the Canadian Foundation for Climate and Atmospheric Science, and is a co-investigator of several other major atmospheric chemistry studies, including MOPITT, MANTRA, MAESTRO, and the Canadian Middle Atmosphere Model. A Fellow of the Royal Society of Canada, Dr. McConnell has served as an associate editor of the *Journal of Geophysical Research* and on several government advisory panels, including the National Research Council's Panel on the Atmospheric Effects of Aviation and the Intergovernmental Panel on Climate Change's working group on Aviation and the Global Atmosphere.

THOMAS MCELROY is a senior research scientist with the Meteorological Service of Canada and an adjunct professor in the Department of Physics at the University of Toronto. His research embraces a broad spectrum of interests, including instrument design, data analysis, modelling, retrieval theory, and ozone science. Dr. McElroy is a co-inventor of the Brewer ozone spectrophotometer and co-developer of the Canadian UV Index. He is also the designer of the "double Brewer," the most accurate ozone-measuring instrument in the Global Ozone Observing System, as well as the SunPhotometer and SunPhotoSpectrometer used aboard the space shuttle by Canadian astronauts Marc Garneau and Steve

MacLean respectively. Dr. McElroy is principal investigator for the MAESTRO instrument used aboard Canada's SCISAT-1 research satellite, launched in August 2003.

NORMAN MCFARLANE is a senior research scientist with the Canadian Centre for Climate Modelling and Analysis of the Meteorological Service of Canada in Victoria. He also holds a limited term professorship in the University of Victoria's School of Earth and Ocean Sciences and an adjunct professorship in the University of Toronto. Dr. McFarlane is one of Canada's pioneering researchers in climate modelling and analysis and has made a number of significant contributions to the field, particularly in areas relating to atmospheric dynamics, cloud processes, and aerosols. He was an expert reviewer for the Third Assessment Report of the Intergovernmental Panel on Climate Change and is currently Associate Editor of the *Journal of Climate*. Dr. McFarlane was awarded a Citation of Excellence by Environment Canada in 2002 and is also a recipient of the Patterson Medal for distinguished contributions to meteorology in Canada (1996) and the Andrew Thompson Prize in applied meteorology (1987).

HAROLD RITCHIE is a senior research scientist with the Meteorological Service of Canada and an adjunct professor in the Department of Oceanography at Dalhousie University. His main areas of research are numerical weather prediction and coupled numerical modelling for environmental prediction. Dr. Ritchie leads the coupled numerical modelling group at Recherche en prévision numérique (RPN), MSC's research centre for numerical weather forecasting in Dorval, Québec, and is also MSC's lead scientist on the Atlantic Environmental Prediction Research Initiative (AEPRI), a multipartner project based in Halifax, N.S., that is developing methods for more comprehensive environmental prediction. This work has led to the implementation of Canada's first operational storm surge prediction and water level alert system. Dr. Ritchie is also working with Dalhousie University and other partners on the development of a Marine Environmental Prediction System that will improve the ability to forecast physical, chemical, and biological changes in the marine environment and assess the impacts of climate change and coastal development.

TED SHEPHERD is a professor of physics at the University of Toronto whose research interests range from theoretical atmospheric dynamics to stratospheric ozone and chemistry-climate coupling. For over 10 years he has been the principal investigator of the MSC-university collaboration responsible for the development of the Canadian Middle Atmosphere Model, a state-of-the-art climate simulation model focused on the representation of ozone-climate interactions. Dr. Shepherd has played leading roles in the 1998 and 2002 WMO/UNEP Ozone Assessments, and is currently a coordinating lead author for the IPCC/TEAP Special Report on Ozone and Climate. He also serves as Chief Editor of the *Journal of the Atmospheric Sciences*, published by the American Meteorological Society. Dr. Shepherd is a recipient of the Natural Sciences and Engineering Research Council's E.W.R. Steacie Fellowship (1995) and the Canadian Meteorological and Oceanographic Society's President's Prize (1995).

RONALD STEWART holds the NSERC Industrial Chair in Extreme Weather in the Department of Atmospheric and Ocean Sciences at McGill University. He was previously a senior research scientist with the Meteorological Service of Canada and served as President of the Canadian Meteorological and Oceanographic Society in 2001–2002. His research interests focus on precipitation, storms, and the water cycle, and he has led or chaired numerous research programs and provided formal scientific advice for many national and international activities on these topics. He has also published widely, with more than 200 papers in the peer-reviewed literature and in conference proceedings and reports. Dr. Stewart is a recipient of the Environmental Research Excellence Award from GKSS in Germany and the President's

Prize of the Canadian Meteorological and Oceanographic Society.

PETER TAYLOR is a professor in the Department of Earth and Atmospheric Science at York University where he specializes in atmospheric boundary layer and mesoscale studies, using a range of numerical models and field programs. His recent work has included applications for the study of surface weather on Mars (to be used in the joint NASA/Canadian Space Agency Phoenix program, scheduled to land on Mars in 2007), field studies of blowing snow in the Arctic, and investigations of severe summer storms in southern Ontario (as part of ELBOW 2001, a joint project with MSC on which he served as chief university scientist). His research group is also actively involved in several modelling projects, including mesoscale modelling, studies of the diurnal cycle in the boundary layer on Earth and Mars, studies with the Canadian land surface scheme (CLASS), and simulation modelling of suspended particles. Dr. Taylor is Co-Chief Editor of the journal *Boundary-Layer Meteorology.*

DAVID WARDLE has been with the Meteorological Service of Canada since 1972 and served as Chief of its Experimental Studies Division from 1989 to 2003. His interests lie in the field of radiometry, specifically the measurement of ozone and other atmospheric constituents and the measurement of solar energy and atmospheric radiation. A co-inventor of the Brewer ozone spectrophotometer and the UV Index, Dr. Wardle began designing radiation-measuring instruments while still a student at Cambridge in the 1960s and was the first person to measure ozone throughout an Arctic winter. He is currently working on improvements to the Brewer instrument and making balloon-based measurements of trace atmospheric constituents as part of the MANTRA project. He is a member of the World Meteorological Organization's National Ozone Managers Committee and its Scientific Advisory Group on UV radiation.

ANDREW WEAVER is a professor and Canada Research Chair in Atmospheric Science in the School of Earth and Ocean Sciences at the University of Victoria. An editor of the *Journal of Climate,* he has written over 130 peer-reviewed papers and was a lead author of chapters in the Intergovernmental Panel on Climate Change's two most recent scientific assessments of climate change. Dr Weaver presently serves on the United Nations World Climate Research Program Working Group on Coupled Modelling and on the Climate Research Committee of the U.S. National Academy of Science. He is also co-chair of the World Climate Research Program's CLIVAR PAGES Intersection project. He was awarded the Natural Sciences and Engineering Research Council's E.W.R. Steacie Memorial Fellowship in 1997 and was elected a Fellow of the Royal Society of Canada in 2001. In 2002 he received a Killam Research Fellowship and was chosen as one of the top 20 scientists in Canada under the age of 40 by the Canadian Institute for Advanced Research and as one of 25 Power Thinkers in British Columbia by *BC Business* magazine. *Time* magazine selected him as one of Canada's top scientists in 2003.

FRANCIS ZWIERS, Chief of the Canadian Centre for Climate Modelling and Analysis, Meteorological Service of Canada, in Victoria, B.C., has worked in climate research at Environment Canada for more than 20 years. Dr. Zwiers's areas of specialization include the analysis of climate variability, climate change detection, climate extremes, and seasonal forecasting. An editor of the *Journal of Climate,* he serves on a number of international comittees and panels and was a lead author of the recent Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

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