CLIMATE SCIENCE AGENDA FOR CANADA

2002-2012

March 31, 2002

Prepared for:

Meteorological Service of Canada
Environment Canada (MSC, EC) and
Canadian Foundation for Climate and
Atmospheric Sciences (CFCAS)

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PREFACE:

The development of a **Climate Science Agenda for Canada – 2002 – 2012** was undertaken at the request of the Meteorological Service (MSC), Environment Canada and of the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS). The drafting was undertaken by James P. Bruce, Senior Associate, Global Change Strategies International Inc. with assistance of Matt Jones. However, the judgments, concepts and ideas contained in the document were the result of:

1. Discussions at a multi-stakeholder workshop held by CFCAS and MSC in Ottawa, 5 March, 2002,
2. An Experts Panel meeting of leading scientists and policy-makers, Ottawa, 18 March 2002,
3. A review of related assessments undertaken internationally, in U.S.A. and in Canada (see Reference list).

The procedure involved preparation of an initial outline based on the 5 March workshop followed by an intensive discussion by the Expert Panel 18 March. A complete draft was then prepared and circulated to the Panel members who provided extensive and valuable reviews and comments. This final draft incorporates most of those comments.

It is hoped that this document will form a sound basis for further consultations and for advancement of Canada's Climate Science Agenda.

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Ottawa, 30 March 2002

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SUMMARY: CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS:

The Policy Framework:

Canadian policies related to **climate change** have a critical urgency in the short-term but must be developed in the longer-term context. In the coming months and decade, Canadian governments, businesses and citizens must:

- Decide in 2002 on measures needed for ratification of the Kyoto Protocol
- Develop suitable carbon trading policies and mechanisms
- Decide by 2006 on the extent to which carbon sinks can be claimed by Canada
- Decide by 2006-8 on optimum strategies for negotiating emission reductions in second commitment period after 2012, in the context of a long-term strategy
- Begin purposeful adaptation measures to minimize adverse climate change impacts on Canadian economy, people and environment, and take advantage of new opportunities
- Implement ratified commitments for the 2008-2012 commitment period

All of these and many lesser decisions have potentially profound impacts on Canada's economy and society. It is imperative that they be underpinned by sound science. At the same time, the **variations of climate** from season to season and year to year can be more effectively responded to in agriculture, water management, energy, transportation and other sectors, on the basis of more reliable science based predictions.

Even if the Kyoto Protocol does not come into force, new alternative international agreements will have to be promoted by Canada, and adaptation measures implemented for a more rapidly changing climate.

In short, Canadian policies and actions must be based upon "Made in Canada" scientific advice of world class standard.

International Comparisons:

To underpin the necessary policy decisions and actions requires a long-term commitment to climate science, both research and systematic data collection. Canada's efforts have been falling behind those of Australia, UK, Germany, Japan and U.S.A. as these countries have recognized

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the central importance of climate science by large increases in support. In Canada, while several programs have provided for increased research for a few years in Universities, government funding has generally fallen behind, leaving Canada's central climate modeling facility supported at a marginal level, programs of systematic observations below world standards, and other key topics inadequately addressed.

Climate change and variability are, for Canada, a major problem with many unknowns, and require a large science commitment to address effectively. Indeed, climate science must be recognized as a "big science" requirement for Canada, since climate and climate change profoundly affect our northern latitudes, economy and society.

SUMMARY OF RECOMMENDATIONS:

1. What is the range of natural variations in climate and can we better predict seasonal climatic conditions?

In order to realize substantial potential economic benefits, Canada should:

i) Increase by 50% Canadian involvement in the international program CLIVAR, Climate Variability and Predictability.

ii) Establish a dedicated unit of about 10 staff for research and issuing seasonal predictions, making use of work of CCCma, RPN and the CMC[1]. An oceans analysis and modeling capability must be included in the unit.

2. What outcomes of human activities and natural factors are forcing changes in climate?

To what extent are Canada's forests, agricultural lands and peat lands, sources and sinks of carbon dioxide, methane and nitrous oxides and can sinks be augmented by verifiable quantities?

Augment support for BIOCAP Canada, carbon cycle modeling, and biospheric sinks and source research. Produce an assessment statement in 2005 on current state of knowledge of Canadian sinks (forests, agriculture, peat lands) including:

- opportunities for enhancement and ensuring continuity,
- reliable, reproducible estimation and measurement methods for sinks suitable to be confirmed internationally, and
- assessment of net effects of afforestation on climate through albedo and water balance changes, and sequestration of atmospheric carbon.

[1] CCCma: Canadian Center for Climate Modeling and Analysis: Environment Canada at the University of Victoria.
RPN: Recherché sur Prévision Numerique, Environment Canada, Montreal
CMC: Canadian Meteorological Center, Environment Canada, Montreal

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3. How can we improve projections of future climate change under human and other forcing factors, needed for mitigation policies and for intelligent adaptation measures over Canadian Territories (land and sea)?

Double the magnitude of effort directed towards improving Global and Regional Climate Models. The government/university arrangements for these research programs and science services at, for example CCCma at University of Victoria, should be built upon, combining government stability of staff and funding, and contributions of University research, professors and graduate students. A suitable building facility for CCCma is urgently required as well as continuing up dating of computer facilities to ensure availability of leading edge equipment. In the longer term, CCCma should grow to about the size of GFDL[2] one of USA's modeling centers (about 80 staff). A more operational capacity for producing RCM results must be created to complement the present University-based research program.

4. What are special issues of climate science on which Canada must focus, for both its own needs and to make an appropriate contribution to understanding the global system?

i) Arctic climate science - A doubling of Arctic climate science support is warranted within the framework of international ACSYS and CliC. This would involve re-instating major logistic and data gathering support, including an ice-breaking vessel for Arctic research and measurements. A portion of the increased effort should be devoted to climate change impacts in this vulnerable region.
ii) The high-latitude oceans with adequate ship time for oceanographic measurements and research.
iii) Research on clouds and water vapor and the cryopheric cycle should be increased 30 – 50%.
iv) More permanent observational programs and modeling of oceans in the Canadian EEZ is needed, but must be augmented by greater involvement and better access to tropical and mid ocean information which strongly influence Canada's climate and coastal oceans.

[2] GFDL: Geophysical Fluid Dynamics Lab., US/NOAA, Princeton
ACSYS: Arctic Climate System Study
CliC: Climate and Cryosphere
AP2000: Action Plan 2000
MSC: Meteorological Service of Canada (Environment Canada)

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5. How vulnerable are Canada's people, resources, and economic activities to climate change and what are the likely physical and economic impacts?

The resources committed to climate impact studies should be greatly increased, and studies should be required to provide costs of impacts, if at all possible. Periodic (every 3 years) summaries of potential impacts and costs should be prepared.

6. To what extent is climate change occurring now? How can we best document the evolution and variations of climate over Canadian territory (land and sea)?

A stronger program for analysis of trends, frequencies, climate variations, based on available records and retrieval of recorded data, is required. The present program concentrates on temperature, total precipitation and stream flow. More attention should be given to short duration rain intensity, thunderstorms and extreme event frequencies, changes in aerial storm rainfall amounts, water vapor, extreme winds, etc. A dedicated staff of 8 to 10 members is required to ensure meeting the needs for continuing up-dated information, just as essential as census information.

While $2.4 mill (AP 2000-MSC) to restore or increase the surface climate observation network North of 60^0N is welcome, a second injection of a like amount is required to fill gaps South of 60^0N. What is more important is that MSC and DFO receive the increased operating funds needed to maintain these programs and existing ones for many decades, and to quality control and make available the data.

Charging Policies:
Charging policies for access to basic climate and related data should be dropped in the interests of encouraging their widespread use for research. The government should also examine the feasibility of making satellite images from RADARSAT (Canadian Space Agency) available for cost of reproduction.

7. How can climate science be made more useful to the public and policy-makers?

Integrated Assessment Model:
The Research Granting Councils should examine the means by which a multi-disciplinary Integrated Assessment Modeling capability can be created in Canada, linked to the GCM of CCCma.

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Science Assessments for Policy Makers:
Arrangements should be made, through CFCAS[3], for preparing and making widely available, a report on the "Implications for Canada of IPCC's[4] Third (Fourth) Assessment Report". Ideally this would cover the reports of all three Working Groups of IPCC.

Coordination:
Establish a broadly based Canadian Committee for Climate and Global Change Science with responsibilities for promotion, coordination, exchanges of views on priorities, and serving as Canadian liaison with international programs (WCRP, IGBP, IHDP, GCOS). (See Section 5) This role could be assigned, with appropriate support, to CFCAS.

Communications:
Environment Canada should undertake leadership to promote more effective dissemination of climate science findings, through a speakers bureau, involving non-governmental as well as government scientists, a roster of media responders, commissioning of articles for magazine and OpEd use. There should be government staff dedicated to "paving the way" for scientists to provide articles, presentations, etc. for the media and public.

[3] CFCAS – Canadian Foundation for Climate and Atmospheric Science

[4] IPCC – Intergovernmental Panel on Climate Change

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1. THE CLIMATE – PUBLIC P0LICY ISSUES:

The Prime Minister, Cabinet members, some business leaders and many scientists have characterized human-induced climate change as the greatest environmental and economic challenge of the 21st century. It is an issue generally acknowledged to have been put on the world's agenda by the international scientific community over the past one and a half decades. Over the same period, the variations in climate, bringing droughts, floods and extreme weather events, have caused major economic and social disruption to Canadians, whether they are due to natural climatic fluctuations or have anthropogenic influences, or what is most likely, both.

While knowledge of these phenomena and of the behavior of the global climate system has greatly improved, much remains to be learned. The main purpose of such learning is to better predict the future – what will next season bring? – and the next 20, 50, 100 years? How much could human actions modify the future climate evolution and what role can Canada's natural resource systems (e.g. forests and agriculture) play?

Many critical issues of public and private policy are at stake. A few examples based on recent experience will illustrate this point. Most rivers and streams from the British Columbia interior eastward to the Lake Superior basin have declined in average flow and minimum flow over the past 30 to 50 years, i.e. a significant drying has been occurring on the southern Prairies. Permafrost has been melting in the Arctic and sub-Arctic with accompanying land slumps disrupting river courses, transportation, buildings, pipelines, wildlife and human activities. Year round ice in the Arctic has declined by 14%, sea level has risen 10 to 20 cm, severe winter snow and ice storms have increased in intensity, temperatures have risen with both positive and negative effects. For appropriate planning of billions of dollars worth of infrastructure, for land use, agriculture, energy, forest and water management and policies, and for economic planning of Canada's basic industries, it is of critical importance to answer with confidence questions of the following nature:

Will the recent trends intensify or moderate in coming decades?
What are the implications for Canada's environment, economy, human health and social structures?
Will there be sufficient water for agriculture to continue to be viable in part of the Prairies and elsewhere?
What should we do about boundary and transboundary water issues?
How soon must we address melting of ice and opening of Arctic navigation, which pose issues of sovereignty as well as transport and pollution prevention.
How can costly urban and rural infrastructure best be maintained with changing design criteria and what magnitude of change should be provided for?

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> Can increased forest impacts from fires, insects and diseases be minimized?
> What can be done to reduce health impacts of longer, more intense, smog episodes?
> Will a changing climate also change uptake or release of greenhouse gases from the biosphere thus slowing or accelerating climate change?

The issue raised by this document is whether Canada is adequately supporting the large-scale science, of a sustained and innovative nature, on appropriate topics, to answer such questions with confidence and to deal with an issue of this magnitude.

> Does the capacity for and organization of climate scientific activity in Canada ensure effective coordination and timely delivery of scientific results to public and private policy makers at all levels?
> Are programs sufficient to attract a continuing stream of young scientists to address this long-term issue?

Scope

The focus of this analysis is climate science, including research and systematic data collection and analysis. It encompasses climate system science (of the atmosphere, ocean, land surfaces) and the first order impacts of climate change and variations. It is focused broadly on the natural sciences since physics, chemistry and biology of ocean and land and their interactions with atmosphere are involved. It is recognized that economic, social and engineering research is also needed, but except to identify some important linkages, they are beyond the scope of this report.

Procedure

This assessment emerged from a process of consultation, first at a workshop in Ottawa, 5 March 2002, organized by the Meteorological Service (MSC), Environment Canada and by Canadian Foundation for Climate and Atmospheric Sciences. Participants included a broad range of scientists, representatives of user agencies, funding bodies and some private sector spokespersons.

Key participants in the 5 March workshop were then convened as an Expert Panel, 18 March, for more detailed, intense, discussions of a Climate Science Agenda for Canada. Global Change Strategies International produced a draft "Agenda" based on these discussions, which was subsequently reviewed and commented on by Panel members. This resulted in revisions, which are incorporated in the present document.

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2. CLIMATE SCIENCE – A BASIC NATIONAL NEED:

Knowledge of the climate system and its effects on Canada must be **regarded as a critical component of the country's infrastructure**. Such knowledge is an essential underpinning for national, provincial, municipal and industrial policies (1) to assist in reducing human impacts on the climate system and (2) to adapt efficiently to variations and changes in climate. Climate has an impact on natural resources, water and energy production and use, forests, snow and ice, wildlife and their habitat and on biodiversity. It profoundly affects many key economic sectors including forestry, energy, agriculture, fisheries, tourism and recreation, transportation (especially air and water). Climate affects the health and well being of Canadians and indeed is a core part of the Canadian psyche. Adapting to the natural variations and extremes of climate and weather has always challenged Canadian ingenuity and activities are finely tuned to the climate of the recent past. The evidence is now compelling that the climate of the past is an unreliable guide to the future, since human actions are now causing increasingly rapid changes in climate. (IPCC 2001) This creates a greater challenge – one requiring the best possible scientific projections of the future climate and assessment of its variability and extremes. To illustrate the issue of extreme events, weather related disaster losses in Canada have increased at least four-fold from the 1980's to the 1990's much more rapidly than the value of facilities and property at risk. Design of storm sewer and drainage systems, of buildings, of transportation systems, of bridges and river structures and many other aspects of fixed infrastructure require information on frequency of extreme events, for safe yet efficient design. Changing climatic conditions must be quantified and taken into account for optimum efficiency of these infrastructure components and protection of lives. Climate science not only defines the problem, it provides the fundamental basis for effective solutions – for example through increasing agricultural and forest sinks and adaptation measures.

At the same time, better knowledge of the climate system as it affects Canada can lead to substantially improved forecasts from a season to a year ahead of climatic conditions. This has major benefits for the Canadian economy. Knowledge of climate is gained through **systematic data collection, analysis and research**. Since the climate system is global, these activities must be conducted in the framework of international efforts. But only Canadians will undertake the data collection and research needed to understand and document how that global system affects Canada. In addition, Canadian territory occupies such a large portion of the world's surface that international projects cannot be truly global without observations from and participation of Canada

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3. INTERNATIONAL COMPARISONS:

Many other countries have greatly enhanced their climate science programs in recent years. This threatens to leave Canada at some disadvantage. It is estimated that Australia has four times as many scientists as Canada working on climate. A central role is played in climate science by the global climate modeling Centers. The Canadian Climate Center for modeling and analysis has a total staff of about 25. The UK's parallel Hadley Center has some 105 staff members of whom 80 are research scientists and the US NOAA's Geophysical Fluid Dynamics Lab (only one of several US centers) has 80 staff members. In Europe and Japan, major increases in climate science funding have been announced and the U.S. Congress is currently considering the President's proposal for a major increase beyond the $1.53 bill for research for 2002. In addition, U.S.A. supports extensive observation programs including a number of satellite missions relevant to climate. On the other hand, Canada has provided increases in funding at universities through several programs, but funding is only committed for a limited period (e.g. CFCAS funds until 2006). At the same time funding for government research and systematic data collection on this topic has declined in real terms in recent years.

Experience world-wide shows that the long term sustained efforts, usually by government institutions, needed for Atmosphere-Ocean Global Climate Model development and testing, and for systematic nationwide observation systems can only be undertaken by government agencies or institutions with assured long-term funding.

4. THE ROLE OF CLIMATE SCIENCE IN POLICY DEVELOPMENT (2002-2012):

The Canadian government must make **critical decisions** in 2002 concerning programs of emissions limitation and increases in sinks that would lead to ratification of the Kyoto Protocol. These decisions must be based largely on science and analyses done to date. By the end of 2006, Canada may also have to take further policy decisions under the Kyoto Protocol concerning the extent and nature of sinks it will declare. This requires improved knowledge of sinks and their behavior. But it is generally recognized that Kyoto represents the first small but important step in a long journey of emission controls to prevent serious climatic dangers. Measures to be undertaken by Canada and other countries in the second and third commitment periods beyond 2012 will be based upon research and analyses begun today. A more complete list of policy and program decisions required of the government is found in the Summary at the beginning of the report.

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While the implementation of the Kyoto Protocol will slow the rate of acceleration of climate change, the climate will continue to change rapidly in coming decades, requiring effective and cost-effective adaptation measures in most economic sectors, and measures to protect Canadians' health and environment. While the Kyoto Protocol is a small step towards the goal of stabilizing the climate, as agreed in the ratified UN Framework Convention on Climate Change, a climate corresponding to a doubling of pre-industrial CO_2, with major changes, now seems almost inevitable. Countries must strive, starting with the Kyoto Protocol, to prevent a 4 x CO_2 world, which would bring catastrophic climate impacts. In Canada, a northern country, climate changes will be much greater than in more temperate zones and this pattern is already being observed, making effective adaptations a key element to retain a competitive economy and protect society. Adaptation planning requires more detailed climate change projections than current science can provide.

Coming into force of the **Kyoto Protocol** and implementation of its provisions, while recognized as a first step, would slow by about a decade the worst effects of climate change allowing a little more time to plan and implement adaptation measures, provided the more detailed research results and impacts analyses are available to guide effective adaptation. Such analyses must encompass impacts on water systems, permafrost, ice, animals and insects, and vegetation, as well as human health, infrastructure and social disruption.

5. INTERDISCIPLINARY AND INTERNATIONAL DIMENSIONS:

The climate system affecting Canada encompasses the physical, chemical and biological characteristics of the atmosphere, the oceans, the land surfaces and their condition, the water, energy and carbon cycles, ice and snow cover. Scientists from many natural sciences involved in studies of these components must work together. Integration of their work is accomplished mainly through Global Climate Models. Earlier work has given Canada one of the very best models of the climate system, the CCCma GCM of the Meteorological Service, Environment Canada based at University of Victoria. Continued refinement of this model requires interaction between the modelers and many research groups studying key processes in the climate system. The model is used to make projections of future climates with and without forcing by greenhouse gases and aerosols.

Coupled atmosphere/upper ocean models can also be used more extensively for seasonal forecasts of climate but require assimilation of global atmosphere/upper oceans observational data. At the same time verification of the models depends upon data from systematic observational programs, and since Canada occupies a large part of the globe, adequate

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observational data from our territory is vital, not only to Canadian model verification, but also for analysis and monitoring of the Canadian climate.

Major **global climate research programs** include the World Climate Research Program (WCRP), which is coordinated by the World Meteorological Organization, the Intergovernmental Oceanographic Commission of UNESCO and the non-governmental International Council for Science. The International Geosphere-Biosphere Program is closely coordinated with WCRP but with a strong emphasis on biological and chemical processes. A Human Dimensions of Global Change program complements the international efforts in the natural sciences. Canadian scientists played a leading role in developing and planning these internationally coordinated efforts in the 1980's and early 1990's. However, in recent years as other governments have increased their climate funding and support compared to Canada, Canadian influence has declined. Nevertheless Canadian projects continue to contribute to several components of these global programs.

The cooperative Global Climate Observing System coordinates the development of sustained observations of atmosphere, oceans and terrestrial systems to meet global and national needs for climate variability and change description, detection and prediction. The coordinated system permits verification of climate models.

In 1988 a climate science **assessment** mechanism, **the Intergovernmental Panel on Climate Change** (IPCC), was established on a global scale, by UN bodies, the World Meteorological Organization and the United Nations Environment Program. Canada has supported this effort with modest funds, but more importantly by serving on the Bureau, and providing a total of over 30 lead authors (of the 1000 globally) for all three Working Groups for the Third Assessment Report, published in 2001. This **Panel** is recognized as the most authoritative voice in weighing and assessing the growing volume of climate science. It has three Working Groups, one on Climate System Science, one on Impacts of Climate Change and Adaptation, and one on Mitigation. The Scientific Basis (Climate System Science) in Working Group I Report, 2001, in addition to assessing research results already reported, addressed the topic "Advancing our Understanding", i.e. an agreed perception of key research needs.

It should also be noted that active Canadian participation in these international science activities pays big dividends. It permits extension of Canadian work by inter-comparison and verification with the large amounts of non-Canadian research. Scientists participating in WCRP, IGBP, and in IPCC, learn about, and bring back to Canada, leading edge research results from many countries, thus avoiding "blind alleys" and permitting Canadian research efforts to build upon rather than re-inventing results from abroad. Further, Canadian scientists can help guide international programs to focus on issues of vital concern to Canada e.g. high latitude effects, permafrost, etc. Both WCRP research plans and IPCC assessments of research needs have been taken into account in developing this research agenda for Canada. In addition, research agendas

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within Environment Canada, particularly the Weather and Environmental Prediction Research Agenda have been consulted in developing the present more broadly based multi-agency and multi-partner agenda.

6. SCIENCE NEEDS AND PRIORITIES – 2002 - 2012

6.1 Prediction of Future Climate – from Seasons to Centuries:

It has been said that the purpose of science is to **predict** the future state of systems. Prediction through better understanding and modeling is a key goal of climate science. For climate this includes, time scales of seasonal forecasting to projections of future climate decades to a century ahead, under anthropogenic and natural forcing factors. Much of the climate science agenda can be described within a prediction framework. In Section 6.1, 6.2 and 6.3, a major portion of the needed effort is outlined in this prediction framework but a few key issues such as the Arctic, and sinks, and climate information for day to day management, are dealt with in special sections.

Table 1

CLIMATE PREDICTION COMPONENTS	
Infrastructure Needs	**Science Needs**
· State of the art computer facilities · A highly qualified staff with assured continuity · International linkages · Global observational data including from Canada: -by systematic observation networks -by paleoclimatic techniques	· A major climate modeling Center · Regional Climate Modeling · Clouds, Water Vapor and Ice Feedbacks · Carbon Cycle model · Improved Ocean boundary layer modeling and modeling of coastal margins · Natural variability understanding · Arctic Atmosphere and Oceans modeling (see 6.5)

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The central hub of climate prediction is the development, maintenance and enhancement of an atmosphere-oceans-ice-land surface Global Climate Model (GCM), which can be used to determine human and other impacts on the climate system in the long run, decades to century. Such models can also be used to make predictions of climate conditions on seasonal to inter-annual scales that are of critical value in water and energy management, agriculture, and in other business and government sectors.

Adequate support of climate prediction capability requires a number of key infrastructure components (see table 1). In addition, the modeling effort can help set priorities on those processes that need to be better understood to be modeled successfully. Some key science needs to support GCM developments are also listed in Table 1. More details on both infrastructure and science components of the predictive system are contained in the following sections. (6.2 and 6.3)

CCCma

Canada's central AOGCM modeling capability, at CCCma (Environment Canada at University of Victoria) has been globally influential until now, but is threatening to fall rapidly behind efforts in many other countries (see Section 3 above) unless major additional support is provided. It was noted that with a staff of 25, it is only 1/3 to 1/4 the size of global modeling centers in other countries. A doubling of funding and resources is an urgent requirement with a goal of a 3 times expansion over the coming decade. The government/university arrangement for CCCma has proven to be very effective, combining government stability and university research through professors and graduate students. This type of arrangement should be continued. It must also be noted that there is an urgent need for better accommodation for CCCma and for ensuring availability of state of the art computer facilities for developing, testing and running the complex models. (See Section 6.2)

6.2 Infrastructure Needs

The World's climate modeling centers strive to have the fastest computer facilities available to develop run, test and inter-compare the complex models. At present, the CCCma models are run on the NEC processors at Canadian Meteorological Center, Montreal. This facility is shared between operational forecast needs of MSC, Climate Modeling and other MSC research needs (e.g. modeling of long range transport of airborne pollutants. University access is also provided. It is understood that the present contract for computer facilities expires early in 2003. In other similar Climate Modeling Centers, e.g. Max Planck Inst. Germany, Hadley Center, UK, more powerful computers are available on a dedicated or high priority basis. A study by U.S. National Research Council suggests that to eventually reach climate modeling with a spatial resolution of

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10 km or less, i.e. to resolve severe weather cells, requires computational throughput of the order of 40 teraflops. (10^{12} floating-point operations per second)[5]

Canada must ensure that either through a shared or a dedicated arrangement, the CCCma and RCM modelers and their collaborators have adequate access to leading edge computer facilities.

Staff and Continuity:
The CCCma has had an impact disproportionate to its size (<20 continuing and about 25 total staff) because of the high capability of core staff. This influence is not sustainable in face of rapid growth of such Centers in Australia, Germany, Japan, UK, and U.S.A. And indeed, model output to meet specific Canadian needs may in future fall behind increasing world class capabilities, without a doubling of permanent staff, and a program to attract bright young graduates.

International Linkages:
Model inter-comparisons between Centers, and model diagnostics require exchanges and cooperation, which in turn require time of senior staff. For example, Canada has not been able to accept an invitation to participate in the re-analysis work of the European Center for Medium Range Weather Forecasting (ECMWF), making these results, valuable for verification of models, less accessible. It is also important to Canada's interests that time-consuming work on the IPCC Assessments be seen as part of the function of key staff members.

Systematic Observations: (See section 6.8)

6.3 Science Needs for Modeling and Prediction(in addition to strengthening Global Climate Modeling Center) (See Section 6.1)

Regional Climate Modeling:
In order to determine impacts of climate variations and change on river basins, agricultural areas, cities, etc., model outputs at a much finer scale than those from Global Climate Models (GCMs) are required. This is accomplished by downscaling through regional models (RCMs), nested within the global model. A modest ($1.4 mill over 3 years) research program on this topic is supported by CFCAS. Additional funding from NSERC and the Quebec OURANOS program increases the effort to about $1 mill/year. A difficulty, however, is that most of the work is done with students, post-Doctorates, and MSc level support people, with only two senior scientists. While this provides for valuable training, the sustained continuity required is difficult to achieve. A more permanent group of 8 to 10 staff members is needed to take advantage of the University based research and apply the model to various regions of Canada for impact and adaptation

[5] U.S. National Research Council (1998) – Capacity of U.S. Climate Modeling to support Climate Change Assessment. 15p.

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studies. It is estimated that the total level of effort needed to achieve most of the potential benefits would have to double. Support should also be continued for a statistical approach to downscaling model results, which will permit inter-comparisons with regional model (RCM) results.

Clouds, Water Vapor, and Cryosphere Feedbacks:
Major feedback loops in the climate system involve clouds, which alter the transfer of radiative energy through the atmosphere, and water vapor, which is a greenhouse gas – although one influenced only indirectly by human activities. These have been generally considered as creating the largest uncertainty in climate models and major international projects have been improving the modeling of these processes. The effects of ice and snow cover on the radiation balance also needs more attention, especially in Canada. Canada's contribution is modest (e.g. CFCAS funding of $400K over 3 years) and needs to be increased somewhat to address Canadian cold climate issues and to ensure access to the best research globally on these topics.

Carbon Cycle Modeling:
An important improvement in GCMs will occur with the full incorporation of carbon cycle models. This would permit the modeling of exchanges of CO_2 with the oceans, forests and land areas, and incorporation of influence of changes in atmospheric concentrations on greenhouse gas releases from these underlying surfaces. Two models (not from Canada) suggest that after 2050, carbon storage in vegetation and soils would begin to shrink because of forest dieback and changes in soil respiration. This needs to be tested for Canadian forests and agriculture. If true, this would have enormously adverse impact on efforts to prevent "runaway" climate change. It needs to be better understood. Development of carbon cycle models is supported under a CFCAS project and limited effort in CCCma. Additional studies contributing to this goal are funded under Action Plan 2000. Better carbon cycle models have important implications for Canada's policies on sinks.

Key to reliability and utility of these models is a better understanding of sources and sinks in various ecosystems, including the influences of climate change, natural disturbance and human activities. Research on these topics is being supported through BIOCAP Canada, CFCAS and NSERC. (See Section 6.4)

Oceans:
The world's oceans exchange energy, momentum and substance (e.g. water, CO_2) with the atmosphere. Modeling the upper layers of the oceans and its interaction with both the deep oceans, that take up heat and CO_2, and the overlying atmosphere, is essential to reliable climate modeling and prediction. Canada has very large territorial waters on three seas, and must maintain an active role in measuring, understanding and modeling, ocean behavior. However, Canada has little global ocean modeling capability. Rather it is concentrating on the coastal and continental shelf regions where changes and variations in ocean climate have profound effects on

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fisheries and fishers. Regional climate models (see above) need to be run more extensively for Canadian ocean areas as well as for land. Much of the Canadian ocean observing capacity rests in Fisheries and Oceans, Canada. Government/university partnerships, such as with the CFCAS-supported SOLAS (Surface Ocean Lower Atmosphere Study) program, provide valuable Canadian contributions to important ocean science issues. It must be noted that the needed oceanographic research and sustained observations require expensive ship time, oceanographic instrumentation, buoys and capability to exploit satellite data.

Natural Climate Variability and Seasonal Prediction:
A better understanding is urgently needed of the natural modes of variation of the climate system (including El Nino Southern Oscillation, Pacific Decadal Oscillation, Arctic Oscillation and North Atlantic Oscillation) and their impacts on Canada's climate. The weather extremes they produce and other sources of extreme events, droughts, floods, severe winter snow and ice storms, intense rain and their trends are critical to Canadians.

Improved understanding is needed to:

a. better distinguish between human-induced and natural effects
b. provide more reliable forecasts of seasonal climatic conditions
c. ensure appropriate adaptation measures

To address these needs, the international WCRP project CLIVAR (Climate Variability and Predictability) is underway and modest Canadian efforts are part of the program.

Efforts in Canada in seasonal forecasting are scattered through several locations. (CCCma, RPN, CCRM, CMC, and private sector CICS). Economic benefits of a more concerted effort would be large – it is estimated that 40% of the economy is climate/weather sensitive. It will be necessary to organize a unit (perhaps a virtual unit) of perhaps 10 staff, with responsibility to make full use of climate and weather model outputs and other techniques to produce seasonal forecasts for Canada based on the best scientific knowledge. They must also maintain a research effort directed towards continuous improvement of predictions.

Water and Energy Cycle:
Knowledge of the cycling of water in the climate system, from precipitation to runoff or storage, through evaporation to water vapor and clouds and back to precipitation is an important element in the flows of water and energy in the climate system. The Global Energy and Water Cycle Experiment (GEWEX) of the WCRP is the framework for studies in a number of countries of water balances over and in major river basins. In Canada, this work is being undertaken mainly within the Mackenzie River basin (MAGS), led by McMaster University and supported by NSERC, with additional involvement of MSC and Geological Survey, NRCan.

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There remains a difficult problem in taking the results from the Mackenzie Basin and basins in other countries in the global program, and scaling these regionalized research results up to the global level for use in GCMs. Additional research is needed to develop methods for overcoming this problem of scale.

However, the GEWEX basin study has important values as well in contributing to assessment of impacts of climate variability and change on water resources. In such northern region studies a better delineation of permafrost and its behavior is urgently needed.

6.4 Biosphere Greenhouse Gas Sinks and Sources:

Forests, peat lands and agricultural lands can absorb greenhouse gases from the atmosphere (sinks) or, release $CO_{2,}$ methane, and nitrous oxide under various circumstances. A critical issue for Canada in connection with the Kyoto Protocol is the extent to which CO_2 uptake by vegetation and soils can be increased to contribute to meeting the 2008-2012 Kyoto target, and how the amounts can be sustained and verified in an internationally acceptable manner. In addition, for those companies wishing to undertake emissions trading for carbon sinks, reliable estimations, measurements and verification of sinks quantities on a much smaller than national scale are required.

Other important questions concern:

- The extent to which rates of sources and sinks are affected by a changing climate.
- Steps to integrate and couple GCMs and RCMs with models of biosphere carbon cycle.
- Assessment of effects of large-scale afforestation on climate due both to albedo changes and sequestration of atmospheric carbon.

Important research and measurements programs have been undertaken over the years, especially by Agriculture and Agri-Food Canada (AAFC) and by Forest Service of NRCan. These efforts are now being augmented by an expanded BIOCAP program in which University research networks are being established to study biospheric greenhouse gas management (e.g. Fluxnet Canada which has financial support from BIOCAP, CFCAS and NSERC), carbon model initiatives (CFCAS), and through the AP (Action Plan) 2000 efforts of AAFC and Environment Canada. These studies need to proceed vigorously with greater sustained funding. Arrangements should be made for a special report summarizing findings by 2005 in a manner that will assist with policy decisions which Canada must take in 2006, and to be of value to businesses wishing to undertake emissions trading.

6.5 The Arctic Climate System:

Behavior of the Arctic Ocean, atmosphere, and ice, has profound effects on the climate of the world and especially the Northern Hemisphere, yet many of the processes are not well

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understood and poorly measured. An international effort to improve this situation is underway in the World Climate Research program through its Arctic Climate System Study (ACSYS). Canada's modest efforts should be increased and extended beyond ACSYS. The ACSYS project office is in Norway, with staff provided as well by Japan and Germany. An international program called CliC (Climate and the Cryosphere) is being mounted as a follow up to ACSYS after 2004. Canada through CCCma, is chairing the ACSYS/CliC Numerical Experimentation Group.

While Arctic processes influence global climate, anthropogenic **climate change** has major impacts in the Arctic. These are already beginning in Canada's far north and Arctic territories. Melting of sea ice presents serious problems to wildlife (e.g. polar bears) and human subsistence hunters and fishers, in the region. It also results in stronger wave action and shore erosion with rising seas and melting permafrost, near many communities (e.g. Inuvik). At the same time navigational conditions are improving with less ice. This will open up navigational opportunities but has implications for Arctic pollution and for Canadian sovereignty. Melting of permafrost, and changes in peat lands and wetlands affect many aspects of infrastructure and wildlife and may result in significant releases of greenhouse gases. Other important impacts have begun to be documented in Canada's North, but limited capability exists to measure, predict and adapt to the changes. Traditional knowledge of indigenous societies is augmenting the information from scientific studies. At the same time, refinement of climate change projections is important to determine, for example, how soon the Northwest Passage will be "ice free" to conventional shipping over an economically viable season.

A major increase, at least a doubling, in measurement and research programs in this region by Canada, is warranted. The logistics of Arctic operations are difficult and costly. Instrumentation must be modified to cope with extreme conditions, communications are difficult, observational networks sparse, and some satellite systems ineffective. Restoration of logistics and support capacity such as that provided by the Polar Continental Shelf project, dedicated access to an ice-breaking vessel for research and measurements, as well as to more fixed station observations and access to satellite data are requirements for an adequate Arctic Climate and Ocean Science program.

6.6 Analyses of Climatic Trends and Variations:

To effectively use a combination of ground-based data, satellite images and other remotely sensed data for weather forecasting, a continuing effort to increase data assimilation capabilities is being developed under the CWRP (Canadian Weather Research Program). Efforts must be directed to applying the lessons learned in weather forecasting to analyze climate variability and trends with combinations of data from various platforms and sources. Such a program requires substantial computer facilities and sophisticated analysis. Several major Centers (ECMWF, NCEP) are undertaking major re-analysis programs as a basis for verification and improvements

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of GCMs. Canada should not try to compete but should participate strongly in international reanalysis efforts to ensure understanding and availability of resulting data products to Canadians.

Much work remains to be done on simpler, but economically vital analyses of data sets. To cite one example, information on short duration high intensity rains for one hour or less, are key to safe and efficient design of costly urban, airport and highway drainage facilities and soil erosion control measures. In U.S.A., many millions of agriculture drainage and erosion control facilities were designed on the basis of rain intensity data up to the 1960s. Analyses of the 30 minutes data from the 1960s to the 1990s indicates a significant upward trend, so many structures are under-designed resulting in frequent flash flooding and more erosion than anticipated. In Canada too, much of the drainage design is based on analyses to the 1960s. A major effort is needed to retrieve and analyze data on more recent events. This is only one example of how analyses of climate variations and trends (not just temperature and precipitation totals) can have major economic benefits. The municipalities and businesses of Canada require more reliable analyzed information on recent trends and variations especially of extreme events. MSC should strengthen its capability for Canadians to make use of the climate record in these ways through a dedicated unit of 8 to 10 staff members.

Canada contributes instruments and observations for international ocean programs, ARGO and GODEA, but does not have adequate arrangements to assimilate the ocean climate and weather data. Support should be given to involvement of a Canadian scientist(s) in one of the international centers undertaking such data assimilation to ensure that the products, with knowledge of their strengths and weaknesses, are available in Canada.

6.7 Vulnerability and Impacts

While Canada has some leading scientists on impact assessments, limited resources have so far been committed to understanding the vulnerability of Canadian resources, infrastructure and people to changes and variations of climate, including increasing frequency of some extreme events. From initial studies to date, it is clear that:

a. availability and quality of water resources could be seriously affected, with declining river flows already evident in southern Canada from interior BC eastward to the Lake Superior basin,
b. agricultural activities would see some benefits from a longer growing season but these could be offset in many southern regions by more frequent and severe droughts,
c. forests would migrate northward and be more affected by fires, insects and diseases,
d. urban drainage facilities would be more frequently overtaxed,
e. coastal communities would face rising sea levels, inundation and shore erosion,

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f. human health could be affected both positively (fewer cold weather deaths) and adversely, (more heat stress-smog episodes and water borne diseases).
g. agricultural drainage and erosion control facilities need to be redesigned,
h. changes in ocean climate and water temperatures in rivers affect fish migration and distribution, with serious impacts on fishing communities,
i. permafrost and ice melting in the Arctic are disrupting water flows wildlife and native subsistence lifestyles

While some benefits have been identified, most effects are negative.

However, the necessary regionally downscaled climate models to allow better quantification of the impacts and their costs, and design of adaptation measures, are still under development in Canada. (See Section 6.3 above) Statistical downscaling of climate model projections, as well, can provide for assessment of vulnerability and impacts in key economic, environmental and health sectors.

A much enhanced impacts assessment program is needed to determine the nature and costs of climate change impacts to Canada. Such assessments are vital to development of balanced climate policy.

6.8 Linkage with Economic and Social Sciences:

Social, economic and engineering sciences have much to contribute to the issue of climate change, but needs in these fields were beyond the scope of this report. One of the ways in which climate related sciences have been linked to the economic and social dimensions of the climate change issue in a few institutions, has been through "integrated assessment models". These are models which link economic models of the nature and costs of emission limitations, or sinks increases, directly through simplified climate models to changes in climate, and even to some impacts.

While the results of such models must be viewed with skeptical eyes, just as GCM development can identify research needs in the natural sciences, so integrated assessment models can identify social and economic processes which need to be better understood through research and data collection.

The Research Councils should consider how such inter-disciplinary work could be initiated in Canada and a Center of Excellence or similar arrangement be established.

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6.9 Science Assessments for Policy Makers:

The international IPCC process has provided authoritative assessments to the international community of the current state of knowledge of the climate system and its probable future. Its reports cover impacts and adaptation as well as means and costs of reduction of greenhouse gas emissions and increasing sinks.

However, the reports are global in scope and often do not provide the more local information needed by Canadian policy makers. For example, IPCC states that high intensity rain events are increasing in many areas (of the globe). Which parts of Canada are in these "many areas"? Rather than duplicating the IPCC, Canada should arrange to have an authoritative group provide a report for policy makers, "Implications for Canada of IPCC's Third (and Fourth) Assessment Report". A higher degree of credibility would result if the Secretariat for such an effort were lodged within a non-governmental organization, such as CFCAS. Modest funding should be provided for production of such reports – to support a Secretariat and for convening a small knowledgeable panel. Periodic reports summarizing results of impact assessment studies and costs should also be organized.

6.10 Systematic Observations of Climate System over Canadian Territory

An overriding requirement to determine trends and variations, to verify models and to determine the nature of climate processes, is an adequate systematic observation network. Indeed, IPCC (2001) states as first priority towards improving understanding to "reverse the decline of observational networks in many parts of the world (including in Canada) and to implement a strategy for accurate, long term, consistent integrated global observations." Canada's networks have been in decline in recent decades, especially in the Arctic and sub-Arctic – areas vital to Canadians and to the world, in understanding climate. The GCOS program provides some international standards of network density against which Canada's efforts can be measured.

Making use of GCOS network guidelines, MSC is wisely using funds from Action Plan 2000 to install or strengthen observational programs at 20 surface observational sites north of 60^0N. This would meet GCOS standards for temperature observations but not for precipitation. There are gaps as well south of 60^0N but funds are not available. Critical stations like Sable Island are periodically threatened. The DFO is using Action Plan 2000 funds to re-establish three critical sea level gauges north of 60^0N and moored instrumentation in the Canada Basin of the Arctic Ocean. In addition, Canada will participate in the global program to measure changes in ocean temperatures and salinity using autonomous drifting profilers.

The actions in the North are important. But observational stations only gain climate change value after several decades of operation. The government must stay the course and continue to fund operation of these stations and observational programs, and fill gaps elsewhere. Remote

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sensing and satellite observations can help in extending geographically the results from fixed observing stations, but cannot replace ground-based measurements and observations.

A further aspect of data collection for climate analysis lies in **paleoclimatology**. Careful collection and analysis of pollen in lake and ocean sediments, air bubbles trapped in past millennia in ice cores, and other means of studying the climate of the past can yield insights into the long term (thousands to millions of years) climatic fluctuations on earth. The factors involved in such fluctuations need to be understood, in order to interpret and place in context, the currently rapid changes in climate over decades to a century. Canadians are undertaking excellent research in paleoclimatology and support must be continued.

Data availability for analyses and research by international groups and within Canada has been a serious issue. Canadian government agencies have, in the past, adopted **charging policies** for climate, water and related data and analysts often do not have adequate funds to pay for them. Even our one satellite for sensing earth's surface (RADARSAT – Canadian Space Agency) charges for images. This means that Canada is sometimes a blank space in hemispheric or global analyses. Since data from satellites from U.S.A., Europe, Japan and China are freely available to Canadian researchers, Canadian policies are seen as a barrier to national and international research. The policies are a continuing source of embarrassment and often inhibit comprehensive research.

Thus, in addition to increasing and maintaining observation programs, Canada should ensure data are readily accessible.

7. COORDINATION MECHANISMS

It is evident that the issues of climate change and variations have very large and long-term economic consequences for Canada. The science needed for wise responses must of necessity move into the "big science" Category, and involve a growing number of partners. Adequate coordination mechanisms are not currently in place. On the one hand, coordination between granting agencies is at times difficult, yet large projects may well need several granting agencies and government departments to support a critical level of effort. At the same time, there is no formal mechanism to coordinate scientific activities on a continuing basis and to gain input from private and public sector policy makers on priorities.

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It is proposed that a broadly based Canadian Committee for Climate and Global Change Science be formed to:

a) assist in exchange of information and coordination of research,
b) stimulate climate science and identify topics of need,
c) ensure effective Canadian liaison with global programs, WCRP, IGBP, GCOS,
d) assist granting body coordination.

8. COMMUNICATING CLIMATE SCIENCE

A major problem exists for climate scientists, especially those studying anthropogenic climate change. Newspapers and other media thrive on controversy, so even though virtually all scientists who have actually studied climate agree on the main thrusts of the science of the enhanced greenhouse effect, the media forever seek alternative views. And of course, since the messages of anthropogenic climate change science are anathema to those depending on fossil fuel related sales, there are always a few academics or other scientists (usually not climate scientists) who can be found to make contrary statements. This poses difficult challenges because it confuses the public (and some policy-makers).

This situation requires that continuing efforts be made by climate scientists who are prepared to speak out through interviews with reporters, editorial boards, and public groups about the issue. A speaker's bureau and a list of media responders need to be maintained (by Environment Canada?) to meet these challenges.

The organization of a persistent long-term campaign of reliable climate information can probably only be coordinated by a government agency such as Environment Canada. However, for credibility, it cannot rely entirely on government staff members as spokespersons or writers. A program that "paves the way" for scientists to provide interviews, articles, etc. is needed since direct approaches by scientists to the media are often rebuffed.

At the same time, the reports of IPCC implications for Canada, as proposed above, periodic summaries of impacts research, and other authoritative publications are required. Articles summarizing such reports for magazines and newspapers, and interviews with authors must be arranged.

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CFCAS should be encouraged to prepare summaries for the public of key findings of the projects they support – perhaps in the form of a periodic newsletter released to the media.

In crafting the climate change messages, it is necessary to simplify complex issues to some extent. However, over-simplification, without recognizing some of the issues still imperfectly understood, may be a disservice to the public, the policy maker or the science community.

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CLIMATE SCIENCE FUNDING (01/02 or 02/03 $000s)
(The table is still incomplete and the classification of resources by activity is tentative.)

PROGRAM FUNDING								**CURRENT INVESTMENTS**		
	AP 2000	**OURANAS**	**CCAF**	**BIOCAP**	**PERD**	**CFCAS**[6]	**NSERC**[7]	**EC**[8]	**DFO**[9]	**All other**
Observations	**2400**							**55500**	**1500**	**10000**
GCMs			**800**			**1046**		**1320**	**300**	**3200**
RCMs		**160**				**793**	**400**	**250**	**380**	
Carbon Cycle						**1572**		**590**		
Processes										
· **Sinks**	**2400**			**300**	**1800**			**2100**	**1600**	**6800**
· **Other**			**400**					**2390**	**400**	**2800**
Climate Variability	**1300**	**1300**				**586**	**430**	**1175**	**1950**	
Impacts and Adaptation	**200**		**400**	**200**	**2100**	**331**		**3400**	**1730**	
Scenarios			**600**					**?**		**?**
Oceans						**1079**	**1300**	**150**	**1330**	**?**
Seasonal Forecasts								**225**		
Climate Data Analysis								**1150**		
Paleo Climate							**1300**			

[6] CFCAS funding is granted for 3 years. The numbers presented above represent estimated annual funding, which has been generated by dividing by three.
[7] NSERC funding is granted for varying durations. The numbers presented represent a multiyear funding for key climate research initiatives that have been identified.
[8] The funding indicated by Environment Canada for observations is primarily for weather forecasting and other operational needs, but the data gathered are subsequently used for climatic purposes.
[9] In addition DFO committed an estimated $1,090K in ship time to these activities.

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