CLIMATE CHANGE AND CLIMATE VARIABILITY

IN ATLANTIC CANADA

Environment Canada Environnement Canada

Volume VI of the Canada Country Study: Climate Impacts and Adaptation

This report has been published by the Atmospheric Science Division, Environment Canada, Atlantic Region.

Further copies can be obtained from:

Inquiry Centre/Informathèque
Environment Canada
phone: 1-800-668-6767
fax: (819) 953-2225
e-mail: enviroinfo@ec.gc.ca

Canadian Cataloguing in Publication Data

Main entry under title :

Climate change and climate variability in Atlantic Canada : Volume VI of the Canada Country Study : climate impacts and adaptation

ISBN 0-662-25923-8
Cat. no. En56-119/4-1997E
Includes bibliographical references.

1. Climatic changes -- Atlantic Provinces -- Forecasting.
I. Abraham, Jim.
II. Canada. Environment Canada.
III. Title: Volume VI of the Canada Country Study, climate impacts and adaptation.

QC981.8C5C54 1997 551.69715 C97-980365-9

Climate Change and Climate Variability in Atlantic Canada

Volume VI of the Canada Country Study:

Climate Impacts and Adaptation

Environment Canada
Atlantic Region
1496 Bedford Highway
Bedford, Nova Scotia B4A 1E5

Editors: Jim Abraham
Teresa Canavan
Roderick Shaw

“This is a component report of the Canada Country Study: Climate Impacts and Adaptation. In addition to a number of summary documents, the first phase of the Canada Country Study will produce six regional volumes, one volume comprising twelve national sectoral reports, and one volume comprising seven cross-cutting issues papers. This is Canada Country Study - Volume I: British Columbia and Yukon Regional Report.

“For further information on the Canada Country Study (CCS), please contact the CCS national secretariat in Toronto, Ontario at 416-739-4389 (telephone), 416-739-4297 (fax), or ccs.cia@cciw.ca (e-mail).”

“Ce rapport est une partie composante de L’Étude pan-canadienne sur l’adaptation à la variabilité et au changement climatique. En plus de quelques documents sommaires, la première phase de L’Étude pan-canadienne produiront six tomes régionaux, un tome comprenant douze rapports nationaux au sujet des les secteurs sociaux et économiques, et un tome comprenant sept papiers concernant les questions polyvalentes. Ce rapport est L’Étude pan-canadienne - Tome 1: Rapport Regional pour la Columbie Britannique et Yukon.

“Pour plusieurs renseignements concernant L’Étude pan-canadienne (ÉPC), contactez le secrétariat national de l’ÉPC à Toronto à 416-739-4389 (téléphone), 416-739-4297 (facs.), ou ccs.cia@cciw.ca (poste élect.).”

Contributions for this report have been extracted from:
(*with a few exceptions****)***

CLIMATE VARIABILITY AND CLIMATE CHANGE IN ATLANTIC CANADA

Proceedings of a Workshop
Halifax, Nova Scotia, 3-6 December 1996

edited for

Environment Canada
1496 Bedford Highway
Bedford, Nova Scotia B4A 1E5

by

Roderick W. Shaw, Ph.D.

Meteorological and Environmental Consultant

Box 2C5, 177 Mason's Point Road
Head of St. Margaret's Bay, Nova Scotia, CANADA B0J 1R0
Phone: (902) 826-7060
Fax: (902) 826-2157
E-mail: rodshaw@isisnet.com

17 March 1997

Table of Contents

PREFACE

The Canada Country Study

Intent - The Canada Country Study (CCS): Climate Impacts and Adaptation is a national assessment of the impacts of climate change and variability on Canada as a whole, including consideration of existing and potential adaptive responses. In presenting this national perspective, it draws upon studies of a number of regional, sectoral and cross-cutting issues, of which this volume is one.

The study was initiated by Environment Canada (EC) and is being lead by the Environmental Adaptation Research Group, a component of EC's Atmospheric Environment Service located in Downsview, Ontario. Among the participants are representatives of various levels of government, the university community, the private sector and non-governmental organizations.

In providing Canadians with a balanced, realistic picture of what climate change and variability means for Canada as a whole, the CCS effort builds upon a number of sectoral and regional impact studies that have been completed during the past decade.

The CCS will provide information to Canadian policy makers in the public and private sectors, socio-economic decision makers, the scientific community both domestically and internationally, non-governmental organizations, and the Canadian general public.

Structure - Work on the CCS is divided into two phases. Phase I began in the summer of 1996 and will conclude in the fall of 1997; it is focussed on an extensive review and assessment of all existing literature, the identification of knowledge gaps, and the development of recommendations for future research. The latter would be addressed in Phase II which is expected to begin in late 1997 and extend over approximately a five-year period.

In Phase I, a number of summary reports will be published - a national policy makers summary, a national plain language summary, and six regional plain language summaries. In addition, the basis of these summaries - 25 component studies and papers - are being published in 8 volumes as follows:

- Vol. I - British Columbia and Yukon
- Vol. II - Arctic
- Vol. III - Prairies
- Vol. IV - Ontario
- Vol. V - Québec
- Vol. VI - Atlantic
- Vol. VII - Sectoral (comprising 12 national papers on agriculture, built environment, energy, fisheries, forestry, human health, insurance, recreation and tourism, transportation, unmanaged ecosystems, water resources and wetlands)
- Vol. VIII - Cross-Cutting (comprising 7 national papers on changing landscapes, domestic trade and commerce, extra-territorial influences, extreme events, integrated air issues, sustainability, and the two economies).

The Climate Background

Climate Change and Variability - Climate may be thought of as a description of the regularities and extremes in weather for a particular location. It is also, however, naturally variable; from our own experience, we know that one summer is often warmer than another, or one winter is colder or snowier than another. Such variability is a normal feature of a stable climate, and is related to changes in ocean currents or sea-surface temperatures, volcanic eruptions, alterations in the sun's output of energy, or other complex features of the climate system some of which are not yet fully understood.

Natural large-scale climate shifts (or climate changes, such as those that resulted in past ice ages or warm interglacial periods) are driven by long-term alterations in the position of the Earth with respect to the sun. Such alterations can be reflected in changes in the composition of the Earth's atmosphere, an important characteristic of which is the occurrence of certain greenhouse gases (such as carbon dioxide and methane). These gases keep the Earth's surface and atmosphere from cooling too rapidly and help to maintain surface temperatures within the range needed to support life.

Greenhouse gas concentrations have been observed to be lowest during periods of cold climate (ice ages) and highest during warm periods. This connection is of concern because human activities since the beginning of the industrial revolution over 200 years ago (mainly involving the burning of fossil fuels) have greatly increased the concentration of such gases in the atmosphere. Scientists expect to see a doubling of the atmospheric composition of carbon dioxide, for example, within the next century. The increase so far is already considered to have had a discernible effect on the Earth's climate, an effect which is expected to continue.

Models and Scenarios - In order to understand how the world's climate may respond, elaborate supercomputer models of the climate system are used. Known as general circulation models or GCMs, these models are used to simulate the type of climate that might exist if global concentrations of carbon dioxide were twice their pre-industrial levels. Although the models disagree about many of the details of a doubled carbon-dioxide climate, the results of the simulations all agree that the Earth would be warmer, on average (with more warming occurring towards the poles), and would experience overall increases in both evaporation and precipitation. These simulations of climate are referred to as "GCM-driven scenarios" - distinct from actual forecasts for the future - since they depict a possible future based on certain assumptions about atmospheric composition. The most recent report of the Inter-governmental Panel on Climate Change (IPCC - *qui vive*), issued in 1995, projects an increase in global surface temperature of 1 to 3.5^{o}C over the next 100 years. This may be compared with the observed increase of 0.3 to 0.6^{o}C over the past 100 years.

For its first Phase, the CCS does not follow a single climate scenario. It reflects the range of scenarios that have been used as a basis for the various papers and reports appearing in the scientific literature. In general, the main model scenarios used come from one of five GCMs which have been developed in Canada, the United States, or the United Kingdom.*

While there is an increasing level of comfort with the validity of GCM results at the global scale, such comfort decreases when we look at the regional scale. For Canada there are broad areas of agreement in model results including warming over much of the western and northern areas, but there is also some disagreement between models as to the location and magnitude of areas of surface temperature or precipitation change, particularly in eastern Canada. This disagreement is reflected in the words of uncertainty that appear at times in this volume of the Canada Country Study.

The International Context

*

- CCC92 - Canadian Centre for Climate Modelling and Analysis 2nd Generation model
- GFDL91 - Geophysical Fluid Dynamics Laboratory model (US)
- GISS85 - Goddard Institute for Space Studies model (US)
- NCAR93 - National Center for Atmospheric Research model (US)
- UKMO95 - UK Meteorological Office model

International concern about the future of our climate has been building steadily over the past 20 years. One of the first important international conferences to look at the issue was held in Canada in 1988 - The Changing Atmosphere: Implications for Global Security. Also that year, the IPCC was established by the World Meteorological Organization and the United Nations Environment Programme with a mandate to assess the science of climate change, its environmental and socio-economic impacts, and possible response strategies. The IPCC subsequently published formal assessments in 1990 and 1995, with a third to follow in 2000 or 2001.

In 1992, the United Nations Conference on Environment and Development was held in Rio de Janeiro and resulted in consensus on a Framework Convention on Climate Change (FCCC). This Convention's objective is "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". It has now come into force and involves commitments to actions including emissions reductions, assistance to developing nations, reporting on emissions inventories, scientific and socio-economic research to reduce uncertainties, as well as education and training. Canada's domestic response to the FCCC has been its National Action Plan on Climate Change.

To date, as the objective of the FCCC would suggest, much of the international emphasis on response strategies for dealing with the impacts of climate change has focussed on reducing emissions of greenhouse gases. Respecting that climate change will be with us for a long time, a very important complement to such reductions is the need to understand the impacts of and to adapt to changing climate. The Canada Country Study is one of Canada's responses to recognizing the importance of impacts and adaptation.

Climate Impacts and Adaptation

The major concern arising from the climate change issue is the impact it may have on our environment, our economy, and therefore, on the way we live both now and in the future.

In Canada, we are accustomed to dealing with variations in climate both geographically and seasonally across the country. These variations have many impacts that can reverberate through natural and man-made systems, including water resources, vegetation and wildlife, agricultural practice, forestry and fisheries, energy supply and demand, buildings and roads, recreation and tourism, the insurance industry, and human health.

At present, there are many good examples of our ability to adapt to the range of climate conditions which we both collectively in our economy and as individuals in our everyday life are used to facing. If we depend upon wildlife species for sustenance, we follow them when migratory routes change; we plant different types of crops in different locations at different times of the year; we construct roads and buildings using designs that are compatible with ground that may or may not be characterized by permafrost or with differing snow and wind loads; we build ships and other marine platforms capable of withstanding expected wave heights and sea-ice conditions; we locate recreational facilities and events where they can benefit from appropriate climate conditions, such as sufficient snow for skiing or enough wind for sailing.

When thinking about adaptation as a way to respond to current climate and we then consider an on-going climate change and its impacts, we look for answers to the following questions so that our future planning can be done most effectively:

- What are the impacts of a changing climate and how will they affect me and my family through our lives?
- Are decisions being made today which will increase our vulnerability in the future because they are not taking such impacts into account?
- Will the approaches we use to adapt to the current climate still be workable in the future, or will new approaches be necessary to adapt to changes beyond our historical experience?
- Will the rate of changing climate allow enough time to adapt?
- Should society become more adaptable or flexible to changes in climate than it is now, and if so, how?

The Canada Country Study is aimed at helping to answer some of these questions.

PRÉAMBULE À L'ÉTUDE PAN-CANADIENNE

L'Objectif - L'étude pan-canadienne sur les impacts et l'adaptation à la variabilité et au changement climatique consiste en une évaluation nationale de notre connaissance des répercussions de la variabilité et du changement climatique sur l'ensemble des secteurs au Canada. À cet objectif premier s'ajoute une volonté d'élaborer les éléments premiers de ce qui constitueraient des mesures d'adaptation à la variabilité et au changement climatiques qui soient adéquates et pertinentes.

Entreprise sous l'initiative d'Environnement Canada, l'Étude pan-canadienne regroupe un grand nombre de participants tant au niveau gouvernemental, que des universités, du secteur privé et des organisations non-gouvernementales. Fondée sur l'ensemble des études d'impacts du changement climatique faites depuis la dernière décennie au Canada, nous croyons que l'Étude pan-canadienne permettra au Canada, d'avoir une idée plus réaliste de la vulnérabilité des divers secteurs de la province face à la variabilité et au changement climatique et de mettre en place, dans les plus brefs délais, des mécanismes d'adaptation visant à réduire la portée de cette vulnérabilité. Ces informations à base scientifique sont primordiales à une prise de décision judicieuse pour l'ensemble des preneurs de décision au pays.

L'Approche - L'Étude pan-canadienne est divisé en deux (2) étapes. La phase I débuta à l'été 1996 et se terminera à l'automne 1997. Cette étape veut faire une revue et une évaluation exhaustive de la littérature existante traitant des répercussions et de l'adaptation à la variabilité et au changement climatique au Canada. Les lacunes actuelles seront identifiées et des recommandations traitant des avenues de recherche future pour combler ces lacunes seront proposées pour une phase II éventuelle qui est prévue de débuter à la fin de 1997 et s'étendant sur une période de 5 ans.

Dans sa phase I, des résumés-synthèse seront publiés - un résumé national dédié aux responsables des politiques, un résumé national d'intérêt général et 6 résumés régionaux d'intérêt général. Ces résumés prendront leurs informations de base de 25 rapports/articles publiés dans 8 tomes soient :

- Tome I - La Colombie-Britannique et le Yukon
- Tome II - L'Arctique
- Tome III - Les Prairies
- Tome IV - L'Ontario
- Tome V - Le Québec
- Tome VI - Les Maritimes
- Tome VII - Les secteurs comprenant 12 sections nationales sur l'agriculture, les infrastructures, l'énergie, la foresterie, les pêcheries, la santé humaine, l'assurance, les loisirs et tourisme, le transport, les écosystèmes, les ressources en eau et les milieux humides.
- Tome VIII - Les enjeux intégrateurs comprenant 8 sections nationales portant sur les aménagements du territoire en évolution, le commerce intérieur, les influences transfrontalières, les frais, les évènements extrêmes, les enjeux atmosphériques, le développement durable et les 2 économies.

La variabilité et le changement climatiques - Le climat peut être décrit comme un ensemble d'évènements météorologiques pour un endroit en particulier ; il est de nature très variable d'une année ou d'une saison à une autre. La variabilité est une caractéristique normale du climat et est suscitée par les différences thermiques des masses d'air, les changements dans la distribution des courants océaniques ou des températures à la surface de l'eau, des éruptions volcaniques, des fluctuations dans l'énergie émise par le soleil ou venant d'autres éléments du système climatique qui ne sont pas encore bien connus.

Ces fluctuations naturelles du climat à très grande échelle sont générées par des mouvements dans la position de la Terre par rapport au soleil. Ce phénomène d'altération se réflète dans des changements dans la composition de l'atmosphère terrestre et indirectement sur la présence plus ou moins abondante de certains gaz à effet de serre (tels le gaz carbonique et le méthane). Ces gaz empêchent la surface et l'atmosphère terrestres de refroidir trop rapidement permettant ainsi aux êtres vivants de survivre sur la planète.

D'après nos connaissances, les concentrations de gaz à effet de serre tendent à être inférieures durant des périodes de climat froid (ères glaciaires) et supérieures lors de climat chaud. L'être humain, par ses activités responsables d'émissions additionnelles de gaz à effet de serre dans l'atmosphère, risque de perturber davantage ce lien précaire entre les concentrations et le climat. En effet, depuis la révolution pré-industrielle, les gaz à effet de serre ont augmenté à un rythme inquiétant pouvant même amener, selon les scientifiques, à un doublement du gaz carbonique, par exemple, dans la deuxième moitié du siècle prochain. Selon les experts internationaux, il est maintenant reconnu que l'homme a une influence perceptible sur le climat de la planète.

Les modèles climatiques et leurs scénarios - Afin d'être en mesure d'évaluer comment le climat global va répondre à cette augmentation des gaz à effet de serre, l'atmosphère est modélisée i.e. simulée en utilisant des ordinateurs de haute puissance. Connus sous le nom de Modèles de Circulation Générale (MCG), ces modèles tentent de simuler le spectre des conditions climatiques qui prévaudraient dans l'éventualité que les concentrations mondiales de gaz carbonique seraient le double que celles observées avant la révolution pré-industrielle (280 ppmv). Même les MCG sont en désaccord sur les détails entourant les scénarios de doublement de CO2, tous s'entendent pour indiquer une réchauffement de la planète, plus accentué vers les pôles, et de façon générale, une augmentation de l'évaporation et des précipitations. Le Groupe Intergouvernemental sur l'Évolution du Climat (GIEC), dans son rapport de 1995, parle d'une hausse globale de la température de 1 à 3,5^{o}C au cours des 100 prochaines années. Comparativement, dans le dernier siècle, on a observé une hausse de température au niveau mondial de 0,3 to 0,6^{o}C. Les simulations des MCG faisant l'hypothèse d'un doublement de gaz carbonique sont communément appellées « scénarios de changement climatique ».

Dans sa phase initiale, l'Étude pan-canadienne ne traite pas d'un scénario en particulier. Elle veut plutôt couvrir la gamme des scénarios proposés par les MCG à travers le monde et qui sont amplement discutés dans la littérature scientfiqiue. Mais, de façon générale, la majorité des études sont basées sur un des 5 MCG développés au Canada, aux Etats-Unis ou en Angleterre. *
*

Bien que de nombreuses études d'intercomparaison entre les MCG qui ont eu lieu depuis les dernières années permettent d'avoir un niveau de confiance en leurs résultats, il n'en reste pas moins que ces MCG sont déficients lorsque l'on

---

*

- CCC92 - Centre Canadien pour la modélization et l'analyse du climat - modèle de seconde génération
- GFDL91 - Geophysical Fluid Dynamics Laboratory model (US)
- GISS85 - Goddard Institute for Space Studies model (US)
- NCAR93 - National Center for Atmospheric Research model (US)
- UKMO95 - UK Meteorological Office model

tente d'aller à une échelle plus régionale ou locale. Au Canada, les scénarios de changement climatique sont assez en accord concernant le réchauffement sur l'Ouest et le Nord du pays. Cependant, ils sont en désaccord quant à l'emplacement et l'intensité des changements dans les patrons de température et de précipitation particulièrement sur l'est du Canada.

Le contexte international - L'intérêt international concernant le futur de notre climat s'est accru depuis les 20 dernières années. Un des pas importants dans l'évolution de cet enjeu fut la tenue de la conférence intitulée « L'atmosphère en évolution » qui s'est tenu à Toronto en 1988. Durant la même année, l'Organisation Météorologique Mondiale et le Programme des Nations Unies sur l'environnement créèrent le Groupe Intergouvernemental sur l'évolution du climat (GIEC) avec comme objectifs de rendre compte sur le niveau de connaissances scientifiques liées au changement climatique, d'estimer les répercussions potentielles de tels changements et d'examiner les stratégies de réponse et d'adaptation pour s'y parer. Le GIEC a ultérieurement publié 2 rapports d'évaluation, un en 1990 et le deuxième en 1995 avec un troisième rapport d'évaluation prévu pour 2000.

En 1992, la Conférence des Nations Unies sur l'Environnement et le Développement se tenait à Rio de Janeiro et mena à l'élaboration de la Convention-Cadre sur le changement climatique. L'objectif de la Convention-Cadre consiste en la « stabilisation des concentrations atmosphériques des gaz à effet de serre à un niveau qui préviendrait une influence anthropogène risqué avec le système climatique ». Actuellement en vigueur, cette entente internationale s'est traduite en des engagements face à la réduction des émissions, l'aide aux pays en développement, la tenue d'inventaires sur les émissions, la nécessité de faire de la recherche scientifique et socio-économique pour réduire les incertitudes face au changement climatique et finalement un plan de sensibilisation et d'éducation sur la problématique. Le Canada a entériné son acceptation de la Convention-Cadre en adoptant le Plan d'Action National sur le Changement climatique. Le Québec a également déposé en 1995 une Stratégie Québécoise sur les gaz à effet de serre.

Jusqu'à présent, l'emphase de la Convention-Cadre a été mise sur la réduction des gaz à effet de serre. Comme l'enjeu du changement climatique en est un de longue haleine, nous devons simultanément tenter de mieux comprendre les répercussions du changement climatique afin d'élaborer et d'implanter des mesures pour s'y adapter. L'Étude pan-canadienne est une initiative directement suscitée par cette volonté.

Les répercussions et l'adaptation climatiques - Quelles seront les répercussions d'un changement climatique sur notre environnement, notre économie et sur notre façon présente et future de vivre ?

Au Canada et plus particulièrement au Québec, nous sommes accoutumés à des variations parfois draconiennes du climat tant au niveau géographique que saisonnier. Ces fluctuations climatiques ont plusieurs conséquences autant sur des environnements naturels ou d'origine humaine tels les ressources en eau, la faune et la flore, les pratiques agricoles, les pêcheries et la foresterie, l'offre et la demande énergétiques, les infrastructures, les loisirs et le tourisme, la santé humaine et les aspects sociaux et l'industrie de l'assurance.

Plusieurs exemples nous reviennent à l'esprit lorsqu'on pense à notre capacité à s'adapter à une gamme de conditions climatiques. Selon la zone géographique et le temps de l'année, on choisit un certain type de semis. Nos routes et nos structures résidentielles et commerciales sont construites pour faire face à un spectre de conditions météorologiques donné ou pour tenir compte du type de sol sur lequel elles sont érigées (pergélisol, chutes de neige, verglas, crues subites, etc..). Des navires ou des plate-formes de forage sont construits pour affronter une gamme de vagues ou de couverts de glace. Des zones récréatives sont développées pour tenir de conditions climatiques avantageuses telles des enneigements appropriés pour la pratique du ski alpin ou de vents favorables à la navigation de plaisance.

Une adaptation appropriée des divers secteurs aux conditions climatiques présentes et futures passe par un questionnement de nos approches et nos attitudes face à la variabilité climatique. Nous nous devons de trouver des réponses aux questions suivantes :

- Quelles sont les répercussions d'un climat en changement sur nous et nos familles ?
- Quelles sont les décisions prises actuellement et qui ont comme conséquences de nous rendre plus vulnérables à une variabilité climatique accrue ?
- Les approches prises actuellement pour tenir compte des conditions climatiques actuelles fonctionneront-elles encore dans le futur dans un contexte de changement climatique ? Quels changements devront être apportés à ces approches pour nous adapter à un environnement climatique modifié ?
- Est-ce que la vitesse à lequel le changement climatique se produira va nous allouer assez de temps pour s'adapter adéquatement ?
- Est-ce que la société du futur devra être plus adaptable ou flexible au changement qu'elle ne l'est présentement ? Si oui, comment faire ?

L'Étude pan-canadienne devra, du moins nous l'espérons, indiquer des pistes de réponses à ces questions.

Introduction

Atlantic Canada's ecosystems, ranging across more than fifteen degrees of latitude, exist in a delicate balance under the influence of the air and the sea. Correspondingly, the socioeconomic conditions are extremely fragile in this part of Canada, and very dependent on the sustainability of our natural resources and environment. The continuing increase in greenhouse gas emissions is expected to result in a changing and/or more varied climate. Some experts maintain that this is already happening, and a greater frequency of weather extremes is now imposing additional stress on natural ecosystems. It is therefore critical that we identify the impacts of a changing climate, and take the steps necessary to adapt as best we can.

Regional Sensitivities to Climate Change

Atlantic Region is sensitive to changes or variations in the climate. Depending on the nature or degree of a change in climate, some of the potential impacts include the following:

Fisheries

- shifts in the distribution of fish species and in migration patterns
- variation in growth rates of species and recruitment success
- changes in the ratio of deep sea to groundfish abundance

Coastal Zone

- accelerated sea-level rise giving enhanced flood risk, accelerated coastal erosion, sediment redistribution and coastal sedimentation
- increases in storm frequency or intensity enhancing erosion and increasing the risk of storm-surge flooding and dyke overtopping
- reduced extent and duration of sea ice would increase both open water fetch and the contribution made by wave energy to coastal erosion

Ecosystems

Water Resources, River Ice Jams and Wetlands

- habitat loss
- interruptions to the life cycle of many species by changes in timing and magnitude of freeze-up/break-up, severity of the spring freshet or duration of the low flow period
- a decrease in river ice would be helpful economically but detrimental to some aquatic species
- shifts in water tables affecting the level of methane and CO_2 emissions from wetlands

Migratory Birds

- shifts in boundaries of winter ranges of terrestrial birds
- changes in range, distribution and breeding success of seabirds
- day length may prove to be a less effective timing mechanism in the annual cycle of birds

Agriculture

- variations in climate having the greatest impact on agriculture include:

    - excess moisture (could lead to more disease)
    - unusually late springs or early frosts
    - drought
    - unusually severe storms
    - unfavourable overwintering conditions
    - exceptionally cool growing season weather
- a warming trend could be beneficial to agriculture except for crops requiring reliable snow cover for survival
    - the Atlantic region has *not* followed the national warming trend of the past century

Forestry

- air temperature influences tree growth rates and the ability of forests to absorb CO_2
- soil temperature affects its nutrient cycle plus the quantity of nutrients available
- late frosts or early extended thaws are damaging to hardwood species
- storm damage (blowdowns) may increase in severity and frequency with increased storminess
- insect outbreaks may increase in length and severity as well as range if warming occurs
- warmer winters and less snow cover could increase deer population reducing forest regeneration and lowering species diversity

Socio-economic Dimensions

- changes in the number of ice free days would affect marine transportation and the offshore oil and gas industry
- changes in precipitation and run-off affect generation of hydroelectric power
- temperature changes alter energy demand
- protective constructions to ward off sea-level rise are costly
- direct costs of extreme events: deaths, standing timber losses and building damages
- indirect costs of extreme events:
    - income and employment losses due to business disruptions during and immediately following an event
    - income and employment gains from emergency response and storm damage repair expenditures

Knowledge Gaps

Future work must endeavour to fill knowledge gaps to increase our ability to understand and reduce the impacts of climate change in the region and to adapt to those effects that are unavoidable.

Monitoring systems must continue to operate and even improve to provide the environmental record to observe changes in climate. Land, ocean (offshore and nearshore), coastal and hydrological measurements are required as well as biomass and composition of various species. Analyses of these data are required.

Climatology

- circular statistics, fractal geometry and chaos theory could be used to investigate the temporal-spatial chaos inherent in climate datasets, rapid short-term changes and intermittent events
- accurate results from regional climate models
- implications of a changing climate on extreme events

Fisheries

- improved knowledge of the life history of species plus further understanding of the role played by the environment, species interaction and fishing in determining the variability of growth, reproduction, distribution and abundance of fish stocks

Coastal Zone

- better understanding of coastal response at storm-event scales and longer time scales
- prediction of changes associated with accelerated sea-level rise on wave dominated coasts

Ecosystems

- implications that changes in run-off will have on the ecosystem
- changes in ice-jam regimes and water levels in wetlands
- effects of climate change on biodiversity
- research is lacking in the northernmost two-thirds of the region which is the most likely area to be affected by climate change

Agriculture

- estimating and reducing the negative impacts of variability and extremes in climate to help the industry cope

Forestry

- long term effects of forest clearing and harvesting (expected to increase with sea-level rise)
- predictions of source/sink activity of Atlantic forests with respect to CO_2
- response of processes involved in primary forest production to changes in CO_2 levels, temperature, precipitation and nitrogen deposit rates

Acknowledgments

This report represents the work of many people including the contributing authors: Dave Sawyer, Teresa Canavan, Peter Lewis, Jim Abraham, Val Swail, Stanley Goldenberg, Lloyd Shapiro, Chris Landsea, Ken Drinkwater, Don Forbes, John Shaw, Bob Taylor, Tom Clair, Spyros Beltaos, Bill Brimley, Tony Diamond, Andy Bootsma, and Roger Cox.

Special thanks to Rod Shaw for preparing a comprehensive summary of the report plus the sections on adaptations and knowledge gaps and to Des O'Neill for reviewing and providing many useful comments on the entire document. The contribution of the cover design by Dick Boak is greatly appreciated.

Finally, thanks to Roger Street, Barrie Maxwell and Nicola Mayer for initiating this report and for their continued support and guidance during its preparation.

Garth Bangay
Regional Director General
Environment Canada
Atlantic Region

Introduction

Les écosystèmes du Canada atlantique, qui s'étendent sur plus de 15 degrés de latitude, coexistent dans un équilibre délicat soumis à l'influence de l'atmosphère et de la mer. Cela explique que la situation socioéconomique de cette région soit extrêmement fragile et lourdement tributaire de la durabilité de ses ressources naturelles et de son environnement. L'augmentation constante des émissions de gaz à effet de serre devrait se solder par un changement climatique et (ou) un climat plus varié. Selon certains experts, le processus a déjà débuté, et la plus grande fréquence des phénomènes météorologiques extrêmes inflige un stress supplémentaire aux écosystèmes naturels. Il est donc impérieux que nous précisions les incidences d'un changement climatique et que nous prenions les mesures nécessaires pour nous y adapter le mieux possible.

Sensibilités régionales au changement climatique

La région de l'Atlantique est susceptible aux changements climatiques ou à la variabilité dans le climat. Selon la nature ou le degré d'un changement climatique, les impacts potentiels comprennent:

Pêches

- Changements dans la distribution des espèces de poissons et dans les courants migratoires.
- Variation des taux de croissance des espèces et du taux de reproduction.
- Changements dans la proportion de poissons de fond et de poissons démersaux.

Zones côtières

- Accélération de l'élévation du niveau de la mer, ce qui multiplie les risques d'inondation, accélère l'érosion côtière, entraîne une redistribution des sédiments et une sédimentation du littoral.
- Augmentation de la fréquence ou de l'intensité des tempêtes, ce qui accentue l'érosion et multiplie les risques d'inondation dues à des soulèvements de tempête et au débordement des digues.
- Diminution de l'étendue et de la durée des glaces de mer, ce qui risque d'augmenter les étendues d'eaux libres et d'accentuer l'érosion côtière provoquée par l'énergie des vagues.

Écosystèmes

Ressources hydriques, embâcles et zones humides

- Disparition d'habitats.
- Interruption du cycle de vie de nombreuses espèces causée par les changements survenant dans le moment et l'ampleur de l'englacement/déglaçage, la gravité des crues printanières ou la durée de la période de faible débit.
- Une diminution des glaces fluviales serait intéressante sur le plan économique mais préjudiciable à certaines espèces aquatiques.
- Changements dans la nappe phréatique, ce qui affecte le niveau des émissions de méthane et de CO_2 des zones humides.

Oiseaux migrateurs

- Changements dans les limites des habitats hivernaux des oiseaux terrestres.
- Changements au niveau de l'habitat, de la distribution et du taux de reproduction des oiseaux marins.
- Il se peut que la longueur du jour soit un mécanisme moins efficace dans le cycle annuel des oiseaux.

Agriculture

- Parmi les changements climatiques qui ont les plus lourdes conséquences pour l'agriculture, mentionnons :
    - l'excès d'humidité (qui risque d'entraîner une augmentation des maladies);
    - les printemps anormalement tardifs ou les gelées précoces;
    - la sécheresse;
    - les tempêtes anormalement fortes;
    - les conditions d'hivernage défavorables;
    - une saison de croissance exceptionnellement fraîche.
- Un réchauffement progressif pourrait être bénéfique à l'agriculture, sauf aux cultures qui ont besoin d'une couverture de neige fiable pour survivre :
    - la région de l'Atlantique ne bénéficie pas depuis un siècle du même réchauffement progressif que le reste du pays.

Sylviculture

- La température de l'air influe sur le taux de croissance des arbres et sur l'assimilation du CO_2 par les forêts.
- La température du sol affecte le cycle des nutriments ainsi que la quantité de nutriments assimilables.
- Les gelées tardives ou les dégels précoces sont préjudiciables aux espèces feuillues.
- Les dégâts causés par les tempêtes (chablis) risquent d'augmenter en fréquence et en intensité avec la multiplication du nombre de tempêtes.
- Les flambées d'insectes risquent d'augmenter en longueur et en gravité ainsi qu'en superficie, advenant un réchauffement progressif.
- Des hivers plus chauds et couverture neigeuse moins épaisse risquent d'aboutir à une augmentation du nombre de chevreuils, ce qui réduira le reboisement naturel et affaiblira la diversité des essences.

Paramètres socioéconomiques

- Un changement dans le nombre de jours sans glace risque d'affecter les transports maritimes de même que l'industrie pétrolière et gazière extracôtière.
- Les changements qui surviennent dans les précipitations et les eaux d'écoulement affectent la production d'hydroélectricité.
- Les variations de température modifient la demande d'énergie.
- Les ouvrages de protection contre l'élévation du niveau de la mer sont coûteux.
- Coûts directs des phénomènes extrêmes : morts, disparition de peuplements forestiers sur pied et dégâts causés aux bâtiments.
- Coûts indirects des phénomènes extrêmes :
    - pertes de revenu et suppressions d'emplois dues aux perturbations qui se produisent durant et immédiatement après un tel phénomène;
    - gains de revenu et d'emplois résultant des dépenses d'intervention d'urgence et de réparation des dégâts causés par les tempêtes.

Manque de connaissances

Les travaux futurs doivent chercher à combler les lacunes de connaissances et nous permettre de mieux comprendre et d'atténuer les répercussions du changement climatique dans la région et de nous adapter aux effets inévitables.

Nous devons continuer à exploiter et même à améliorer les systèmes de surveillance qui constituent les dossiers environnementaux permettant d'observer les changements climatiques. Nous devons continuer à mesurer la masse continentale, les océans (hauturiers et semi-hauturiers), les côtes et les ressources hydrologiques de même que la biomasse et la composition de diverses espèces. Nous devons également procéder à une analyse de ces données.

Climatologie

- Les statistiques circulaires, la géométrie fractaire et la théorie du chaos pourraient servir à étudier le chaos temporel-spatial qui est inhérent aux ensembles de données climatiques, aux changements rapides à court terme et aux phénomènes intermittents.
- Les résultats des modèles climatiques régionaux sont précis.
- Implications d'un changement climatique sur les phénomènes extrêmes.

Pêches

- C'est en connaissant mieux l'histoire de la vie des espèces et en comprenant mieux le rôle joué par l'environnement, l'interaction des espèces et la pêche que nous arriverons à déterminer la variabilité au niveau de la croissance, de la reproduction, de la distribution et de l'abondance des stocks de poissons.

Zones côtières

- Meilleure compréhension de la réaction des côtes face aux tempêtes à l'échelle individuelle et à une échelle de plus longue durée.
- Prévisions des changements résultant d'une accélération de l'élévation du niveau de la mer sur les côtes dominées par les vagues.

Écosystèmes

- Répercussions des changements dans les eaux d'écoulement sur l'écosystème.
- Changements dans les régimes d'embâcle et les niveaux d'eau dans les zones humides.
- Effets du changement climatique sur la biodiversité.
- Les deux tiers de la région situés le plus au nord et qui risquent d'être le plus touchés par le changement climatique souffrent d'une pénurie de recherches.

Agriculture

- Il faut estimer et atténuer les incidences négatives de la variabilité et des extrêmes climatiques pour aider le secteur privé à s'y adapter.

Sylviculture

- Effets à long terme de la coupe et de la récolte des forêts (qui devraient s'accentuer avec l'élévation du niveau de la mer).
- Prévisions de l'activité source-puits des forêts de l'Atlantique par rapport au CO_2.
- Réaction des procédés qui entrent en jeu dans la production forestière primaire face à l'altération des concentrations de CO_2, des températures, des précipitations et des taux de dépôt d’azote.

Remerciements

Ce rapport est le fruit du travail de nombreuses personnes, notamment de : Dave Sawyer, Teresa Canavan, Peter Lewis, Jim Abraham, Val Swail, Stanley Goldenberg, Lloyd Shapiro, Chris Landsea, Ken Drinkwater, Don Forbes, John Shaw, Bob Taylor, Tom Clair, Spyros Beltaos, Bill Brimley, Tony Diamond, Andy Bootsma et Roger Cox.

Nous remercions en particulier Rod Shaw qui a préparé le résumé de synthèse du rapport et les sections sur les adaptations et le manque de connaissances, ainsi que Des O'Neill qui a analysé tout le document et formulé de nombreuses remarques fort utiles à son sujet. La conception de la couverture par Dick Boak est grandement appréciée.

Enfin, merci à Roger Street, Barrie Maxwell et Nicola Mayer d'avoir entrepris ce rapport. Nous leur sommes reconnaissants de leur appui indéfectible et de leurs conseils durant sa préparation.

Garth Bangay
Directeur général régional
Environnement Canada
Région de l'Atlantique

Summary

Roderick W. Shaw
Meteorological and Environmental Consultant
Box 2C5, 177 Mason's Point Road
Head of St. Margaret's Bay, Nova Scotia, CANADA B0J 1R0

1. THE CANADA COUNTRY STUDY

The Canada Country Study is a national evaluation of the impacts of climate variability and change for Canada, and the potential for adaptation to such impacts. Two phases are involved. Phase I is a literature search of existing knowledge and will include identification of research gaps and priorities. Phase II will address the latter through the development and implementation of new research projects.

This document represents the Atlantic Region contribution to Phase I. It is based largely upon the results of a symposium *Climate Variability and Climate Change in Atlantic Canada* that took place in Halifax, Nova Scotia on 3-6 December 1996.

2. ATLANTIC REGIONAL CONTEXT

2.1 Physiography

The Atlantic Region contains a wide diversity of terrestrial, freshwater and marine environments, that are the habitats for a broad variety of wildlife, and support the activities of 2.3 million people. The Maritime Provinces fall within the Atlantic Maritime ecozone, while Newfoundland is part of the Boreal Shield ecozone. Labrador touches on four ecozones: Taiga Shield, Southern Arctic, Arctic Cordillera and Boreal Shield. The nature of the Region - its biota, climate and patterns of human settlement and activities - is strongly influenced by its marine associations and the characteristics of these ecozones.

Water

The Maritime Provinces have more than 25,000 inland surface water bodies. Labrador and insular Newfoundland have an estimated 135,000 each. This large number of small surface water bodies is an advantage for wildlife habitat. On the human side, nearly 1.2 million people in the Region rely entirely on groundwater for their domestic water needs.

The Region has about 40,000 km of coastline, the estuaries and coastal zones of which provide habitat for large populations of a wide variety of seabirds, shorebirds, marine mammals, and commercially important finfish and shellfish. Many of the Region's human settlements are on or near the coast, as we depend on the coastal waters for transportation, food, and recreation. In physical terms, the coastal zone varies from tidal mudflats to sand beaches to rocky shoreline.

Our most extensive salt marshes are found in the estuaries of the upper Bay of Fundy. Other areas include the southwest coast of N.S., and the Hillsborough River and Bay on Prince Edward Island. These, and other smaller salt marshes, are important nursery areas for a number of species of fish, and provide habitat for a wide variety of wildlife. Approximately 65% of Maritime saltmarsh remain dyked for farming.

Land

Forty-one percent of the land of the Region is forested land. There are four forest regions: Acadian, Boreal (Predominantly Forest), Boreal (Forest and Barren), and Great Lakes - St. Lawrence.

Bogs, marshes, swamps, fens and peatlands cover 17% of the land surface of Newfoundland-Labrador, and 1-8% of the landscape of the Maritime provinces. These wetlands provide a variety of ecological functions (habitat, hydrologic and biogeochemical), and produce a variety of wildlife useful to humans (fur-bearing animals and ducks).

The Region's relatively short cool growing season and relative lack of good quality soils inhibits farming in many locations. The most important agricultural areas are the Annapolis Valley (fruit orchards), Prince Edward Island (potato and grain productions) and northwestern New Brunswick (potatoes). There is limited agricultural production in Newfoundland and Labrador.

Wildlife

Some 60 species of mammals, 171 birds, 13 reptiles, 14 amphibians and 55 fishes, frequent the terrestrial, freshwater and marine habitats in the Region. Marine mammals include polar bears, seals and a variety of whales, dolphins and porpoises. Terrestrial animals range in size from the moose to the shrew. The largest herd of caribou in the world ranges over part of Labrador. The Region's extensive coastal areas provide habitat for a wide variety of seabirds and coastal birds, both breeding and non-breeding. Important areas are the coastal waters of Newfoundland and Labrador, and the mudflats of the upper Bay of Fundy (particularly for migratory shorebirds). The marine fish of the Region include the anadromous Atlantic salmon, and several species of commercially important finfish, for example, cod, haddock and pollock. Wildlife related expenditures in the Region are estimated at $393 million annually.

2.2 Historical and Cultural Setting

The population of the four Atlantic provinces, 2.3 million people (1991 census), accounts for only about 9% of Canada's total population. Population growth in the Atlantic Provinces since the middle 1800s has been slow but steady, increasing only by a factor four, in contrast to the factor ten increase in the population of Canada. During the past two decades, from 1971 to 1986, there was an increase of 0.2 million, or about 10%. This is an increase of only 0.7% per year, somewhat lower than the Canadian average. This difference in growth can be attributed to, among other things, rapid growth in the more diversified economy of central Canada.

Settlement patterns in Atlantic Canada originally reflected the transportation modes available: on rivers or in coastal areas, or at railway junctions where goods were transferred. All provincial capitals, for example, have access to the ocean.

2.3 Socio-economic Overview

Regional Income

The Atlantic Canadian economy can be characterized as diverse, with a heavy reliance on primary and related industries. The percentage of the total economy accounted for by the primary industries (agriculture, fishing and forestry) are as follows in the region: Newfoundland - 2.3%; Prince Edward Island - 11.6%; Nova Scotia - 3.5%; New Brunswick - 4.0%. These percentages are greater in Atlantic Canada than the Canadian average of 2.8%.

The manufacturing sector is 5-12% below the national average as a proportion of the total economy with the manufacturing industries related to the primary sector contributing greatly. For example, in Nova Scotia, the two largest manufacturing industries in 1992 were fish processing, which accounted for 17% of the value of all manufacturing sector shipments, and other food products, which accounted for 15%. In Newfoundland, even with the moratorium on groundfish, GDP for the fish processing sector accounted for approximately 35% of manufacturing GDP.

Gross Domestic Product (GDP)

GDP per capita (GDP divided by the provincial population) for the Atlantic provinces remains consistently below the national average. In 1991, as a proportion of national GDP per capita, Newfoundland was 67%, PEI was 66%, Nova Scotia was 80%, and New Brunswick was 76%. The performance of individual sectors, such as fishing and agriculture, in Atlantic Canada does impact overall economic performance.

Employment

As with GDP, primary and related industries account for a large proportion of employment in Atlantic Canada. Relative to Canada, the proportion of employment in resource dependent industries relative to all industries ranges between 3% (Nova Scotia) and 14% (PEI) above the national average. In Nova Scotia, fish processing was the largest employer in manufacturing industries in 1995. In Newfoundland, fishing and fish processing account for a significant level of total employment.

Economic Implications of Climate Change

The climate change literature identifies primary resource based economies as being most susceptible to impact from climate change and variability. Given the above noted composition of the Atlantic Canadian economy, the region is likely more sensitive to climate change than other parts of Canada. Further details are given in Section 4.6 of this Executive Summary and Section 3 of the main report.

3. THE CLIMATE OF ATLANTIC CANADA

3.1 General Description

Large-scale Influences on Atlantic Canada's Climate

Global atmospheric circulation patterns, ocean currents and sea ice extent are major influences on the current climate of this region due to its location on the eastern edge of North America. Local topography and sea surface temperature contribute to differences in climate within the region. On a global scale, the Atlantic Region lies within the zone of prevailing westerly winds. This zone is characterized by the passage of a series of high and low pressure systems. Paths taken by these systems are further influenced by ocean currents and continental topography.

In the northern hemisphere, areas of low pressure develop when cold dry air originating over Northern Canada drifts southeastward and encounters warm moist air moving poleward from the Caribbean Sea. These systems are more intense during the winter months. Analyses of previous storm tracks reveal that many of these systems affect the Atlantic Region. Significant temperature differences in air masses affecting the district explain the large annual temperature ranges recorded at observing sites. An abundant annual supply of precipitation can be attributed to these synoptic scale storms with additional contributions from tropical storms and local convective storms.

In summary, Nova Scotia, Prince Edward Island and Southern New Brunswick have been classified as having a moist continental climate while Northern New Brunswick, Newfoundland and Labrador are classified within the boreal forest climate zone. The tundra climate covering much of Northern Canada includes the northerly tip of Labrador.

Effects of the Nearby Atlantic Ocean

Sea ice gradually spreads southward along the coast of Labrador, eastern Newfoundland, the Gulf of St. Lawrence and Cabot Strait during the winter months. As the ice retreats in the spring, sea surface temperatures gradually increase, particularly in the Gulf of St. Lawrence. An exception is the eastern extremity of the Gulf which is influenced by the cold Labrador Current. This current maintains cool sea surface temperatures along the eastern coasts of Labrador and Newfoundland and has some effect on waters to the south of Nova Scotia. Warmer waters of the Gulf Stream extend farther northward during the summer months modifying surface temperatures south of Nova Scotia. Onshore winds produce a moderating effect on the climate of adjacent land areas throughout the year.

Regional Temperature and Precipitation

Temperature

During the winter, the warmest average temperatures are found in southwestern Nova Scotia and the Avalon Peninsula of Newfoundland, with mean temperatures dipping a few degrees below freezing. Remaining areas of Newfoundland and Nova Scotia, plus Prince Edward Island and southern New Brunswick, are the next warmest followed by northern New Brunswick and southeastern Labrador. Labrador's northerly latitude contributes to its having the coldest temperatures in the region with means near minus 20C inland.

Central New Brunswick has the highest temperatures during the summer months with means near 20C followed by the rest of the Maritimes and central Newfoundland. Newfoundland's south coast, Avalon Peninsula and Northern Peninsula are the next warmest areas, followed by Labrador.

Precipitation

Frequent low pressure systems combined with the ocean bring a generous supply of precipitation to the Atlantic Provinces. Southeast winds accompanying storms pick up moisture from the sea giving southern coasts of Newfoundland (over 1700 mm/year) and Nova Scotia, plus the Fundy shore of New Brunswick, the greatest amounts of annual precipitation. Northern Newfoundland, northern Nova Scotia, Prince Edward Island and much of New Brunswick receive lesser amounts (but still in excess of 1000 mm/year).

Although precipitation is almost exclusively liquid throughout the summer months in the region, rain, freezing rain and snow are common during the winter in southern areas. In fact, more rain than snow (expressed as water equivalent) occurs on average along the southern coasts of Newfoundland and Nova Scotia in the winter.

3.2 Trends in the Climatology of Atlantic Canada

Temperature

Although there has been a worldwide warming trend of 0.3 to 0.6C, and a warming of 1.1C in Canada overall, the Atlantic Region has experienced a warming trend from 1895 to the mid 1950s, followed by a cooling trend into the 1990s. During the period 1948-1995, Atlantic Canada has experienced a marked cooling of 0.7C with seasonal trends as follows: winter (-2.2C); spring (0.0C); summer (+0.5C); and autumn (-0.8C).

Precipitation

Trends in precipitation are much more difficult to determine than those in temperature. This is due mainly to the difficulty in obtaining accurate and consistent measurements of rainfall and snowfall amounts and to the wide temporal and spatial variation in annual amounts. The national trend indicates an increase in precipitation since 1948 but a decrease since the mid 1980s. The Atlantic Region has experienced an increase since 1948. Despite the regional increase in precipitation, there has been a *decrease* in annual snow cover over southern Canada during the period 1971-90.

Cloud Cover

A complex relationship exists between cloud cover and global warming and cooling. Cloud cover in the Atlantic Region has appeared to increase by 1% since 1953, but this change is not statistically significant.

Temperature and Precipitation Extremes

During the period 1944-90 there was:

1) a decrease in the number of days per year with a maximum temperature above 25C;
2) an increase in the number of days per year with a minimum temperature below -15C;
3) an increase in the number of daily precipitation events above 20mm; and
4) a very slight increase in the number of daily snowfall events above 15cm.

3.3 Climate Variability

Compared to the effort that has been put into predicting climate change, relatively little work has been done in defining the variability of current climate or investigating climate fluctuations of the recent past. An apparent increase in year-to-year temperature variability since the early 1970’s has been reported during the winter season. In addition, a 30% decrease in cyclone frequency in the Maritimes and New England States was detected during winter seasons from 1931-32 to 1984-85. The second generation Canadian Climate Centre general circulation model predicts, for a doubling of atmospheric CO_2, a decrease in the total number of cyclones in both winter hemispheres but an increase in frequency of *intense* cyclones, particularly in the northern hemisphere. Little change is predicted in the position of storm tracks.

3.4 Extreme Events

Each year Environment Canada Weather Centres in the Atlantic Region issue hundreds of inland weather warnings and thousands of marine warnings. Heavy snowfalls and rainfalls, gale to hurricane force winds, high waves and storm surges are among the extreme events that result in injury or death and cause significant economic losses like property or crop damage. Events that exceed the normal range of variability in temperature or precipitation that result in flooding, drought, heat waves, cold spells or winter thaws can also be considered as extreme. Obviously, a climate change that impacts on the frequency or severity of extreme events is of major concern to Atlantic Canadians.

The meteorological phenomena most associated with extreme events include extratropical cyclones (most often winter storms), tropical cyclones (hurricanes), or summer severe weather (mesoscale convective systems). While there has been some study of the behavior and prediction of these systems, very little work has been done in examining the implications of climate change on these events in Atlantic Canada, and further research is required.

Ocean Waves

During the past 5-6 years there have been a number of extreme storm events on either side of the North Atlantic Ocean. In 1990, extreme waves crushed the superstructure of the drilling platform Ekofisk in the North Sea. In 1992, a storm severely damaged west Norwegian coastal settlements, while in 1993 the master of Ocean Weather Ship "Mike" reported that, in 35 years experience in the Norwegian Sea, he had never before encountered such severe wave conditions.

In the western Atlantic, on Halloween day 1991, a moored buoy south of Nova Scotia reported the highest waves ever measured by an instrument (17.3 m significant wave height, with maximum waves estimated at more than 31 m). On March 15, 1993 the "Storm of the Century" produced record high waves at buoys along the U.S. and Canadian east coasts, including a significant wave height of 16.3 m at the buoy south of Nova Scotia. In September 1995, Hurricane Luis hit the liner *Queen Elizabeth II* with estimated 29 m maximum waves, corroborated by a nearby buoy which reported significant waves of 17 m, and estimated maximum waves exceeding 30 m.

These events caused many questions to be asked. Foremost among these were: (1) Is the climate changing?; and (2) Are storms becoming more frequent? more severe?

The first major concern in looking at the long-term trend and variability in ocean waves is that there are no long term reliable wave data sets. As a result of the lack of reliable observed data, Canada and other countries turned to wave hindcast models to provide the data for engineering design as well as climate trend and variability analysis. The hindcast accuracy is very good for storms, as has been shown in many hindcast evaluation studies. A caveat relates to the modelling of very high sea states, i.e. significant wave height greater than 12 m. There seems to be a tendency for all classes of wave model to under predict these extreme storms. Overall, however, hindcasting has provided a very good estimate of storm waves, using a consistent methodology.

Some results of the analysis using hindcast models are as follows:

- There is no discernible trend in magnitude or frequency of extreme wave heights on the east coast of Canada, but there is significant inter-annual variability.

- Any <u>apparent</u> trend in the magnitude and frequency of extreme waves is completely caused by two or three recent events on Scotian shelf (since 1991)

- The extreme events of the early 1990's on the Scotian shelf may represent a change in large-scale circulation patterns, but on the other hand are not inconsistent with events experienced earlier in the century

Hurricanes

During most of the years 1970-87, the North Atlantic hurricane basin experienced a relative lull in overall tropical cyclone activity. The below-normal activity was especially evident in drastically reduced numbers of hurricanes affecting the Caribbean Sea and Maritime Canadian regions and basin-wide numbers of major hurricanes (MHs), and almost a total absence of MH landfalls affecting the east coast of the U.S. After the experience of renewed "normal" activity in 1988 and 1989 (with five MHs during those two years), it was suggested that the Atlantic basin was returning to a long-term period of higher activity such as what was experienced back in the decades of the 1950s and 1960s and during some earlier periods. The heightened activity in 1988 and 1989 was followed, however, by a marked reduction in activity from 1991-94. As a result of the resumption of the below-normal activity, the notion that the Atlantic basin had entered a high-activity regime was for the most part discarded.

The lull finally ended in early 1995 and was followed by one of the most active hurricane seasons in the Atlantic on record, with almost every measure of activity over twice the long-term mean. Of particular note was that the season produced five MHs for the first time since 1964. The chief issue is whether or not the activity of the 1995 season was simply an anomalous "spike" or a harbinger of multi-decadal-scale climate shifts signaling the probability of greater activity over the next ~10-20 years.

There is evidence of certain changes in Atlantic sea surface temperatures with a shift towards warmer conditions in the Northern Hemisphere beginning around 1988. This change was accompanied by a shift towards a reduced increase of wind speed with height in the main development region of the Atlantic hurricane basin (a band between ~10° and 20°N, stretching between the west coast of Africa and Central America), a condition more favorable for increased tropical cyclone activity, especially major hurricanes. If these changes are indeed taking place on decadal or multi-decadal scales rather than on a year-to-year basis, then the Atlantic basin may continue to see over the next decade or so, on the average, heightened activity on the order of what was seen in the 1950s and 60s rather than the suppressed activity of the 1970s and most of the 80s. What *might* be expected would be several years with very high activity, while most years would be close to average or slightly above average and only a few far below average. If the past holds the key to the future in this case, the overall increase would mean significant increases in the numbers of hurricanes affecting the Caribbean Sea and Maritime Canadian regions, basin-wide numbers of major hurricanes, and major hurricane landfalls affecting the east coast of the U.S.

The possible implications of these changes are staggering. The fact that major hurricanes have historically accounted for most of the damage and deaths due to tropical cyclones, combined with the fact that there has been a dramatic population increase along hurricane-vulnerable coasts during the two inactive decades, add up to the potential for massive monetary loss, especially when major cities are impacted. In addition there is a potential for large loss of life in the case of an incomplete evacuation during a rapidly intensifying system.

4. REGIONAL SENSITIVITIES TO CLIMATE CHANGE

4.1 Fisheries and Plankton

Fish stocks vary depending upon both fishing practices and natural factors, including environmental change. It is difficult to resolve the relative importance of human and natural factors, but factors such as temperature can have a pronounced effect upon the growth of fish species, spawning and reproduction, distribution, abundance and migration, and catchability and availability. The effects may be location- and species-dependent. For example, the incubation of Atlantic cod eggs on the Scotian Shelf varies from 8 days at 14C to 42 days at 1C. Thus eggs in colder water are more vulnerable to predation due to longer exposure times and may, therefore, experience lower survival rates.

Climate change can be expected to result in shifts in the distribution of fish species, with the most obvious changes occurring near the northern or southern boundaries of their range. Migration patterns will shift causing changes in arrival times along the migration route. Growth rates are expected to vary with the amplitude and direction being species dependent. Recruitment success could be affected by changes in the time of spawning, fecundity rates, survival rate of larvae, and food availability. Another sensitivity associated with climate change is a change in the vertical temperature structure of the water which may lead to changes in the ratio of pelagic to groundfish abundance.

4.2 Coastal Zone

The best estimate of global sea-level rise by the United Nations Intergovernmental Panel on Climate Change is about 0.5 m by 2100. Associated changes in atmospheric circulation may also lead to changes in storm climatology, ocean wave climate, storm-surge probability, and other factors relevant to coastal stability. Sea-level changes resulting from thermal expansion in the ocean will vary geographically, such that some regions may experience negative or negligible change, while others will be subjected to larger increases in mean sea level. Further complication is introduced by natural sources of variability in the climate system, such as the occurrence of El Niño and the Southern Oscillation, the North Atlantic Oscillation, secular variation in tropical and extratropical storm occurrence and ocean wave climate, arctic and sub-arctic sea-ice extent, and other factors. Saltmarsh deposits and other coastal systems contain evidence for natural fluctuations in sea level at time scales of the order of 100 years, implying that the accelerated sea level rise observed over the past century may be partly or wholly natural in origin.

Demand for coastal property in Atlantic Canada is already on the rise, with upward pressure on prices. Under these circumstances, the financial risk associated with a given physical hazard (e.g. coastal erosion or flooding) is greatly increased.

There are two types of potential effects of climate change on the Atlantic coastal zone: 1) effects of accelerated sea-level rise; and 2) effects of variable storminess. These may be summarized as follows:

1) Relative sea level is rising now along most parts of the coast in Atlantic Canada. Accelerated sea level rise over the past century may be a response to global climate change or it may represent medium-term (century-scale) natural variance in the rate of sea-level rise. There is evidence to suggest that global sea level is rising at a rate of 1 to 2 mm/year and a further increase of about 0.5 m is anticipated by the year 2100. This will be added to vertical crustal movement (subsidence at rates as high as 0.3 m/century) in many parts of Atlantic Canada. The result will be an enhanced flood risk in some areas and accelerated coastal erosion in others. Sediment redistribution and coastal sedimentation will occur in some places.

2) Variations in storminess, including possible increases in storm frequency or intensity, can be expected to cause enhanced erosion in some places and may affect the risk of storm-surge

flooding and dyke overtopping in the Bay of Fundy. Possible increases in open-water fetch and wave energy during the winter months, due to reduced extent and duration of winter sea ice, particularly in the Gulf of St. Lawrence and northeast Newfoundland, may also contribute to coastal erosion losses.

4.3 Ecosystem Science and Water Resources

Water resources

Precipitation and temperature are the principle driving forces behind the hydrological cycle and anticipated changes in climate are expected to significantly alter Canada's fresh water resources. The timing of the climate change could also be gradual or stepwise. Increased variation manifested as seasonal time shifts or rapid swings in seasonal climate variables could change the normal characteristics of the water cycle, creating havoc for human or ecosystem users of the resource.

Habitat loss is a major concern especially in the Atlantic Region as there may be no alternatives for some species. The timing and magnitude of specific hydrologic events such as freeze-up/break-up, the severity of the spring freshet, or the duration of the low flow period is vital to the life cycle of many species.

On the human side of the ecosystem, the accumulation of long term flow and climate data have been invaluable in aiding the safe and economical design of dams, bridges, water supplies and other infrastructure whose design and integrity are influenced by the extremes of the hydrologic cycle.

Preliminary analyses in Nova Scotia and on the Island of Newfoundland showed that the number of days with ice in rivers has increased since 1952. Preliminary comparisons of ice data with winter season temperatures showed that there was a cause and effect relationship between the temperature and ice, but for whatever reason it did not completely explain the trend.

During the last 25 years there appears to be a dramatic decrease in runoff in Nova Scotia streams especially during the winter. What appears to be a trend from 1970 toward lower winter runoff is also the same period of higher ice in rivers and a full cause-and-effect relationship is being determined.

River Ice Jams

Ice jamming in Canadian rivers has a multitude of socio-economic impacts such as flooding, damage to private property and infrastructure, interference with navigation, and inhibition of hydropower generation. The average tangible cost of ice jamming to the Canadian economy is estimated at $60 million per year. A much greater amount is attributed to missed hydro-power generation opportunities due to inadequate understanding of river ice processes. Atlantic Canada is one of the most-seriously affected regions

Ice jams, and the surges that follow their release, have many detrimental impacts on aquatic life. Habitat loss due to bed and bank scour, fish mortality due to stranding on the floodplains, very high concentrations of fines, abrupt water quality changes, long range transport of pollutants, deposition of fine sediment and degradation of spawning habitat, are but a few examples. Ice jams also have positive ecological effects, such as the replenishment of floodplain habitat with nutrients and sediment for the sustenance of many aquatic, terrestrial and avian species, during the spring flood.

The ice regime may be modified by climate change in different ways over different parts of the country. In temperate regions such as southwestern Ontario, and parts of British Columbia and Atlantic Canada, the brief and capricious river ice cover may disappear completely, or become more intermittent. This should be good news on the socio-economic front, but could be disruptive to aquatic species that depend on the ice cover for winter survival.

Wetlands

Because they are defined by the location of seasonal and permanent water tables, wetlands are closely linked to climate. Balances between precipitation and temperature which control total water input and outputs are critical in determining the very existence of wetlands. Changes in the evapotranspiration balance leading to lower water tables may thus cause the disappearance of wetlands along with the ability of basins to absorb water and increase flood risks in certain areas.

Water levels and flows through wetlands also control their carbon content and fluxes. Aquatic dissolved organic carbon fluxes are closely linked to water flow through the basins. Furthermore, water levels control the level of methane and CO_2 emissions from wetlands. Shifts in water tables due to a changing climate will change the relative importance of the gases and their impact on the global atmospheric carbon cycle.

Migratory Birds

Boundaries of winter ranges of terrestrial birds will likely shift northwards with warmer winters; the northern boundaries of many species of songbird coincide with January isotherms reflecting daily energy requirements of about 2.5 times the Basal Metabolic Rate.

Beyond general correlations between 'bad' (i.e. wet and cold) summer weather, and lower bird productivity, the influence of climate on breeding success has not been explored in Atlantic Canada. In many seabirds, both breeding distribution and the timing of breeding are related to sea-surface temperatures. Since these temperatures are likely to change as the climate warms, noticeable changes in distribution and breeding success of seabirds can be expected.

Among marine birds, changes in range will likely follow changes in the distribution of prey such as capelin, arctic cod, herring, sand-lance etc., which in turn will accompany changes in water-temperature and salinity.

Rising sea level is likely to inundate coastal staging grounds which are essential for shorebirds and waterfowl migrating between arctic breeding grounds and southern winter quarters. The most obvious examples in this region are the saltwater marshes connecting New Brunswick and Nova Scotia, and the mud flats at the head of the Bay of Fundy.

The timing of many events in a bird's annual cycle, including migration, breeding and moult, is frequently triggered by changes in day length. This timing mechanism may prove maladaptive in a changing climate, when the linkage between day length and changing food supply, habitat availability, movement of air-masses, etc., becomes uncoupled as these climatic events change but daylength does not.

Storms at any time of year can have severe effects on birds. Cold snaps in late spring frequently cause large-scale mortality in small birds, and summer storms can kill shorebirds on their breeding grounds and greatly reduce breeding success among bird groups as varied as songbirds and seabirds.

4.4 Agriculture

The agricultural sector is particularly sensitive to climate change and variability because of its direct dependence on the weather and climate. Along with soils, climate, to a large extent, determines the types of crops that can be grown in the Atlantic region, where these are best produced, the yield and quality that is achievable with present-day technology and the types of management practices used.

The availability of corn heat units (CHU) has very significant impact on which crop species, varieties and/or hybrids producers choose to grow and on the productivity of their farms. For example, average CHU in the three Maritime provinces range from a high of about 2800 in the Annapolis valley to less than 1700 in northern New Brunswick. With present-day available hybrids, grain corn has good potential in areas with >2500 CHU, is marginal in 2300-2500 heat unit areas, and is generally not feasible in areas with <2300 CHU.

Growing degree-days above 5°C (GDD) vary from less than 1000 to over 1800 in parts of the Annapolis and lower Saint John River valleys. Differences in GDD particularly impact the potential of long season crops such as spring wheat, potatoes and forages.

Spatial variations in winter climates have significant impact on survival (and hence the suitability) of overwintering crops such as winter wheat, clover, alfalfa, strawberries, tree fruits and ornamental trees and shrubs. The risk of winter injury to apples is rated from low in the Annapolis valley to high in many areas of New Brunswick

Significant climate-induced differences in soil moisture deficits and spring field workdays occur in the region. These differences impact farm management decisions such as machinery size, labour requirements, irrigation and drainage system design.

Temporal variability in climate exerts perhaps even greater impact on agriculture than the spatial differences that are encountered in the Atlantic region. Variations that likely have the greatest impact on agriculture include excess moisture, unusually late spring or early fall frosts, drought, unusually severe storms, unfavourable overwintering conditions and exceptionally cool growing season weather.

The Atlantic region has apparently not followed the national warming trend of about 1°C during the last 100 years. Overall, the temperature changes are relatively insignificant and likely have had little or no impact on agriculture compared to that of climatic variability.

Precipitation seems to have increased and become more variable over the past 100 years. This may have impacted agriculture through reduced drought stress but may have increased problems in coping with excess moisture*. While long term changes in precipitation are statistically significant, they are still relatively small in comparison to the yearly variability that growers must contend with*.

From the foregoing analyses, we can conclude that climate change over the past 100 years has had relatively little impact on agriculture compared to the variability, with the possible exception of precipitation which appears to have increased and become more variable.

Climatic changes that may occur in the future could have significant impact on agriculture in the Atlantic region. Rising CO_2 concentrations accompanied by a warming trend would be beneficial to agriculture, particularly if new crop varieties that are better adapted to any changed conditions are selected. Warming could be expected to improve the competitiveness of the agricultural industry by expansion of production in corn, soybeans, tree fruits and specialty crops. Increased moisture supply would reduce any losses in yield due to drought, but likely result in increased disease pressure (particularly from foliar-type fungal diseases such as potato blight, which thrive in wet weather), increase the leaching of nutrients and chemicals to the ground water, reduce the number of days suitable for field work and result in greater soil erosion. A change to drier conditions would have the opposite effect. Milder winters could significantly impact the survival of many crops such as alfalfa, clover, winter wheat, strawberries, tree fruits and grapes, and improve the potential of these crops in many areas. However, negative effects on survival could be experienced in some areas where warming results in less reliable snow cover.

4.5 Forestry

Climatic factors may influence tree growth rates and the ability of forests to absorb atmospheric carbon dioxide. One possible scenario of future climate suggests warmer winters and springs but cooler summers for most of the Maritimes. This may increase growth rates of conifers if the length of growing season significantly increases due to the warmer springs. Warmer soils also means a faster nutrient cycle and more nutrients. Certainly, earlier springs would have to be accompanied by an extension of frost free days here in Atlantic Canada, as late frosts or early extended thaws would be more damaging to the hardwood species if refreezing occurred after dehardening of buds and roots.

Changes in forest extent due to melting permafrost is not an issue in the Maritimes but changes in tree line at altitude may occur.

Gains in carbon storage by the forest due to higher productivity will be partially offset by increased decomposition rates in the soils and peat. Transient losses in the mature forest due to disturbances may account for additional loss in carbon storage. The ability of the young forest to absorb atmospheric carbon dioxide could be reduced by other stresses such as air pollution, especially tropospheric ozone, acid rain and acid fog.

In the event of climate change, there is some expectation for a move to a more temperate mixed forest, with some loss of boreal characteristics. In the short term, transient behaviour of our forests will depend on the adaptability of each species population in the current forest, and the regional manifestation of climatic change.

The predicted changes in Fire Weather Index would vary from being reduced in southern Quebec, with only slight increases in the southern Maritimes, increasing slightly more over Cape Breton and east Newfoundland. The uncertainty in these predictions, however, is increased by other disturbances such as blowdown, insect outbreaks, and declines, which affect fuel quality and fire risk.

It is likely that the Balsam Woolly Adelgid would present a serious problem if the winter temperature of the boreal forest increased, because this insect seems to be controlled in its northward extension due to intolerance of dormant adelgids of temperatures below -34^{C}.

There is evidence that beech trees escape beech bark disease (caused by the beech scale insect) at altitude and in the northern parts of their range, indicating that this insect too, may be limited by climate and thus, may pose a greater risk with warmer winters under climatic warming.

It has also been suggested that, in the northern limits of the spruce budworm, the ends of outbreaks may be associated with late spring frosts that destroy the early foliage. As climate warms, fewer late frosts may increase the length and severity of outbreaks in these northern areas.

Storm damage (blowdowns) may possibly increase in severity and frequency with global warming due to an increase in storminess. The effects of other disturbances serve to open the canopy and may increase the possibility of blowdown, as will the move towards more softwood plantations.

Warmer winters and less snow accumulation may lead to extensions of overwintering areas for deer which means more available food and decreased predation. These effects can, in turn, lead to higher population levels which can affect forest regeneration and lower species diversity.

4.6 Socio-economic Dimensions

The United Nations Intergovernmental Panel on Climate Change concludes that natural ecological systems, socioeconomic systems, and human health are all sensitive to both the magnitude and the rate of climate change. Despite an increasing body of literature on the comprehensive socioeconomic impacts of climate change, however, most of the climate change socioeconomic research has focused on impacts to agriculture, forestry, and coastal zone resources. By far the best-studied areas are agricultural impacts and the costs of sea level rise.

Agriculture

Based on a review of the general literature, a range of the annual impact on agriculture due to a doubling of atmospheric CO_2 is estimated to be a reduction of GDP of the order of 0.047% to 0.2%. Using these ranges and recognizing a high degree of uncertainty inherent in transferring these values to Atlantic Canada, annual damages to agriculture are estimated to be in the order of $20 to $88 million per year. This damage represents a range of 2% to 10% of current agricultural GDP. Therefore, it can be reasonably argued that agriculture in Atlantic Canada will be significantly affected by climate change. The magnitude of the change in economic value will be highly dependent upon the response of crop yield to climate change, including CO_2 fertilization, the size of transition costs and the adaptability of farmers to climate change. However, at this time, a high degree of uncertainty exists with respect to these variables. On-going research should decrease uncertainty about the impacts.

Forestry

One researcher has found that, under a doubling of atmospheric CO_2, Canada's potential harvest would increase by a total amount of 7.5%. For forests in Atlantic Canada, forest productivity is anticipated to increase by an average of 15-16%. Another paper suggests that Quebec forests could increase annual yields by anywhere from 50% to 100%. To calculate the economic value of increased forest yields, one study assumed three scenarios with yield changes of 5% and 7.5% and 15% and then calculated a socioeconomic benefit for Canada based on these changes. For the foregoing three increases in yield, the increase in yearly forest harvest value in Atlantic Canada were estimated to be 17, 25 and 50 million dollars per year, respectively.

Fisheries

From a socioeconomic perspective, it is clear that impacts to the fishery sector, including both the recreational and commercial fisheries, will occur and that they will likely be significant. However, it is not possible to determine the size of this impact at this time. Given the importance of the fishery to the Atlantic Canadian economy, the high degree of uncertainty about the potential climate change impacts on the fishery is an area of concern. Additional research in this area is clearly required.

Transportation

Although transportation in the Atlantic Region is often not identified as a sector sensitive to climate change, it could be significantly affected. Marine transportation sectors which could be affected by changes in climate, and the number of ice free days in particular, include sub-sectors such as the coast guard, with major ice breaking expenditures (in 1986 they were $22 million (1996 dollars)), ferry service, ports and harbors, and shipping. A recent study on transportation in the Northwest Territories found that changes in the number of ice free days would result in measurable economic impacts. It was found that increases in the number of ice free days would result in decreased operating costs for marine transportation as well as a lengthening of the shipping season. Given the reliance of ferry service and marine shipping in the Atlantic Region, changes in the number of ice free days can be expected to result in socioeconomic changes. Decreases in the number of ice free days will benefit the region.

Offshore Oil and Gas Development

Off-shore oil and gas exploration and development could experience socioeconomic effects if the number of ice free days changes with climate change. One study has determined that downtime for exploration activities in the Atlantic Region due to ice delays cost approximately $130,000 (1996 dollars) per 24 hours of downtime. A loss of $52 million in the extreme ice year of 1984-5 occurred. Other costs would be related to operating and maintenance costs associated with changes in the number of ice free days.

Hydropower

Climate change would alter the ability of the utilities in the Atlantic Region to generate hydroelectric power due to changes in precipitation and, therefore, annual run-off. For example, based on estimates of water flow needed to generate hydropower and the value of Labrador hydropower exported to the United States, for every +/-10% change in annual run-off in Labrador, the economic value of exported hydropower changes by +/-$73 million. Therefore, this sector is highly sensitive to climate change in the Atlantic Region.

Energy Demand

Changes in the mean annual temperature are widely believed to result in changes in space heating and cooling requirements. To determine the sensitivity of energy demand to temperature change, a relationship between temperature, degree days and the value of a degree day, in terms of energy requirements, is often used. It is thereby possible to estimate changes in energy demand and therefore economic value for the Atlantic Region. A preliminary analysis indicates that, for every 1C change in the mean annual temperature, energy demand changes by $46 million per year.

Sea Level Rise

There are two types of costs associated with sea-level rise: (a) capital costs of protective constructions; and, b) the recurrent annual cost of foregone land services. In response to sea-level rise, defensive structures would likely be constructed to protect valuable lands and property, such as cities and ports, whereas less valuable lands such as coastal wetlands would not be protected. A Charlottetown, PEI, study found that a 1 metre sea-level rise would cause significant social and economic impacts and threaten the city’s waterfront developments, including over 250 buildings, streets, sewer systems and parks.

Given the body of literature on the damages associated with sea-level rise, preliminary estimates for Atlantic Canada can be made. For example, annual defensive expenditures associated with sea-level rise have been estimated for Canada to be approximately 0.03% of GDP. Applying this number to Atlantic Canada's GDP in 1996, damages are estimated the be in the order of $117 million. This does not include damages such as loss of habitat, salt intrusion into groundwater, and income loss from dry land inundation. Three studies found sea-level rise to account for 11%-20% of the total climate change impacts on the United States which puts them in the range of 0.012% to 0.02% of GDP. Applying this range to Atlantic Canada's GDP in 1995 provides estimates of total sea-level rise damages in the order of $49 to $86 million (1996 dollars).

A review of a number of studies indicates a 50% loss of wetlands associated with a 1 metre sea-level rise resulting from a doubling of atmospheric CO_2. In the Maritime Provinces, total wetland area is 3,600 km^2. Much of the literature assumes a value of US$5 million/$km^2$ for wetland, a value that is extremely high for Atlantic Canada. One report estimates the value of Atlantic Canada wetlands to be in the $21,000/$km^2$ range (adjusted to 1996 dollars). Using this estimate, wetland damages from climate change are estimated to be in the order $77 million annually for the Maritime Provinces.

Extreme Events

The economic effects of extreme events can be direct or indirect. Direct effects are impacts on human, natural and human-made capital stocks. Examples of direct effects would include deaths (human stock), standing timber losses (natural stock) and building damages (human-made stock). Indirect effects stem from alterations in the flow of goods and services in an economy as a result of a extreme event. These would include income and employment losses due to business disruptions during and immediately after the event. Income and employment gains would result from emergency response and storm damage repair expenditures.

To date, there has been no comprehensive study of the costs associated with extreme events in the Atlantic Region, although the Insurance Bureau of Canada has recorded the value and number of claims associated with significant property damages resulting from atmospheric hazards in Canada. During the period from July 1987 to 1995, for example, there were 43 "natural disasters" resulting in major multiple-payment occurrences. Twenty-one percent of the storms occurred in the period from September to March. The median value of claims is reported at $12 million with 3,300 claims registered. Of the 43 events, two were exclusive to the Atlantic Region: the wind event in October 1992 in Avalon, Newfoundland, with $8.2 million in claimed damages and 4,100 claims; and, the 1995 summer storm (Hortense) in Nova Scotia with 1,200 claims and $3 million in claimed damages.

Summary of Socioeconomic Effects

Based on predictions in the literature about the order of magnitude of socioeconomic impacts, annual damages for developed countries and regions could be between 1% and 1.5% of Atlantic Canada's 1995 GDP, or $417 to $625 million per year (1996 dollars). Given the high reliance on primary industries in the Atlantic Region, damages are likely to be in the upper range.

5. ADAPTATION

5.1 General

Research will in all likelihood result in improved estimates of the impact of climate caused by increasing concentrations of greenhouse gases, but reliable predictions of climatic change on a regional scale are still some time away. In addition, even if large reductions in the emissions of greenhouse gases were to take place now, there might still be changes in climatic means and variability because of the inertia of the ocean-earth-atmosphere system. Therefore, it would be prudent to assume that adaptive management and use within the next several decades of natural and man-made resources such as forests, agriculture and coastal structures may have to be carried out in the face of climatic uncertainty.

While the development of climate models with better regional resolution needs to proceed, the vulnerability of ecosystems to climate change, and the exploration of adaptive measures, should be a priority for the Canada Country Study in Atlantic Canada. At the symposium *Science and Policy Implications of Atmospheric Issues in Atlantic Canada*, held in Halifax, Nova Scotia in December 1995, the following response was given to the question: “What aspects of climatic change are of greatest importance in the Atlantic Region?”:

> **Despite the uncertainty in the projections of climatic change in the Atlantic Region, it is important to have an estimate of the sensitivity of Atlantic Canada resources to climate changes in either direction. Such resources include agriculture, forests, wildlife, the fishery, coastal infrastructure, transportation, tourism and the human population.**

To the question: “What activities are needed to asses the sensitivity of the Atlantic Region to climate change?”, the 1995 workshop replied:

> **Formation of an interdisciplinary and multisectoral (public, private, academia) group to develop a matrix of sensitivity of various components of the environment of the Atlantic Region to climatic change. One dimension of the matrix would be the aspect of the resource (using indicators such as freshwater availability or forest biodiversity); the other would be climatic variables such as temperature, precipitation, frequency of sea level rise or storm surges. This activity would make use of existing information, ecosystem studies and modelling results.**

Adaptation would be most appropriate in sectors in which there is a large degree of human activity or investment in human infrastructure, such as fishing (including aquaculture), forestry, agriculture and the coastal zone, and where there is great sensitivity to Climate Change.

5.2 Fishing

The report of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 1996) suggests adaptation measures for the fishing industry, including aquaculture. Following are a few examples, modified slightly to apply to this region, with the first two applying regardless of further changes in climate:

- modify and strengthen fisheries management policies.

- promote fisheries conservation and environmental education among fishermen on an international basis

- preserve and restore wetlands, estuaries, floodplains and bottom lands - essential habitats for most fisheries

- adjust to possible changes in relative abundance of species and distributional shifts in fish stocks.

- for aquaculture, expanding the number of species and increasing the area in which operations could be located.

5.3 Coastal Zone

Concerns affecting the coastal zone associated with climate change could include greater storm variability, changes in wave climatology and increased sea-level rise.

- Environmental monitoring networks (now rapidly declining) provide the basis for assessing vulnerability to climate change, evaluating impacts and planning adaptation.

- Coping with global sea-level rise:

    - Given the low population density and large, mostly natural coastline, the recommended strategy for adapting to sea-level rise is to allow the coastline to retreat and avoid costly engineering solutions.

    - In some areas, such as Argentia, Newfoundland and parts of the Bay of Fundy marshlands, protection of the coastline is warranted.

    - A Canada-wide approach to coastal zone management could be developed.

- Increased erosion and overtopping of beaches and other structures are serious consequences of sea-level rise.

- With regard to flooding, for example in the Bay of Fundy, an important objective must be to determine the probability of the dykes being overwhelmed by the coincidence of a storm surge and high tides. Consideration should be given to the extent of potential flooding, and the infrastructure at risk.

5.4 Agriculture

- The agricultural industry should, in general, be able to adjust relatively well to any *long term gradual* changes in climate that may occur, taking advantage of any improvement in conditions while minimizing the negative impacts of a less favourable climate. However, *variability and extremes* in climate that will occur will likely have greater impact and be more difficult for producers to cope with.

- There are measures that could be implemented that would reduce the negative impacts of climate change and take advantage of any improvements in the climate that may occur. A few examples follow:
    i) Increased use of irrigation and wider adoption of soil management practices and crop rotations;
    ii) Wider adoption of drainage practices and erosion control methods;
    iii) Increased adoption of active and passive frost prevention methods;
    iv) Increased efficiency in field tillage, planting and harvesting operations;
    v) Development of new crop varieties.

5.5 Forestry

A likely scenario for this region is a cooling down in the summer due to the southerly movement of arctic melt water and warmer in the winter due to greenhouse effect. Expectations may lead to large swings in seasonality (late frosts or extended thaws) and increases in extreme weather events (tropical storms and hurricanes). This scenario may lead to increased mortality and salvage operations and a glut of wood on the market. This would require:

a) imaginative substitution of non-timber products with forest products to maintain carbon storage.

b) rapid reforestation with tree species and genotypes better adapted to climatic variability (swings in seasonality) would be required for the transition period to a warmer climate and is the deliverable of ongoing research by the Canadian Forest Service.

c) improved forestry practices that reduce the impacts of harvesting especially selective or partial cuts that open up the canopy to wind and design of appropriate methods to protect plantations.

d) a flexible, responsive and cooperative forest industry to respond to all aspects of rapid changes in salvage, production of goods and marketing.

e) a strategic approach to research for the selection of appropriate species and provenances, together with management techniques that will maximize forest ecosystem production and biodiversity, as well as carbon storage in a warming environment while providing required wildlife habitat and recreation objectives.

f) increased management of deer populations which under reduced snow pack and forest disturbance may increase and threaten regeneration and biodiversity necessary to maintain long term carbon sequestration.

g) extensive monitoring of forest health to provide early warning of changes and provide through research cause effect relationships to feed into models to better predict future changes in forest species composition.

6. KNOWLEDGE GAPS

Future work must endeavour to fill knowledge gaps to increase our capacity to understand and reduce the effects of climate change in the Region, and to adapt to those effects that are unavoidable. Furthermore, to avoid knowledge gaps in the future, monitoring systems must continue to operate and to even improve in order to provide the environmental record that will allow us to observe climate change, and our efforts to forestall and adapt to it. While it is important in the present economic situation to make the observing networks as efficient as possible, it is important to leave future generations a sufficient legacy of data so as to not restrict their ability to address questions of importance to them. *We cannot look at a replay if we have not made the tape!*

6.1 Climatological Monitoring, Analyses and Modelling

- Climate researchers require access to long-term datasets, updated continuously and collected on a broad regional or global scale.

- The Climate Change Network is sparse and declining. Stations have decreased steadily from a peak of 2915 stations in 1991 to 2483 stations in 1996. Another problem is a lack of northern stations.

- Like most countries, Canada essentially lacks offshore observing systems. Needed are regular, long-term, systematic, and cost-effective ocean measurements that are relevant to global climate systems and are subject to continuous examination.

- Traditional statistics cannot incorporate the temporal-spatial chaos inherent in climate datasets, rapid short-term changes or intermittent events. Use of other techniques, such as circular statistics, fractal geometry and chaos theory should be considered.

- A new statistical approach is needed for climate modelling. The short length of time and the short cycles we are often dealing with means that traditional statistics are often of little use. It is recommended that paleoclimatology be used for looking back and discovering long-term cycles.

- More accurate climate models are needed. Global models are improving but there is much work to be done. The oceanographic community is starting to model the coastal shelf, but as yet this is not well-coupled to the deep oceans. More accurate regional models are also needed.

- Some climatic process needs to be identified linking environmental signals such as crop yields and fish catches in Europe, Atlantic Canada and the Black Sea.

- It is essential that we maintain (or enhance) the moored buoy network and validate offshore platforms for long term wind/wave monitoring.

- Wave hindcast models (including wind aspects) still need work in relation to extreme conditions; mesoscale effects may be important.

6.2 Extreme Events

- Little or no work examining the implications of a changing climate has been done in Atlantic Canada on:

    - the frequency or severity of extreme events
    - storms in transition from tropical to extra-tropical
    - trends in summer severe weather

6.3 Fisheries and Plankton

- Quantitative predictions of the consequences of climate change on the fish resources of Atlantic Canada will require good regional atmospheric and oceanic models of the response of the ocean to climate change, improved knowledge of the life histories of those species for which predictions are required and further understanding of the role of environment, species interactions and fishing play in determining the variability of growth, reproduction, distribution and abundance of fish stocks.

- For the marine aquaculture industry, the role of climate will become more important. It will be more and more useful to define and predict local climate variability and the critical values of environment conditions, since these are still poorly defined.

- To understand the impact of climate variations on the marine ecosystem, it is essential to monitor not only the biomass, but also the species composition.

- A good knowledge of the food chains in the ocean is essential for a better understanding of the efficiency of transfer from primary production to fish stocks

6.4 Coastal Zone

- Improved prediction of climate-change impacts in the coastal zone will require a better understanding of coastal response at storm-event scale and at longer time scales.

- We need to enhance our ability to predict the changes that would occur on wave-dominated coasts in the next century if accelerated sea-level rise were to occur.

- Long-term tide gauges for monitoring rates of relative sea-level rise must be maintained, perhaps in combination with satellite altimetry, absolute gravity, and other techniques.

- Long-term coastal wave instruments must also be maintained for analysis of wave climate, detection of trends, improvement of wave prediction, and documentation of storm waves.

- A regular schedule of repetitive, large-scale, vertical aerial photography should be carried out to observe changes in the coastline.

- An analysis of historical data should be carried out to derive reliable estimates of coastal retreat, sea-level rise, storm-surge climatology, and wave climate.

- Regular surveys of representative "indicator" sites along the coast should be continued.

- Closer links need to be established between shoreline monitoring crews and storm surge forecasters who have access to real time marine measurements. The forecasters could provide storm alerts to the survey crews who could measure shoreline changes sooner, obtain better post-storm observations which could be used to develop a better relationship between wave heights, water levels and beach response.

- It is critical that the network of wave buoys, especially inshore buoys, be maintained, not abandoned.

6.5 Ecosystem Sciences and Water Resources

Water Resources

- Proper monitoring of key elements of the climate/hydrologic mechanisms over the long term is vital to increasing our understanding of these processes so that preventative or adaptive measures may be taken to reduce the impact on society.

- An important question is whether the anticipated effect of climate change will exacerbate or mitigate a cyclic trend in runoff, how long the trend will last and what are the implications for the entire ecosystem

River Ice Jams

- Neither Global Circulation Models nor river ice science is sufficiently advanced to identify some of the changes in the ice-jam regime of Canadian rivers that may be expected under the global warming scenario.

- There is a need to explain the relationship between ice cover in rivers and winter temperatures, and how it might change with a shift in climate.

Wetlands in Atlantic Canada

- Research thus far suggests that water levels in wetlands might change significantly with shifts in climate but how these translate into actual wetland distributions has not yet been determined and remains an important unknown in attempting to understand the implications of climate change.

Migratory Birds

- In Atlantic terrestrial ecosystems we know very little about the relation between climate and the timing of breeding.

- Extreme events such as cold snaps and summer storms can have severe effects on birds. More attention will need to be paid to their possible impacts.

General

- Estimates of precipitation on finer geographic and temporal scales, are needed to predict effects of climate change on biodiversity in general, including birds.

- Efforts should continue to be made to exploit proxy climate records archived in the terrestrial and marine sediments in the Atlantic Region to examine ecosystem response to climate change

- There is a lack of research in the northernmost two-thirds of the region which is most likely to be affected by climate change.

6.6 Agriculture

- Any progress that can be made in estimating and reducing the negative impacts of variability and extremes in climate should help the industry to cope with any long term climate changes that may occur.

6.7 Forestry

- There is little research and much uncertainty concerning multiple effects of climatic factors and other stresses such as air pollution i.e. SO_2, NH_4, NO_x and O_3, together with the deposition from the atmosphere of acidifying substances and heavy metals.

- The long term effects of population migration (associated forest clearing and harvesting) due to extension of farmable land and industrial development are also uncertain. These will be exacerbated by movements of people due sea level rise .

- Atlantic forests are predicted to become stronger absorbers of atmospheric carbon dioxide. All predictions of source/sink activity are subject to much uncertainty, and the regional disparities in predicted responses argue strongly for reducing uncertainties on a regional basis.

- There is much uncertainty globally about how processes involved in primary forest production in Atlantic Canada will respond to increasing atmospheric CO_2 concentrations, in combination with rising temperature, changes in precipitation, and uncertain nitrogen deposition rates. Uncertainty also exists concerning whether carbon storage in soils will increase or decrease as climate changes, and whether more nitrogen or less nitrogen will be made available to roots.

6.8 Socio-economic Aspects of Climate Change

- There is a lack of information in the literature specific to climate change and socioeconomic impacts in Atlantic Canada in particular. For the most part, recent regional work concentrates on physical responses to climate change. While this provides a solid understanding of the economic sectors at risk from climate change, preliminary socioeconomic investigations within the Atlantic Canadian context are not available. However, this lack of information at the regional level should not preclude preliminary socioeconomic investigations.

Résumé

Roderick W. Shaw
Conseilller en météorologie et en environnement
C.P. 2C5, 177, chemin Mason's Point
Head of St. Margaret's Bay (Nouvelle-Écosse) CANADA B0J 1R0

1. L'ÉTUDE PAN-CANADIENNE

L'Étude pan-canadienne est une évaluation nationale des répercussions de la variabilité et des changements climatiques sur le Canada et de son potentiel d'adaptation à ces effets. Cette étude comporte deux phases. La phase I est une recension de la documentation existante dont le but est de préciser les lacunes et les priorités en matière de recherche. La phase II portera sur les priorités par la conception et l'exécution de nouveaux projets de recherche.

Ce document représente la contribution de la région de l'Atlantique à la phase I. Il repose essentiellement sur les résultats d'un colloque intitulé *Variabilité et changements climatiques dans le Canada atlantique*, qui s'est tenu à Halifax (Nouvelle-Écosse) du 3 au 6 décembre 1996.

2. CONTEXTE RÉGIONAL DE L'ATLANTIQUE

2.1 Physiographie

La région de l'Atlantique compte un vaste éventail de milieux terrestres, dulçaquicoles et marins qui tiennent lieu d'habitats à toute une variété de ressources fauniques et qui épaulent les activités de 2,3 millions de personnes. Les provinces Maritimes appartiennent à l'écozone maritime atlantique, alors que Terre-Neuve fait partie de l'écozone du Bouclier boréal. Le Labrador pour sa part est à cheval sur quatre écozones : le Bouclier taïga, le sud de l'Arctique, la Cordillère de l'Arctique et le Bouclier boréal. La nature de la région (son biote, son climat et ses modes de colonisation et d'activité humaine) est fortement influencée par ses rapports avec la mer et par les caractéristiques de ces écozones.

Eau

Les provinces Maritimes comptent plus de 25 000 nappes d'eau de surface intérieures. Le Labrador et l'île de Terre-Neuve en comptent chacun environ 135 000. Ce grand nombre de petites nappes d'eau de surface est un atout considérable pour l'habitat faunique. Sur le plan humain, près de 1,2 million de personnes de la région sont entièrement tributaires de la nappe d'eau souterraine pour leurs besoins en eau.

La région compte environ 40 000 km de côtes, dont les estuaires et les zones côtières tiennent lieu d'habitats à de nombreuses personnes et à toute une variété d'oiseaux marins, d'oiseaux de grève, de mammifères marins ainsi que de poissons et crustacés revêtant une importance commerciale. Bon nombre des établissements humains de la région sont sur la côte ou à proximité, car la population dépend des eaux côtières pour ses transports, son alimentation et ses loisirs. Sur le plan physique, la zone côtière varie de slikkes à des plages de sable à des rivages rocheux.

On trouve la plupart des marais salants dans les estuaires du fond de la baie de Fundy. On en trouve également sur la côte sud-ouest de la Nouvelle-Écosse, dans la baie et sur la rivière Hillsborough ainsi que sur l'île du Prince-Édouard. Ces marais et d'autres plus petits sont d'importantes zones d'alevinage pour un certain nombre d'espèces de poissons, et ils tiennent lieu d'habitat à toute une variété d'animaux fauniques. Environ 65 % des marais salants des Maritimes sont entourés de digues pour l'agriculture.

Sol

Quarante et un pour cent du sol de la région est recouvert de forêts. On compte quatre régions forestières : la région acadienne, la région boréale (essentiellement forestière), la région boréale (recouverte de forêts et de terrains dénudés) et la région des Grands Lacs – Saint-Laurent.

Tourbières, marais et marécages couvrent 17 % de la superficie de Terre-Neuve et du Labrador et entre 1 et 8 % de la superficie des provinces Maritimes. Ces terres humides servent à diverses fonctions écologiques (habitat, hydrologie et biogéochimie) et produisent toute une variété d'animaux utiles à l'homme (animaux à fourrure et canards).

La saison de croissance relativement courte et fraîche de la région et l'absence relative de sols de qualité sont des entraves à l'agriculture dans bien des endroits. Les zones agricoles les plus importantes sont la vallée de l'Annapolis (vergers), l'Île-du-Prince-Édouard (culture de la pomme de terre et des céréales) et le nord-ouest du Nouveau-Brunswick (culture de la pomme de terre). La production agricole de Terre-Neuve et du Labrador est plutôt limitée.

Faune

Environ 60 espèces de mammifères, 171 espèces d'oiseaux, 13 espèces de reptiles, 14 espèces d'amphibiens et 55 espèces de poissons fréquentent les habitats terrestres, dulçaquicoles et marins de la région. Parmi les mammifères marins, on trouve des ours polaires, des phoques et toute une variété de baleines, de dauphins et de marsouins. Les animaux terrestres sont de taille variable et vont de l'orignal à la musaraigne. C'est au Labrador que l'on trouve le plus grand troupeau de caribous du monde. Les longues côtes de la région procurent un habitat à toute une variété d'oiseaux marins et d'oiseaux de grève, aussi bien nicheurs que non nicheurs. Les zones les plus importantes sont les eaux côtières de Terre-Neuve et du Labrador ainsi que les slikkes et le fond de la baie de Fundy (surtout pour les oiseaux de grève migrateurs). Parmi les poissons marins de la région, il faut citer le saumon anadrome de l'Atlantique et plusieurs espèces de poissons d'importance commerciale comme la morue, l'aiglefin et la goberge. On estime à 393 millions de dollars par an les dépenses liées à la faune dans la région.

2.2 Milieu historique et culturel

La population des quatre provinces de l'Atlantique, qui se chiffre à 2,3 millions d'habitants (recensement de 1991), ne représente qu'environ 9 % de l'ensemble de la population canadienne. La croissance démographique des provinces de l'Atlantique depuis le milieu du XIX^{e} siècle est lente quoique régulière, puisqu'elle n'a que quadruplé alors que la population canadienne a plus que décuplé. Pendant près de 20 ans, soit entre 1971 et 1986, la hausse a été de 0,2 million de personnes, soit environ 10 %. Cela représente une hausse d'à peine 0,7 % par an, ce qui est nettement moins élevé que la moyenne canadienne. Cette différence de croissance est attribuable entre autres à la croissance rapide de l'économie plus diversifiée du centre du Canada.

Les modes de colonisation du Canada atlantique reflétaient à l'origine les moyens de transport disponibles : les rivières et les zones côtières ou encore les carrefours ferroviaires où l'on procédait au transbordement des marchandises. Les capitales de toutes les provinces, par exemple, ont accès à l'océan.

2.3 Aperçu socioéconomique

Revenu régional

L'économie du Canada atlantique se caractérise par sa diversité et est lourdement tributaire des industries du secteur primaire et autres industries connexes. Le pourcentage de l'économie globale que représentent les industries du secteur primaire (agriculture, pêche et sylviculture) s'établit ainsi dans la région : Terre-Neuve – 2,3 %; Île-du-Prince-Édouard – 11,6 %; Nouvelle-Écosse – 3,5 %; Nouveau-Brunswick – 4,0 %. Ces pourcentages sont plus élevés dans le Canada atlantique que la moyenne canadienne qui se situe à 2,8 %.

Le secteur manufacturier accuse un retard de 5 à 12 % par rapport à la moyenne nationale en pourcentage de l'économie totale et est principalement constitué d'industries manufacturières ayant un rapport avec le secteur primaire. Par exemple, en Nouvelle-Écosse, les deux plus grosses industries manufacturières en 1992 étaient la transformation du poisson, qui représentait 17 % de la valeur de toutes les expéditions du secteur manufacturier, et d'autres produits alimentaires, à hauteur de 15 %. À Terre-Neuve, malgré le moratoire décrété sur la pêche des poissons de fond, le PIB du secteur de la transformation du poisson représentait environ 35 % du PIB du secteur manufacturier.

Produit intérieur brut (PIB)

Le PIB par habitant (PIB divisé par la population) dans les provinces de l'Atlantique reste nettement inférieur à la moyenne nationale. En 1991, en proportion du PIB national par habitant, Terre-Neuve affichait 67 %, l'Î.-P.-É., 66 %, la Nouvelle-Écosse, 80 % et le Nouveau-Brunswick, 76 %. Le rendement de chaque secteur, comme la pêche et l'agriculture, dans le Canada atlantique a des conséquences sur la performance économique globale.

Emploi

À l'instar du PIB, les industries du secteur primaire et les industries connexes comptent pour une part importante de l'emploi dans le Canada atlantique. Par rapport au Canada, la part de l'emploi dans les industries tributaires des ressources naturelles par opposition à toutes les industries se situe entre 3 % (Nouvelle-Écosse) et 14 % (Î.-P.-É.) au-dessus de la moyenne nationale. En Nouvelle-Écosse, le secteur de la transformation du poisson était le plus gros employeur du secteur des industries manufacturières en 1995. À Terre-Neuve, la pêche et la transformation du poisson comptent pour une large part de l'emploi total.

Répercussions économiques des changements climatiques

La documentation existante sur les changements climatiques précise que ce sont les économies tributaires des matières premières qui sont les plus vulnérables à l'impact des changements et de la variabilité climatiques. Compte tenu de la trame de l'économie du Canada atlantique, il y a de fortes chances pour que la région soit plus vulnérable aux changements climatiques que d'autres régions du Canada. On trouvera d'autres précisions à ce sujet à la section 4.6 de ce résumé général et à la section 3 du rapport principal.

3. LE CLIMAT DU CANADA ATLANTIQUE

3.1 Description générale

Influences à grande échelle qui s'exercent sur le climat du Canada atlantique

Les grands courants de circulation atmosphérique du globe, les courants océaniques et l'étendue des glaces de mer influent considérablement sur le climat de la région en raison de sa situation sur la côte est de l'Amérique du Nord. La topographie locale et la température de la mer en surface expliquent les différences climatiques que l'on note dans la région. À l'échelle du globe, la région de l'Atlantique se situe dans la zone des vents d'ouest dominants. Celle-ci se caractérise par le passage d'une série d'anticyclones et de creux dépressionnaires. La trajectoire que suivent ces systèmes subit l'influence des courants océaniques et de la topographie continentale.

Dans l'hémisphère nord, les creux barométriques se forment lorsqu'un courant d'air sec froid provenant du Nord canadien se dirige vers le sud-est et rencontre un courant d'air chaud humide en provenance de la mer des Caraïbes se dirigeant vers le pôle. Ces systèmes sont plus intenses durant l'hiver. Les analyses des trajectoires des tempêtes nous apprennent que beaucoup de ces systèmes touchent la région de l'Atlantique. Les grands écarts de température des masses d'air qui touchent la région expliquent l'amplitude annuelle des températures que l'on enregistre dans les stations d'observation. L'abondance des précipitations annuelles est sans doute attribuable à ces tempêtes synoptiques auxquelles il convient d'ajouter les tempêtes tropicales et les tempêtes locales de type convectif.

En conclusion, on peut dire que la Nouvelle-Écosse, l'Île-du-Prince-Édouard et le sud du Nouveau-Brunswick ont un climat continental humide alors que le nord du Nouveau-Brunswick, Terre-Neuve et le Labrador se situent dans la zone climatique de la forêt boréale. Le climat de toundra qui caractérise la majeure partie du Nord canadien englobe l'extrémité nord du Labrador.

Effets de l'océan Atlantique

Les glaces marines gagnent progressivement le sud le long de la côte du Labrador, l'est de Terre-Neuve, le golfe du Saint-Laurent et le détroit de Cabot durant les mois d'hiver. Lors du retrait des glaces au printemps, la température de la mer en surface s'élève progressivement, particulièrement dans le golfe du Saint-Laurent. L'extrémité est du golfe fait exception à la règle puisqu'il subit l'influence du courant froid du Labrador. Ce courant garde froide la température de la mer en surface le long des côtes est du Labrador et de Terre-Neuve, et il exerce un certain effet sur les eaux du sud de la Nouvelle-Écosse. Les eaux plus chaudes baignées par le Gulf Stream s'étendent plus au nord durant les mois d'été, ce qui modifie les températures en surface au sud de la Nouvelle-Écosse. Les vents de la côte ont un effet modérateur sur le climat des zones continentales attenantes durant toute l'année.

Températures et précipitations régionales

Température

L'hiver, on enregistre les températures moyennes les plus chaudes dans le sud-ouest de la Nouvelle-Écosse et la presqu'île Avalon de Terre-Neuve, la température moyenne chutant quelques degrés en dessous du point de congélation. Viennent ensuite les autres secteurs de Terre-Neuve et de la Nouvelle-Écosse, puis l'Île-du-Prince-Édouard et le sud du Nouveau-Brunswick, qui sont suivis par le nord du Nouveau-Brunswick et le sud-est du Labrador. La latitude du Labrador explique que l'on y rencontre les températures les plus froides de la région, avec des moyennes proches de –20 C à l'intérieur des terres.

C'est le centre du Nouveau-Brunswick qui enregistre les températures les plus élevées durant les mois d'été, avec des moyennes proches de 20 C, puis viennent le reste des Maritimes et le centre de Terre-Neuve. Viennent ensuite la côte sud de Terre-Neuve, la presqu'île Avalon et la péninsule Great Northern, suivis en dernier lieu par le Labrador.

Précipitations

La fréquence des creux dépressionnaires associée à la présence de l'océan explique l'ampleur des précipitations qui s'abattent sur les provinces de l'Atlantique. Les vents du sud-est qui accompagnent les tempêtes ramassent l'humidité de la mer, gratifiant ainsi les côtes sud de Terre-Neuve (plus de 1 700 mm par an) et de la Nouvelle-Écosse, ainsi que la côte Fundy du Nouveau-Brunswick des plus abondantes précipitations annuelles. Le nord de Terre-Neuve, le nord de la Nouvelle-Écosse, l'Île-du-Prince-Édouard et une bonne partie du Nouveau-Brunswick reçoivent des quantités inférieures (qui dépassent néanmoins 1 000 mm par an).

Même si les précipitations qui s'abattent sur la région sont presque exclusivement sous forme liquide durant les mois d'été, la pluie, la pluie verglaçante et la neige sont courantes l'hiver dans les régions du sud. De fait, il tombe plus de pluie que de neige (exprimée en équivalent en eau) en moyenne le long des côtes sud de Terre-Neuve et de la Nouvelle-Écosse l'hiver.

3.2 Tendances climatologiques du Canada atlantique

Température

En dépit d'une tendance au réchauffement mondial qui se situe entre 0,3 et 0,6 C, et d'un réchauffement de 1,1 C au Canada en général, la région de l'Atlantique a connu un réchauffement progressif de 1895 jusque vers le milieu des années 1950, suivi d'un refroidissement progressif jusque dans les années 1990. Durant la période 1948-1995, le Canada atlantique a connu un refroidissement marqué de 0,7 C avec les tendances saisonnières suivantes : hiver (–2,2 C); printemps (0,0 C); été (0,5 C); et automne (–0,8 C).

Précipitations

Les tendances des précipitations sont beaucoup plus difficiles à établir que celles des températures. Cela s'explique principalement par la difficulté que l'on a à obtenir des mesures exactes et uniformes des tranches pluviométriques et des apports neigeux et de l'ampleur des écarts temporels et spatiaux dans les apports annuels. La dynamique nationale indique une hausse des précipitations depuis 1948, mais une baisse depuis le milieu des années 1980. La région de l'Atlantique a enregistré une hausse depuis 1948. En dépit de la hausse régionale des précipitations, on a constaté une baisse de l'épaisseur annuelle de la neige au sol sur le sud du Canada durant la période 1971-1990.

Nébulosité

Il existe un rapport complexe entre la nébulosité et le réchauffement et le refroidissement de la planète. Il semble que la nébulosité ait augmenté de 1 % dans la région de l'Atlantique depuis 1953, mais un tel changement n'est guère significatif sur le plan statistique.

Extrêmes de température et de précipitations

Durant la période 1944-1990, on a enregistré :

1) une baisse du nombre de jours par an où la température maximum dépasse 25 C;
2) une hausse du nombre de jours par an où la température minimum est inférieure à –15 C;
3) une augmentation du nombre d'événements de précipitations quotidiens de plus de 20 mm;
4) une très légère hausse du nombre de chutes de neige quotidiennes de plus de 15 cm.

3.3 Variabilité climatique

Par rapport aux efforts déployés pour prédire les changements climatiques, on a tenté relativement peu de choses pour définir la variabilité du climat actuel ou étudier les fluctuations climatiques du passé récent. On signale une hausse apparente de la variabilité thermique d'une année à l'autre depuis le début des années 1970 durant l'hiver. De plus, on a constaté une baisse de 30 % de la fréquence des cyclones qui se sont abattus sur les Maritimes et les États de la Nouvelle-Angleterre durant les hivers de 1931-1932 à 1984-1985. Le modèle de circulation générale de la deuxième génération du Centre climatologique canadien prévoit, moyennant un doublement du CO_2 atmosphérique, une baisse du nombre total de cyclones dans les deux hémisphères en hiver, mais une augmentation de la fréquence des cyclones de forte intensité, particulièrement dans l'hémisphère nord. Ce modèle prévoit peu de changements dans le tracé des trajectoires des tempêtes.

3.4 Phénomènes extrêmes

Chaque année, les centres météorologiques d'Environnement Canada dans la région de l'Atlantique émettent des centaines d'alertes météorologiques à l'intérieur des terres et des milliers d'alertes en mer. Les fortes chutes de neige et précipitations liquides, les vents de la force d'une tempête ou d'un ouragan, les fortes vagues et les ondes de tempête sont parmi les phénomènes extrêmes qui peuvent faire des blessés ou des morts et provoquer d'importantes pertes économiques, comme des dégâts matériels ou des dégâts aux cultures. On peut également qualifier d'extrêmes les phénomènes qui dépassent l'amplitude normale de variabilité des températures ou des précipitations et qui provoquent des inondations, des sécheresses, des vagues de chaleur, des vagues de froid ou des dégels en hiver. Manifestement, un changement climatique qui a des répercussions sur la fréquence ou la gravité des phénomènes extrêmes présente un grand intérêt pour les Canadiens de l'Atlantique.

Parmi les phénomènes météorologiques que l'on peut qualifier d'extrêmes, il faut mentionner les cyclones extratropicaux (le plus souvent des tempêtes hivernales), les cyclones tropicaux (ouragans) ou les conditions extrêmes estivales (orages convectifs de méso-échelle). Même s'il y a eu certaines études sur le comportement et la prévision de ces systèmes, on n'a presque rien fait pour tenter d'analyser les répercussions des changements climatiques sur ces phénomènes dans le Canada atlantique, et de plus amples recherches s'imposent donc.

Vagues océaniques

Depuis cinq ou six ans, on a enregistré un certain nombre de tempêtes exceptionnelles des deux côtés de l'Atlantique Nord. En 1990, des vagues d'une hauteur exceptionnelle ont littéralement fracassé la superstructure de la plate-forme de forage Ekofisk dans la mer du Nord. En 1992, une tempête a sérieusement endommagé des villages côtiers de l'ouest de la Norvège alors qu'en 1993 le capitaine du navire météorologique « Mike » a déclaré qu'en 35 ans de navigation dans la mer de Norvège, il n'avait jamais rencontré des vagues aussi exceptionnelles.

Sur la côte ouest de l'Atlantique, le jour de l'Halloween en 1991, une bouée captive au sud de la Nouvelle-Écosse a signalé les plus fortes vagues jamais enregistrées par un instrument de mesure

(17,3 m de hauteur d'onde significative, avec des vagues d'une hauteur maximum estimée à plus de 31 m). Le 15 mars 1993, la « tempête du siècle » a produit des vagues d'une hauteur record mesurées par les bouées situées le long de la côte est du Canada et des États-Unis, notamment une vague de 16,3 m enregistrée par la bouée située au sud de la Nouvelle-Écosse. En septembre 1995, l'ouragan Luis a provoqué des vagues d'une hauteur maximum de 29 m qui ont littéralement ballotté le paquebot *Queen Elizabeth II*, mesure corroborée par une bouée située à proximité qui a mesuré des vagues de 17 m avec une hauteur maximum estimée à plus de 30 m.

Tous ces phénomènes nous obligent à nous poser des questions, dont les principales sont : 1) assiste-t-on à un changement climatique? 2) les tempêtes augmentent-elles en fréquence? et en intensité? La principale préoccupation qui vient à l'esprit lorsqu'on examine la dynamique et la variabilité à long terme des vagues océaniques est qu'il n'existe pas d'ensembles de données fiables sur les vagues à long terme. En raison de cette pénurie d'observations fiables, le Canada et d'autres pays se sont tournés vers les modèles de prévisions a posteriori afin d'obtenir les données nécessaires pour la conception technique et l'analyse de la dynamique et de la variabilité climatiques. L'exactitude de ces modèles a posteriori est excellente pour les tempêtes, comme en témoignent les nombreuses études de rétrospection. Il faut néanmoins prendre garde à la modélisation des états de mer exceptionnels, c'est-à-dire des vagues d'une hauteur supérieure à 12 m. Toutes les catégories de modèles de vague semblent avoir tendance à sous-estimer ces tempêtes exceptionnelles. Dans l'ensemble, toutefois, la rétrospection permet une très bonne estimation des vagues de tempête, au moyen d'une méthodologie uniforme.

Voici certains résultats de l'analyse des modèles de prévision a posteriori :

- Il n'y a pas de tendances discernables dans l'ampleur ou la fréquence des vagues de hauteur exceptionnelle sur la côte est du Canada, même si l'on note une variabilité inter-annuelle significative.

- Toute tendance apparente dans l'ampleur et la fréquence des vagues exceptionnelles s'explique exclusivement par deux ou trois événements récents survenus sur le plateau néo-écossais (depuis 1991).

- Il se peut que les événements exceptionnels du début des années 1990 sur la plate-forme Scotian témoignent d'un changement dans les courants de circulation à grande échelle mais qu'ils ne soient pas incompatibles en revanche avec les événements enregistrés plus tôt durant le siècle.

Ouragans

Durant la plupart des années entre 1970 et 1987, le bassin des ouragans de l'Atlantique Nord a connu une accalmie relative au chapitre de l'activité globale des cyclones tropicaux. Cette activité inférieure à la normale s'est surtout manifestée par une baisse draconienne du nombre d'ouragans qui ont frappé la mer des Caraïbes et la région des Maritimes et du nombre de gros ouragans (GO), et par l'absence quasi totale de GO qui ont frappé la côte est des États-Unis. Après un retour à un niveau d'activité « normal » en 1988 et en 1989 (avec cinq GO durant ces deux années), on a pensé que le bassin de l'Atlantique était sur le point de connaître un regain d'activité analogue à ce que la région avait connu dans les années 1950 et 1960 et à certaines périodes antérieures. Mais ce regain d'activité en 1988 et en 1989 a cédé la place à une baisse marquée de l'activité cyclonique entre 1991 et 1994. Compte tenu de cette reprise d'une activité inférieure à la normale, on a presque entièrement écarté l'idée que le bassin de l'Atlantique allait connaître à nouveau un niveau d'activité élevé.

La trêve a finalement pris fin au début de 1995 et a cédé la place à l'une des saisons d'ouragans les plus actives de mémoire d'homme dans l'Atlantique, chaque mesure d'activité étant plus de deux fois supérieure à la moyenne à long terme. Il faut signaler que la saison a produit cinq GO pour la première fois depuis 1964. On s'est donc demandé si oui ou non l'activité de la saison 1995 était tout bonnement une crête anormale ou le signe avant-coureur d'un changement climatique à plusieurs échelles et sur plusieurs décennies signalant la probabilité d'un regain d'activité au cours des 10 à 20 prochaines années.

On a la preuve de certains changements dans les températures de l'océan Atlantique en surface qui accompagnent le réchauffement progressif constaté dans l'hémisphère nord depuis 1988. Ce changement s'est accompagné d'une augmentation réduite de la vitesse des vents dans la principale zone de l'Atlantique où se forment les ouragans (bande entre le 10^e et le 20^e parallèle s'étendant de la côte ouest de l'Afrique à l'Amérique centrale), situation plus propice à l'augmentation de l'activité cyclonique tropicale, surtout les gros ouragans. Si ces changements se produisent effectivement sur une ou plusieurs décennies et non pas d'une année à l'autre, il se pourrait alors que le bassin atlantique connaisse dans la prochaine décennie un regain d'activité d'une ampleur comparable à ce qu'on a enregistré dans les années 1950 et 1960, au lieu de la baisse enregistrée dans les années 1970 et la majeure partie des années 1980. On peut donc s'attendre à plusieurs années d'activité très intense, la plupart des années se situant près de la moyenne ou légèrement au-dessus et quelques années seulement étant très nettement au-dessous de la moyenne. Si le passé permet de prédire l'avenir dans ce cas, l'augmentation globale signifiera une hausse significative moyenne du nombre d'ouragans touchant la mer des Caraïbes et la région des Maritimes, du nombre de gros ouragans dans tout le bassin et de gros ouragans qui déferlent sur la côte est des États-Unis.

Les répercussions possibles de ces changements sont énormes. Le fait que les gros ouragans soient à l'origine de la plupart des dégâts et des morts causés par les cyclones tropicaux, ajouté au fait qu'il y a eu une hausse spectaculaire de la population le long des côtes vulnérables aux ouragans durant les deux décennies d'inactivité, multiplie les risques de pertes financières colossales, surtout si de grosses villes sont touchées. On court par ailleurs le risque d'une véritable hécatombe en cas d'évacuation incomplète durant une tempête qui gagne rapidement en intensité.

4. SENSIBILITÉS RÉGIONALES AUX CHANGEMENTS CLIMATIQUES

4.1 Les pêches et le plancton

Les stocks de poissons varient selon les méthodes de pêche et certains facteurs naturels, notamment les changements d'ordre environnemental. Il est difficile de déterminer l'importance relative des facteurs humains et naturels, mais des facteurs comme la température peuvent avoir un effet marqué sur la croissance des espèces de poissons, la fraie et la reproduction, la distribution, l'abondance et les migrations, sans compter le potentiel de capture et la disponibilité. Ces effets sont sans doute tributaires de l'endroit et de l'espèce. Par exemple, la durée d'incubation des oeufs de morue de l'Atlantique sur le plateau néo-écossais varie de 8 jours à 14 C à 42 jours à 1 C. C'est ainsi que les oeufs dans les eaux plus froides sont plus vulnérables aux prédateurs en raison de leur plus long délai d'exposition, ce qui peut aboutir à un taux de survie inférieur.

On peut d'ores et déjà prévoir que les changements climatiques entraîneront une nouvelle répartition des espèces de poissons, les changements les plus frappants devant se produire à proximité des limites nord ou sud de leur habitat. Les courants migratoires changeront eux aussi et entraîneront une modification des moments d'arrivée le long de la trajectoire migratoire. On peut s'attendre à ce que les taux de croissance varient en fonction de l'amplitude et de la direction qui, elles, dépendent de l'espèce. Le taux de recrutement risque d'être touché par les changements intervenant dans le moment de la fraie, les taux de fécondité, le taux de survie des larves et la disponibilité de nourriture. Un autre facteur de sensibilité qui se rattache au changement climatique est un changement qui se produit dans la structure thermique verticale de l'eau, qui peut se solder par des modifications dans la proportion de poissons pélagiques et de poissons démersaux.

4.2 Zone côtière

La meilleure estimation de l'élévation du niveau de la mer à l'échelle planétaire, que l'on doit au groupe d'experts intergouvernemental des Nations unies sur le changement climatique, est d'environ 0,5 m d'ici l'an 2100. Les changements qui surviendront parallèlement dans les courants de circulation atmosphérique risquent aussi d'aboutir à des changements dans la climatologie des tempêtes, le climat des vagues océaniques, la probabilité des soulèvements de tempête et d'autres facteurs ayant un rapport avec la stabilité côtière. Les changements du niveau de la mer qui résulteront de l'expansion thermique de l'océan varieront selon le lieu géographique, à tel point que certaines régions enregistreront un changement négatif ou négligeable alors que d'autres connaîtront une élévation plus élevée du niveau moyen de la mer. La situation est d'autant plus complexe qu'il y a des sources naturelles de variabilité dans le système climatique, comme le courant El Niño et l'oscillation australe, l'oscillation nord-atlantique, la variation séculaire des tempêtes tropicales et extratropicales et du climat des vagues océaniques, l'étendue des glaces marines dans l'Arctique et la zone subarctique et encore bien d'autres facteurs. Les sédiments des marais salants et d'autres systèmes côtiers prouvent qu'il y a des fluctuations naturelles dans le niveau de la mer selon une échelle temporelle de 100 ans, ce qui incite à penser que l'élévation accélérée du niveau de la mer que l'on observe depuis un siècle est sans doute d'origine partiellement ou entièrement naturelle.

La demande de propriétés riveraines dans le Canada atlantique est déjà à la hausse, avec une pression inflationniste sur les prix. Dans ces conditions, les risques financiers qui se rattachent à un danger physique quelconque (comme l'érosion du littoral ou les inondations) sont d'autant plus grands.

Le changement climatique a deux types d'effets potentiels sur les zones côtières de l'Atlantique :
1) accélération de l'élévation du niveau de la mer; 2) variabilité des tempêtes. Voici comment on peut les résumer :

1) Le niveau relatif de la mer s'élève aujourd'hui le long de la majeure partie de la côte du Canada atlantique. Il se peut que l'élévation accélérée du niveau de la mer depuis un siècle soit une réaction au changement climatique planétaire ou qu'elle représente une variation naturelle à moyen terme (à l'échelle d'un siècle) dans le rythme d'élévation du niveau de la mer. Certaines preuves incitent à croire que le niveau de la mer s'élève au rythme de 1 à 2 mm par an et qu'une autre élévation d'environ 0,5 m est à prévoir d'ici l'an 2100. Cela viendra s'ajouter au mouvement vertical de la croûte terrestre (taux de subsidence pouvant atteindre 0,3 m par siècle) dans de nombreuses régions du Canada atlantique. Il en résultera une multiplication des risques d'inondations dans certaines régions et une accélération de l'érosion côtière dans d'autres. Dans certains endroits, on assistera à une redistribution des sédiments et à une sédimentation du littoral.

2) Les variations qui toucheront le régime de tempêtes, notamment l'augmentation possible de la fréquence ou de l'intensité des tempêtes, entraîneront une érosion accrue dans certains endroits et augmenteront les risques d'inondations dues à des marées de tempête et au débordement des digues dans la baie de Fundy. Il se peut également qu'une augmentation des étendues d'eau libre et de l'énergie des vagues durant les mois d'hiver due à une diminution de l'étendue et de la durée des glaces marines l'hiver, surtout dans le golfe du Saint-Laurent et le nord-est de Terre-Neuve, contribue à l'érosion des côtes.

4.3 Science des écosystèmes et ressources hydriques

Ressources hydriques

Les précipitations et les températures sont les principaux éléments moteurs du cycle hydrologique, et les changements climatiques prévus devraient sensiblement altérer les ressources d'eau douce du Canada.

Il se peut également que le changement climatique soit graduel ou progressif. Les variations accrues qui se manifestent comme changements saisonniers ou comme successions rapides des variables climatiques saisonnières risquent de modifier les caractéristiques normales du cycle de l'eau, causant des ravages pour l'être humain et les consommateurs d'eau des écosystèmes.

La disparition des habitats est une sérieuse préoccupation dans la région de l'Atlantique, car certaines espèces n'ont aucune solution de rechange. Le moment et l'ampleur d'événements hydrologiques particuliers comme l'englacement ou la débâcle, la gravité des crues nivales printanières ou la durée de la période de bas débit sont d'importance vitale pour le cycle de vie de nombreuses espèces.

Du côté humain de l'écosystème, l'accumulation de données à long terme sur le débit et le climat a grandement contribué à la conception économique et sécuritaire des barrages, des ponts, des réservoirs d'eau et d'autres infrastructures dont la conception et l'intégrité subissent l'influence des extrêmes du cycle hydrologique.

Les analyses préliminaires menées en Nouvelle-Écosse et sur l'île de Terre-Neuve démontrent que le nombre de jours sans glace dans les rivières a augmenté depuis 1952. Les comparaisons préliminaires des données sur les glaces et des températures hivernales démontrent qu'il y a un rapport de cause à effet entre la température et la glace, sans toutefois que l'une explique entièrement l'autre.

Il semble qu'au cours des 25 dernières années il y ait eu une baisse spectaculaire du ruissellement des cours d'eau en Nouvelle-Écosse, surtout l'hiver. Cette baisse du ruissellement hivernal depuis 1970 correspond à une augmentation des glaces dans les rivières et l'on est en train d'établir un rapport de cause à effet.

Formation d'embâcles dans les rivières

La formation d'embâcles dans les rivières canadiennes a une quantité d'effets socioéconomiques au nombre desquels il faut citer les inondations, les dégâts causés aux propriétés privées et aux infrastructures, l'entrave à la navigation et le ralentissement de la production d'hydroélectricité. On estime que les coûts tangibles moyens de la formation d'embâcles pour l'économie canadienne se chiffrent à 60 millions de dollars par an. Une somme beaucoup plus importante est attribuable aux occasions ratées de produire de l'hydroélectricité en raison de la mauvaise compréhension que l'on a du phénomène des glaces fluviales. Le Canada atlantique est l'une des régions les plus gravement touchées.

Les embâcles et les poussées qui suivent la dispersion des glaces ont de nombreux effets délétères sur la vie aquatique. La disparition d'habitats attribuable à l'affouillement du lit et des rives, la mortalité halieutique due à l'échouage dans le périmètre d'inondation, les très fortes concentrations de minerai pulvérulent, les changements soudains dans la qualité de l'eau, le transport à grande distance des polluants, le dépôt de sédiments fins et la dégradation de l'habitat de frai n'en sont que quelques exemples. Les embâcles ont également des effets écologiques positifs, comme le réapprovisionnement en nutriments et en sédiments de l'habitat du périmètre d'inondation, ce qui assure l'alimentation de nombreuses espèces aquatiques, terrestres et aviaires durant les crues nivales printanières.

Le régime des glaces peut être modifié de différentes façons par les changements climatiques dans différentes régions du pays. Dans les régions tempérées comme le sud-ouest de l'Ontario et certaines régions de la Colombie-Britannique et du Canada atlantique, la couverture de glace fluviale qui est capricieuse et de brève durée risque de disparaître complètement ou de devenir plus intermittente. Cela devrait être une bonne nouvelle sur le plan socioéconomique, mais moins bonne pour les espèces aquatiques qui dépendent de la couverture de glace pour leur survie l'hiver.

Zones humides

Comme elles sont définies en fonction de l'emplacement des nappes phréatiques saisonnières et permanentes, les zones humides ont un rapport étroit avec le climat. L'équilibre entre les précipitations et la température qui régit les apports et les sorties d'eau globales revêt une importance cruciale pour déterminer l'existence d'une zone humide. Les changements intervenant dans le bilan d'évapotranspiration entraînant un abaissement de la nappe phréatique risquent donc d'entraîner la disparition des zones humides et de rendre les bassins incapables d'absorber l'eau, ce qui augmentera les risques d'inondation dans certains secteurs.

Les niveaux et les débits de l'eau dans les zones humides contrôlent également leur teneur en carbone et les flux de carbone. Les flux de carbone organique dissous dans l'eau ont un rapport étroit avec le débit d'eau dans les bassins. En outre, les niveaux d'eau contrôlent le niveau des émissions de métal et de CO_2 qui s'échappent des zones humides. Toute modification de la nappe phréatique résultant d'un changement climatique altérera l'importance relative des gaz et leur incidence sur le cycle du carbone atmosphérique global.

Oiseaux migrateurs

Il y a des chances pour que les limites des aires d'hivernage des oiseaux terrestres se déplacent vers le nord en cas de réchauffement des hivers; les limites nord de nombreuses espèces d'oiseaux chanteurs coïncident avec les isothermes de janvier et reflètent des besoins énergétiques quotidiens environ 2,5 fois supérieurs au rythme métabolique basal.

En dehors des corrélations générales entre de « mauvaises » conditions météorologiques l'été (c.-à-d. humides et froides) et une baisse de la productivité des oiseaux, l'influence du climat sur le taux de reproduction n'a pas été étudié dans le Canada atlantique. Chez de nombreux oiseaux marins, la répartition et le moment de la reproduction ont un rapport avec les températures de la mer en surface. Vu que ces températures ont toutes les chances de changer avec un réchauffement du climat, on peut s'attendre à des changements appréciables dans la répartition et le taux de reproduction des oiseaux marins.

Chez les oiseaux marins, on constatera sans doute des changements dans l'habitat qui feront suite aux changements survenant dans la distribution des proies comme le capelan, la morue polaire, le hareng, le lançon, etc., lesquels iront de pair avec les changements intéressant la température de l'eau et sa salinité.

Il y a des chances pour que l'élévation du niveau de la mer inonde les points d'escale côtiers indispensables aux oiseaux de grève et à la sauvagine qui migrent entre les aires de reproduction de l'Arctique et leurs quartiers d'hiver plus au sud. Les exemples les plus évidents dans cette région sont les marais salants qui relient le Nouveau-Brunswick à la Nouvelle-Écosse et les slikkes à l'embouchure de la baie de Fundy.

Les nombreux phénomènes qui surviennent dans le cycle annuel d'un oiseau, notamment la migration, la reproduction et la mue, sont souvent déclenchés par des changements dans la longueur du jour. Il se peut que ce mécanisme ne soit pas adapté à un changement climatique, alors que le rapport entre la longueur du jour et la modification des disponibilités alimentaires, l'habitat disponible, le mouvement des masses d'air, etc. n'existe plus à mesure que ces phénomènes climatiques changent mais que la longueur du jour reste la même.

À tout moment de l'année, les tempêtes peuvent avoir des effets délétères sur les oiseaux. Les vagues de froid à la fin du printemps provoquent souvent une forte mortalité chez les oisillons, tandis que les tempêtes d'été peuvent tuer les oiseaux de grève dans leurs aires de reproduction et considérablement réduire le taux de reproduction d'espèces aussi variées que les oiseaux chanteurs et les oiseaux marins.

4.4 Agriculture

Le secteur agricole est particulièrement vulnérable au changement et à la variabilité climatiques puisqu'il est directement tributaire du temps et du climat. Au même titre que les sols, le climat détermine dans une large mesure les types de végétaux que l'on peut cultiver dans la région de l'Atlantique, l'endroit où ils auront le meilleur rendement, le rendement et la qualité réalisables avec les techniques d'aujourd'hui et les méthodes de gestion utilisées.

L'existence des unités thermiques maïs (UTM) a des conséquences très profondes sur les espèces, les variétés et (ou) les hybrides que les agriculteurs choisissent de cultiver et sur la productivité de leurs exploitations. Par exemple, l'UTM moyenne dans les trois provinces Maritimes varie d'un maximum d'environ 2800 dans la vallée de l'Annapolis à moins de 1700 dans le nord du Nouveau-Brunswick. Avec les plantes hybrides qui existent aujourd'hui, le maïs-grain présente un fort potentiel dans les régions où l'UTM est supérieure à 2500, un potentiel marginal dans les régions où l'unité thermique se situe entre 2300 et 2500, et il n'est pas cultivable dans les régions où l'UTM est inférieure à 2300.

Le nombre de degrés-jours supérieurs à 5 C (DJ) varie de moins de 1000 à plus de 1800 dans certaines parties des vallées de l'Annapolis et du bas du fleuve Saint-Jean. Les écarts de DJ ont un impact particulièrement marqué sur le potentiel de cultures saisonnières longues comme le blé de printemps, la pomme de terre et les fourrages.

Les variations spatiales des climats hivernaux ont un profond impact sur la survie hiémale (et par conséquent la convenance) des cultures comme le blé d'hiver, le trèfle, la luzerne, les fraises, les arbres fruitiers ainsi que les arbres et les arbrisseaux décoratifs. Les risques de lésions que courent les pommes l'hiver sont estimés faibles dans la vallée de l'Annapolis et élevés dans de nombreuses régions du Nouveau-Brunswick.

La région est soumise à d'importantes différences d'origine climatique dans le taux d'humidité du sol et les journées de travail printanières. Ces différences ont une incidence sur les décisions des agriculteurs quant à la taille des machines, aux besoins en main-d'oeuvre, ainsi qu'à la conception des systèmes d'irrigation et de drainage.

La variabilité temporelle du climat a sans doute un plus gros effet sur l'agriculture que les différences spatiales observées dans la région de l'Atlantique. Parmi les variations qui ont sans doute l'impact le plus profond sur l'agriculture, mentionnons l'humidité excessive, les gels anormalement tardifs le printemps ou anormalement précoces l'automne, la sécheresse, les tempêtes anormalement violentes, les conditions de survie hiémale défavorables et une saison de croissance exceptionnellement fraîche.

Il semble que la région de l'Atlantique n'ait pas suivi la tendance nationale au réchauffement d'environ 1 C que l'on constate depuis 100 ans. Dans l'ensemble, les changements de température sont relativement peu importants et n'auront sans doute pas d'effets ou presque sur l'agriculture, par rapport à ceux de la variabilité climatique.

Les précipitations semblent avoir gagné en importance et en variabilité depuis 100 ans. Cela a certainement eu un impact sur l'agriculture en raison du moindre stress dû à la sécheresse, mais il a fallu en revanche faire face à un excès d'humidité. *Alors que les changements à long terme dans les précipitations sont significatifs sur le plan statistique, ils sont encore relativement minimes par rapport à la variabilité annuelle à laquelle les agriculteurs doivent s'adapter.*

D'après ce qui précède, nous pouvons déduire que les changements climatiques survenus depuis 100 ans ont eu relativement peu d'effets sur l'agriculture par rapport à la variabilité du climat, à l'exception possible des précipitations qui semblent avoir gagné en intensité et en variabilité.

Les changements climatiques susceptibles de se produire à l'avenir risquent d'avoir une incidence profonde sur l'agriculture dans la région de l'Atlantique. La hausse des concentrations de CO_2 qui accompagne le réchauffement progressif pourrait être bénéfique à l'agriculture, surtout si les agriculteurs optent pour de nouvelles variétés mieux adaptées à ces nouvelles conditions. On peut également s'attendre à ce que le réchauffement améliore la compétitivité du secteur agricole qui pourra accroître sa production de maïs, de soja, d'arbres fruitiers et de cultures spéciales. Le plus fort taux d'humidité neutralisera toute baisse du rendement due à la sécheresse, mais se traduira sans doute par une augmentation des maladies (surtout des affections fongiques de type foliaire comme le mildiou de la pomme de terre qui adore l'humidité), il accroîtra la lixiviation des nutriments et des substances chimiques dans la nappe souterraine, abaissera le nombre de jours où l'on peut s'adonner à l'agriculture et se soldera par une plus grande érosion du sol. En revanche, des conditions plus sèches auraient l'effet contraire. Les hivers plus doux risquent d'avoir un effet significatif sur la survie de nombreuses cultures comme la luzerne, le trèfle, le blé d'hiver, les fraises, les arbres fruitiers et les raisins, et d'améliorer le potentiel de ces cultures dans de nombreuses régions. Toutefois, dans certaines régions où le réchauffement risque de se traduire par une couverture neigeuse moins fiable, on s'expose à des effets négatifs sur la survie.

4.5 Sylviculture

Les facteurs climatiques exercent une influence sur le taux de croissance des arbres et sur la capacité des forêts à absorber le dioxyde de carbone atmosphérique. Selon un scénario possible, les Maritimes pourraient connaître des hivers et des printemps plus doux mais des étés plus frais. Ce phénomène risque d'entraîner une augmentation du taux de croissance des conifères advenant un rallongement significatif de la saison de croissance à cause de printemps plus chauds. Des sols plus chauds entraînent également une accélération du cycle des nutriments et une plus grande abondance de ces substances. Certes, des printemps plus précoces s'accompagneront d'une augmentation du nombre de jours sans gel dans le Canada atlantique tandis que des gels tardifs ou des dégels précoces seront préjudiciables aux espèces feuillues en cas de nouveau gel après le ramollissement des bourgeons et des racines.

Les Maritimes n'ont pas à craindre une modification de l'étendue forestière en raison de la fusion du pergélisol, même s'il peut se produire des changements dans la limite de végétation des arbres en altitude.

Les gains de carbone emmagasiné par la forêt attribuables à une productivité plus élevée seront partiellement neutralisés par une augmentation du rythme de décomposition des sols et de la tourbe. Il se peut que les pertes provisoires dans la forêt parvenue à maturité dues à des dérangements expliquent la perte supplémentaire de carbone emmagasiné. La capacité d'une forêt jeune à absorber le dioxyde de carbone atmosphérique risque d'être entravée par d'autres stress comme la pollution atmosphérique, surtout l'ozone troposphérique, les pluies acides et les brumes acides.

En cas de changement climatique, on peut s'attendre à avoir une forêt mixte plus tempérée, accompagnée de la disparition de certaines caractéristiques boréales. À court terme, le comportement de nos forêts dépendra de l'adaptabilité de chaque essence dans la forêt actuelle et de la manifestation régionale du changement climatique.

Les changements prévus dans l'indice forêt-météo (IFM) oscilleront entre une baisse dans le sud du Québec, une légère hausse dans le sud des Maritimes et une hausse plus importante au Cap-Breton et dans l'est de Terre-Neuve. L'incertitude de ces prévisions est toutefois accentuée par d'autres dérangements comme les chablis, les flambées d'insectes et les déclins qui peuvent affecter la qualité du bois de chauffage et augmenter les risques d'incendie.

Il y a de fortes chances pour que le puceron lanigère du sapin représente une grave menace en cas d'augmentation de la température hivernale de la forêt boréale, vu que cet insecte semble être maîtrisable lorsqu'il fait des incursions dans le nord en raison de l'intolérance du puceron dormant aux températures inférieures à –34 C.

On a la preuve que les hêtres échappent à la maladie de l'écorce du hêtre (causée par la cochenille du hêtre) en altitude et dans les habitats nordiques, ce qui semble démontrer que cet insecte peut lui aussi être maîtrisé par le climat et risque donc de poser une plus grave menace advenant des hivers plus chauds qui accompagnent un réchauffement climatique.

Il semble également que, dans les limites nordiques de la tordeuse des bourgeons de l'épinette, il y ait un rapport entre la fin des épidémies et les gels printaniers tardifs qui détruisent les jeunes feuilles. Advenant un réchauffement climatique, la baisse du nombre de gels tardifs risque d'accroître la longueur et la gravité des flambées dans ces régions nordiques.

Les dégâts causés par les tempêtes (chablis) augmenteront sans doute en gravité et en fréquence avec un réchauffement global en raison de la multiplication des tempêtes. D'autres dérangements ont pour effet d'ouvrir le couvert forestier et d'accroître les risques de chablis, tout comme la plantation d'un plus grand nombre de feuillus.

L'adoucissement des hivers accompagné d'une moindre accumulation de neige se soldera par un accroissement des aires d'hivernage pour les chevreuils, ce qui signifie davantage de disponibilités alimentaires et une baisse de la prédation. Ces effets entraîneront à leur tour une élévation des niveaux de population, ce qui affectera la régénération des forêts et réduira la diversité des essences.

4.6 Paramètres socioéconomiques

Le Groupe d'experts intergouvernemental des Nations unies sur le changement climatique en déduit que les systèmes écologiques naturels, les systèmes socio-économiques et la santé de l'être humain sont tous vulnérables à l'ampleur et au rythme du changement climatique. En dépit d'une somme croissante de documents sur les effets socioéconomiques détaillés des changements climatiques, la plupart des recherches socioéconomiques sur le changement climatique se sont concentrées sur ses impacts sur l'agriculture, la sylviculture et les ressources des zones côtières. Les paramètres qui ont fait l'objet des études les plus fouillées sont de loin les impacts sur l'agriculture et les coûts d'une élévation du niveau de la mer.

Agriculture

Si l'on se base sur une recension de la documentation générale, l'effet annuel d'un doublement du CO_2 atmosphérique sera une réduction du PIB de l'ordre de 0,047 % à 0,2 %. Si l'on utilise cette fourchette et que l'on admet le haut niveau d'incertitude inhérent à l'application de ces valeurs au Canada atlantique, on peut évaluer que les dégâts annuels subis par l'agriculture se situeront entre 20 et 88 millions de dollars par an. Ces dégâts représentent une fourchette de 2 à 10 % du PIB agricole actuel. On peut donc raisonnablement affirmer que l'agriculture du Canada atlantique sera sérieusement touchée par le changement climatique. L'ampleur du changement en termes économiques dépendra beaucoup de la réponse des cultures au changement climatique, notamment du taux de fertilisation du CO_2, de l'ampleur des coûts de transition et de l'adaptabilité des agriculteurs au changement climatique. Pour l'instant toutefois, une forte incertitude persiste au sujet de ces variables. Les recherches en cours devraient permettre d'atténuer cette incertitude.

Sylviculture

Un chercheur a découvert que, avec un doublement du CO_2 atmosphérique, la récolte potentielle du Canada augmentera de 7,5 % dans l'ensemble. Pour les forêts du Canada atlantique, la productivité devrait s'accroître en moyenne de 15 à 16 %. Selon un autre article, les forêts du Québec devraient voir leur rendement annuel s'accroître d'entre 50 et 100 %. Pour calculer la valeur économique de rendements forestiers accrus, une étude présume trois scénarios qui donnent des changements de 5, 7,5 et 15 % avant de calculer les retombées socioéconomiques de ces changements pour le Canada. À ces trois hausses de rendement correspondent respectivement des hausses de 17, 25 et 50 millions de dollars par an dans la valeur annuelle des récoltes forestières dans le Canada atlantique.

Pêches

Dans une optique socioéconomique, il est clair que le secteur des pêches, notamment la pêche récréative et la pêche commerciale, ne sera pas épargné par ces effets, qui seront sans doute significatifs. Il est toutefois impossible pour l'instant d'en déterminer l'ampleur. Compte tenu de l'importance des pêches pour l'économie du Canada atlantique, le fort niveau d'incertitude qui entoure les effets possibles du changement climatique sur les pêches donne matière à préoccupation. Il est manifeste que d'autres recherches s'imposent dans ce domaine.

Transports

Même si le secteur des transports dans la région de l'Atlantique n'est pas souvent considéré comme vulnérable au changement climatique, il risque néanmoins d'être sérieusement touché. Les éléments du transport maritime qui risquent d'être touchés par le changement climatique, et en particulier par le nombre de jours sans glace, sont la Garde côtière qui doit engager chaque année d'importantes dépenses de déglaçage (22 millions de dollars en 1986 [dollars de 1996]), les services de traversier, les ports et havres et la navigation. Selon une récente étude sur les transports dans les Territoires du Nord-Ouest, toute variation dans le nombre de jours sans glace aura des retombées économiques mesurables. On a en effet établi qu'une augmentation du nombre de jours sans glace entraînera une diminution des charges d'exploitation des transports maritimes de même qu'un rallongement de la saison de navigation. Compte tenu de l'importance des services de traversier et de la navigation maritime dans la région de l'Atlantique, toute modification du nombre de jours sans glace aura sans doute des retombées socioéconomiques. Toute baisse du nombre de jours sans glace sera bénéfique pour la région.

Énergie extracôtière

L'exploration et le développement des gisements de pétrole et de gaz extracôtiers risquent de subir des effets socioéconomiques advenant un changement dans le nombre de jours sans glace résultant du changement climatique. Selon une étude, l'immobilisation des activités d'exploration dans la région de l'Atlantique en raison des retards dus à la glace coûte environ 130 000 $ (dollars de 1996) par tranche de 24 heures. En 1984-1985, année de glaces extrêmes, les pertes se sont chiffrées à 52 millions de dollars. Tout changement dans le nombre de jours sans glace entraînera d'autres coûts d'exploitation et d'entretien.

Hydroélectricité

Le changement climatique risque d'entraver la capacité des services publics dans la région de l'Atlantique de produire de l'hydroélectricité en raison des changements au niveau des précipitations et, par voie de conséquence, du débit d'écoulement annuel. Si l'on se fonde par exemple sur les estimations du débit d'eau qu'il faut pour produire de l'hydroélectricité et de la valeur de l'hydro-électricité exportée par le Labrador vers les États-Unis, pour tout changement de ±10 % dans le coefficient d'écoulement annuel au Labrador, la valeur économique de l'hydroélectricité exportée varie de ±73 millions de dollars. On le voit donc, ce secteur est éminemment vulnérable au changement climatique dans la région de l'Atlantique.

Demande énergétique

Beaucoup pensent que les changements survenant dans la température moyenne annuelle entraînent des changements dans les besoins de chauffage et de climatisation des espaces vitaux. Pour calculer la sensibilité de la demande énergétique aux changements de température, on se sert souvent du rapport entre la température, le nombre de degrés-jours et la valeur d'un degré-jour en termes de besoins énergétiques. Il devient ainsi possible d'estimer les changements de la demande énergétique et, par conséquent, leur valeur économique pour la région de l'Atlantique. Une analyse préliminaire nous révèle que, pour tout changement de 1 C dans la température moyenne annuelle, la demande énergétique varie pour sa part de 46 millions de dollars par an.

Élévation du niveau de la mer

Deux types de coûts se rattachent à l'élévation du niveau de la mer : a) les coûts d'immobilisation des ouvrages de protection; b) les coûts annuels renouvelables des services terrestres dont on sera privé. Pour contrecarrer l'élévation du niveau de la mer, il faudra sans doute construire des ouvrages d'endiguement pour protéger les biens-fonds et les propriétés de valeur, comme les villes et les ports, tandis que d'autres terres de moindre valeur comme les zones humides côtières ne seront pas protégées. Une étude réalisée à Charlottetown (Î.-P.-É.) prétend qu'une élévation d'un mètre du niveau de la mer aura d'importantes conséquences sociales et économiques et menacera le front de mer de la ville qui se compose de plus de 250 édifices, rues, systèmes d'égout et parcs.

Compte tenu du nombre de documents sur les dégâts que causera une élévation du niveau de la mer, il est possible de faire des estimations préliminaires pour le Canada atlantique. Par exemple, les dépenses défensives annuelles se rattachant à l'élévation du niveau de la mer ont été estimées pour le Canada à environ 0,03 % du PIB. Si l'on applique ce pourcentage au PIB du Canada atlantique en 1996, on obtient des dégâts se chiffrant à environ 117 millions de dollars. Cela exclut les dégâts comme les pertes d'habitat, les infiltrations de sel dans la nappe phréatique et les pertes de revenu résultant de l'inondation des terres sèches. Trois études estiment que l'élévation du niveau de la mer représente entre 11 et 20 % de l'ensemble des incidences du changement climatique sur les États-Unis qu'elles estiment à entre 0,012 % et 0,02 % du PIB. Si l'on applique cette fourchette au PIB du Canada atlantique en 1995, on obtient des estimations des dégâts totaux causés par l'élévation du niveau de la mer se chiffrant entre 49 et 86 millions $ (dollars de 1996).

Une analyse d'un certain nombre d'études révèle la disparition de la moitié des zones humides advenant une élévation d'un mètre du niveau de la mer résultant d'un doublement du CO_2 atmosphérique. Dans les provinces Maritimes, la superficie totale occupée par les zones humides est de 3 600 km^2. La majeure partie de la documentation existante estime la valeur des zones humides à 5 millions de dollars US le kilomètre carré, ce qui est extrêmement élevé pour le Canada atlantique. Selon un rapport, la valeur des zones humides du Canada atlantique se situe à 21 000 $ le kilomètre carré (ajustée en dollars de 1996). Si l'on se fonde sur cette estimation, on peut estimer que les dégâts causés par le changement climatique aux zones humides se chiffreront à 77 millions de dollars par an dans les provinces Maritimes.

Phénomènes extrêmes

Les incidences économiques des phénomènes extrêmes peuvent être directes ou indirectes. Les effets directs concernent le capital humain, le capital naturel et le capital artificiel. Comme exemples de conséquences directes, mentionnons les morts (capital humain), les pertes de peuplements forestiers sur pied (capital naturel) et les dégâts causés aux édifices (capital artificiel). Les conséquences indirectes désignent une modification de l'écoulement des produits et des services dans une économie résultant d'un phénomène extrême. Mentionnons les pertes de revenu et d'emploi attribuables aux perturbations commerciales durant et juste après le phénomène. Il y aura néanmoins des gains de revenu et d'emploi qui résulteront des interventions d'urgence et des dépenses engagées pour réparer les dégâts causés par la tempête.

À ce jour, aucune étude détaillée n'a été faite sur les coûts se rattachant aux phénomènes extrêmes dans la région de l'Atlantique, même si le Bureau d'assurance du Canada a calculé la valeur et le nombre de demandes de règlement résultant des dégâts matériels importants attribuables aux dangers atmosphériques au Canada. Durant la période allant de juillet 1987 à 1995, par exemple, on a recensé 43 « catastrophes naturelles » qui se sont soldées par des paiements multiples d'importance majeure. Vingt et un pour cent des tempêtes sont survenues entre septembre et mars. La valeur moyenne des demandes de règlement dont le nombre atteint 3 300 est estimée à 12 millions de dollars. Sur les 43 phénomènes, deux étaient propres à la région de l'Atlantique : les grands vents qui ont soufflé en octobre 1992 sur Avalon (Terre-Neuve) ont causé pour 8,2 millions de dollars de dégâts et entraîné 4 100 demandes de règlement; et la tempête de l'été 1995 (Hortense) en Nouvelle-Écosse a donné lieu à 1 200 demandes de règlement et à 3 millions de dollars de versements.

Résumé des effets socioéconomiques

Si l'on se fonde sur les prévisions de la documentation existant sur l'ampleur des incidences socioéconomiques, les dégâts annuels subis par les pays et les régions développés pourraient se situer entre 1 et 1,5 % du PIB de 1995 du Canada atlantique, soit entre 417 et 625 millions de dollars par an (dollars de 1996). Compte tenu de la grande importance des industries du secteur primaire dans la région de l'Atlantique, il y a de fortes chances pour que les dégâts se situent à l'extrémité supérieure de cette fourchette.

5. ADAPTATION

5.1 Généralités

Les recherches permettront selon toute vraisemblance de peaufiner les estimations des effets du climat causés par l'augmentation des concentrations de gaz à effet de serre, même si des prévisions fiables sur les changements climatiques à l'échelle régionale ne sont pas pour demain. De plus, advenant que d'importantes réductions des émissions de gaz à effet de serre aient lieu dès aujourd'hui, il pourrait toujours y avoir des changements dans les moyennes et la variabilité climatiques en raison de l'inertie de l'ensemble océans – masses terrestres – atmosphère. C'est pourquoi il semble prudent de penser qu'il faudra adapter au cours des prochaines décennies la gestion et l'utilisation des ressources naturelles et artificielles comme les forêts, l'agriculture et les ouvrages côtiers face à l'incertitude climatique qui prévaut.

Même s'il faut concevoir des modèles climatiques offrant une meilleure résolution régionale, la vulnérabilité des écosystèmes aux changements climatiques et l'étude de mesures d'adaptation doivent constituer des priorités pour L'Étude pan-canadienne dans le Canada atlantique. À l'occasion du symposium *Les répercussions scientifiques et politiques des problèmes atmosphériques dans le Canada* *atlantique* qui a eu lieu à Halifax (Nouvelle-Écosse) en décembre 1995, voici la réponse qui a été donnée à la question : « Quels sont les paramètres du changement climatique qui revêtent le plus d'importance pour la région de l'Atlantique? » :

> **En dépit de l'incertitude des projections du changement climatique dans la région de l'Atlantique, il est important de pouvoir estimer la sensibilité des ressources du Canada atlantique aux changements climatiques dans l'un ou l'autre sens. Ces ressources englobent l'agriculture, les forêts, la faune, les pêches, les infrastructures côtières, les transports, le tourisme et la population humaine.**

À la question : « De quelles activités a-t-on besoin pour évaluer la sensibilité de la région de l'Atlantique au changement climatique? », le symposium de 1995 a apporté la réponse suivante :

> **La création d'un groupe interdisciplinaire et multisectoriel (secteur public, secteur privé, milieu universitaire) chargé d'élaborer une matrice de la sensibilité des divers éléments de l'environnement de la région de l'Atlantique au changement climatique. Un des éléments de la matrice sera constitué par les ressources (en utilisant des indicateurs comme la disponibilité d'eau douce ou la biodiversité forestière); l'autre sera constitué par les variables climatiques comme la température, les précipitations, la fréquence d'élévation du niveau de la mer ou les soulèvements de tempête. Une telle activité s'appuiera sur les données existantes, les études des écosystèmes et les résultats des modélisations.**

L'adaptation sera la réponse la plus appropriée dans les secteurs qui se caractérisent par un fort volume d'activité humaine ou de gros investissements dans les infrastructures humaines comme la pêche (y compris l'aquaculture), la sylviculture, l'agriculture et les zones côtières qui sont les plus sensibles au changement climatique.

5.2 Pêches

Le rapport du Groupe de travail II au deuxième rapport d'évaluation du Groupe d'experts intergouvernemental sur le changement climatique (IPCC, 1996) propose des mesures d'adaptation pour l'industrie de la pêche, notamment pour l'aquaculture. En voici quelques exemples, légèrement modifiés pour pouvoir être appliqués à cette région, les deux premiers étant applicables quels que soient les changements futurs qui se produiront au niveau du climat :

- modifier et raffermir les politiques de gestion des pêches;
- favoriser la conservation des pêches et la sensibilisation des pêcheurs à l'environnement à l'échelle internationale;
- préserver et reconstituer les zones humides, les estuaires, les plaines d'inondation et les basses terres, qui sont des habitats essentiels pour la plupart des pêches;
- s'ajuster aux changements pouvant survenir dans l'abondance relative des espèces et la distribution des stocks de poissons;
- pour l'aquaculture, multiplier le nombre d'espèces et augmenter la superficie d'implantation de ces types d'exploitations.

5.3 Zone côtière

Les inquiétudes que suscite la zone côtière par rapport au changement climatique ont un rapport avec la plus grande variabilité des tempêtes, les changements dans la climatologie des vagues et l'élévation du niveau de la mer.

- Les réseaux de surveillance de l'environnement (qui accusent aujourd'hui un déclin rapide) tiennent lieu de base pour évaluer la vulnérabilité aux changements climatiques, en évaluant les impacts et en planifiant les mesures d'adaptation.
- Pour faire face à l'élévation du niveau de la mer global :
    - compte tenu de la faible densité de population et de la longueur du littoral, pour l'essentiel vierge, la stratégie préconisée pour s'adapter à l'élévation du niveau de la mer est de permettre le retrait de la ligne de côte et d'éviter ainsi des solutions techniques fort coûteuses;
    - dans certaines régions, comme Argentia, Terre-Neuve et certaines parties des marais de la baie de Fundy, la protection du littoral se justifie;
    - on pourrait élaborer une démarche pancanadienne pour gérer la zone côtière.
- L'érosion accrue et l'engloutissement des plages et d'autres ouvrages sont des conséquences graves de l'élévation du niveau de la mer.
- Pour ce qui est des inondations, par exemple de la baie de Fundy, il faut déterminer les risques de submersion des digues résultant de la coïncidence d'un soulèvement de tempête et d'une haute marée. Il faut tenir compte de l'étendue des inondations possibles et des infrastructures menacées.

5.4 Agriculture

- Le secteur agricole devrait en général relativement bien s'ajuster à tout changement climatique *graduel à long terme*, en profitant de l'amélioration des conditions tout en minimisant les incidences négatives d'un climat moins favorable. Toutefois, *la variabilité et les extrêmes climatiques* qui se produiront auront sans doute des effets plus marqués et seront plus difficiles à gérer pour les agriculteurs.

- Il y a des mesures à prendre pour atténuer les effets négatifs du changement climatique et profiter des améliorations climatiques qui surviennent. En voici quelques exemples:

    i) usage accru de l'irrigation et adoption généralisée de pratiques de gestion des sols et de rotation des cultures;
    ii) généralisation des pratiques de drainage et des méthodes de lutte contre l'érosion;
    iii) adoption généralisée de méthodes actives et passives de prévention du gel;
    iv) efficacité accrue des opérations de labourage, de plantation et de récolte;
    v) développement de nouvelles variétés de cultures.

5.5 Sylviculture

Un scénario probable pour cette région est un refroidissement des étés en raison du mouvement vers le sud des eaux de fonte de l'Arctique et un réchauffement des hivers dû à l'effet de serre. On peut s'attendre à d'importantes fluctuations saisonnières (gels tardifs ou dégels prolongés) et à une augmentation des phénomènes météorologiques extrêmes (tempêtes tropicales et ouragans). Ce scénario risque de se solder par une augmentation du nombre de morts et des opérations de sauvetage et par une saturation de bois sur le marché. Cela appellera:

a) le remplacement inventif des produits non ligneux par des produits forestiers pour assurer l'emmagasinement du carbone;

b) le reboisement rapide par des essences et des génotypes mieux adaptés à la variabilité climatique (fluctuations saisonnières) pendant la période de transition à un climat plus chaud; telle est la conclusion des recherches menées par le Service canadien des forêts;

c) l'amélioration des pratiques forestières pour atténuer les impacts de la récolte, notamment des coupes sélectives ou partielles qui ouvrent le couvert forestier au vent et conception de méthodes appropriées pour protéger les plantations;

d) l'assouplissement, la réceptivité et la collaboration de l'industrie forestière pour réagir à tous les éléments des changements rapides en ce qui concerne les opérations de sauvetage, la production de biens et leur commercialisation;

e) une démarche de recherche stratégique pour choisir les essences et les provenances qui conviennent, ainsi que des techniques de gestion qui maximiseront la production et la biodiversité des écosystèmes forestiers, sans oublier l'emmagasinement du carbone dans un milieu qui se réchauffe tout en répondant aux objectifs nécessaires en matière d'habitats fauniques et de loisirs;

f) la gestion accrue des populations de chevreuils qui risquent d'augmenter en raison d'une diminution de l'épaisseur de la neige au sol et du dérangement des forêts et de menacer le reboisement et la biodiversité nécessaires au maintien de l'emmagasinement du carbone à long terme;

g) la surveillance intensive de l'état de santé des forêts pour donner rapidement l'alerte en cas de changement et en établir les rapports de cause à effet afin de les intégrer dans les modèles pour mieux prédire les changements futurs de la composition des essences forestières.

6. MANQUE DE DONNÉES

Les recherches futures doivent s'efforcer de remédier au manque de données pour nous permettre de mieux comprendre et d'atténuer les effets du changement climatique dans la région et de nous adapter aux effets inévitables. En outre, pour éviter les lacunes futures, il faut continuer d'utiliser les systèmes de surveillance et même les améliorer pour nous doter des registres environnementaux qui nous permettront d'observer les changements climatiques, de les anticiper et de nous y adapter. Même s'il importe dans la conjoncture économique actuelle de rendre les réseaux d'observation aussi efficaces que possible, il faut également laisser aux générations futures un patrimoine de données suffisant pour leur permettre de résoudre les problèmes qui revêtiront pour elles de l'importance. *Il est impossible de repasser un film s'il n'a pas encore été tourné!*

6.1 Surveillance, analyses et modélisation climatologiques

- Les chercheurs en climatologie doivent avoir accès à des ensembles de données à long terme, constamment mises à jour et recueillies sur une vaste échelle régionale ou mondiale.

- Le Réseau sur le changement climatique est disséminé et sur le déclin. Le nombre de stations a régulièrement baissé pour passer d'un record de 2 915 en 1991 à 2 483 en 1996. Il y a par ailleurs le problème de la pénurie de stations dans le Nord.

- À l'instar de la plupart des pays, le Canada manque essentiellement de systèmes d'observation en pleine mer. Il faut donc des mesures océaniques régulières, à long terme, systématiques et rentables qui présentent de l'intérêt pour les systèmes climatiques mondiaux et qui fassent l'objet d'un examen suivi.

- Les statistiques traditionnelles ne peuvent incorporer le chaos temporel-spatial inhérent aux ensembles de données climatiques, aux changements rapides à court terme ou aux phénomènes intermittents. Il faut donc envisager le recours à d'autres techniques comme les statistiques circulaires, la géométrie fractaire et la théorie du chaos.

- Il faut adopter une nouvelle démarche statistique pour la modélisation climatique. La brièveté du délai et des cycles que nous devons souvent étudier signifie que les statistiques traditionnelles sont rarement d'une grande utilité. On recommande donc d'utiliser la paléoclimatologie pour la rétrospection et la découverte des cycles à long terme.

- Nous avons besoin de modèles climatiques plus précis. Les modèles globaux s'améliorent mais il reste encore beaucoup de travail à accomplir. Le milieu océanographique commence à modéliser la plate-forme littorale mais, jusqu'ici, cela n'a été associé à aucune bonne mesure des mers profondes. Des modèles régionaux plus précis sont également nécessaires.

- Il faut également préciser certains phénomènes climatiques qui constituent des signaux environnementaux entre le rendement des cultures et les prises de poissons en Europe, dans le Canada atlantique et dans la mer Noire.

- Il est indispensable que nous conservions (ou améliorions) le réseau de bouées captives et que nous validions les plates-formes de forage extracôtières pour la surveillance à long terme des vents et des vagues.

- Les modèles de prévisions des vagues a posteriori (y compris certains aspects des vents) doivent encore être peaufinés par rapport aux phénomènes extrêmes; il se peut que les effets à méso-échelle revêtent de l'importance.

6.2 Phénomènes extrêmes

- Peu de recherches portant sur les répercussions d'un changement climatique ont été réalisées dans le Canada atlantique sur :

    - la fréquence ou l'intensité des phénomènes extrêmes;
    - les tempêtes en transition du statut de tempête tropicale à celui de tempête extra-tropicale;
    - la dynamique des phénomènes météorologiques significatifs l'été.

6.3 Pêches et plancton

- Les prévisions quantitatives des conséquences du changement climatique sur les ressources halieutiques du Canada atlantique nécessiteront de bons modèles atmosphériques et océaniques régionaux sur la réponse de l'océan au changement climatique, ainsi qu'une amélioration des connaissances sur l'historique des espèces sur lesquelles il faut faire des prévisions et une meilleure compréhension du rôle joué par l'environnement, les interactions entre espèces et la pêche pour déterminer la variabilité des taux de croissance, de reproduction et de distribution et l'abondance des stocks de poissons.

- Pour le secteur de l'aquaculture marine, le rôle du climat revêtira de plus en plus d'importance. Il sera de plus en plus utile de définir et de prédire la variabilité climatique locale et les valeurs critiques des conditions environnementales, vu qu'elles sont pour l'instant très mal définies.

- Pour comprendre l'impact des variations climatiques sur l'écosystème marin, il est essentiel de surveiller non seulement la biomasse, mais également la composition des espèces.

- Une solide connaissance des chaînes alimentaires dans l'océan est indispensable pour mieux comprendre l'efficacité du passage de la production primaire aux stocks de poissons.

6.4 Zone côtière

- Pour améliorer la prévision des impacts du changement climatique sur la zone côtière, il faudra mieux comprendre la façon dont le littoral réagit à une tempête à l'échelle du phénomène et à des échelles à plus long terme.

- Nous devons être mieux en mesure de prévoir les changements qui se produiront sur les côtes dominées par les vagues au siècle prochain, advenant une accélération de l'élévation du niveau de la mer.

- Il faut maintenir des limnimètres à long terme pour surveiller le rythme d'élévation relative du niveau de la mer, peut-être en association avec l'altimétrie satellitaire, la gravité absolue et d'autres techniques.

- Il faut également maintenir des instruments de mesure des vagues côtières à long terme pour analyser le climat des vagues, en dégager les tendances, améliorer la prévision des vagues et illustrer les vagues de tempête.

- Il faut réaliser un programme de photographies aériennes verticales, répétitives et à grande échelle pour observer les changements qui affectent le littoral.

- Il faut procéder à une analyse des données historiques pour en extraire des estimations fiables sur le retrait du littoral, l'élévation du niveau de la mer, la climatologie des soulèvements de tempête et le climat des vagues.

- Il faut poursuivre les relevés réguliers des sites représentatifs le long du littoral.

- Il faut resserrer les liens entre les équipes chargées de surveiller le littoral et les prévisionnistes des soulèvements de tempête qui ont accès à des mesures maritimes en temps réel. Les prévisionnistes peuvent fournir des alertes de tempête aux équipes de relevé qui pourront alors mesurer plus rapidement les changements le long du littoral, obtenir de meilleures observations après la tempête, lesquelles pourront servir à mieux préciser le rapport entre la hauteur des vagues, le niveau de l'eau et la réaction des plages.

- Il est indispensable que le réseau de bouées de mesure des vagues, surtout les bouées le long du littoral, soit maintenu et non pas abandonné.

6.5 Sciences des écosystèmes et ressources hydriques

Ressources hydriques

- La surveillance judicieuse des principaux éléments des mécanismes climatiques/hydrologiques à long terme est indispensable pour mieux comprendre ces phénomènes afin de pouvoir prendre des mesures de prévention ou d'adaptation pour en atténuer l'impact sur la société.

- Il faut se demander si l'effet prévu du changement climatique accentuera ou atténuera la tendance cyclique dans les eaux d'écoulement, combien de temps cela durera et quelles en sont les implications pour tout l'écosystème.

Embâcles

- Ni les modèles de circulation générale ni les sciences des glaces fluviales ne sont suffisamment avancés pour permettre d'identifier certains des changements auxquels on peut s'attendre dans le régime d'embâcles des rivières canadiennes dans le scénario d'un réchauffement de la planète.

- Il faut pouvoir expliquer le rapport entre l'englacement des rivières et les températures hivernales et les changements qui pourraient résulter d'un changement climatique.

Les zones humides dans le Canada atlantique

- Les recherches menées jusqu'ici incitent à croire que le niveau de l'eau dans les zones humides risque de changer de manière appréciable advenant un changement climatique, même si l'on n'a pas encore déterminé l'effet que cela aura sur la répartition des zones humides, question qui demeure une inconnue de taille lorsqu'on essaie de comprendre les répercussions du changement climatique.

Oiseaux migrateurs

- Dans les écosystèmes terrestres de l'Atlantique, on sait peu de choses sur le rapport entre le climat et le moment de la reproduction.

- Les phénomènes extrêmes comme les vagues de froid et les tempêtes estivales peuvent avoir des conséquences très néfastes sur les oiseaux. Il faut donc prêter davantage attention à leurs effets possibles.

Généralités

- Les estimations des précipitations à des échelles géographiques et temporelles plus fines sont nécessaires pour prévoir les effets du changement climatique sur la biodiversité en général, notamment sur les oiseaux.

- Il faut continuer à exploiter les relevés climatiques indirects archivés dans les sédiments terrestres et marins de la région de l'Atlantique afin d'étudier la réponse des écosystèmes au changement climatique.

- On constate une pénurie de recherches sur les deux tiers de la région les plus au nord qui risquent le plus d'être touchés par le changement climatique.

6.6 Agriculture

- Tout progrès que l'on fera dans l'estimation et l'atténuation des effets négatifs de la variabilité et des extrêmes climatiques devrait aider l'industrie à faire face aux changements climatiques qui risquent de se produire à long terme.

6.7 Sylviculture

- Peu de recherches ont été faites et beaucoup d'incertitude persiste sur les effets multiples des facteurs climatiques et d'autres stress comme la pollution atmosphérique, c'est-à-dire SO_2, NH_4, NO_x et O_3, sans oublier le dépôt des substances acidifiantes et des métaux lourds qui se trouvent dans l'atmosphère.

- Les effets à long terme des migrations de population (avec la coupe et la récolte des forêts qui s'y rattachent) imputables à l'accroissement des terres arables et au développement industriel sont toujours incertains. Ces effets seront aggravés par les mouvements de population attribuables à l'élévation du niveau de la mer.

- On prévoit que les forêts de l'Atlantique absorberont plus de dioxyde de carbone atmosphérique. Toutes les prévisions de l'activité source-puits sont auréolées d'une grande incertitude, et les disparités régionales des réactions prévues militent fortement pour une baisse de cette incertitude à l'échelle régionale.

- Il existe une grande incertitude globale sur la façon dont les processus qui entrent dans la production forestière primaire dans le Canada atlantique réagiront à l'augmentation des concentrations de CO_2 dans l'atmosphère, à l'élévation des températures, à la modification du régime des précipitations et aux rythmes incertains de dépôt de l'azote. Il existe également une certaine incertitude sur l'augmentation ou la baisse de l'emmagasinement du carbone dans les sols au fur et à mesure des changements climatiques et sur la quantité d'azote qui sera assimilable par les racines.

6.8 Paramètres socioéconomiques du changement climatique

- La documentation existante manque de données sur le changement climatique et ses retombées socio-économiques dans le Canada atlantique en particulier. Pour l'essentiel, les recherches régionales menées récemment se concentrent sur les réactions physiques face au changement climatique. Même si cela permet de bien comprendre les secteurs économiques menacés par le changement climatique, il n'existe aucune étude socioéconomique préliminaire consacrée en propre au Canada atlantique. Cette pénurie de données à l'échelon régional ne devrait toutefois pas empêcher les études socioéconomiques préliminaires.

1.0 Regional Context

This chapter describes the physiography, historical settlement patterns, culture and socio-economic state of Atlantic Canada.

1.1 *Physiography*

Peter B. Eaton, Alan G. Gray, Peter W. Johnson and Eric Hundert
(1994) *State of the Environment in the Atlantic Region, pp 1-2*
Minister of Supply and Services

The Atlantic Region contains a wide diversity of terrestrial, freshwater and marine environments, that are the habitats for a broad variety of wildlife, and support the human activities of 2.3 million people. The Maritime Provinces fall within the Atlantic Maritime ecozone, while Newfoundland is part of the Boreal Shield ecozone. Labrador touches on 4 ecozones: Taiga Shield, Southern Arctic, Arctic Cordillera and Boreal Shield. The nature of the Region - its biota, climate and patterns of human settlement and activities - is strongly influenced by its marine associations and the characteristics of these ecozones.

Water

The Maritime Provinces have more than 25,000 inland surface water bodies. Labrador and insular Newfoundland have an estimated 135,000 each. This large number of small surface water bodies is an advantage for wildlife habitat. The largest freshwater river system in the Region is the Churchill in Labrador, followed by the Saint John and the Miramichi in N.B., and the Exploits River in Nfld. Precipitation and runoff are highly variable from season to season and year to year, ranging from 400 mm to over 1,400 mm of precipitation per year. Lakes and rivers in zones of igneous geology often also drain large expanses of bogs and fens and thus receive high loads of dissolved organic matter. Nearly 1.2 million people in the Region rely entirely on groundwater for their domestic water needs.

The Region has about 40,000 km of coastline, the estuaries and coastal zones of which provide habitat for large populations of a wide variety of seabirds, shorebirds, marine mammals, and commercially important finfish and shellfish. Many of the Region's settlements are on or near the coast, as we depend on the coastal waters for transportation, food, and recreation. In physical terms, the coastal zone varies from tidal mudflats to sand beaches to rocky shoreline.

Our most extensive salt marshes are found in the estuaries of the upper Bay of Fundy. Other areas include the southwest coast of N.S., and the Hillsborough River and Bay on P.E.I. These, and other smaller salt marshes, are important nursery areas for a number of species of fish, and provide habitat for a wide variety of wildlife. An estimated 65% of Maritime saltmarsh remains dyked for farming.

Land

Forty-one percent of the land of the Region is forested land. This figure falls to 31% of the total if only the 16.7 million ha of productive forestland is considered. There are four forest regions: Acadian, Boreal (Predominantly Forest), Boreal (Forest and Barren), and Great Lakes - St. Lawrence. Damage and mortality from insects, disease and fire are inherent to the forests of the Region.

Bogs, marshes, swamps, fens and peatlands cover 17% of the land surface of Newfoundland-Labrador, and 1-8% of the landscape of the Maritime provinces. These wetlands provide a variety of ecological functions (habitat, hydrologic and biogeochemical), and produce a variety of wildlife useful to humans (fur-bearing animals and ducks). They also offer unique education and research opportunities.

The Region's relatively short cool growing season and relative lack of good quality soils inhibits farming in many locations. While the Region lacks Class 1 agricultural land, there is a reserve of arable land. The most important agricultural areas are the Annapolis Valley (fruit orchards), P.E.I. (potato and grain productions and northwestern New Brunswick (potatoes). There is limited agricultural production in Newfoundland/Labrador.

Wildlife

Some 60 species of mammals, 171 birds, 13 reptiles, 14 amphibians and 55 fishes frequent the terrestrial, freshwater and marine habitats in the Region. Marine mammals include polar bears, seals and a variety of whales, dolphins and porpoises. Terrestrial animals range in size from the moose to the shrew. The largest herd of caribou in the world ranges over part of Labrador. The Region's extensive coastal areas provide habitat for a wide variety of seabirds and coastal birds, both breeding and non-breeding. Important areas are the coastal waters of Newfoundland and Labrador, and the mudflats of the upper Bay of Fundy (particularly for migratory shorebirds). The marine fish of the Region include the anadromous Atlantic salmon, and several species of commercially important finfish, e.g., cod, haddock and pollock. Wildlife related expenditures in the Region are estimated at $393 million annually.

Special Places and Species

Despite earlier extinction of species, and slow and inadequate moves to preserve special habitat and recreational land, Atlantic Canada is endowed with a wide variety of special places and species.

The Great Auk, Labrador Duck, Passenger Pigeon and Sea Mink are now extinct. The timber wolf, walrus, grey whale and wolverine have been eliminated from most or all of the region. On a national basis, there are 16 endangered species, 6 threatened species, and 14 vulnerable species of birds, plants, mammals and fish found in the Region. In addition, a number of other species are under threat on a provincial basis. Human-induced alterations or destruction of habitat are the principal stresses on these species.

The figure of 12% has been proposed internationally as a measure of the amount of land that should be protected from human disturbance. Protecting representative areas is equally important, however. The amount of protected land in the Region only amounts to 3% of the total, in spite of a wide variety of federal, provincial and private initiatives. Moreover, not all the protected land is fully protected; the total includes provincial wilderness reserves in which hunting and logging are allowed.

1.2 *Historical/Cultural Setting*

Peter B. Eaton, Alan G. Gray, Peter W. Johnson and Eric Hundert
(1994) *State of the Environment in the Atlantic Region, pp 25-26*
Minister of Supply and Services

The population of the four Atlantic provinces, 2.3 million people (1991 census), accounts for only about 9% of Canada's total population. Nova Scotia has the highest population with 899,942; New Brunswick is next with 723,900; Newfoundland with 568,474 and Prince Edward Island has the smallest population with 129,765.

Population growth in the Atlantic Provinces since the middle 1800s has been slow but steady, increasing only four times to the ten times increase in the population of Canada. During the past two decades, from 1971 to 1986, there was an increase of 0.2 million, or about 10%. This is an increase of only 0.7% per year, somewhat lower than the Canadian average. This difference in growth can be attributed, among other things, to rapid growth in the more diversified economy of central Canada.

Settlement patterns in Atlantic Canada originally reflected the transportation modes available. Most towns and cities were located on rivers or in coastal areas, or at railway junctions where goods were transferred such as Truro and Moncton. All provincial capitals, for example, have access to the ocean. These are included in the following list of the metropolitan areas (1991 census): Halifax - Dartmouth, population, 253,704; Sydney, 32,100; Charlottetown, 33,153; Summerside, 10,988; St. John's, 121,029; Corner Brook, 22,047; Saint John, 90,457; Moncton, 80,744; and Fredericton, 45,364.

Urban growth has been the largest type of growth in Canada, but in this Region, although it is still significant, increases in the numbers of people living in rural non-farming areas is just as important. The proportion of the farming population, however, has diminished greatly over the past 40 years in all four Atlantic Provinces. In fact, the highest rate of rural land conversion in Canada, 979 ha/1,000 population increase (conversion of rural farmland to other uses such as forest, urban, wetland or other non-farming use), occurred in New Brunswick between 1981 and 1986; Newfoundland was third (86 ha/1,000), Nova Scotia was fifth (81 ha/1,000), but P.E.I. had the lowest rate of conversion in Canada (13 ha/1,000) (Environment Canada 1989).

1.3 *Socio-Economic Overview*

Dave Sawyer
EnviroEconomics
Halifax, Nova Scotia

This paper presents an overview of the Atlantic Canadian economy. General economic indicators are presented including employment and Gross Domestic Product (GDP) by industry and province. Comparisons are also regularly made to the Canadian economy.

The Economy

Some Basic Indicators

In Table 2 - 1, a number of indicators of the Atlantic Canadian economy are presented. As can be seen, unemployment in Newfoundland and PEI are well above the national average. Employment in Nova Scotia and New Brunswick, while above the national average, are only slightly greater. GDP per capita in 1995 was well below the national average for all provinces in Atlantic Canada.

Table 2 - 1

Socio-Economic Indicators, 1995

	Newfoundland	PEI	Nova Scotia	New Brunswick	Canada
Population	575,000	136,000	938,000	760,000	29,606,000
Labour Force	242,000	69,000	437,000	354,000	14,928,000
Unemployment Rate	18.3%	14.9%	12.1%	11.5%	9.5%
GDP/Capita	$17,318	$19,051	$20,000	$20,833	$26,347
% of Canada	65.73%	72.31%	75.91%	79.07%	

Source: Statistics Canada. Provincial Economic Accounts.

Regional Income

The Atlantic Canadian economy can be characterized as diverse, with a heavy reliance on primary and related industries, such as fishing and fish processing. An overview of GDP by province and industry is presented in Table 2 - 3 and the proportion of total GDP from primary industries is presented in Table 2 -

2. As can be seen, the primary industries as a proportion of the total economy are greater in Atlantic Canada (Table 2 - 2) than the Canadian average.

Table 2 - 2

GDP of Primary Industries as a Proportion of Total Economy, 1995

	Agriculture	Fishing	Forestry	Total Primary Industries
Newfoundland	0.35%	1.19%	0.81%	2.34%
PEI	9.20%	2.04%	0.39%	11.62%
Nova Scotia	1.18%	1.59%	0.77%	3.53%
New Brunswick	1.21%	1.00%	1.78%	3.99%
Canada	2.11%	0.15%	0.54%	2.8%

Source: Statistics Canada - Cat. No. 15-203-XPB

The manufacturing sector is 5-12% below the national average as a proportion of the total economy (Table 2 - 3) with the manufacturing industries related to the primary sector contributing greatly. For example in Nova Scotia, the two largest manufacturing industries in 1992 were fish processing, which accounted for 17% of the value of all manufacturing sector shipments, and other food products, which accounted for 15%.[1] In Newfoundland, even with the moratorium on groundfish, GDP for the fish processing sector accounted for approximately 35% of manufacturing GDP.

Table 2 - 3

GDP by Industries and Province, 1995. Constant 1986 Dollars

Sector	Newfoundland	PEI	Nova Scotia	New Brunswick	Canada
Goods Producing Industries	**26.17%**	**30.62%**	**25.18%**	**31.04%**	**34.26%**
Agriculture	0.35%	9.20%	1.18%	1.21%	2.11%
Fishing and Trapping	1.19%	2.04%	1.59%	1.00%	0.15%
Logging	0.81%	0.39%	0.77%	1.78%	0.54%
Mining	4.35%	0.00%	1.62%	1.78%	4.36%
Manufacturing	6.95%	8.70%	11.92%	14.02%	18.87%
Construction	7.49%	7.21%	5.62%	6.65%	5.13%
Transport and Utilities	5.65%	3.08%	2.48%	4.62%	7.48%
Service Industries	**73.83%**	**69.38%**	**74.82%**	**68.96%**	**65.74%**
Total Economy (millions $)	$6,579	$1,816	$13,184	$10,638	$542,534
% Total Canadian Economy	1.21%	0.33%	2.43%	1.96%	

Source: Statistics Canada Cat. No. 15-203-XPB

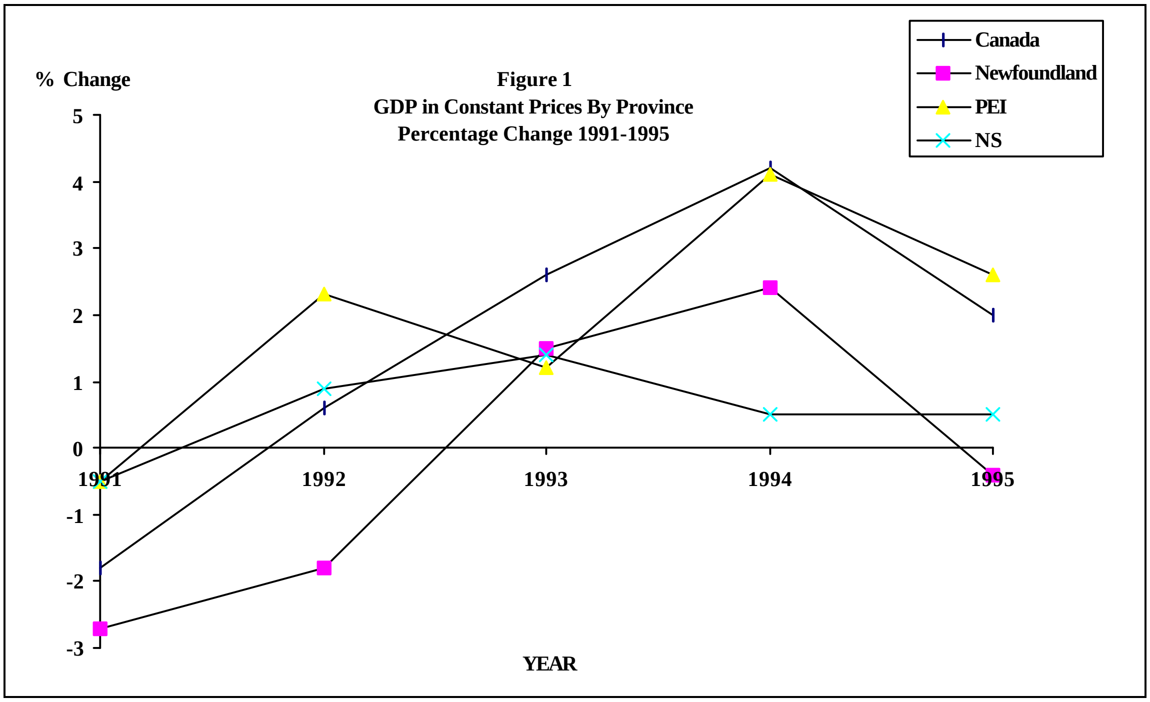
GDP Change Over Time

In Figure 1, the yearly percentage change in GDP is presented for the Atlantic economy. Much of the variation in the yearly GDP can be explained due to changes in individual industries. In Newfoundland, for example, GDP losses in the fishery due to the groundfish moratorium were offset by increases in

[1] Nova Scotia Department of Finance. *Nova Scotia Statistical Review 1996*. Halifax, NS.

construction in 1993 and 1994 owing to Hibernia. The result was positive economic growth despite the losses in fishing and related activities. Construction sector increases continued though 1994, but fell in 1995 as Hibernia construction slowed. Coupled with decreases in government spending in 1995 and low fish catches relative to the past, the GDP growth decreased in 1995 relative to 1994.

In PEI, a good potato harvest in 1992 resulted in substantial positive GDP growth (Agricultural GDP grew 26% relative to 1991). A sharp increase in construction activity in 1994, due to the fixed link project, likely offset an average agricultural performance in 1994 to result in a sharp percentage change in GDP versus 1993. Decreasing construction GDP was offset in 1995 by a very good potato year. The net result was strong economic growth in that year. As we can see, the performance of individual sectors, such as fishing and agriculture, in Atlantic Canada does impact overall economic performance.



Source: Statistics Canada Cat. No. 15-203-XPB

Employment

As with GDP, primary and related industries account for a large proportion of employment in Atlantic Canada (Table 2 - 4). Relative to Canada, the proportion of employment in resource dependent industries relative to all industries ranges between 3% (Nova Scotia) and 14% (PEI) above the national average.

Fish processing accounts for a large proportion of employment. In Nova Scotia, fish processing was the largest employer in manufacturing industries in 1995. In Newfoundland, fishing and fish processing account for a significant level of total employment.

Table 2 - 4 Employment in Resource Dependent Industries as a Proportion of All Industries, 1991				
	Agriculture and Food Products	Fishing and Fish Products	Forest and Forest Products	Total Resource Dependent Industries
Newfoundland	1.5%	12.3%	2.7%	16.5%
PEI	10.4%	9.8%	0.9%	21.1%
Nova Scotia	3.2%	4.8%	2.2%	10.2%
New Brunswick	3.9%	3.8%	5.2%	12.9%
Canada	**4.5%**	**0.7%**	**2.0%**	**7.2%**

Source: Statistics Canada - Cat. No. 11-509E

In Table 2 - 5, employment by province and industry is presented. Employment in Atlantic Canada in 1995 was 7% of the total employment in Canada. High employment in transportation industries in Atlantic Canada can be explained by the need to haul primary industry outputs to markets and to processing facilities. Employment in manufacturing industries is below the national average for all provinces.

Table 2 - 5 Employment by Industry and Province, 1995.					
	Newfoundland	PEI	Nova Scotia	New Brunswick	Canada
Goods Producing Industries	**22.3%**	**29.0%**	**22.9%**	**25.8%**	**27.0%**
Agriculture	1.1%	6.6%	2.2%	2.2%	3.2%
Fishing and Trapping	4.7%	4.1%	1.7%	1.2%	0.2%
Logging	1.2%	0.0%	0.8%	1.3%	0.7%
Mining	3.0%	0.0%	1.0%	1.3%	1.3%
Manufacturing	6.6%	8.5%	11.2%	12.8%	15.3%
Construction	5.6%	6.8%	4.9%	5.4%	5.4%
Transportation and Utilities	9.1%	6.8%	7.8%	8.6%	7.6%
Service Industries	39.0%	35.8%	37.7%	37.3%	37.3%
Total Employment (thousands)	197.3	58.37	384.3	313.6	13,506
% Total Canadian Employment	1.46%	0.43%	2.85%	2.32%	

Source: Statistics Canada Cat. No. 15-203-XPB

Income Distribution
During 1990 in Canada, 60% of the population received less than $35,000 of income while in Atlantic Canada, 60% of the population received incomes of less than $20,000. This difference implies that the disparity between rich and poor in Atlantic Canada is greater than the difference in Canada.[2]

GDP per capita (GDP divided by the provincial population) for the Atlantic provinces remains consistently below the national average. In 1991, as a proportion of national GDP per capita, Newfoundland was 67%, PEI was 66%, Nova Scotia was 80%, and New Brunswick was 76%. A variety

[2] ACOA. 1994. *Atlantic Canada: Facing the Challenge*. DRI/McGraw-Hill

of alternative income per capita measures, reported over the years 1971-1989, highlight a similar disparity between incomes in Atlantic Canada and Canada.[3] It can be concluded that incomes in Atlantic Canada remain below the Canadian average.

Distribution of Economic Activity by Sub-Provincial Region

In Table 2 - 6, labour force by industry is used to highlight comparisons of the regional structure of industry compared with the Canadian average. An index is used where the labour force for each industry in each sub-region, as reported in the 1991 census, is compared with the Canadian average. If the index for the industry is below one, then, on average, there is less activity for that industry in that region compared with the Canadian average. Conversely, a number greater than one would indicate a higher proportional level of activity relative to Canada.

Table 2 - 6

Industry Structure by Sub-Provincial Region, 1991
(National Average = 1)

	Primary	Manufacturing	Construction	Transportation	Government Service	% Population
Newfoundland						
Avalon Peninsula	0.59	0.70	1.10	0.93	1.77	10.8
South Coast	1.70	1.59	0.86	1.35	1.46	2.4
North Peninsula -Labrador	1.23	0.08	0.24	0.23	0.73	5.5
Notre Dame	1.86	1.11	1.19	1.13	0.99	6.0
PEI	**2.42**	**0.71**	**1.00**	**1.15**	**1.54**	**5.6**
Nova Scotia						
Annapolis Valley	1.56	0.81	1.26	1.87	1.66	5.0
North Shore	1.59	1.12	1.08	1.60	0.94	7.0
Cape Breton	1.66	0.70	0.98	2.17	1.07	7.1
South Shore	2.01	1.48	0.76	1.23	0.92	5.6
Halifax	0.25	0.46	0.88	2.07	2.09	13.8
New Brunswick						
Moncton	0.59	0.65	0.98	1.90	1.20	7.4
Edmunston	1.93	1.31	0.97	1.33	0.82	3.7
Chaleur - Miramichi	1.86	1.09	1.23	0.81	1.11	7.8
Saint John	0.61	1.06	1.00	1.06	0.95	7.3
Fredericton	0.81	0.41	0.97	0.80	2.70	5.0

Source: Statistics Canada 1991 Census and EnviroEconomics.

Based on the information in the table, a number of conclusions can be made. First, it is clear that the Atlantic Canadian economy is heavily reliant on primary industries. Sub-regions, with the exception of those containing major cities, are dominated by primary industries. Other related industries such as transportation are also high relative to the national average.

[3] Bradfield, M., 1988. *Regional Economics: Analysis and Policies in Canada*. McGraw-Hill Ryerson, Toronto, and ACOA 1994.

Secondly, sub regions within provincial economies vary considerably in structure. In Nova Scotia for example, the index of industry structure for primary industries ranges between 0.25 for Halifax, and 2.01 for the South Shore. This disparity between urban and rural regions within Atlantic Canada is consistent.

Conclusion

Based on the information presented in the above sections, four conclusions can be made about the Atlantic Canadian economy:

- the industrial structure of the economy is greatly varied between provinces and sub-regions with primary industries dominating the non-urban areas;
- the performance of individual industries can impact provincial economies in the Atlantic region, especially the primary sectors;
- income and employment disparities exist amongst regions in Atlantic Canada and relative to the Canadian average; and,
- the economy of Atlantic Canada is diversified, however the primary sectors and related industries account for a high proportion of economic activity, relative to the Canadian average.

The climate change literature identifies primary resource based economies as being most susceptible to impact from climate change and variability. Given the above noted composition of the Atlantic Canadian economy, the region is likely more sensitive to climate change than other parts of Canada.

2.0 Climate of Atlantic Canada

A general description of the present climatology of Atlantic Canada is presented in this chapter followed by results of analyses of trends in the data. Brief comments are given on a few studies that have been completed on climate variability in the region.

2.1 *General Description*

Teresa Canavan
Atmospheric Science Division, Atmospheric Environment Branch, Environment Canada
1496 Bedford Highway, Bedford, Nova Scotia B4A 1E5

Global atmospheric circulation patterns, ocean currents and sea ice extent are major influences on the current climate of this region due to its location on the eastern edge of North America. Local topography and sea surface temperature contribute to differences in climate within the region.

Temperature and precipitation measurements are most frequently used to describe the climate of a location. Additional data including air pressure, wind velocity, humidity, sunshine and cloudiness give more complete information.

Descriptions of the climate of the Atlantic Region can be found in several publications and in a number of government documents plus a few detailed investigations of particular topics are available for this region.

LARGE SCALE INFLUENCES ON ATLANTIC CANADA’S CLIMATE

On a global scale, the Atlantic Region lies within the zone of prevailing westerly winds. This zone is characterized by the passage of a series of high and low pressure systems. Paths taken by these systems are further influenced by ocean currents and continental topography. In the northern hemisphere, areas of low pressure develop when cold dry air originating over Northern Canada drifts southeastward and encounters warm moist air moving poleward from the Caribbean Sea. These systems are more intense during the winter months when differences in air mass temperatures are greater. Analyses of previous storm tracks reveal that many of these systems affect the Atlantic Region. Significant temperature differences in air masses affecting the district explain the large annual temperature ranges recorded at observing sites. An abundant annual supply of precipitation can be attributed to these storms with additional contributions from tropical storms and local convective activity in some areas.

EFFECTS OF THE NEARBY ATLANTIC OCEAN

Sea ice gradually spreads southward along the coast of Labrador, eastern Newfoundland, the Gulf of St. Lawrence and Cabot Strait during the winter months while unfrozen waters to the south provide a heat source for Nova Scotia and southern New Brunswick. A discussion of the interannual variability of sea ice extent along the Labrador and Newfoundland coasts is given by Prinsenberg et al (1996).

As the ice retreats in the spring, sea surface temperatures gradually increase, particularly in the Gulf of St. Lawrence. An exception is the eastern extremity of the Gulf which is influenced by the cold Labrador Current. This current maintains cool sea surface temperatures along the eastern coasts of Labrador and Newfoundland and has some effect on waters to the south of Nova Scotia. Warmer waters of the Gulf Stream extend farther northward during the summer months modifying surface temperatures south of Nova Scotia. Coastal cooling is less pronounced in areas adjacent to warmer waters of the Gulf of St. Lawrence than elsewhere in the region during the summer. In addition to sea ice and ocean currents, high tides of the Bay of Fundy cause deeper water to be mixed with surface water maintaining relatively cool surface water temperatures in summer and warm temperatures in winter. (Dzikowski *et al*., 1984). Onshore winds produce a moderating effect on the climate of adjacent land areas throughout the year.

WORLD CLIMATE ZONES: CLASSIFYING THE ATLANTIC REGION

Daily temperature and precipitation measurements as well as other factors such as vegetation have been used to classify areas of the world into climatic zones. Strahler and Strahler [1994] describe Nova Scotia, Prince Edward Island and Southern New Brunswick as having a moist continental climate while Northern New Brunswick, Newfoundland and Labrador are classified within the boreal forest climate zone. The tundra climate covering much of Northern Canada includes the northerly tip of Labrador.

Because the world is represented by only 13 climate zones, these zones must ignore local discrepancies. Hence, further refinement of global classifications by analyses of regional data is required. For instance, an inland site for the Maritime Provinces (Fredericton, New Brunswick) was selected to represent a moist continental climate. Although Fredericton does display a large annual temperature range, its precipitation amounts are lower in summer than in winter, contrary to the definition given for this zone. Goose Airport, Labrador, selected to represent the boreal forest climate zone, displays most characteristics of this zone including a large annual temperature range, short summer, long cold winter and a peak in precipitation during the summer. However, its annual precipitation amount is ample unlike sites typical of this zone.

REGIONAL CLIMATE RECORDS

The most recent set of 30 year climate normals published by the Canadian government is for the period of 1961-90. Extreme values are given for the period of record for each station. Temperature and precipitation records are available for most observing sites. Records of air pressure, wind velocity, solar radiation, sunshine, cloudiness, fog, humidity, visibility and thunderstorms provide useful information for describing the climate more completely although these are available for fewer locations.

Temperature

During the winter season, warmest average temperatures are found in southwestern Nova Scotia and the Avalon Peninsula, Newfoundland with mean temperatures dipping a few degrees below freezing. Remaining areas of Newfoundland and Nova Scotia, plus Prince Edward Island and southern New Brunswick, are the next warmest followed by northern New Brunswick and southeastern Labrador. Labrador's northerly latitude contributes to its having the coldest temperatures in the region with means near minus 20°C inland.

Central New Brunswick has the highest temperatures during the summer months in the Atlantic Region with means near 20°C followed by the rest of the Maritimes and central Newfoundland. Newfoundland's south coast, Avalon Peninsula and Northern Peninsula are the next warmest areas followed by Labrador. Areas in central Labrador have daytime maximums higher than coastal Newfoundland but nighttime minimums are cooler.

Precipitation

Frequent low pressure systems combined with the ocean bring a generous supply of precipitation to the Atlantic Provinces. Southeast winds accompanying storms pick up moisture from the sea giving southern coasts of Newfoundland (over 1700 mm) and Nova Scotia, plus the Fundy shore of New Brunswick, the greatest amounts of annual precipitation. Northern Newfoundland, northern Nova Scotia, Prince Edward Island and much of New Brunswick receive lesser amounts (but still in excess of 1000 mm). Areas to the lee of higher terrain in northern New Brunswick and central Labrador receive greater amounts of precipitation during the summer months than in winter.

Although precipitation in the region is almost exclusively liquid throughout the summer months, rain, freezing rain and snow are common during the winter in southern areas. More rain than snow (i.e., water equivalent) occurs on average along the southern coasts of Newfoundland and Nova Scotia in the winter.

LITERATURE REVIEW

Descriptions of the climate of the Atlantic Region can be found in a few atlases and other books. Additional information is available in a number of workshop proceedings, government documents and occasionally in master's theses which usually focus on a particular location and topic. A bibliography follows listing information sources identified during a recent literature search.

A review of the Meteorological and Geoastrophysical Abstracts for 1990 to September 1996 revealed that only two articles focusing specifically on climatological studies within the Atlantic region were published in refereed journals included in this grouping. The number of publications increases however when the search is expanded to include topics such as agriculture, forestry and fisheries using climatological data. These topics are discussed in other sections of this report by specialists in these areas.

Workshop proceedings and government documents include a few studies using long-term data from specific sites in this region to determine trends. Results of such studies give some indication of actual changes occurring in the region and provide useful comparisons with sophisticated model predictions. Further study using additional long-term monitoring data could prove useful in answering many of the questions associated with the climate change issue in the Atlantic Region.

REFERENCES

Côté, P.W.
1989. *Ice Limits Eastern Canadian Seaboard*, Ice Centre, Ottawa, Environment Canada.

Dzikowski, P.A., G. Kirby, G. Read and W.G. Richards
1984. *The Climate for Agriculture in Atlantic Canada*. Atlantic Provinces Agricultural Services Coordinating Committee, Publication No. ACA 84-2-500. Agdex No. 070, 52 pp.

Eaton, P., A. Gray, P. Johnson and E. Hundert
1994. *State of the Environment in the Atlantic Region*, Minister of Supply and Services.

Environment Canada
1993. *Canadian Climate Normals 1961-90, Atlantic Provinces*, Minister of Supply and Services Canada.

Phillips, D.
1990. *The Climates of Canada*, Minister of Supply and Services Canada.

Prinsenberg, S.J., I.K. Peterson and A. van der Baaren
1996. Interaction between Atmosphere and Ice Cover off Labrador and Newfoundland from 1962 to 1994. Workshop Proceedings. Environment Canada - Atlantic Region, Occasional Report No. 9, pp. 195-199.

Robertson, A., S. Porter and G. Brodie [Editors]
1993. *Climate and Weather of Newfoundland and Labrador*, Creative Publishers, Robinson-Blackmore Printing & Publishing Ltd., St. John's, Newfoundland.

Strahler, A. and A. Strahler
1994. *Introducing Physical Geography*, John Wiley & Sons, Inc.

Bibliography

National Reports/Publications (referencing Atlantic Canada)

1. Boughner, C.C. and M.K. Thomas (1959). *The Climate of Canada.* Canada Year Book, Ottawa.

2. Brown, R.D. and B. Goddison (1996). *Interannual Variability in Reconstructed Canadian Snow Cover, 1915-1992.* Journal of Climate, Vol. 9, No. 6, pp 1299-1318.

3. Cember, R.P. and D.S. Wilks (1993). *Climatological Atlas of Snowfall and Snow Depth for the Northeastern United States and Southeastern Canada.* Northeast Regional Climate Centre Research Series, No. 93-1, Cornell University, Ithaca, N.Y.

4. Environment Canada (1995). *The State of Canada's Climate: Monitoring Variability and Change*. Environment Canada, State of the Environment (SOE) Report No. 95-1.

5. Environment Canada (1994). *Canada's National Report on Climate Change: Actions to Meet Commitments under the United Nations Framework Convention on Climate Change.* Environment Canada.

6. Environment Canada (1993). *Canadian Climate Normals, 1961-90.*

7. Environment Canada (1991). *Climate Change and Canadian Impacts : the Scientific Perspective.* Climate Change Digest: CCD 91-01.

8. Environment Canada (1987). *Canadian Climate Impacts Program.* Climate Change Digest; CCD 87-01.

9. Environment Canada (1984). *Climatic Atlas of Canada: A Series of Maps Portraying Canada's Climate.*

10. Gan,T.Y. (1995). *Trends in Air Temperature and Precipitation for Canada and North-eastern USA.* International J. Climatology, Vol. 15, pp 1115-1134.

11. Gullett, D.W. and W.R. Skinner (1992). *The State of Canada's Climate: Temperature Change in Canada 1895-1991***.** Environment Canada SOE Report No. 92-2.

12. Gullett, D., W. Skinner and L. Vincent (1992). *Development of an Historical Canadian Climate Database for Temperature and other Climate Elements.* Climatological Bulletin, Vol. 26, No. 2, pp 125-131.

13. Hare, F. K. (1989). *Canada and the Changing Atmosphere.*

14. Hare, F. Kenneth and M. K. Thomas (1974). *Climate Canada.* Wiley Publishers of Canada Limited.

15. Hengeveld, H. (1995). *Understanding Atmospheric Change: A Survey of the Background Science and Implications of Climate Change and Ozone Depletion*. 2nd Edition. State of the Environment Report No. 95-2.

16. Higuchi, K. (1980). *A Study on Variability of Canadian Climate.* Environment Canada, Canadian Climate Centre Report No. 80-4, pp 29.

17. Hogg, W.D. (1992). *Time Series of Daily Rainfall Extremes.* American Meteorological Society. Fifth Conference on Climate Variations, Oct 14-18,1991.

18. Karl,T.R., P.Y. Groisman, R.W. Knight, and R.R. Heim Jr. (19). *Recent Variations of Snow Cover and Snowfall in North America and their Relation to Precipitation and Temperature Variations.* Journal of Climate, Vol. 6(7), pp 1327-1344.

19. Koeppe, C.E. (1931). *The Canadian Climate.* McKnight & McKnight, Bloomington, Illinois.

20. Manning, F.D. (1983). *Climatic Extremes for Canada*. Environment Canada, Atmospheric Environment Service, No. 3-83.

21. Phillips, D.W. (1990). *The Climates of Canada.* Minister of Supply and Services Canada.

22. Phillips, D.W. and G.A. McKay (1981). *Canadian Climate in Review - 1980.* Minister of Supply and Services Canada.

23. Rogalsky, J. (1964). *Statistical Climatic Summaries for Aviation at Sixteen Major Canadian Airports.* Department of Transport, TEC 525.

24. Schwartz, G. (1977). *The Climate Advisor: the Complete Reference Guide to Climate and Weather in the United States, Canada, Mexico, Caribbean.* Flushing, N.Y., Climate Guide Publications, pp 332.

25. Thomas, M. K. (1979). *A Bibliography of Canadian Climate, 1972-1976.* Hull, Minister of Supply and Services.

26. Thomas, M. K. (1973). *A Bibliography of Canadian Climate, 1958-1971.* Ottawa, Information Canada.

27. Thomas, M. K. (1961). *A Bibliography of Canadian Climate, 1763-1957.* Meteorological Branch, Department of Transport.

28. Thomas, M. K. (1953). *Climatological Atlas of Canada.* Ottawa National Research Council pp 256.

Atlantic Canada Regional Reports/Publications

1. Barks, E.A. and W.G. Richards (1986). *The Climatology of Tropical Cyclones in Atlantic Canada.* Environment Canada Internal Document, AE-ASSSD86-04.

2. Bengtsson, L., Botzet, M. and M.Esch (1996). *Will Greenhouse Gas-induced Warming over the Next 50 Years Lead to Higher Frequency and Greater Intensity of Hurricanes?* Telllus, Vol.48A(1), pp 57-73.

3. Brown, R.D. (1986). *Climatology of Severe Storms Affecting Coastal Areas of Eastern Canada*. Ottawa, Environment Canada, Technical Document, No. 20.

4. Danard, M.B., El-Sabh, M.I. and T.S. Murty (1990). *Recent Trends in Precipitation in Eastern Canada.* Atmosphere-Ocean, Vol.28(1), pp 140-145.

5. Daoust, M. (1993). *Interannual Temperature Variability and Cyclone Frequency over Eastern Canada and the New England States. A Case Study: Winter Seasons 1931-32 to 1984-85.* McGill University, Montreal, Centre for Climate and Global Change Research Report No. 93-7.

6. Eaton, Peter B., A.G. Gray, P.W. Johnson and E. Hundert (1994). *State of the Environment in the Atlantic Region*. Environment Canada, Atlantic Region.

7. Galbraith, P.W. (1980). *Hurricanes and Tropical Storms in Atlantic Canada: A Brief Review.* Environment Canada Internal Document, AE-ASSD80-06.

8. Gates, A.D. (1980). *Climatic Requirements for the Heating of Buildings in the Maritime Provinces.* Environment Canada Internal Document, AE-ASSD80-04.

9. Gates, A.D. (1975). *The Tourism and Outdoor Recreation Climate of the Maritime Provinces.* Environment Canada Publication in Applied Meteorology, REC-3-73.

10. Houtman, Nick (1994). *A Regional Response to Global Climate Change: New England and Eastern Canada: Symposium Summary.* Environment Canada, Climate Change Digest, CCD 94-03.

11. Khandekar, M.L. (1996). *The Atlantic Hurricane Season of 1995: Global Warming or Interannual Variations?* Atmospheric Newsletter, Vol. 24(2), pp 25-27.

12. Lambert, S.J. (1995). *The Effect of Enhanced Greenhouse Warming on Winter Cyclone Frequencies and Strengths.* Journal of Climate, Vol.8(5), pp 1447-1452.

13. Lewis, P.J. and I. E. MacSwain (1996). *A Temperature-Precipitation Departure Index as an Indicator of Climate Variability. A Case Study of the Maritime Provinces of Canada.* Environment Canada Report MAES 1-96.

14. Middleton, W.E.K. (1935). *The Climate of the Gulf of St. Lawrence and Surrounding Regions in Canada and Newfoundland, as it affects Aviation.* Meteorological Service of Canada Internal Publication, Canadian Meteorological Memoirs No. 1.

15. Morgan, M.R., Drinkwater, K.F. and Pocklington, R. (1993). *Temperature Trends at Coastal Stations in Eastern Canada*. Climatological Bulletin 27: 135-153.

16. Shaw, R.W., (1995). *Science and Policy Implications of Atmospheric Issues in Atlantic Canada.* Workshop Proceedings, Environment Canada - Atlantic Region Occasional Report No. 6.

17. Stokoe, Peter (1990). *Implications of Climate Change for Small Coastal Communities in Atlantic Canada.* Environment Canada, Climate Change Digest; CCD 90-01.

18. Stokoe, Peter (1988). *Socio-economic Assessment of the Physical and Ecological Impacts of Climate Change on the Marine Environment of the Atlantic Region Phase 1.* Environment Canada, Climate Change Digest, CCD 88-07.

Nova Scotia Reports/Publications

1. Amirault, F. and W. Richards (1984). *The Climate of Sable Island.* Environment Canada Internal Publication, AE-ASSD84-08.

2. Canavan, T.A. (1992). *Climatology of Sea Breezes at Shearwater Airport, Nova Scotia and Prototype Expert System Design.* MSc. Thesis, Dalhousie University, Halifax, N.S.

3. Department of Development (1973). *Nova Scotia Development Atlas: Climate.* Nova Scotia Climatology Series, Halifax.

4. Environment Canada (1992). *The Climate of Nova Scotia: A One Day Symposium.*

5. Gates, A.D. (1981). *A Note on the Precipitation Climate of Kejimkujik National Park.* Environment Canada Internal Publication, AE-ASSD81-07.

6. Gates, A.D. (1976). *Climatological Analysis of Freeze Data for Truro.* Environment Canada Internal Publication, AE-ASSD76-01.

7. Gates, A.D. and A.D.J. O'Neill (1976). *The Climate of the Bay of Fundy.* Environment Canada Internal Publication, AE-ASSD76-06.

8. Kinsman, G.B. (1954). *Relation of Horticultural Crops to the Climatic Regions of Nova Scotia.* MSc. Thesis, University of New Hampshire.

9. MacLaren Plansearch Limited, Halifax, N.S. (1988). *Mesoscale Climate Data for Major Agriculture Areas of Nova Scotia.* Agriculture Canada Project Report.

10. O'Neill, A.D.J. (1977). *Climate and Ice in the Strait of Canso Region.* Environment Canada Internal Publication, AE-ASSD77-06.

11. Richards, W.G. (1984). *Inventory of Climate Information for Nova Scotia.* Environment Canada Internal Document, AE-ASSD84-05.

12. Richards, W.G. (1982). *The Climate of the Bay of Fundy.* Environment Canada Internal Publication, AE-ASSD82-05.

13. Watson, W.B. (1974). *The Climate of Kejimkujik National Park, Nova Scotia.* Environment Canada, Atmospheric Environment Service, Publications in Applied Meteorology No. 4-73, pp 113.

New Brunswick Reports/Publications

1. Coligado, M.C. (1968). *Risk Analyses of Weekly Climatic Data for Agricultural and Irrigation Planning Bathurst, New Brunswick.* Department of Agriculture, Tech. Bull. 21.

2. Day, E.E.D., R.J. McCalla, H.A. Millward and B.S. Robinson (1977). *The Climate of Fundy National Park and its Implications for Recreation and Development.* Atlantic Region Geographical Series Number 1, Department of Geography, Saint Mary's University, Halifax, N.S.

3. Dickison, R.B.B. and B.G. Steeves (1989). *Impact of Climate Change on New Brunswick Water Resources.* Supply and Services Canada and Environment Canada.

4. MARTEC Limited (1987). *Effects of a One Metre Rise in Mean Sea-level at Saint John, New Brunswick and the Lower Reaches of the Saint John River.* Environment Canada, Climate Change Digest, No. 87-04.

5. Richards, W.G. and M.P. Russell (1995). *Socio-Economic Impacts of the Warmer Winter of 1952/53 in New Brunswick.* Environment Canada Report MAES 95-4.

6. Watson, W.B. (1977). *The Climate of Kouchibouguac National Park.* Environment Canada, Atmospheric Environment Service, Project Report No. 27, CCC-PR-27.

Newfoundland Reports/Publications

1. Hall, J. and M. Wadleigh (1993). *The Scientific Challenge of our Changing Environment.* Conference Proceedings, Canadian Global Change Program, Incidental Report Series No. IR93-2.

2. Hare, K.F. (1953). *The Climate of Quebec and Labrador.* Department of Transport, Meteorological Branch.

3. Hare, K.F. (1950). *Climate of the Eastern Canadian Arctic and Sub-arctic, with Special Reference to Northern Quebec, Labrador, Newfoundland and the Surrounding Seas.* Montreal, McGill University.

4. Robertson, A., S. Porter and G. Brodie (1993). *Climate and Weather of Newfoundland and Labrador.* Workshop Proceedings, Creative Publishers, St. John's, NF.

5. Environment Canada (1989). *Workshop on the Climate and Weather of Newfoundland and Labrador: November 20-22, 1989.*

6. Ketch, L.A. (1985). *Newfoundland Farm Forecast Regions: A Climatological Summary.* Environment Canada, Atmospheric Environment Service Internal Report.

7. Peach, J.A. (1984). *The Tourism and Outdoor Recreation Climate of Newfoundland and Labrador.* Environment Canada, Atmospheric Environment Service, Internal Publication, CCC-CR-84-4.

8. Department of Transport, Meteorological Branch (1964). *The Climate of Newfoundland.* Text and tables reproduced from Boughner, C.C. and M.K. Thomas (1959**),** *The Climate of Canada,* Canada Year Book, Ottawa. (See page 4 for references to the climate of Newfoundland 1945-1963.)

9. Department of Environment and Lands, Government of Newfoundland and Labrador (1992). *Water Resources Atlas of Newfoundland.*

Prince Edward Island Reports/Publications

1. Department of Agriculture and Forestry, Soil and Water Division. (1970). *The Climate of Prince Edward Island Tignish Area, May - October 1970.*

2. Lane, P. and Associates, (1988). *Preliminary Study of the Possible Impacts of a One Metre Rise in Sea Level at Charlottetown, Prince Edward Island: Summary of a Report.* Environment Canada, Climate Change Digest; CCD 88-02.

3. Vass, Stanley E. (1981). *Climate Change and Variability; Some Implications for Prince Edward Island,* A background paper for the CCREM Seminar and workshop, Charlottetown.

Sea Ice

1. Brown, R. D. (1993). *Implications of global climate warming for Canadian east coast sea-ice and iceberg regimes over the next 50-100 years : a summary of a report.* Environment Canada, Climate Change Digest CCD 93-03.

2. Public Works Canada (1988). *Final Report: Study of the Sea Ice Climate of the Northumberland Strait.* Ottawa, Ontario.

3. Walker, A. E. (1987). *A Climatological Analysis of Eastern Canadian Seaboard Maximum Ice Content Using Passive Microwave.* Ottawa : National Library of Canada, Canadian theses on microfiche.

Marine Climatology

1. Clarke, A. (1993). *The Ocean's Role in the Global Climate System.* University of Prince Edward Island Faculty Seminar series: March 5, 1993; sound recording.

2. Environment Canada, Atmospheric Environment Service (1977). *Wave Climatology of the Northwest Atlantic Ocean.* Pp 58.

3. Neu, H. J. A. (1982). *11-year Deep-water Wave Climate of Canadian Atlantic Waters.* Bedford Institute of Oceanography, Canadian technical report of hydrography and ocean sciences; No. 13.

4. Newell, J.P. (1986). *Regional Marine Climate Comparisons for Offshore Drilling Locations Worldwide.* St. John's, Newfoundland, Seaconsult Ltd.

5. Swail, V. and L.D. Mortsch (1984). *A Review of the State-of-the-Art in Marine Climatology on the East Coast of Canada.* Environment Canada, Atmospheric Environment Service, No. 36.

6. United States, Naval Weather Service Detachment (1982). *U.S. Navy Marine Climatic Atlas of the World.* Volume 9: World-wide means and standard deviations.

2.2 ***Trends***

Peter J. Lewis

Atmospheric Science Division, Atmospheric Environment Branch, Environment Canada
1496 Bedford Highway, Bedford, Nova Scotia B4A 1E5

Temperature trends in the Atlantic Region are considered in comparison with global and Canadian trends. Trends in precipitation and cloud cover are also briefly considered. Most of the analyses were performed by the Climate Monitoring and Data Interpretation Division of the Climate Research Branch, Atmospheric Environment Service, Downsview Ontario (see Environment Canada 1995). Some preliminary work by the author on trends in temperature and precipitation extremes in the Maritime Provinces is also briefly reviewed.

The data sets used in most of the analyses were the Historical Canadian Climate Database (HCCD) (Gullett et al 1992). There are 131 HCCD sites across Canada, which is split into 11 Climate Regions. With the exception of Labrador, all of the region lies in the Atlantic Canada climate zone where there are 15 HCCD stations. The stations selected are long term sites, missing data gaps have been filled. The station data sets have been tested for homogeneity and the data has been adjusted for inconsistencies.

TEMPERATURE TRENDS

Global temperature trends since 1895 show a warming trend of 0.3 to 0.6^{o}C (IPCC 1995). The trend is characterized by a warming from 1895 to the 1940s, followed by a cooling trend until the mid seventies, then a marked warming into the mid 90s. Globally, the 10 warmest years on record have occurred since 1980. On a national basis, Canada shows a similar warming and cooling pattern with a higher overall warming trend of ~1.1^{o}C since 1895. The Atlantic region, in contrast, shows a warming trend from 1895 which peaked in the mid 50s followed by a cooling trend into the 90s (Fig 1). However, the overall linear warming trend of 0.4^{o}C (1895-1991) in Atlantic Canada is not statistically significant. For the period (1895-1995) the warming trend in the Atlantic Region has decreased to 0.2^{o}C. On a seasonal basis the only statistically significant trend for the period (1895-1992) is a warming of 0.8^{o}C for the summer season.

Complete data sets for all 11 Climate Regions across Canada are only available for the period 1948-95. For this period, the temperature trend in Atlantic Canada shows a marked difference from that in Canada as a whole with a cooling of 0.7^{o}C. The national trend for Canada for this period is a warming of 0.5^{o}C. Seasonally, the regional trends are: winter (-2.2^{o}C); spring (0.0^{o}C); summer (+0.5^{o}C); and autumn (-0.8^{o}C).

For the approximately 40% of the land area currently analyzed over the globe, nighttime minimum temperatures have typically increased by twice as much daytime maximums over the last 40 years (IPCC, 95). Over Canada, 1895-91 temperature minimums have increased by 1.4^{o}C while maximums have increased by 0.6^{o}C. During the same period, minimums in Atlantic Canada have increased by only 0.2^{o}C while maximums have increased by 0.4^{o}C.

PRECIPITATION

Trends in precipitation are much more difficult to determine than those in temperature. This is due mainly to the difficulty in obtaining accurate and consistent measurements of rainfall and snowfall amounts and to the wide temporal and spatial variation in annual amounts. Due to lack of data, analyses of national trends are restricted to 1948 onwards. The national trend shows an increase in precipitation since 1948 but a decline since the mid 80’s. The Atlantic Region shows an overall increasing trend since 1948. Globally, precipitation has increased over land in high latitudes in the Northern Hemisphere especially in the cold season (IPCC, 1995).

CLOUD COVER

A complex relationship exists between cloud cover and global warming and cooling. Changes in cloud characteristics could be as important as changes in cloud cover. Globally cloudiness appears to have increased since the 1950's over the oceans. In many land areas where the daily temperature range has decreased, cloudiness increased from the 1950's at least to 1970's. Records of cloud cover in Canada are only available in digital format since 1953. Atlantic Canada has shown an increase in cloud cover of 1% (1953-91); however, this increase is not statistically significant. On a seasonal basis the Atlantic Regional trends in cloud cover are: winter -2%; spring +2%; summer +2%; and fall +2%.

TEMPERATURE AND PRECIPITATION EXTREMES

Some preliminary analyses of trends in extreme temperature and precipitation events have been undertaken for an 8 station data set in the Maritime provinces for the period 1944-90. These indicate the following:

1) a decreasing trend in the number of days per year with a maximum temperature above 25^{o}C;
2) an increasing trend in the number of days per year with a minimum temperature below -15^{o}C;
3) an increasing trend in the number of daily precipitation events above 20mm; and
4) a very slightly increasing trend in the number of daily snowfall events above 15cm.

REFERENCES

Gullett, D.W. and W.R. Skinner
1992. The State of Canada's Climate: Temperature Change in Canada 1895-1991**.** Environment Canada SOE Report No. 92-2.

Gullett, D., Skinner, W. and Vincent, L
1992. Development of an Historical Canadian Climate Database for Temperature and Other Climate Elements. Climatological Bulletin 26 (2) p. 125-131.

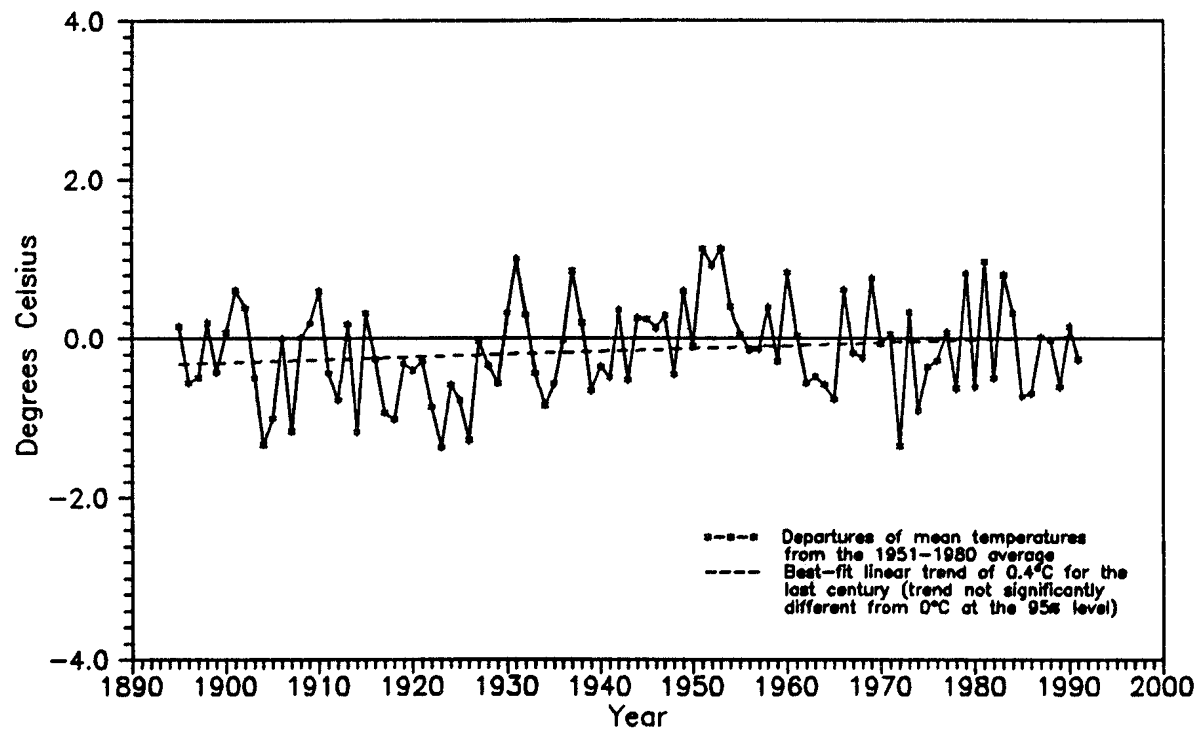
Environment Canada
1995. The State of Canada's Climate: Monitoring Variability and Change. State of the Environment Report No. 95-1.

Intergovernmental Panel on Climate Change
1995. *The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, WMO, United Nations Environment Program, Geneva.

Atlantic Canada Temperature Trend

1895 – 1991

ANNUAL TEMPERATURE DEPARTURES



SOURCE: Environment Canada.

2.2.1 *Additional Trend Analyses*

Teresa Canavan

Atmospheric Science Division, Atmospheric Environment Branch, Environment Canada
1496 Bedford Highway, Bedford, Nova Scotia B4A 1E5

Additional analyses of trends in the Atlantic Region by Morgan et al (1996) are in agreement with those presented above by Lewis. Gan (1995) also found cooling trends in eastern Canada and north-eastern USA and no obvious trends in precipitation although he notes that more stations indicate increasing amounts of precipitation. Danard et al (1989) detect increased precipitation in Eastern Canada by comparing data from 1931-60 to 1951-80. Karl et al (1993) found a significant decrease in annual snow cover over southern Canada from 1971-90 although the total precipitation increased.

REFERENCES

Danard, M.B., El-Sabh, M.I. and Murty, T.S.
1990. Recent Trends in Precipitation in Eastern Canada. Atmosphere-Ocean 28 (1), p. 140-145.

Gan, T.Y.
1995. Trends in Air Temperature and Precipitation for Canada and North-Eastern USA. International Journal of Climatology, Vol. 15, p. 1115-1134.

Karl, T.R., Groisman, P.Y., Knight, R.W. and Heim, Jr., R.R.
1993. Recent Variations of Snow cover and Snowfall in North America and Their Relation to Precipitation and Temperature Variations. Journal of Climate. Vol 6, p. 1327-1344.

Morgan, M.R. and Pocklington, R.
1996. The Chilling Aspects of Global Warming in Atlantic Canada. Workshop Proceedings. Environment Canada - Atlantic Region, Occasional Report No. 9, pp. 184-194.

2.3 *Climate Variability*

Teresa Canavan

Atmospheric Science Division, Atmospheric Environment Branch, Environment Canada
1496 Bedford Highway, Bedford, Nova Scotia B4A 1E5

“Compared to the effort that has been put into predicting climate change, relatively little work has been done in defining the variability of current climate or investigating climate fluctuations of the recent past.” (Lewis et al 1996). Lewis et al (1996) suggest a simple technique to combine fluctuations of temperature and precipitation for a given period as a temperature-precipitation departure index and find increased fluctuation in this index at two locations in the Maritime Provinces since 1950.

Daoust (1993) finds an apparent increase in interannual temperature variability since the early 1970’s during the winter season.

Daoust (1993) reports a 30% decrease in cyclone frequency in the Maritimes and New England States during winter seasons from 1931-32 to 1984-85. Lambert (1995), using a 2 X CO_2 simulation of the second generation Canadian Climate Centre general circulation model, predicts a decrease in the total number of cyclones in both winter hemispheres but an increase in frequency of intense cyclones, particularly in the northern hemisphere. He finds little change in the position of the storm tracks.

Topliss (1986) investigates the linkage between the North Atlantic Oscillation (NAO) and climate variability in North America and Europe finding a disruption in the normal pattern for the first two decades of this century and a distortion during the 1920's.

According to Robertson (1996):

> "The traditional paradigms of normality in statistics and Euclidean geometry cannot deal with the myriad of interscale relationships that characterize the ever-changing forest vegetation and growth. The new paradigms of circular (directional) statistics, fractal geometry and chaos theory have emerged that can describe and explain the architecture and changes of forested landscapes."

Robertson (1996) defines circular (directional) statistics, fractal geometry and chaos theory and suitable applications including climatological studies where they have proven useful. An extensive reference list accompanies this paper describing further work in this area.

REFERENCES

Daoust, M.
1993. Interannual temperature variability and cyclone frequency over Eastern Canada and the New England States. A Case Study: Winter seasons 1931-32 to 1984-85. C2GCR report No. 93-7.

Lambert, S.J.
1995. The Effect of Enhanced Greenhouse Warming on Winter Cyclone Frequencies and Strengths. Journal of Climate. Vol. 8, p. 1447-1452.

Lewis, P.J. and MacSwain, I.E.
1996. A Temperature-Precipitation Departure Index as an Indicator of Climate Variability - A Case Study of the Maritime Provinces of Canada. Environment Canada - Atlantic Region, Atmospheric Environment Branch Report MAES 95-4.

Robertson, A.
1996. Contributions to Newfoundland Climatology. Workshop Proceedings. Environment Canada - Atlantic Region, Occasional Report No. 9, pp. 200-207.

Topliss, B.J.
1996. Within the Bounds of the NAO: Canada-UK Inter-Relations of Temperature and Rainfall: Implications for Agriculture and Oceanography? Workshop Proceedings. Environment Canada - Atlantic Region, Occasional Report No. 9, pp. 208-212.

2.4 *Extreme Events*

Jim Abraham

Atmospheric Science Division, Atmospheric Environment Branch, Environment Canada
1496 Bedford Highway, Bedford, Nova Scotia B4A 1E5

Each year Environment Canada Weather Centres in the Atlantic Region issue hundreds of inland weather warnings and thousands of marine warnings. Heavy snowfalls and rainfalls, gale to hurricane force winds, high waves and storm surges are among the extreme events that result in injury or death and cause significant economic losses like property or crop damage. Events that exceed the normal range of variability in temperature or precipitation that result in flooding, drought, heat waves, cold spells or winter thaws can also be considered as extreme. Obviously, a climate change that impacts on the frequency or severity of extreme events is of major concern to Atlantic Canadians.

The meteorological phenomena most associated with extreme events include extratropical cyclones (most often winter storms), tropical cyclones (hurricanes), or summer severe weather (mesoscale convective systems). While there has been some study of the behavior and prediction of these systems, very little work has been done in examining the implications of climate change on these events in Atlantic Canada, and further research is required.

Extratropical Cyclones
In North America, the highest frequency of explosive cyclogenesis occurs along the eastern coastal regions of the continent (Gyakum et al. 1996). These rapidly developing storms, deepening at a rate of at least 24 hPa in 24 hours, are often referred as “bombs” (Sanders and Gyakum, 1980). Given the fact that Atlantic Canada is located within this favoured zone of intense cyclogenesis, two major scientific studies were conducted in the past couple of decades. The Canadian Atlantic Storms Program (CASP) was conducted from 15 January to 15 March 1986 (CASP I) and from 15 January to 15 March 1992 (CASP II). The meteorological component of these field programs are summarized by Stewart et al. (1987) and Stewart (1991).

There is a strong interannual variability in the occurrence of explosively deepening cyclones. Gyakum et al. (1996) compare the 11 cyclones that took place in 1990 with the 27 observed during CASP II in 1992. This degree of variability inevitably results in some difficulty detecting or predicting trends in extreme events due to the increase in greenhouse gases. Nevertheless, Lambert (1996) did examine the trend in intense winter cyclone events in the northern hemisphere between 1899 and 1991. He found a sharp increase in intense events in both the Atlantic and Pacific basins after 1970. Furthermore, he noted the increase occurred most notably in the Atlantic over the Davis Strait, off Labrador and over Newfoundland. This is consistent with Lambert (1995), who found that the cyclone climatology from doubled CO_2 general circulation models showed an increase in the number of intense events.

The oceanographic response to intense cyclones is also an important aspect of these storms, and did receive significant attention during the CASP experiments. In particular, storm surges and waves are potentially very destructive. Some recent examination of the statistics related to extreme waves and significant storm surges has been done (Swail 1996 and Parkes et al. 1997). Swail’s paper has been included in this document.

Tropical Cyclones
Tropical cyclones form and intensify into hurricanes (maximum surface winds of 64 knots or 119 km/h) over warm ocean waters in low latitudes. These systems frequently recurve northeastwards and accelerate under the influence of a strengthening upper air wind field associated with the middle latitudes. Figure 1 shows plot of Atlantic tropical cyclone trajectories (1956-96), with two or three storms on average passing through Atlantic Canada and the adjacent marine waters each year. While these

storms are often in the decay stage as hurricanes, some do retain enough intensity to have significant impact (e.g. Mayfield and Lawrence, 1996 for Hurricane Luis). Others interact with mid-latitude disturbances like happened with Hurricane “Hazel” in 1954 (Knox, 1955), with the resulting hybrid storm perhaps more deadly than the original pure tropical system.

The science community is still undecided on the impact of an increase in greenhouse gases on the frequency or intensity of tropical cyclones (e.g. Houghton et al. 1996). Others conclude than the natural variability will mask any changes resulting from global warming (e.g. Gray, 1995). Furthermore, despite the threat, there has been relatively little study on the nature of storms in transition from tropical to extra-tropical in Atlantic Canada (e.g. Abraham et al, 1991), and therefore no work dealing with the effect a changing climate might have on these hybrids. Goldenberg (1996) has examined the inter-decadal trends in Atlantic tropical cyclones, and his paper is included in this document.

Summer Severe Weather

The moderating influence of cool oceanic waters results in a relatively low incidence of intense mesoscale convection in Atlantic Canada. A recent study on operational forecasting of summer severe convection in Canada (Joe et al. 1995) mainly focuses on activities from Quebec, Ontario and the Prairies. However, the more continental regime experienced by New Brunswick and western Labrador does result in a relative maximum occurrence of severe weather events, like tornadoes (Newark, 1984,1988). There has been no known study examining trends in severe weather in Atlantic Canada. However, one conclusion in a warmer climate might be a transition to a more continental regime, resulting in more frequent occurrences of summer severe weather.

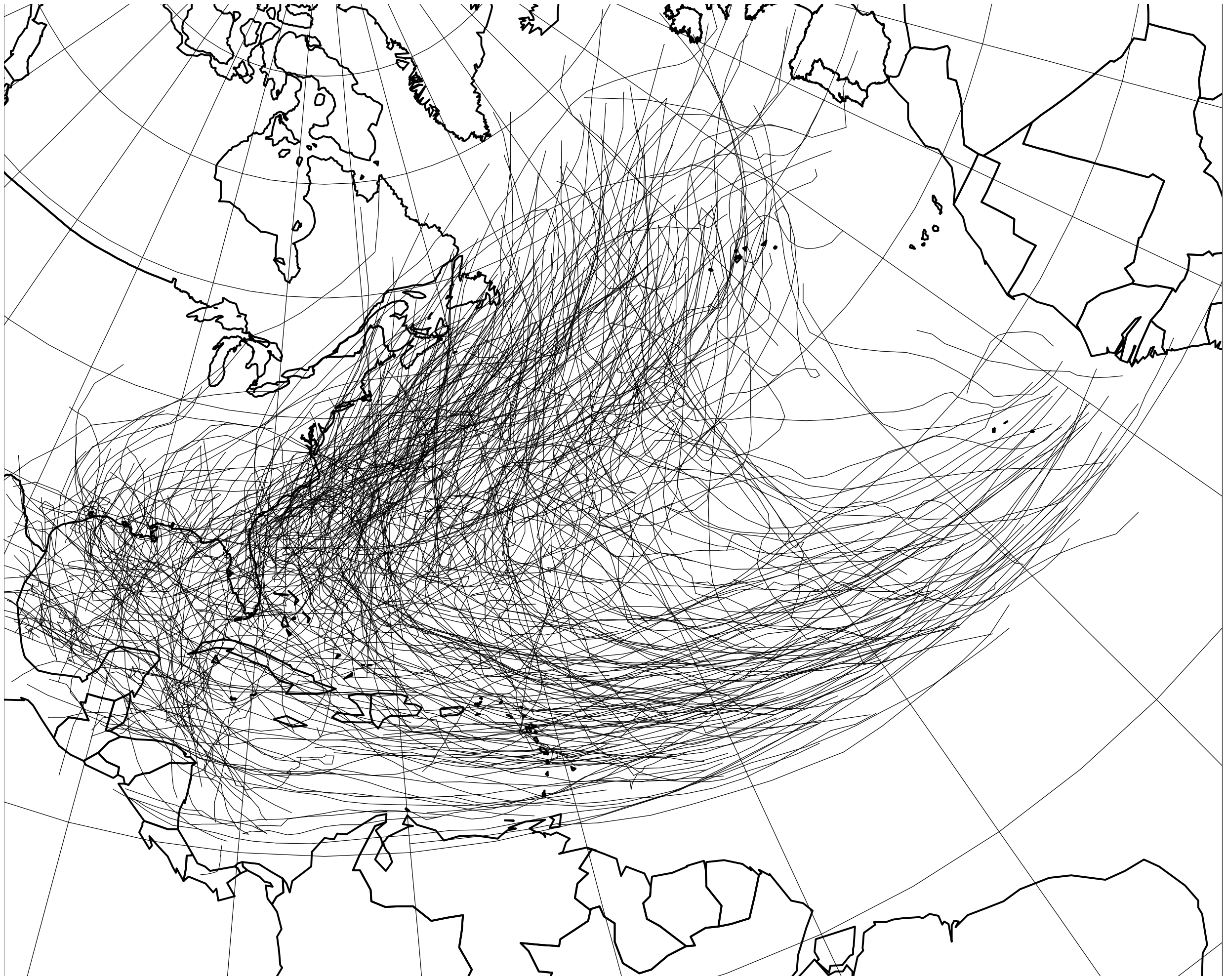


Figure 1: Historical tracks of Atlantic Tropical Cyclones 1956-1996.

References

Abraham, J., K. MacDonald and P. Joe. 1991. The Interaction of Hurricane Hugo with the Mid-Latitude Westerlies, *Proc. 19th Conf. on Hurricanes and Tropical Meteorology,* May 6-10, Miami, FL, Amer. Met. Soc., 124-129.

Goldenberg, S.B., L.J. Shapiro and C.W. Landsea. 1996. The Hyper-Active 1995 Atlantic Hurricane Season: A Spike or a Harbinger of Things to Come?, *Proc. Symposium on Climate Change and Variability in Atlantic Canada*, Dec. 3-6, Halifax, N.S., Environment Canada, 113-119.

Gray, W., C.W. Landsea, P.W. Mielke, Jr., and K.J. Berry. 1995. Summary of 1995 Atlantic tropical cyclone activity and verification of authors' seasonal prediction. Dept. of Atmospheric Sc., Colorado State University, Ft. Collins, CO 80523. 27pp.

Gyakum, J.R., D-L Zhang, J. Witte, K. Thomas and W. Wintels. 1995. CASP II and the Canadian Cyclones during the 1989-92 Cold Seasons, *Atmosphere-Ocean* ***34(1)***: 1-16.

Houghton, J.T., L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell, Eds. 1996. Climate Change 1995: *The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, New York, 572 pp.

Joe, P.J., C. Crozier, N. Donaldson, D. Etkin, E. Brun, S. Clodman, J. Abraham, S. Siok, H-P Biron, M. Leduc, P. Chadwick, S. Knott, J. Archibald, G. Vickers, S. Blackwell, R. Drouillard, a. Whitman, H. Brooks, N. Kouwen, R. Verret, G. Fournier and B. Kochtubajda, 1195. Recent Progress in the Operational Forecasting of Summer Severe Weather. *Atmosphere-Ocean* **33(1):** 249-301.

Knox, J.L., 1955. The Storm "Hazel", synoptic resumé of its development as it approached Southern Ontario. *Bull. Am. Meteorol. Soc.* **36:** 239-246.

Lambert, S.J., 1996. Intense Extratropical Northern Hemisphere Winter Cyclone Events: 1899-1991. *J. Geophys. Res.* **10 (16):** 21319-21325.

Lambert, S.J., 1995. The effect of enhanced greenhouse warming on winter cyclone frequencies and strengths. *J. Clim.,* **8:** 1447-1452.

Mayfield, M. and M. Lawrence. 1996. Atlantic Hurricanes. *Weatherwise*. **49 (1):** 34-41

Newark, M.J., 1988. The tornado hazard in Canada. *Natural and Man-Made Hazards.* M.I. El-Sabh and T.S. Murty (Eds.), 743-748.

Newark, M.J., 1984. Canadian tornadoes, 1953-1979. *Atmosphere-Ocean.* **22:** 343-353.

Parkes, G.S., L.A. Ketch and C.T. O'Reilly, 1997. Storm Surge events in the Maritimes. *Proc., 1997 Canadian Coastal Conf.* 21-24 May, Guelph, ON. 115-129.

Sanders, F. and J.R. Gyakum. 1980. Synoptic-dynamic climatology of the "bomb." *Mon. Weather. Rev.* **108**: 1589-1606

Stewart, R.E. 1991. Canadian Atlantic Storms Program: Progress and plans for the meteorological component. *Bull. Am. Meteorol. Soc.* **72:** 364-371.

Stewart, R.E., R.W. Shaw and G.A. Isaac. 1987. Canadian Atlantic Storms Program: the meteorological field project. *Bull. Am. Meteorol. Soc.* **68:** 338-345.

Swail, V.R., 1996. Analysis of Climate Variability in Ocean Waves in the Northwest Atlantic Ocean. *Proc. Symposium on Climate Change and Variability in Atlantic Canada*, Dec. 3-6, Halifax, N.S., Environment Canada, 313-318.

2.4.1 *Ocean Waves*

Analysis of Climate Variability in Ocean Waves In the Northwest Atlantic Ocean

Val R. Swail

Climate Research Branch
Atmospheric Environment Service
Downsview, Ontario M3H 5T4

INTRODUCTION

During the past 5-6 years or so there have been a number of extreme storm events on either side of the North Atlantic Ocean. In 1990, extreme waves crushed the superstructure of the drilling platform Ekofisk in the North Sea. In 1992, a "3000-year return period storm" severely damaged west Norwegian coastal settlements, while in 1993 the master of Ocean Weather Ship "Mike" reported that in 35 years experience in the Norwegian Sea he had never before encountered such severe wave conditions.

In the western Atlantic, on Halloween day 1991, a moored buoy south of Nova Scotia reported the highest waves ever measured by an instrument (17.3 m significant wave height, with maximum waves estimated at more than 31 m). On March 15, 1993 the "Storm of the Century" produced record high waves at buoys along the U.S. and Canadian east coasts, including a significant wave height of 16.3 m at the buoy south of N.S. Then in September 1995, Hurricane Luis hit the liner *Queen Elizabeth II* with estimated 29 m maximum waves, corroborated by a nearby buoy which reported significant waves of 17 m, and estimated maximum waves exceeding 30 m.

These events caused many questions to be asked. Foremost among these were: (1) Is the climate changing?; and (2) Are storms becoming more frequent? more severe?

The offshore oil and gas industry adopted a wait-and-see attitude; the insurance industry in Europe raised premiums.

These questions were also being addressed at an international meeting of scientists and offshore interests in Reykjavik Iceland in March 1993. As a result of the Reykjavik meeting the WASA (Waves and Storms in the Atlantic) project was established with European Community funding and the participation of external experts. At the same time a Canadian program (smaller) was established in parallel with WASA.

WAVE DATA

The first major concern in looking at the long-term trend and variability in ocean waves was that there were no long term reliable ***wave*** data sets. Ships definitely did not provide the necessary observational quality, nor the stationary location. Drilling platform data were of better quality, but were spatially and temporally extremely restricted. Moored buoys provided the best source of quality data, and in some locations along the U.S. continental margin, included more than 10 years of data. However, this period was still far too short for analysis of trend and variability, and in Canadian waters the length of the buoy record was far less than that.

As a result of the lack of reliable observed data, Canada and other countries turned to wave hindcast models to provide the data for engineering design as well as climate trend and variability analysis. A recently produced CD-ROM contains the wind and wave data for the 82 most severe wave-producing storms in Canadian Atlantic waters from 1957-1995.

The hindcast quality versus measurements is very good for storms, as has been shown in many hindcast evaluation studies (Cardone and Swail, 1995). Recent hindcasts for the North Sea, using newly-developed state-of-the-art techniques, show virtually unbiased results with a scatter index for a 6-year continuous hindcast of 17%, over a wide range of sea states. Similar results have been consistently obtained for other ocean basins, including the northwest Atlantic off Canada.

A caveat to the hindcast quality statement relates to the modelling of very high sea states, i.e. significant wave height greater than 12 m. There seems to be a tendency for all classes of wave model to underpredict these extreme storms (Cardone et al., 1995). This may be due to mesoscale effects (jet streaks), wave model deficiencies, scaling relationships of the wind in fully developed seas, or a combination of the above. Overall, however, hindcasting has provided a very good estimate of storm waves, using a *consistent* methodology.

ANALYSIS OF THE TREND AND VARIABILITY OF STORM WAVES OFF THE EAST COAST OF CANADA

Examination of the storm wave data for 1957-95 off the east coast of Canada shows some interesting results. On the Scotian slope, for example, there is an apparent trend towards increasing wave heights in storms when a simple linear trend line is fitted to the entire data record (see Figure 1). This apparent trend is also evident in data from other points along the Scotian Shelf extending to the southwest Grand Banks. However, on the northern Grand Banks near the Hibernia location there is no trend at all, and farther to the northeast in the Labrador Basin, the trend, if any, is towards reduced storm waves. On the Scotian Shelf the apparent increasing trend in wave heights is accompanied by a similar increase in wind speed, while on the Grand Banks the wind speed trend line was as flat as that for the waves. This is in contrast to the findings of Bacon and Carter (1991) in the eastern Atlantic, who found a trend in mean wave heights over a 20-year period, with no corresponding increase in wind speeds.

Further examination of the Scotian slope data reveals that the apparent trend to increased wave heights over the 40-year period is entirely due to 2 or 3 events in the past 5 years. A linear trend line fitted to the 1957-90 data alone shows no trend, or even a slight decrease in storm wave heights (Figure 1). This points out an inherent danger in applying simple linear trend analysis over a long time span which may contain significant interdecadal variability. It is not evident that these 2 or 3 recent events fall outside the natural variability of waves over the past century. Resio et al. (1995) showed, at least in a qualitative sense, that similar large waves may have occurred in the early part of this century. Preliminary WASA results (WASA, 1995) showed similar findings.

EXTENDING WAVE CLIMATE VARIABILITY ANALYSIS TO THE CENTURY TIME SCALE

In order to further investigate wave climate variability on a century time scale a 40-year continuous wave hindcast is presently being carried out at AES, based on the NCEP (U.S. National Centers for Environmental Prediction) global re-analysis for 1957-96 (BAMS reference). The objective of this “Reference Wave Climatology for the North Atlantic Ocean” project is: “To produce a high-quality, homogeneous, long-term wind and wave data base for assessment of trend and variability in the wave climate of the North Atlantic Ocean. The results of the wave hindcast will be related to large scale features of the general circulation and via a downscaling approach used to infer wave conditions back to 1900.

The reference wave climatology will cover the domain from the equator to 75°N, from 20°E to 80°W; the grid spacing will be 0.625° latitude by 0.833° longitude, giving 9076 sea grid points. The time period will be 1957-1996. The wave hindcast will use a 3rd generation deep water wave model. All wind and wave fields will be archived at every grid point each 3 hours for 40 years on CD-ROM; wave spectra will be archived at a few selected points.

The key to the wave hindcast will be the wind fields used to drive it. The NCEP re-analysis wind fields should provide an unbiased forcing field over the 40-year period, using all available data and a consistent numerical model for the complete period of analysis. This should remove the problems encountered by WASA in attempting to use archived Fleet Numerical Meteorology and Oceanography Center (FNMOC) wind fields; the inhomogeneities encountered in that data set were so severe that removal of them was found to be impossible.

The results from this reference wave climatology will give us, finally, the information we need in order to properly investigate the spatial changes in the wave climate over the past 40 years, and through the downscaling approach, to investigate variability over the past century.

CONCLUSIONS AND GENERAL OBSERVATIONS

- *There is no discernible trend in magnitude or frequency of extreme wave heights on the east coast of Canada, but there is significant inter-annual variability (as was found in WASA).*

- *Any apparent trend is all caused by two or three recent events on Scotian shelf (since 1991); this illustrates the real danger in using simple linear trend analysis over a long time period which contains cyclical behaviour.*

- *The extreme events of the early 1990's on the Scotian shelf may represent a change in large-scale circulation patterns, but are not inconsistent with events experienced earlier in the century*

- *A statistical downscaling approach is required to extend trend and variability analyses to 1900.*

- *It is essential that we maintain (or enhance) the moored buoy network and validate offshore platforms for long term wind/wave monitoring*
  .

- *Wave hindcast models (including wind aspects) still need work in relation to extreme conditions; mesoscale effects may be important.*

- *The tropical storm population must be revisited in light of Hurricane Luis experience.*

- *The use of historical synoptic weather maps creates a bias towards more extreme conditions in recent years due to increased observational densities, satellite observations and improved numerical models.*

- *Experimental results from strap-down accelerometers shows waves are underestimated by about 10%; "maximum" waves reported until at least 1997 are incorrect and should be avoided.*

REFERENCES

Bacon, S. and D.J.T. Carter
1991.Wave Climate Changes in the North Atlantic and the North Sea. International Journal of Climatology, 11, 545-558.

Cardone, V.J. and V.R. Swail
1995. Uncertainty in Prediction of Extreme Storm Seas. Proc. 4th International Workshop on Wave Hindcasting and Forecasting, October 16-20, 1995, Banff, Alberta. Environment Canada. p. 1-20.

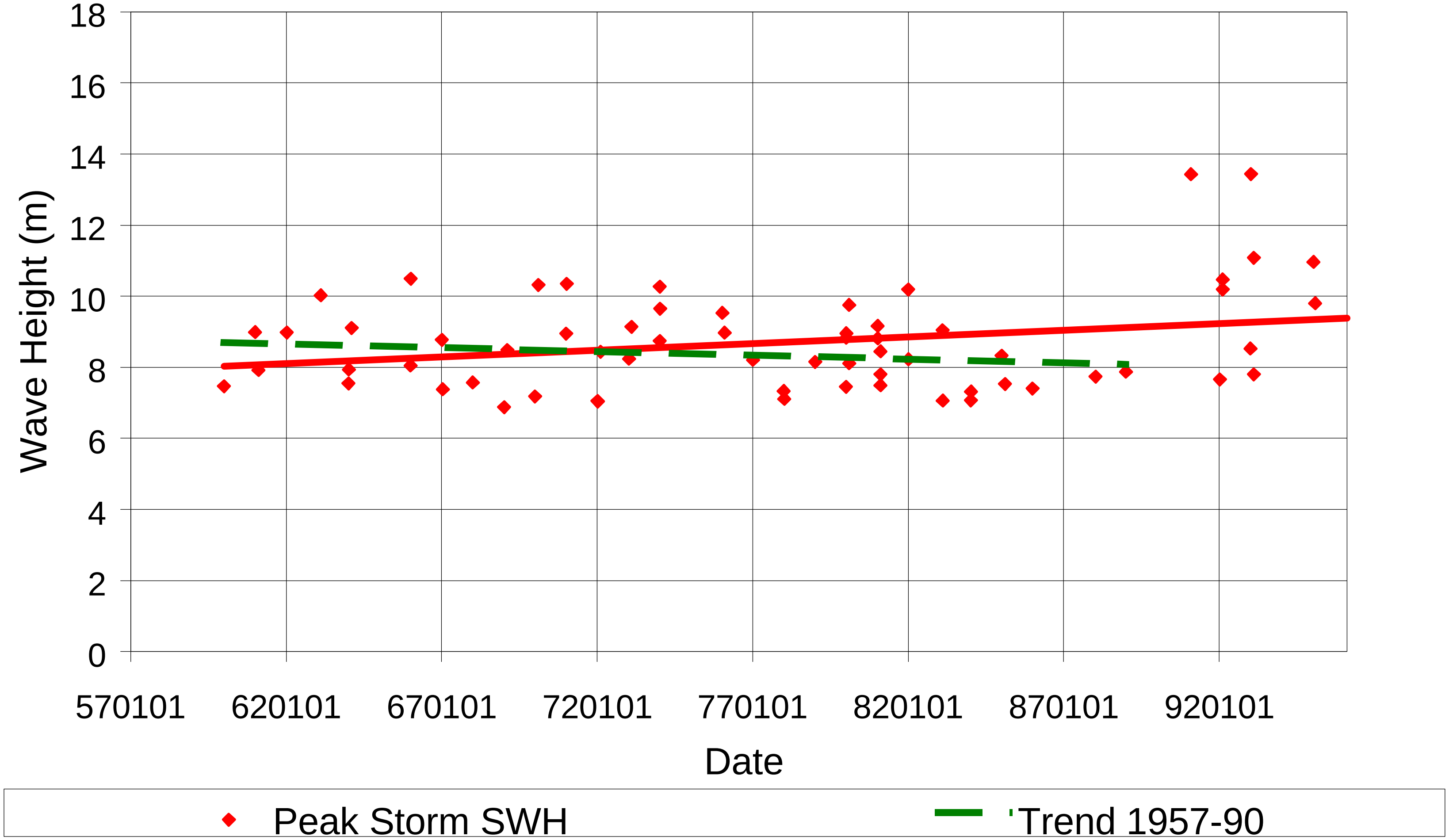
Cardone, V.J. R.E. Jensen, D.T. Resio, V.R. Swail and A.T. Cox, 1995
Evaluation of Contemporary Ocean Wave Models in Rare Extreme Events: The Halloween Storm of October 1991 and the Storm of the Century of March 1993. Jour. Atmos. Ocean. Tech., Vol 13, No. 1, p. 198-230.

NCEP
1996. The NCEP/NCAR 40-Year Reanalysis Project. Bull. AMS, Vol. 77, No. 3, p. 437-471.

Resio, D.T., V.R. Swail and R.L. Atkins, 1995
A Study of Relationships Between Large-Scale Circulation and Extreme Storms in the North Atlantic Ocean. Proc. 4th International Workshop on Wave Hindcasting and Forecasting, October 16-20, 1995, Banff, Alberta. Environment Canada. p. 65-80.

WASA
1995. The WASA Project: Changing Storm and Wave Climate in the Northeast Atlantic and Adjacent Seas? Proc. 4th International Workshop on Wave Hindcasting and Forecasting, October 16-20, 1995, Banff, Alberta. Environment Canada. p. 31-44.

Figure 1. Variability of Scotian Slope Storm Waves



2.4.2 *Hurricanes*

The Hyper-Active 1995 Atlantic Hurricane Season: A Spike or a Harbinger of Things to Come?

Stanley B. Goldenberg[a], Lloyd J. Shapiro[b] and Christopher W. Landsea[a]
[a]Hurricane Research Division /AOML/NOAA, 4301 Rickenbacker Cswy., Miami, Florida 33149. E-mail: <goldenberg@aoml.noaa.gov>
[b]Department of Atmospheric Science, Colorado State University, Ft. Collins, Colorado 80523.

During most of the years 1970-87, the North Atlantic hurricane basin had experienced a relative lull in overall tropical cyclone activity. The below-normal activity was especially evident in drastically reduced numbers of hurricanes affecting the Caribbean Sea and Maritime Canadian regions and basin-wide numbers of major hurricanes[1] (MHs), and almost a total absence of MH landfalls affecting the east coast of the U.S. After the experience of renewed "normal" activity in 1988 and 1989 (with five MH during those two years), it was suggested that the Atlantic basin was returning to a long-term period of higher activity such as what was experienced back in the decades of the 1950s and 1960s and some earlier periods. The heightened activity in 1988 and 1989 was followed, however, by a marked downturn in activity from 1991-94. As a result of the resumption of the below-normal activity, primarily attributed to wind anomalies driven by the highly anomalous, long-lasting warm sea-surface temperature (SST) event (El Niño) in the tropical Pacific, the notion that the Atlantic basin had entered a high-activity regime was pretty much discarded.

The warm event in the Pacific finally ended in early 1995 and was followed by one of the most active hurricane seasons in the Atlantic on record with almost every measure of activity over twice the long-term mean. Of particular note was that the season produced five MHs for the first time since 1964. The chief issue being addressed in the current study is whether or not the activity of the 1995 season was simply an anomalous "spike" or a harbinger of multi-decadal-scale climate shifts signaling the probability of greater activity over the next ~10-20 years. Long-term climate changes are typically associated with slowly evolving fluctuations in the world's oceans. Some of these oceanic fluctuations will be examined and related to Atlantic tropical cyclone activity.

Most of the tropical cyclones in the Atlantic basin form from easterly (African) wave disturbances which move off of the African coast primarily between 10° and 15°N. Although the number of easterly waves in the tropical Atlantic tends to be fairly steady from year to year, the fraction of these that develop into tropical cyclones exhibits substantial variability. The easterly waves account for ~60% of the Atlantic basin tropical storms and minor hurricanes but ~85% of the MHs. The vast majority of the easterly-wave spawned MHs began development (i.e., reached tropical depression strength) in the southern band between ~10° and 20°N, stretching between the west coast of Africa and Central America, called the "main development region" (MDR) by Goldenberg and Shapiro 1996 (hereafter referred to as GS96). The implication of the vast majority of MHs developing in the MDR is that they are far more sensitive to conditions in the deep tropics than tropical storms or minor hurricanes and hence are much more sensitive to interannual and interdecadal fluctuations of environmental conditions in the tropics. The main key to understanding fluctuations in tropical cyclone activity in the Atlantic, especially on the interannual and interdecadal scales, is to focus on the MDR, across a portion of which *all* easterly waves *must* travel, at least initially. Conceptually, the tropical cyclone activity (and especially MH activity) can be thought of as operating similar to a sluice gate that "opens" and "shuts" in the MDR to allow easterly waves to "pass", i.e., to develop. (For a more complete discussion of this concept and of other issues addressed in this article, see Goldenberg, *et al*., 1997; hereafter referred to as G97.)

The climatic factors that "operate" the sluice gate can be separated into those having "local" and "remote" effects. A factor having a local effect is one that is located in the actual region of tropical

---

[1]MH corresponds to categories 3, 4 or 5 on the Saffir-Simpson scale (maximum sustained surface wind speed of 50 m s^{-1}). Hurricanes of categories 1 and 2 will be referred to as minor hurricanes.

cyclone development, i.e., usually in the MDR, and has a direct thermodynamic or dynamic connection to development. A factor having a remote effect is one that is located away from the actual region of tropical cyclone development, but is either associated with (i.e., an indicator of), or causes, via teleconnections, fluctuations in conditions in the MDR.

The primary local factor is the magnitude of the vertical shear between the upper- and lower-troposphere, $|V_Z|$. It is well accepted that strong V_Z inhibits the formation and intensification of tropical cyclones, primarily by preventing the symmetric organization of deep convection. Conditions for development are usually deemed unfavorable when local $|V_Z|$ exceeds ~7.5 m s^{-1}. During August-September-October (ASO), the peak three months of the Atlantic hurricane season during which virtually all of the MHs form, westerly V_Z dominates most of the Atlantic basin, especially over the MDR, where the climatological $|V_Z|$ is greater than 10 m s^{-1} for most of that region (GS96). These climatologically high values for $|V_Z|$ are the main reason why the Atlantic basin is not usually favorable for development, even during ASO when the SSTs are sufficiently high and easterly waves are abundant. Increased (decreased) $|V_Z|$ is generally caused by upper-level westerly (easterly) and lower-level easterly (westerly) anomalies which add to (subtract from) the climatological upper-level westerlies and lower-level easterlies over the MDR (GS96).

One of the main remote factors are SST fluctuations in the equatorial Pacific associated with El Niño/Southern Oscillation (ENSO). Positive (negative) SST anomalies associated with an El Niño (La Niña) event have been linked to unfavorable (favorable) conditions for development in the Atlantic basin due to an increase (decrease) in $|V_Z|$ over the MDR (GS96). Another remote factor that has been linked to interannual variability in Atlantic basin tropical cyclone activity are rainfall fluctuations over the western Sahel (Landsea and Gray 1992) with positive (negative) rainfall anomalies associated with favorable (unfavorable) conditions. The Sahel rainfall factor has also been attributed primarily to its association with changes in $|V_Z|$ over the MDR (GS96).

EVIDENCE FOR A MULTI-DECADAL SCALE SHIFT

Observations of Tropical Cyclone Activity

The first and most important indicator of a possible long-term shift is in the tropical cyclone activity itself. If one thinks of the interdecadal-scale fluctuations modulating the interannual-scale changes, then it is easy to see why not only the overall activity for the active decades was higher, but also the maximum values for activity were much higher. Although one might expect to see strong interannual fluctuations in activity in both active and inactive periods, the inhibiting environmental influences during the inactive decades seem to set a “cap” on the possible levels of activity. It is the assumption here that it would be highly unlikely to see certain levels of activity in the decades when decadal-scale fluctuations of certain environmental conditions are not in the phase favorable for Atlantic tropical cyclone development.

The parameter “Net Tropical Cyclone” (NTC) activity (see G97) gives a type of measure of the overall activity in a season, Figure 1 shows the Atlantic basin values of NTC for each of the seasons from 1950 through 1996. The mean for the years 1970-94 is only 75% compared to a mean of 116% for the more active period 1944-69. It is striking to note that only five years during the period 1970-94 had even marginally above average activity (i.e., >100%) compared to 15 of the earlier period being above normal. In addition, there was an apparent cap of 140% for NTC during the inactive decades. The more active 1944-69 period, however, equaled this cap two times and exceeded it six times. In 1995, for the first time since 1969, the NTC cap was exceeded with a value of 231%. In addition, the cap has been exceeded during 1996 with an operational value of 198%.

If years with values of NTC 150% are designated as “hyper-active” years, then there were *five* hyper-active years during the more active 1944-69 period , while *no* years were hyper-active during the years 1970-94. The hyper-active year 1995 marked the first such year since 1969. The hyper-active years occurred, on the average, every five years or so during the previous active decades. However, 1996 has exceeded 150% NTC giving the Atlantic two hyper-active years in a row for the first time since the 1932 and 1933 seasons (154% and 225% respectively). These two successive hyper-active years give a strong reason to suspect that the Atlantic basin has made the transition to a more active regime, probably on a multi-decadal scale. Evidence for this transition is also strongly evident in MH activity (see G97).

Decadal-scale fluctuations in SST

Fluctuations in western Sahel rainfall have been shown to be associated with "local" SST fluctuations in the eastern tropical Atlantic, and "remote" SST fluctuations in the midlatitudes in the Atlantic (both North and South) and in the equatorial Pacific (associated with El Niño). The key region for interannual SST fluctuations, as shown by the empirical orthogonal function (EOF) analysis of global SSTs is the Pacific Ocean, primarily the region associated with El Niño (as shown in the second mode: SST EOF2). The key regions for decadal-scale fluctuations (SST EOF3) are the midlatitudes in the Atlantic Ocean, with opposite phases in the North and South Atlantic, i.e., the North-South Atlantic dipole. Ward (1997) has shown that the multi-decadal scale fluctuations in Sahel rainfall are related to the interhemispheric SST differences, i.e., the North-South dipole, while the interannual variability in the rainfall is more closely associated with central and western Pacific SST fluctuations. It is likely that the same teleconnection patterns that are producing the fluctuations in Sahel rainfall are also contributing to changes in environmental conditions in the MDR in the Atlantic, in particular, $\boldsymbol{V_Z}$, that are affecting Atlantic basin activity.

Ward (personal communication 1996) has noticed an increase in rainfall for the Sahel region of Africa and for an "all-India" index (both calculated for July-September) during the period 1988-95 compared to the 1970-87 period. This has been observed in conjunction with a warming of the Northern Hemisphere (mid-latitude) SSTs compared to those of the Southern Hemisphere. These upturns which began in 1988 in rainfall and Northern Hemisphere SSTs were accompanied by a decrease in the positive values of the "multi-decadal" SST EOF3 which has been positive since 1968.

Another SST indicator which points to a recent change on the decadal time scale in the Atlantic was presented in Hansen and Bezdek (1996). They examined the temporal and spatial fluctuations in the upper and lower deciles of low-pass filtered (at four years), locally normalized SST anomalies in the North Atlantic. The decadal-scale fluctuations (not shown here) basically point to warmer SSTs in the North Atlantic for the decades of the 1950s and 60s, predominately colder in the 1970s and 80s, with a reversal again (warmer anomalies dominating) manifesting itself in the late 1980s, more specifically 1987 or 1988. This shows a strong association with the observed decadal-scale fluctuations in MH activity in the Atlantic basin; greater activity in the earlier decades followed by the relatively inactive 1970s and 80s. The significance of the change at the end of the 1980s will be discussed in Sect. 3.

Vertical Shear Changes in the Main Development Region

Although a warmer tropical North Atlantic would seem to enhance tropical cyclone activity as a local effect (see Sect. 1), *it is unlikely that this is the main physical connection between the warmer (colder) North Atlantic and active (inactive) Atlantic hurricane seasons*. Shapiro and Goldenberg (1997) suggest that the local SST effect plays either a *negligible* role (in the case of MHs) or at best (in the case for all hurricanes) is a *second-order effect* for increased activity. The predominate effect, as discussed in Sect. 1, is more likely the fluctuations in $|\boldsymbol{V_Z}|$ in the MDR. It is certainly possible that the same favorable conditions for increased Sahel rainfall, i.e., warmer North Atlantic SSTs, also, by associative arguments, result in decreased $|\boldsymbol{V_Z}|$ over the MDR. In other words, the decadal-scale SST fluctuations affecting Atlantic hurricane (particularly MH) activity would likely produce the connection via changes in the upper- and lower-level zonal circulations over the MDR.

Figure 2 shows the fluctuations in ASO $|\boldsymbol{V_Z}|$ (see G97 for data description) for an area in the MDR that exhibits some of the strongest correlations between $|\boldsymbol{V_Z}|$ and MH fluctuations (GS96). The ASO $|\boldsymbol{V_Z}|$ in the MDR experienced a noticeable shift towards lower (more favorable) values starting in 1988. The years since the shift have had *much* lower than average $|V_Z|$ values with the exception of the four years (1991-94) affected by the long-lasting anomalous tropical Pacific warm event. In addition, the lower than average values are the most favorable $|V_Z|$ values in that region since 1975, the beginning of this wind data set. The shift starting with 1988 is noticeable in both the upper- and lower-level winds (not shown) for this region. The mechanism for reduced $|V_Z|$ is the reduction of upper-level westerlies and lower-level easterlies.

DISCUSSION

The evidence presented in this study examined certain multi-decadal scale changes in Atlantic SSTs with a shift towards warmer conditions in the Northern Hemisphere beginning around 1988. This shift was accompanied by a shift towards lower vertical shear in the main development region of the Atlantic hurricane basin, a condition more favorable for increased tropical cyclone activity, especially major hurricanes. Although the lower, more favorable vertical shear conditions were modified somewhat from 1991 through 1994 during the long lasting El Niño event, the favorable values quickly resumed in 1995 as soon as the equatorial Pacific warming event had concluded. It seems indeed likely that a decadal-scale shift, associated with decadal-scale changes in Atlantic SSTs, towards a more favorable environment for Atlantic tropical cyclone development took place around 1988 but was subsequently temporarily masked by the highly anomalous, long lasting El Niño during the beginning of the 1990s.

If these changes are indeed taking place on decadal or multi-decadal scales rather than interannual scales, then the Atlantic basin may continue to see over the next decade or so, on the average, heightened activity on the order of what was seen in the 1950s and 60s rather than the suppressed activity of the 1970s and most of the 80s. What might be expected would be several years with very high activity, while most years would be close to average or slightly above average and only a few far below average. This would be dramatically different from the inactive decades when most years were below (often well below) average, some years were about average and very few years even just moderately above average. If the past holds the key to the future in this case, the overall increase would mean significant increases in the numbers of hurricanes affecting the Caribbean Sea and Maritime Canadian regions, basin-wide numbers of MHs, and MH landfalls affecting the east coast of the U.S.

The possible implications of these changes are staggering. The fact that major hurricanes have historically accounted for most of the damage and deaths due to tropical cyclones combined with the fact that there has been a dramatic population increase along the United States hurricane-vulnerable coasts during the two inactive decades, add up to the potential for massive monetary loss, especially when major cities are impacted. In addition there is a potential for large loss of life in the case of an incomplete evacuation during a rapidly intensifying system.

Concerning the question as to whether the increase in activity experienced in 1995 is due to anthropogenic global warming, Gray *et al*. (1995) states that; “The large increase in 1995 Atlantic activity ... was the result of natural variations in global circulation patterns and we are able to predict a portion of this increase without invoking global warming or greenhouse gas increases. Therefore, there is *no plausible way* that increases in man-induced greenhouse gases can be even *remotely* related to this year’s extremely active Atlantic basin hurricane season.” There have been various studies investigating a possible impact, if any, on the number and strengths of Atlantic basin hurricanes *if* the earth experiences a long-term global warming. The results are inconclusive (Houghton, *et al*. 1996), with some studies documenting an increase while others suggest a decrease in associated activity. In addition, the historical multi-decadal scale variability in Atlantic hurricane activity is much greater than what could be “expected” at the present time from a small, gradual global temperature increase.

Caution must be used in applying the conclusions suggested in this study. Firstly, extrapolation, especially for decadal (and longer) time scales, certainly has a high level of uncertainty. One of the main difficulties in observing long-term fluctuations in tropical cyclone activity is that the reliable data extends back only about 50 years. If the temporal scale being addressed here is on the order of 40 years, i.e., ~20 years of higher activity and ~20 years of lower activity, then only about one complete cycle has been adequately sampled. In addition, it is unlikely that the signal is so “clean” that it would always be manifested as the same time length of favorable and unfavorable conditions, i.e., the current favorable conditions might only last a total of 5-10 years or could extend for 20-30 years, etc.

Secondly, increased activity during a particular year does not automatically mean increased storm-related damage. Even relatively inactive years can produce hurricane-spawned disasters. It is not how many systems develop in a particular year that determine the amount of damage, but how many systems actually impact land and where. Far more damage can been done by one major hurricane impacting a heavily populated area than by several major hurricanes hitting sparsely populated areas, or of course, not making landfall at all. For example, there was ~$25 billion in damage to the United States caused by Hurricane Andrew in 1992, the only major hurricane during a relatively inactive year (NTC = 66%), compared to less than $6 billion in damage to the United States during 1995, one of the most active years on record (NTC = 231%) with five major hurricanes. In addition, disasters can occur even from weaker systems due to flooding. It is still obvious, however, that active years have a greater overall *potential* for more regions to be impacted than inactive years.

REFERENCES

Goldenberg, S.B., and L.J. Shapiro
1996: Physical mechanisms for the association of El Niño and West African rainfall with Atlantic major hurricane activity. *J. Climate,* 9, 1169-1187.

__, __, and C.W. Landsea
1997: Are we seeing a long-term upturn in Atlantic basin major hurricane activity related to decadal-scale SST fluctuations? Preprints, *7th Conf. on Climate Variations.* Long Beach, CA, Amer. Meteor. Soc., 305-310.

Gray, W., C.W. Landsea, P.W. Mielke, Jr., and K.J. Berry
1995: Summary of 1995 Atlantic tropical cyclone activity and verification of authors’ seasonal prediction. 27 pp. [Available from Dept. of Atmospheric Sc., Colorado State University, Ft. Collins, CO 80523.]

Hansen, D.V., and H.F. Bezdek
1996: On the nature of decadal anomalies in North Atlantic sea surface temperature. *J.Geophys. Res.*, **101**(C4), 8749-8758.

Houghton, J.T., L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell, Eds.
1996: Climate Change 1995: *The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, New York, 572 pp.

C.W. Landsea and W.M. Gray
1992: The strong association between western Sahel monsoon rainfall and intense Atlantic hurricanes. *J. Climate*, **5**, 435-453.

Shapiro, L.J. and S.B. Goldenberg
1997: Atlantic sea surface temperatures and hurricane formation. Submitted to *J. Climate*.

Ward, M.N.
1997: Diagnosis and short-lead time prediction of summer rainfall in tropical North Africa at interannual and multi-decadal timescales. Submitted to *J. Climate*.

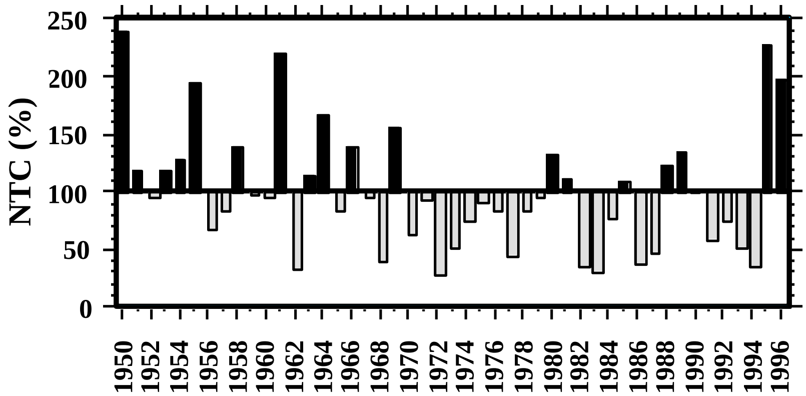


Figure 1. Net Tropical Cyclone activity (NTC) for the North Atlantic basin. Values for above (>100%) and below (<100%) average activity are shown as solid and shaded columns, respectively.

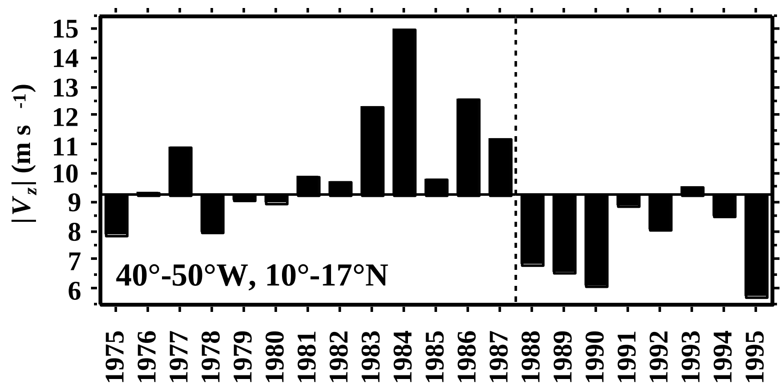


Figure 2. Average of ASO $|V_z|$ for the region from 40° to 50°W longitude and 10° to 17°N latitude. Solid horizontal reference line corresponds to sample (1975-95) mean.

3.0 Regional Climate Sensitivities

This chapter contains contributions from various researchers working in areas that are particularly sensitive to climate change and variability in this region. The final paper, describing socio-economic dimensions, covers each of the topics discussed.

3.1 *Fisheries and Plankton*

Impacts of Climate Variability on Atlantic Canadian Fish and Shellfish Stocks

K.F. Drinkwater

Fisheries and Oceans Canada
Bedford Institute of Oceanography
Dartmouth, Nova Scotia B2Y 4A2

Frank *et al*. (1988, 1990) were the first to examine the response of fish and shellfish stocks in Atlantic Canada to possible climate change scenarios. Their approach was to use published relationships between environment and fish to predict the response of fish stocks to the possible atmospheric CO_2-induced climate changes in the physical oceanography of the northwest Atlantic region suggested by Wright *et al*. (1986). Frank and co-workers noted that lack of understanding of the linkages between environmental changes and fish stocks, and the dangers of extrapolating beyond the original conditions used to formulate such linkages, produced the largest uncertainty in forecasting the response to possible future climate changes. This statement continues to hold, although our understanding has increased and new linkages have been established. While GCMs (general circulation models) have improved in the years since the late 1980s, predictions of CO_2-induced climate change on a regional basis are not yet considered to be reliable, including those for the Atlantic Region of Canada. In the absence of such regional climate change information, I have focused upon reviewing the major linkages between fisheries and the environment, providing examples of the fisheries response to past climate variations in Atlantic Canada. It includes several examples of linkages established since the Frank *et al*. (1990) study but is not intended to be a fully comprehensive review of environmental effects on fisheries, a job clearly beyond the scope of the present study.

Fish and shellfish respond directly to climate fluctuations as well as to changes in their biological environment (predators, prey, species interactions, disease) and to fishing pressures. While this multi-forcing sometimes makes it difficult to establish unequivocal linkages between changes in the physical environment and the response of fish or shellfish stocks, some effects are clear (see reviews by Cushing and Dickson, 1976; Bakun *et al*., 1982; Cushing 1982; Sissenwine, 1984; Shepherd *et al*., 1984; Sharp, 1987). These include effects on the growth and reproduction of individual fish, as well as the distribution and abundance of fish populations. Within this paper the term fish refers to both finfish (vertebrates) and shellfish (invertebrates) unless otherwise stated. The influence on abundance occurs principally through effects on recruitment (how many young survive long enough to potentially enter the fishery) but in some cases may also be due to direct mortality of adult fish. How does the environment affect fish? This occurs through four main processes; direct physiological effects, diseases, food and predators (Shepard *et al*. 1984). Physiological effects include those metabolic processes influenced by temperature and salinity. Fish often seek optimal temperature or salinity regimes or avoid sub-optimal conditions. Ocean climate changes can thus lead to distributional changes. If caught in sup-optimal conditions, performance is reduced leading to starvation or increased predation. Certain environmental conditions are more conducive to diseases than others. For example, warm waters can trigger disease outbreaks; likewise, cold temperatures can limit them. The environment affects feeding rates and competition, as well as the abundance, quality, size, timing, spatial distribution, and concentration of food. It also affects predation through influences on the abundance and distribution of predators.

Fish are influenced not only by temperature and salinity conditions but also by mixing and transport processes. For example, mixing can affect primary production through promoting nutrient replenishment of the surface layers and influence the encounter rate between larvae and prey organisms. Also, ichthyoplankton (fish eggs and larvae) can be dispersed by the currents, which may carry them into or away from areas of good food production, into or out of optimal temperature or salinity conditions, and perhaps ultimately determine whether they are lost to the original population. The remainder of the paper provides some examples of these effects within Atlantic Canadian waters.

ENVIRONMENT/FISHERIES LINKAGES: SOME EXAMPLES

Growth

Environmental conditions have a marked effect on the growth of many fish species. For example, mean bottom temperatures account for 90% of the observed (10-fold) difference in growth rates between different Atlantic cod (*Gadus morhua*) stocks in the North Atlantic (Brander, 1994, 1995). Warmer temperatures lead to faster growth rates. Regional studies have shown similar results (Fleming, 1960; Shackell *et al*., 1995). In the northwest Atlantic, the largest cod are found on Georges Bank with a 4 year old fish being, on average, five times bigger than one off Labrador and Newfoundland. Temperature not only accounts for differences in growth rates between cod stocks but also year-to-year changes in growth rates within a stock. Thus, sea temperature declines since the mid-1980s are responsible for approximately 50% of the recent observed decrease in size-at-age of Atlantic cod on the northeastern Scotian Shelf (Campana, 1995) and off Newfoundland (de Cárdenas, 1996; Shelton *et al*., 1996). This is particularly important given that 50-75% of the declines in the spawning stock biomass of the Newfoundland, Gulf of St. Lawrence and northeastern Scotian Shelf cod stocks during this period were caused by reduced weight-at-age (Sinclair, 1996). Fifty percent of the decline in recent years of weight-at-age of the 4 to 8 year old northern cod can be accounted for by the weight at age 3 indicating size at an early age affects future fish production (Krohn and Kerr, 1996). Since 1979, the weight of northern cod older than 4 years have been lower than expected based on predictions from weight at age 3 suggesting the growth environment for these older fish has also worsened (Krohn and Kerr, 1996).

Temperature-dependent growth rates are not restricted to cod. Cold bottom temperatures resulted in decreased growth rates of adult American plaice (*Hippoglossoides platessoides*) on the Grand Bank during the 1980s (Brodie, 1987), and reduced length-at-age and weight-at-age for ages 3 and 4 capelin (*Mallous villosus*) off Newfoundland during the 1990s have been shown to be a direct response to cold ocean temperatures (Nakashima, 1996). Fifty percent of the interannual variations of growth of herring (*Clupea harengus harengus*) ages 3-7 in St. Mary’s and Placentia bays were accounted for by the March to December water temperatures (Winters *et al*., 1986). Growth rates of larvae have also been found to be temperature dependent for many species in the northwest Atlantic including Atlantic cod, haddock (*Melanogrammus aeglefinus*) and winter flounder (*Pseudopleuronectes americanus*) (Morse, 1989).

Reduced growth rates at lower temperatures are, in part, due to changes in feeding rates. Laboratory experiments by McKenzie (1934, 1938) found that Atlantic cod from the Bay of Fundy and Scotian Shelf ate well at temperatures within their normal tolerance range but ceased feeding at very high (>17°C) or very low temperatures (<0°C). He also noted that at low temperatures cod had difficulty swallowing and the size of the food particles consumed decreased as the cod were unable to open their mouths as wide as in warmer water (McKenzie, 1938). Kohler (1964) found feeding rates for Atlantic cod increased with temperature over the range 4° to 13°C, a result consistent with that of McKenzie (1934, 1938). Reduced feeding with subsequent weight loss at low temperatures for adult American plaice from the Grand Banks has also been measured in the laboratory by Morgan (1992). Besides lower feeding rates, reduced growth may also arise through delayed spawning (see below), initially causing a short growing season, and subsequently smaller size latter in life.

Spawning and Reproduction

In addition to growth, the environment affects the reproductive cycle of fish and shellfish. For example, the age of sexual maturity of certain fish species is determined by ambient temperatures. Atlantic cod off Labrador and the northern Grand Banks mature at age 7 and in the northern Gulf of St. Lawrence and the eastern Scotian Shelf at age 6 while in the warmer waters off southwest Nova Scotia and on Georges Bank they mature at 3.5 and 2 years, respectively (Myers *et al*., 1996a).

Spawning times too are influenced by temperature. Cold temperatures typically result in delayed spawning through slow gonad development as has been observed in Atlantic cod on the northern Grand Bank (Hutchings and Myers, 1994a). While warm temperatures promote gonad development resulting in earlier spawning, the relationship between temperature at the spawning site and time of spawning depends on local hydrography and fish distribution. In contrast to the positive relationship between local temperatures and time of spawning on the northern Grand Banks, cold temperatures lead to earlier spawning of cod off southern Newfoundland (Hutchings and Myers, 1994a). However, these fish reside in warm offshore waters and move onto St. Pierre Bank prior to spawning. In very cold years on the Bank, they appear to delay migration onto the Bank thereby remaining in the warm offshore waters longer, resulting in faster gonad development and an earlier readiness to spawn.

Temperature-dependent spawning again is not limited to cod. In the early 1990s, extremely low temperatures during spring off Newfoundland delayed capelin spawning by over a month which lead to slow growth rates and poor condition (Nakashima, 1996). Marak and Livingston (1970) found a 1.5° to 2°C temperature change produced a difference in spawning time of haddock on Georges Bank by a month with earlier spawning and a longer duration in warm years. From studies in the Baie des Chaleurs within the Gulf of St. Lawrence, spawning of the giant scallop (*Placopecten magellanicus*) has been shown to be associated with rapid temperature changes caused by wind-induced upwelling (Bonardelli *et al*., 1996). It therefore follows that interannual variations in timing of spawning likely depends upon wind forcing.

Miller *et al*. (1995) found that 52% and 70% of the seasonal variance of egg and larval size at hatch, respectively, of Atlantic cod on the Scotian Shelf are temperature dependent over the range 2° to 14°C with size decreasing as temperature increases. Similar dependence of egg size on temperature was found by Ware (1977) for Atlantic mackerel (*Scomber scombrus*) in the Gulf of St. Lawrence. This is believed to be in part an ecological advantage in order to match available prey size at the time of hatching as the latter is temperature dependent (Ware, 1977).

Incubation times of cod eggs are also temperature dependent. Page and Frank (1989) found they varied from 8 to 42 d at 14° to 1°C, respectively, for Atlantic cod on the Scotian Shelf. Thus eggs in colder water are more vulnerable to predation due to longer exposure time and may therefore experience lower survival.

Distribution and Migration

Temperature is one of the primary factors, together with food availability and suitable spawning grounds, in determining the large-scale distribution pattern of fish and shellfish. Because most fish species or stocks tend to prefer a specific temperature range (Coutant, 1977; Scott, 1982), long-term changes in temperature can lead to expansion or contraction of the distribution range of certain species. These are generally most evident near their northern or southern boundaries; warming results in a distributional shift northward and cooling draws species southward.

Capelin, a cold-water pelagic species and the major food source of Atlantic cod off Newfoundland and Labrador, spread southward as far as the Bay of Fundy when temperatures declined south of Newfoundland in the mid-1960s and retracted northward as temperatures rose in the 1970s (Tibbo and Humphreys, 1966;

Colton, 1972; Frank, *et al*., 1996). During cooling in the later half of the 1980s and into the 1990s, capelin again extended their range, eastward to Flemish Cap and southward onto the northeastern Scotian Shelf off Nova Scotia (Frank *et al*., 1996; Nakashima, 1996). For example, small quantities of capelin began to appear in the groundfish trawl surveys on the Scotian Shelf in the mid-1980s and since then numbers have increased dramatically (Frank *et al*., 1996). Initially only adult capelin were caught but in recent years juveniles have appeared, suggesting capelin are successfully spawning.

This recent shift appears to be part of a larger scale ecosystem change. While capelin were spreading onto the Scotian Shelf, Arctic cod (*Boreogadus saida*) were moving southward. Another small cold-water pelagic fish, its primary grounds have traditionally been the Labrador Shelf stretching southward to northern Newfoundland. Recently these fish have pushed southward to the Grand Banks and into the Gulf of St. Lawrence in large numbers. This southward movement was suggested by Gomes *et al*. (1995) and substantiated from annual autumn ground surveys off Newfoundland through the 1990s (Lilly *et al*., 1994; K. Zwanenburg and G. Howell, Bedford Institute of Oceanography, personal communication). Recent southward shifts in the distribution of groundfish species off Newfoundland and Labrador have also been documented; Atlantic cod by de Young and Rose (1993), Taggart *et al*. (1994) and Rose *et al*. (1994), and of fish assemblages consisting of both commercial (e.g. Greenland halibut (*Reinhardtius hippoglossoides*) and American plaice) and non-commercial species by Gomes *et al*. (1995).

Changes in distribution were also observed during the warming trend in the 1940s in the Gulf of Maine which produced a northward shift in abundance and distribution of Atlantic mackerel, American lobster (*Homarus americanus*), yellowtail flounder (*Limanda ferruginea*), Atlantic menhaden (Brevoortia tyrannus), and whiting (*Merluccius bilinearis*) as well as the range extension of more southern species such as the green crab (*Carcinus maenas*) (Taylor *et al*., 1957). In contrast, during the cooling trend in the Gulf of Maine from 1953-1967, American plaice extended their range southward while butterfish (*Peprilus triancanthus*) retracted southward to their more traditional distributional range prior to the warm 1950s (Colton, 1972). Mountain and Murawski (1992) have documented north-south shifts in distribution as a function of temperature within the Gulf of Maine. The weighted-mean catch for 14 out of 30 stocks investigated from groundfish surveys conducted during 1968 to 1989 was found to increase northward with increasing temperature. This relationship was found to be strongest for Atlantic mackerel, Atlantic herring and silver hake (*Merluccius bilinearis*).

Many species that migrate appear to key on environmental conditions. For example, Atlantic mackerel migrate from their overwintering grounds off the Middle Atlantic Bight across the Gulf of Maine along the Atlantic coast of Nova Scotia and into the Gulf of St. Lawrence. Their arrival at any location along their route requires temperatures warmer than 7° to 8°C (Sette 1950). Similarly, the north-south migrations of American shad along the Atlantic coast of North America are regulated by the seasonal movement of waters in the 13°-18°C range (Leggett and Whitney, 1972). The timing and geographical distribution of Atlantic salmon (*Salma salar*) along the Newfoundland and Labrador coasts are dependent upon the arrival of the 4°C water (Narayanan *et al*., 1995). April sea surface temperatures and ice conditions in the southern Gulf of St. Lawrence determines the average arrival time of Atlantic herring on their spawning grounds (Lauzier and Tibbo, 1965; Messieh, 1986). Ice conditions also appear to control the arrival time in spring of Atlantic cod onto the Magdalen Shallows in the Gulf of St. Lawrence (Sinclair and Currie, 1994). This is in contrast to their return migration in the autumn to the deep waters in the Laurentian Channel south of Cabot Strait which appears to be unrelated to environmental conditions.

Abundance and Recruitment

Understanding recruitment variability has been the number one issue in fisheries science this century. Evidence of changes in fish abundance in the absence of fishing suggests the likelihood of environmental causes. Since the advent of intensive fishing, it has become increasingly difficult to sort out the relative importance of fishing versus environment as the cause of recruitment variability. Still, recruitment levels have frequently been associated with variations in temperature during the first years of life of the fish (Drinkwater and Myers, 1987). The recruitment levels of Atlantic cod off West Greenland, Labrador and Newfoundland have generally been high when ocean temperatures are warm and decrease when temperatures are cold (Taggart *et al*., 1994), but the warm periods were also those in which the spawning stock biomass were high and thus temperature as the main cause of recruitment decline can not be confirmed. During the last 10 years of extremely cold temperatures in the northern regions, recruitment from Labrador to the Grand Bank has been poor. At the same time, as previously mentioned, cod moved further southward. A recent hypothesis suggests these two features are related; in cold years, spawning tends to occur at southerly locations where larval retention and hence survival is poor (de Young and Rose, 1993). Other studies have suggested that the collapse of the cod stocks was not caused by a low larval survival index (recruitment/spawning stock biomass) and attributes the poor state of the fish stocks to overfishing (Myers *et al*., 1996b). In the Gulf of St. Lawrence, the survival index of Atlantic cod is weakly related to the freshwater runoff from the St. Lawrence River system (Chouinard and Frechet, 1994). High survival occurs only when runoff is above normal although years of high runoff do not always lead to high survival, implying other factors are also important. The discharge is not considered to have a direct effect on the cod but may be a proxy for food resources through influences on nutrient levels, phytoplankton production or zooplankton abundance.

Atlantic salmon, unlike their Pacific cousins, are multi-year spawners. Most of those that spawn in the rivers of eastern Canada in summer, later migrate to the Labrador Sea where they overwinter (Reddin and Shearer, 1987). The young salmon, or "smolts", also travel to the Labrador Sea where they reside until ready to return to the rivers. There is large variability in the numbers of salmon returning to the rivers of eastern Canada each year. The similarity in the interannual variability from different rivers over widely separated regions suggests that the numbers of returning salmon are most likely determined in the marine environment. A wintertime index of the areal extent of sea surface temperatures (4°-8°C) in the Labrador Sea conducive for salmon has been developed which shows a high positive correlation with the number of salmon returning to North America during the following spring and summer (Friedland *et al*., 1993; Reddin and Friedland, 1993). This winter index is now used to predict prefishery abundance of salmon entering the rivers during the following late spring or summer. It is one of few examples where environment is used to predict fish abundance for fisheries assessment purposes.

American lobster landings in Canada and the United States increased steadily during the 1980s and into the 1990s to all time historic highs in most regions. This is due primarily to higher recruitment rather than increased fishing effort (Drinkwater *et al*., 1996). Relationships between temperature and lobster landings had been established in several areas (i.e. from the Gulf of Maine to the Gulf of St. Lawrence) prior to the large increase in landings showing higher landings during warm temperatures. This suggested that perhaps the recent high landings may have been due to a large scale warming trend. However, examination of the data showed no such warming and using recent temperature data, the temperature-landing relationships were unable to predict any significant rise in landings during the 1980s and 1990s (Drinkwater *et al*., 1996). This is an example of a "failed" relationship, one in which a linear regression between an environmental variable and fish or shellfish abundance was established only to find that it was unable to explain the observed abundance in later years. These can arise because abundance is usually controlled by more than one variable. There may be one dominant variable for a period of time but then later another variable or variables become dominant.

While most of the examples mentioned above have involved changes in temperature, there is also a transport-related effect on recruitment. Eggs and larvae are affected by currents. The 1987 haddock year class on eastern Georges Bank, which appeared to have been spawned normally in early spring, was located almost entirely in the Middle Atlantic Bight by June. This unusually large southwestward displacement was the result of an enhanced transport of water from the bank (Polochek *et al*., 1992). Recent improvements in numerical models of the currents over the continental shelves have allowed scientists to study the potential drift patterns of eggs and larvae (Werner *et al*., 1993; Lough *et al*., 1994). Advection into unfavourable sites leads to reduced recruitment if the fish die or if they can not make it back to the parent stock to reproduce (Sinclair, 1988). One example of transport related effects on recruitment involves Gulf Stream rings off northeastern United States and eastern Canada. Large meanders in the Gulf Stream will sometimes pinch off and separate from the stream to form Gulf Stream rings or eddies. Eddies on the north side of the stream rotate clockwise and tend to trap warm Sargasso Sea water in their center giving rise to the terminology “warm-core” rings. Those rings that approach the shelf often entrain large amounts of shelf water offshore, transporting it off the shelf into the adjacent deeper slope water region. Greater numbers of Gulf Stream rings close to the continental shelf during the spawning or larval periods has been shown to lead to reduced recruitment in 15 of 17 groundfish stocks, including Atlantic cod, redfish, haddock, pollock and yellowtail flounder (Myers and Drinkwater, 1989). The leading hypothesis is that rings entrain shelf waters laden with eggs and larvae, transporting them off the shelf where they may die because they cannot find appropriate habitat. Death can also occur if they encounter temperatures that are too high, as observed in the waters off Georges Bank by Colton (1959).

Catchability and Availability

Climate can also affect the fishery through influences upon availability and catchability. Availability is how many fish there are for the fishermen to catch and catchability is how difficult it is for the fishermen to catch them. Availability and catchability depend not only upon the total abundance of fish but upon when and how they are distributed. For example, if migrating fish such as herring are abundant but do not arrive on the fishing grounds during the time the fishery is permitted to fish, then the availability is low. Also, if fish are abundant but widely distributed such that concentrations are low, then catchability is also likely to be low. Similarly, if the fish are not very abundant but highly concentrated then catch rates in those areas containing fish are good. The environment can affect catchability, e.g. when temperatures are low, lobster are known to move slowly, reducing the potential for encountering lobster traps, and hence cause reduced catchability (McLeese and Wilder, 1958). The landings in cod traps off Newfoundland have also been shown to depend upon temperature variability (Templeman, 1966). If the traps are located in waters that are too cold, catches are low. Only when the temperatures are warm enough do catches increase. Similar results were observed in cod traps from Quebec off the north shore of the Gulf of St. Lawrence (Rose and Leggett, 1988).

Catch rates in the groundfish surveys conducted by the Canadian Government have also been shown to be influenced by environment conditions. For example, the abundance of age 4 Atlantic cod on the eastern Scotian Shelf caught in the annual spring surveys is greater during years when a larger proportion of ocean bottom is covered by CIL waters, i.e. temperatures less the 5^{o}C and salinities of 32-33.5‰ (Smith *et al*., 1991). This may result from cod seeking preferred conditions or an inability to avoid the trawls due to reduced swimming speeds at lower temperatures (Smith and Page, 1996).

Aquaculture

Aquaculture is rapidly expanding in Atlantic Canada and is projected to continue this pace into the future. Climate variability is important to this relatively new industry for Atlantic Canada. Decreasing temperatures may cause low minimum temperatures through the year, possibly causing mass mortalities, especially on the east coast of Canada. Long-term temperature trends will affect what species of fish or shellfish are suitable, whether there is a possibility of expansion or contraction of suitable aquaculture sites. General warming may allow aquaculture sites to expand into regions previously unavailable because either sea temperatures were too cold or there was a presence of sea ice. Growth rates of the fish or shellfish and their food requirements are temperature dependent. Aquaculturists are also interested in predictions of wind mixing which contributes to flushing (i.e. the exchange of water between the aquaculture site and the surrounding waters). Low flushing can lead to decreased oxygen, greater potential for the spread of diseases and, in the case of filter feeders such as muscles, reduced food availability.

SUMMARY

This paper has provided several examples of the affects of environment and environmental variability on fish stocks and aquaculture. As stated by Frank *et al*. (1990), taking the step to then predict the response of local marine organisms to possible climate change scenarios becomes a highly speculative exercise. However, observations of changes to the fish stocks due to climate variability in the past allow us to predict some general responses. Climate change (and here we will not deal with the amplitude nor sign of the change at this point) can be expected to result in distributional shifts in species with the most obvious changes occurring near the northern or southern boundaries of their range. Migration patterns will shift causing changes in arrival times along the migration route. Growth rates are expected to vary with the amplitude and direction being species dependent. Recruitment success could be affected due to changes in time of spawning, fecundity rates, survival rate of larvae, and food availability. Although not discussed within this paper, another possibility associated with climate change is a change in stratification (due to differences in heating, freshwater, and vertical mixing rates) which may lead to changes in the ratio of pelagic to groundfish abundance (Frank *et al*., 1990). If stratification increased, more of the production is expected to be recycled within the upper layers of the oceans and less reach the bottom. Under such a scenario higher pelagic production and lower groundfish production would be expected.

Qualitative predictions of the consequences of climate change on the fish resources of Atlantic Canada will require good regional atmospheric and oceanic models of the response of the ocean to climate change, improved knowledge of the life histories of those species for which predictions are required and further understanding of the role of environment, species interactions and fishing play in determining the variability of growth, reproduction, distribution and abundance of fish stocks. This multi-forcing and numerous past examples of “failed” environment-fish relationships indicate the difficulty fisheries scientists face in providing reliable predictions of the fish response to climate change.

REFERENCES

Bakun, A., J. Beyer, D Pauly, J.G. Pope and G.D. Sharp.
1982. Ocean sciences in relation to living marine resources: a report. Canadian Journal of Fisheries and Aquatic Sciences 39: 1059-1070.

Bonardelli, J.C., J.H. Himmelman and K. Drinkwater.
1996. Relation of spawning of the giant scallop, *Placopecten magellanicus*, to temperature fluctuations during downwelling events. Marine Biology 124: 637-649.

Brander, K.M.
1994. Patterns of distribution, spawning, and growth in North Atlantic cod: the utility of inter-regional comparisons. ICES marine Science Symposium 198: 406-413.

Brander, K.M.
1995. The effects of temperature on growth of Atlantic cod (*Gadus morhua* L.) ICES Journal of Marine Science 52: 1-10.

Brodie, W.B. 1987.
American plaice in divisions 3LNO - an assessment update. NAFO Scientific Council Research Document 87/40.

Campana, S.E., R.K. Mohn, S.J. Smith and G. Chouinard.
1995. Spatial visualization of a temperature-based growth model for Atlantic cod (*Gadus morhua*) off the eastern coast of Canada. Canadian Journal Fisheries and Aquatic Sciences 52: 2445-2456.

Chouinard, G.A. and A. Fréchet.
1994. Fluctuations in the cod stocks of the Gulf of St. Lawrence. ICES marine Science Symposium 198: 121-139.

Colton, J.B.Jr.
1959. A field observation of mortality of marine fish larvae due to warming. Limnology and Oceanography 4: 219-222.

Colton, J.B.Jr.
1972. Temperature trends and the distribution of groundfish in continental shelf waters, Nova Scotia to Long Island. Fisheries Bulletin 70: 637-657.

Coutant, C.C.
1977. Compilation of temperature preference data. Journal of the Fisheries Research Board of Canada 34: 739-745.

Cushing, D.H.
1982. Climate and fisheries. Academic Press, London.

Cushing, D.H. and R.R. Dickson.
1976. The biological response in the sea to climatic changes. Advances in Marine Biology 14: 1-122.

de Cárdenas, E. 1996.
Some considerations about annual growth rate variations in cod stocks. NAFO Science Council Studies 24: 97-107.

deYoung, B. and G.A. Rose
1993. On recruitment and distribution of Atlantic cod (*Gadus morhua*) off Newfoundland. Canadian Journal of Fisheries and Aquatic Sciences 50: 2729-2741.

Drinkwater, K.F. and R.A. Myers.
1987. Testing predictions of marine fish and shellfish landings from environmental variables. Canadian Journal of Fisheries and Aquatic Sciences 44: 1568-1573.

Drinkwater, K.F., G.C. Harding, K.H. Mann and N. Tanner
1996. Temperature as a possible factor in the increased abundance of American lobster, Homarus americanus, during the 1980s and early 1990s. Fisheries Oceanography 5: 176-193.

Fleming, A.M.
1960. Age, growth and sexual maturity of cod (Gadus morhua L.) in the Newfoundland area, 1947-1950. Journal of the Fisheries Research Board of Canada 17: 775-809.

Friedland, K.D., D.G. Reddin and J.K. Kocik.
1993. Marine survival of North American and European Atlantic salmon: effects of growth and environment. ICES Journal of Marine Science 50: 481-492.

Frank, K.T., J.E. Carscadden and J.E. Simon.
1996. Recent excursions of capelin (*Mallotus villosus*) to the Scotian Shelf and Flemish Cap during anomalous hydrographic conditions. Canadian Journal of Fisheries and Aquatic Sciences 53: 1473-1486.

Frank, K.T., R.I. Perry and K.F. Drinkwater.
1990. Predicted response of northwest Atlantic invertebrate and fish stocks to CO2-induced climate change. Transactions of the American Fisheries Society 119: 353-365.

Frank, K. T., R.I. Perry, K.F. Drinkwater and W.H. Lear.
1988. Changes in the fisheries of Atlantic Canada associated with global increases in atmospheric carbon dioxide: a preliminary report. Canadian Technical Report of Fisheries and Aquatic Sciences 1652, 52 p.

Gomes, M.C., R.L. Haedrich, and M.G. Villagarcia.
1995. Spatial and temporal changes in the groundfish assemblages on the north-east Newfoundland/Labrador Shelf, north-west Atlantic, 1978-91. Fisheries Oceanography 4: 85-101.

Hutchings, J.A. and R.A. Myers.
1994. Timing of cod reproduction: interannual variability and the influence of temperature. Marine Ecology Progress Series 108: 21-31.

Kohler, A.C.
1964. Variations in the growth of Atlantic cod (*Gadus morhua* L.) Journal of the Fisheries Research Board of Canada. 21: 57-100.

Krohn, M. and S. Kerr
1996. Declining weight-at-age in northern cod and the potential importance of the early-years and size-selective fishing mortality. NAFO Scientific Council Research Document 96/56, Serial No. N2732, p. 10.

Lauzier, L.M. and S.N. Tibbo
1965. Water temperature and the herring fishery of Magdalen Islands, Quebec. International Commission of the Northwest Atlantic Fisheries Special Publication 6: 591-596.

Leggett, W.C. and R.R. Whitney
1972. Water temperature and the migrations of American shad. Fishery Bulletin 70: 659-670.

Lilly, G.R., H. Hop, D.E. Stansbury and C.A. Bishop
1994. Distribution and abundance of polar cod (*Boreogadus saida*) off southern Labrador and eastern Newfoundland. ICES CM 1994/O:6.

Lough, R.G., W.G. Smith, F.E. Werner, J.W. Loder, F.H. Page, C.G. Hannah, C.E. Naimie, R.I. Perry, M. Sinclair and D.R. Lynch.
1994. Influence of wind-driven advection on interannual variability in cod egg and larval distributions on Georges Bank: 1982 vs 1985. ICES marine Science Symposium 198: 356-378**.**

Marak, R.R. and R. Livingstone Jr
1970. Spawning date of Georges Bank haddock. ICNAF Research Bulletin 7: 56-58.

McKenzie, R.A.
1934. Cod and water temperature. Biological Board of Canada, Atlantic Progress Report No. 12, pp. 3-6.

McKenzie, R.A.
1938. Cod take smaller bites in ice-cold water. Fisheries Research Board of Canada, Atlantic Progress Report No. 22, pp. 12-14.

McLeese, D.W. and D.G. Wilder
1958. The activity and catchability of the lobster (Homarus americanus) in relation to temperature. Journal of the Fisheries Research Board of Canada 15: 1345-1354.

Messieh, S.N.
1986. The enigma of Gulf herring recruitment. NAFO Scientific Council Research Document 86/103, Serial No. N1230, p. 22.

Miller, T.J., T Herra and W.C. Leggett
1995. An individual-based analysis of the variability of eggs and their newly hatched larvae of Atlantic cod (Gadus morhua) on the Scotian Shelf. Canadian Journal of Fisheries and Aquatic Sciences 52: 1088-1093.

Morgan, M.J. 1992
Low-temperature tolerance of American plaice in relation to declines in abundance. Transactions of the American Fisheries Society 121: 399-402.

Morse, W.W. 1989. Catchability, growth, and mortality of larval fishes. Fishery Bulletin 87: 417-446.

Mountain, D.B. and S.A. Murawski
1992. Variation in the distribution of fish stocks on the northeast continental shelf in relation to their environment, 1980-1989. ICES marine Science Symposium 195: 424-432.

Myers, R.A. and K.F. Drinkwater
1989. The influence of Gulf Stream warm core rings on recruitment of fish in the northwest Atlantic. Journal of Marine Research 47: 635-656.

Myers, R.A., J.A. Hutchings and N.J. Barrowman
1996. Hypotheses for the decline of cod in the North Atlantic. Marine Ecology Progress Series 138: 293-308.

Myers, R.A., G. Mertz and P.S. Fowlow
1996. The population growth rate of Atlantic cod (*Gadus Morhua*) at low abundance. NAFO Scientific Council Research Document 96/40, p. 18.

Nakashima, B.S.
1996. The relationship between oceanographic conditions in the 1990s and changes in spawning behaviour, growth and early life history of capelin (*Mallutus villosus*). NAFO Scientific Council Studies 24: 55-68.

Narayanan, S., J. Carscadden, J.B. Dempson, M.F. O'Connell, S. Prinsenberg, D.G. Reddin and N. Shackell.
1995. Marine climate off Newfoundland and its influence on Atlantic salmon (*Salmo salar*) and capelin (*Mallotus villosus*). p. 461-474. *In* R.J. Beamish [ed.] Climate change and northern fish populations. Canadian Special Publication of Fisheries and Aquatic Sciences 121.

Page, F.H. and K.T. Frank
1989. Spawning time and egg stage duration in northwest Atlantic haddock (Melanogrammus aeglefinus) stocks with emphasis on Georges and Brown Bank. Canadian Journal of Fisheries and Aquatic Sciences 46 (Supplement 1): 68-81.

Polocheck, T., D. Mountain, D. McMillan, W. Smith and P. Berrien
1992. Recruitment of the 1987 year class of Georges Bank Haddock (*Melanogrammus aeglefinus*): the influence of unusual larval transport. Canadian Journal of Fisheries and Aquatic Sciences 49: 484-496.

Reddin, D.G. and K.D. Friedland
1993. Marine environmental factors influencing the movement and survival of Atlantic salmon, p. 79-103. In D. Mills [ed.] Salmon in the Sea. Blackwell Scientific Publications Ltd., London, U.K.

Reddin, D.G. and W.M. Shearer
1987. Sea-surface temperature and distribution of Atlantic salmon in the Northwest Atlantic Ocean. American Fisheries Society Symposium on Common Strategies in Anadromous/Catadromous Fishes 1: 262-275.

Rose, G.A. and W.C. Leggett
1988. Atmosphere-ocean coupling and Atlantic cod migrations: the effects of wind forced variations in sea temperatures and currents on nearshore distributions and catch rates of *Gadus morhua*. Canadian Journal of Fisheries and Aquatic Sciences 45: 1234-1243.

Rose, G.A., B.A. Atkinson, J. Baird, C.A. Bishop and D.W. Kulka
1994. Changes in distribution of Atlantic cod and thermal variations in Newfoundland waters, 1980-1992. ICES marine Science Symposium 198: 542-552.

Scott, J.S.
1982. Depth, temperature and salinity preferences of common fishes of the Scotian Shelf. Journal of Northwest Atlantic Fishery Science 3: 29-39.

Sette, O.E.
1950. Biology of the Atlantic Mackerel (*Scomber scombrus*) of North America, Part II-migrations and habits. Fishery Bulletin 49: 251-358.

Shackell, N.L., K.T. Frank, W.T. Stobo and D. Brickman
1995. Cod (*Gadus morhua*) growth between 1956 and 1966 compared to growth between 1978 to 1985, on the Scotian Shelf and adjacent areas. ICES Paper CM 1995/P:1, 18 p.

Sharp, G.D.
1987. Climate and fisheries: cause and effect or managing the long and short of it all. *In* Payne, A.I.L., J.A. Gulland, and K.H. Brink (ed.), South African Journal of Marine Science 5: 811-838.

Shelton, P.A., G.R. Lilly and E. Colbourne
1996. Patterns in the annual weight increment for 2J3KL cod and possible prediction for stock projection. NAFO Scientific Council Research Document 96/47, p. 19.

Shepherd, J.G., J.G. Pope and R.D. Cousens
1984. Variations in fish stocks and hypotheses concerning their links with climate. Rapports et procès-verbaux des réunions, Conseil International pour l'Exploration de la Mer 185: 255-267**.**

Sinclair, A. and L. Currie
1994. Timing of cod migration into and out of the Gulf of St. Lawrence based on commercial fisheries, 1986-1993. DFO Atlantic Fisheries Research Document 94/47.

Sinclair, A.
1996. Recent declines in cod species stocks in the northwest Atlantic. NAFO Scientific Council Studies 24: 41-52.

Sinclair, M.
1988. Marine populations: an essay on population regulation and speciation. University of Washington Press, Seattle, 252 p.

Sissenwine, M.P.
1984. Why do fish populations vary? In, R.M. May (ed.), Exploitation or Marine Communities, Dahlem Konferenzen 1984, Springer-Verlag, Berlin, Germany.

Smith, S.J. and F. Page
1996. Associations between Atlantic cod (*Gadus morhua*) and hydrographic variables: implications for the management of the 4VsW cod stock. ICES Journal of Marine Science 53: 597-614.

Smith, S.J., R.I. Perry and L.P. Fanning
1991. Relationships between water mass characteristics and estimates of fish population abundance from trawl surveys. Environmental Monitoring and Assessment 17: 227-245.

Taggart, C.T., J. Anderson, C. Bishop, E. Colbourne, J. Hutchings, G. Lilly, J. Morgan, E. Murphy, R. Myers, G. Rose and P. Shelton
1994. Overview of cod stocks, biology, and environment in the Northwest Atlantic region of Newfoundland, with emphasis on northern cod. ICES marine Science Symposium 198: 140-157.

Taylor, C.C. H.B. Bigelow and H.W. Graham
1957. Climate trends and the distribution of marine animals in New England. Fisheries Bulletin 57: 293-345.

Templeman, W.
1966. Marine resources of Newfoundland. Fisheries Research Board of Canada Bulletin 154, 170 p.

Tibbo, S.N. and R.D. Humphreys
1966. An occurrence of capelin (Mallotus villosus) in the Bay of Fundy. Journal of the Fisheries Research Board of Canada 23: 463-467.

Ware, D.M.
1977. Spawning time and egg size of Atlantic mackerel, *Scomber scombus*, in relation to the plankton. Journal of the Fisheries Research Board of Canada 34: 2308-2315.

Werner, F.E., F.H. Page, D.R. Lynch, J.W. Loder, R.G. Lough, R.I. Perry, D.A. Greenberg and M.M. Sinclair
1993. Influences of mean advection and simple behaviour on the distribution of cod and haddock early life stages on Georges Bank. Fisheries Oceanography 2: 43-64.

Winters, G.H., J.P. Wheeler and E.L. Dalley
1986. Survival of a herring stock subjected to a catastrophic event and fluctuation environmental conditions. Journal Conseil international Exploration du Mer 43: 26-43.

Wright, D.G., R.M. Hendry, J.W. Loder and F.W. Dobson
1986. Oceanic changes associated with global increases in atmospheric carbon dioxide: a preliminary report for the Atlantic coast of Canada. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1426: 78 p.

3.2 *Coastal Zone*

Climate Change Impacts in the Coastal Zone of Atlantic Canada

D.L. Forbes, J. Shaw and R.B. Taylor

Geological Survey of Canada (Natural Resources Canada),
Bedford Institute of Oceanography,
Dartmouth, Nova Scotia, B2Y 4A2

Climate warming is predicted to cause an increase in global sea level, as well as changes in storm characteristics, ocean wave climate, sea-ice cover, and ecological zonation. These may have a significant impact on coastal stability, flood and storm hazards, and socio-economic activity or investment in the coastal zone. The Atlantic coast of Canada is already adjusting to rising relative sea levels (reflecting a combination of crustal subsidence and sea-level rise [SLR]). Accelerated SLR, combined with a possible increase in storm activity, can be expected to increase coastal erosion, flood hazards, storm damage, and associated property loss over coming decades if existing scenarios for climate change are valid. The prediction of impacts is complicated both by limited understanding of possible changes in storm climatology and by limitations in our ability to predict coastal response. There is a need for recognition of sea-level rise and climate change issues in municipal planning strategies and zoning regulations. Adaptive measures that allow retreat or accommodation to environmental change at the coast will reduce the risk of damage and ultimately reduce costs. Improved prediction of climate-change impacts in the coastal zone will require a better understanding of coastal response at storm-event scale and at longer time scales, both of which require sustained funding for long-term monitoring of water levels, waves, and coastal change.

INTRODUCTION

Climate change scenarios and impacts in the coastal zone

Increasing concentrations of greenhouse gases in the atmosphere are widely believed to be influencing the earth's radiation balance in such a way as to cause global warming (IPCC, 1990). Increased temperatures may lead to thermal expansion of the ocean, melting of glaciers, and other outcomes contributing to an increase in ocean volume. The best estimate of global sea-level rise [SLR] under the IS92a scenario is about +0.5 m by 2100 (Wigley and Raper, 1992; IPCC, 1995). Changes in atmospheric composition may also lead to increased storm intensity (Emanuel, 1987), possible changes in storm tracks and frequency (Broccoli and Manabe, 1990; Haarsma *et al*., 1992), and changes in other factors relevant to coastal stability, such as surface winds, ocean waves, storm surges, and ice conditions.

Although the impact of each factor may be predictable to a certain extent, it is difficult to forecast the combined effects, given the large uncertainty that still prevails in various estimates of change. Mikolajewicz *et al*. (1990) showed that sea-level changes resulting from thermal expansion in the ocean will vary geographically, such that some regions may experience negative or negligible change, while others will be subjected to larger increases in mean sea level. Further complication is introduced by natural sources of variability in the climate system, such as El Niño and the Southern Oscillation (e.g. Diaz and Pulwarty, 1993), the North Atlantic Oscillation (e.g. Maul and Hanson, 1991), secular variation in tropical and extratropical storm occurrence and ocean wave climate (e.g. Hayden, 1981; Dolan *et al*., 1988; Bacon and Carter, 1993), arctic and sub-arctic sea-ice extent (e.g. Mysak *et al*., 1990; Hill and Jones, 1990), and other factors.

Global sea-level rise

Detecting the various contributions to secular trends in mean sea level is an ongoing challenge (Gornitz, 1995). Direct human influence may be a factor (Sahagian *et al*., 1994; Gornitz *et al*., 1994), but the reality of a human-induced greenhouse effect remains controversial. Global sea level appears to be rising at a rate between 0.1 and 0.2 m/century (Warrick and Oerlemans, 1990), with some estimates slightly higher. There is widespread evidence to suggest a recent increase in the rate of sea-level rise (e.g. Carrera and Vanícek, 1988; Peltier and Tushingham, 1989; Gornitz and Seeber, 1990; Varekamp *et al*., 1992), part of which may be attributable to greenhouse warming. However, saltmarsh deposits and other coastal systems contain evidence for natural fluctuations in sea level at time scales of the order of 100 years (e.g. van de Plassche, 1991; Tanner, 1995; Shaw *et al*., 1997), implying that accelerated SLR observed over the past century may be partly or wholly natural in origin.

Issues considered in this review

In this brief review, we consider the potential impacts of future climate variability and trends under two major categories:

- effects of accelerated sea-level rise;
- effects of variable storminess;

and conclude with a brief consideration of ice effects and socio-economic implications. Other effects may be anticipated, including changes in ocean and estuarine circulation, water temperature, precipitation, wind regime, and associated ecological changes that may have far-reaching effects on the marine and coastal environment.

ACCELERATED SEA-LEVEL RISE

General issues

The potential impacts of higher mean water level in the coastal zone extend far beyond the effects of direct flooding. A rise in mean sea level has a direct impact across the tidal spectrum, affecting the joint probability distribution of tides and storm surges or storm-wave runup. Tidal amplification may also be a factor (Gehrels *et al*., 1995). Quite apart from any changes in tidal range, inlet hydraulics or estuarine circulation, altered flood frequency has important implications for saltmarsh dynamics and ecology. Perhaps the most important (and widely overlooked) impact of higher mean sea level is its effect on wave energy at the coast. Deeper water in the nearshore allows larger waves to approach the shore before breaking. Larger waves arriving higher on the beach produce higher runup and shear stress, increasing the frequency of overtopping on coastal landforms and structures and greatly enhancing the potential for coastal erosion.

Relative sea level (the position of the water line with respect to reference points on land) has been changing systematically throughout southeastern Canada for thousands of years, due to the interplay between crustal loading (by ice or water) and the level of the global ocean. In some cases, these changes have resulted in shoreline movements of tens of kilometres or more (Shaw *et al*., 1993). Along the coast of Labrador, relative sea level has been falling for the past 9000 years (Andrews, 1989), while much of Newfoundland and parts of the Maritime Provinces experienced falling sea levels in the early Holocene (a term used to describe the past 10 000 years of postglacial time) before relative sea level began to rise again (e.g. Scott and Medioli, 1980; Stea *et al*., 1992; Shaw and Forbes, 1995). Rising relative sea levels have prevailed in most parts of Atlantic Canada south of the Gulf of St. Lawrence and Strait of Belle Isle for the past few thousand years. In the Halifax area, relative sea level has risen at least 40 m in the past 10 000 years (Shaw *et al*., 1993; Stea *et al*., 1994). Tide-gauge data from Halifax indicate a rising trend of 0.36 m/century since 1920 (Shaw and Forbes, 1990). A large part of this change is attributable to crustal subsidence (Grant, 1975) but as much as a third may be due to the global rise in sea level. The latter will be superimposed on any crustal motion, leading to an acceleration of the existing sea-level rise in the Maritimes and Newfoundland.

Observed and anticipated effects

Coastal flooding

Low-lying coastal lands are subject to inundation under high tides and storm surges. The frequency of such flooding and the landward limits of flooding will increase with a rise in mean relative sea level. Related effects may include saline groundwater intrusion, backwater flooding in coastal streams, and changes in saltmarsh zonation. Areas susceptible to flooding occur throughout the region, some of the most extensive being around the margins of drowned-valley estuaries in Prince Edward Island (e.g. Hillsborough Bay, where wide intertidal flats and marshes are up to 1 km wide), along the Gulf coast of New Brunswick and Nova Scotia (e.g. the Tantramar Marsh region in the provincial boundary area), and locally elsewhere (e.g. parts of St. George's Bay on the west coast of Newfoundland).

The salt marsh coast of the Bay of Fundy is highly vulnerable to future sea-level rise. An extensive system of dykes, initiated in the late 1630s and maintained and extended over the intervening years, now encloses 85% of the former marsh area (Nova Scotia Department of Agriculture and Marketing, 1987). Whereas natural marsh surfaces might keep pace with rising relative sea levels, the elevation of enclosed lands behind the dykes has lagged behind rising sea level. Mean sea level has risen by 1.3 m since 1630 and 0.44 m since 1869 (Shaw *et al*., 1997), necessitating ongoing expenditures to compensate for subsidence and maintain the dykes at high enough levels to prevent flooding. Accelerated SLR will increase the cost of dyke maintenance. The greatest concern, however, is the risk of overtopping and inundation associated with storm surges superimposed on high tides.

Accelerated SLR is sometimes seen as a threat to coastal marshland, assuming that the rate of marsh growth does not keep pace with rising tide levels. The presence of relict marsh deposits on the present continental shelf (e.g. Forbes *et al*., 1989; Shaw *et al*., 1993) indicates that long-term submergence over hundreds of years can lead to abandonment. The maintenance of marsh area then depends on the rate of marsh expansion, which is a complex function of terrain, sediment supply, recruitment and other factors. Under some circumstances, as at some sites along the Eastern Shore of Nova Scotia, marsh expansion may occur even under rapidly rising sea level (Scott, 1980; Carter *et al*., 1992; Nichol and Boyd, 1992). Where high rates of erosion at the outer coast are supplying large volumes of sediment to the estuary, rapid accretion on marsh surfaces may enable a transformation to freshwater marsh, producing a vertical sequence contrary to the normal transgressive sequence of marine incursion over terrestrial deposits (Carter *et al*., 1989; Jennings *et al*., 1993).

Flooding of urban property, utility infrastructure, and port facilities has been recognised as a potential impact of future sea-level rise at a number of major ports and urban centres in the region. Some communities are already vulnerable to flooding during high astronomical tides and storm surges, sometimes exacerbated by high runoff. The town of Placentia, in southern Newfoundland, is a case in point (ShawMont Martec Ltd, 1985; Forbes *et al*., 1989). This community, occupying a gravel beach-ridge plain on an otherwise rugged coast, has a long history of flooding. Recent residential, commercial, and institutional development on the strandplain have increased the value of property at risk. The proposed development of a new nickel smelter at nearby Argentia will place added demand on this 'prime' coastal real estate.

In a detailed study to evaluate the impact of a 1 m rise of sea level at Charlottetown (Lane and Associates Ltd, 1988), it was found that some of the highest-value property in the downtown core and significant parts of the sewage system would be flooded. This points to the need for recognition of sea-level and climate-change issues in building codes and municipal planning guidelines.

Coastal erosion

Wave action at the toe of a coastal cliff is one of the primary factors determining the rate of shoreline recession (e.g. Robinson, 1977; Sunamura, 1977). Toe erosion and undercutting exert a critical control on the cliff profile and its overall stability. As noted earlier, higher water levels promote higher wave energy at the shoreline by shifting the locus of wave breaking higher up the profile. Numerous studies, particularly in the Great Lakes, have demonstrated an empirical link between lake levels and erosion rates on cohesive till bluffs (e.g. Amin and Davidson-Arnott, 1995), consistent with theoretical expectations.

Many factors can influence the coastal response to rising sea level. Erosion of boulder-rich glacial deposits, common in Atlantic Canada, can lead to accumulation of protective boulder lags at the cliff base and across the nearshore, reducing wave energy and erosion rates (Forbes and Syvitski, 1995). Coastal progradation can occur where sediment supply exceeds the quantity required to maintain shoreline stability. It can even be argued that accelerated SLR may increase sediment supply from eroding coastal segments, leading to more rapid shoreline progradation at down-drift or bayhead sediment sinks (Forbes *et al*., 1995b). Changing sediment budgets can lead to closure of tidal inlets or changes in inlet configuration (Armon and McCann, 1979; Reinson, 1980), causing localised erosion and flooding.

On sandy coasts, simple geometrical models have been used to predict erosion as a function of relative sea-level rise (Bruun, 1962). However, the assumptions underlying Bruun's model, including a closed sediment budget and preservation of an equilibrium nearshore profile, are rarely satisfied. The trajectory of a shoreline under rising sea level depends on a number of factors, including sediment supply and accommodation space (Cant, 1991). Nevertheless, a long-term rise in sea level generally produces regional submergence, tending to promote erosion along susceptible coasts. In a Canada-wide assessment of coastal sensitivity to sea-level rise, Shaw *et al*. (1994) identified parts of Atlantic Canada, particularly in the southern Gulf of St. Lawrence, as among the most susceptible to greater instability under accelerated SLR (cf. Owens and Bowen, 1977).

Numerous studies have documented processes and rates of coastal erosion and landward shoreline migration along the Gulf coasts of New Brunswick (e.g. Ganong, 1908; Airphoto Analysis Associates Consultants Ltd, 1975; Reinson, 1980), Prince Edward Island (e.g. Forward, 1960; Armon and McCann, 1979; LRIS, 1988), Nova Scotia (e.g. Bowen *et al*., 1975; Taylor *et al*., 1985; Shaw *et al*., 1993), and Newfoundland (e.g. Forbes *et al*., 1995a). Severe localised erosion is also documented at numerous sites in the Bay of Fundy (e.g. Atlantic Air Survey, 1976) and along the Atlantic coasts of Nova Scotia (e.g. Bowen *et al*., 1975; Taylor *et al*., 1985, 1995; Shaw *et al*., 1993; Covill *et al*., 1995) and Newfoundland (Shaw and Forbes, 1992; Liverman *et al*., 1994).

In summary, it is anticipated that rising sea levels will tend to threaten shoreline stability in many parts of the region. Although some areas will experience shoreline accretion, erosion will be a greater problem in many places. Property losses may become significant if this hazard is not recognised in development planning and regulation.

VARIABLE STORMINESS

General issues

The challenge in determining probable impacts of changing storm climate in the coastal zone lies *both* in the specification of storm climatology (frequency, intensity, storm paths) and in predicting the coastal response. Many processes on wave-dominated shores occur at scales of hours to weeks and are associated with storm-scale variation in the nearshore wave field. The shore-zone response is reasonably well understood at this scale, involving many aspects of sand beach morphodynamics (e.g. Bowen, 1980; Wright and Short, 1984), although some components such as washover channels and nearshore bars may develop and persist for longer time intervals (e.g. Hale and Greenwood, 1980; Boczar-Karakiewicz *et al*., 1995). The larger-scale system response to decadal or interdecadal variance in storm climate is less well specified, in part because there are few sufficiently long and detailed records of coastal behaviour (see, however, Wijnberg, 1995). It is not always clear to what extent changes are driven by extreme events, by secular changes in climate, or by internal feedback within the coastal system (Forbes and Liverman, 1996). Long-term cyclic behaviour has been demonstrated in some systems, where observations at time intervals of a few weeks over 10 years or more may be necessary to resolve the range of stationary variance (e.g. Clarke and Eliot, 1988; Short and Hall, 1993). The response of a given coastal system, particularly gravel-dominated ones, may depend critically on the antecedent condition of the shore and its susceptibility to erosion or overtopping (Forbes *et al*., 1995b, 1997).

Proxy indicators of varying storminess in the recent geological record of eastern Canada include variations in the number, thickness, and texture of sandy storm layers in coastal and shelf basins (Kontopoulos and Piper, 1982; Piper *et al*., 1983). Storms may also be recorded in backbarrier ponds and marshes (Liu and Fearn, 1993; Devoy *et al*., 1996), although this source has not been exploited in eastern Canada (and care may be needed to avoid possible confusion with tsunami deposits). General historical accounts provide evidence for variations in storminess, such as a lull in the incidence of hurricanes at Bermuda in the mid-1700s (Emanuel, 1995), or the occurrence of extreme events such as the Saxby Gale (Desplanque, 1974).

The observational record of tropical storms in the western North Atlantic extends back to 1871 (Neumann *et al*., 1981) and shows marked variation in the annual frequency, as well as in the frequency of storms penetrating as far north as the Canadian Maritimes. Similarly, extratropical storm tracks and storm intensity vary from year to year (e.g. Brown *et al*., 1986; Dolan and Davis, 1992). The instrumental record of wave climate in the North Atlantic, though still limited, is beginning to show some evidence of interdecadal trends (Neu, 1984; Jónsson, 1994).

Funding pressures are threatening the already sparse networks for measurement of water levels and waves in eastern Canada, yet the data provided by long-term monitoring programs are essential for an understanding of environmental forcing and coastal response under variable or changing climate.

Observed and anticipated effects

Storm-surge flooding

Overtopping of dykes and extensive flooding of low-lying areas around the Bay of Fundy can occur when a northeast-tracking low-pressure system and associated storm surge moves up the bay in phase with the tidal wave (Shaw *et al*., 1997). This occurred during the notorious Saxby Gale of 5 October 1869, which caused extensive flooding, and again on 10 January 1997, when very high tides caused severe damage to facilities up to 100 years old at Hall's Harbour and extensive flooding along the Nova Scotia coast (Delaney, 1997). The recurrence intervals for such events are poorly defined and the effect of global warming on surge probability is uncertain. It is clear, however, that higher mean sea levels will increase the frequency of flooding at any given level, assuming no shoreline adjustment or change in surge probability.

Coastal erosion

Recent work on interdecadal variance in coastal recession rates along the Atlantic coast of Nova Scotia (e.g. Orford *et al*., 1992; Orford and Carter, 1995; Forbes *et al*., 1997) has shown that phases of instability on susceptible barrier beaches can be related to a low-pass filtered index of positive water-level residuals in the Halifax tide-gauge record. This is taken as a surrogate for storm-surge frequency at a decadal scale and shows high values in the late 1920s and early 1930s, low values through the 1940s and early 1950s, and high values again after 1954. Photogrammetric analysis shows landward migration of barrier beaches at rates as high as 14 m/a (Covill *et al*., 1995) at times of combined rapid sea-level rise and high storm-surge frequency (Forbes *et al*., 1997). Some systems show a delayed response resulting from local site conditions that impede erosion; others show an enhanced response when highly erodible material is exposed in the nearshore; while yet others remain stable under all but the most extreme events because they have developed robust high structures through several decades or centuries of self-organisation (Forbes *et al*., 1995b). The high barriers may be susceptible to rapid downcutting and washover when stability thresholds are exceeded in exceptional storms.

The Geological Survey of Canada [GSC] and collaborating provincial agencies have established an extensive network of monitoring sites to determine rates and processes of coastal erosion, the impact of individual storm events, and trends or long-term cycles in coastal stability in the Atlantic Provinces and elsewhere. The results are beginning to indicate significant trends in some areas. Taylor *et al*. (1995) showed that some sites on the Nova Scotia coast experienced dune growth and cliff stability during the early to mid 1980s, whereas erosion of dunes and more rapid cliff retreat were evident in the early 1990s.

Storm impacts vary considerably from site to site, depending on the morphodynamic status of individual coastal cells, the duration and intensity of the storm, the incident wave characteristics, and other factors such as the interval between storms. Extreme events can leave an imprint lasting many years, such as large-scale swash cusps (95 m in wavelength) formed on the beach at Holyrood Pond (St. Mary's Bay) in southeast Newfoundland during a storm in March 1985 (Forbes *et al*., 1995b). Such features may then control washover processes and other aspects of beach response during subsequent large wave runup events. In another example, massive translation of a gravel barrier at Story Head on the Eastern Shore of Nova Scotia, involving 16 to 20 m of movement during a single storm event in late December 1995, may have been facilitated by a smaller storm 10 days earlier with very high water levels (Taylor *et al*., 1997). The same study has also shown that the most damaging storms are those that coincide with storm surges at high water, or storms of long duration (several tidal cycles) coinciding with spring tides.

Coastal erosion can be a major cause of concern where valuable land, residential structures, and other capital investments are threatened by cliff retreat (e.g. Eyles *et al*., 1985). Cliff erosion may be effected primarily by removal of material at the cliff base, a process largely controlled by wave energy (which varies as the square of the wave height) and water level (enhanced by high tide, storm surge, wave setup or runup), or it may involve slumping and gullying, processes dominated by lithological and geotechnical properties of the soil and by runoff and groundwater conditions. The latter can lead to rapid headward erosion and property loss, as documented at Romaines in western Newfoundland (Forbes *et al*., 1995a). Weather conditions favouring one type of erosion (wind, storm surge, waves) may differ from those contributing to the other (heavy precipitation), further complicating the prediction of climate change impacts.

OTHER ISSUES

Sea ice and shore ice

Sea ice is an important factor affecting coastal stability in parts of Atlantic Canada, particularly the Gulf of St. Lawrence and northeast Newfoundland (Forbes and Taylor, 1994). Possible increases in open-water fetch during the winter storm season, resulting from higher sea-surface temperatures and reduced extent or duration of winter sea ice, could increase mean wave energy and contribute to coastal erosion losses. This effect has been predicted for a doubled CO_2 scenario in the Beaufort Sea (Solomon and Forbes, 1994).

Ice-foot development is an important phenomenon on shores in Atlantic Canada, not only in the Gulf of St. Lawrence (Owens, 1976), but in the Bay of Fundy (Knight and Dalrymple, 1976) and on the outer Atlantic coast as well (Taylor *et al*., 1997). While the effects of an ice foot and nearshore ice complex may include contributions to sediment transport (by ice rafting) and nearshore scour (by development of a reflective natural seawall and seaward displacement of wave breaking), the ice foot commonly serves a protective role on beaches in this region (Taylor *et al*., 1997). Therefore, less common or persistent ice-foot development under warmer conditions might contribute to shore erosion in a minor way.

Socio-economic interactions and management implications

Socio-economic responses to climate change may exacerbate certain impacts. Under a scenario of global warming, for example, we might anticipate increasing recreational use of coastal lands in eastern Canada, leading to greater risk associated with expansion of shore-zone development and the growth of property values. Demand for coastal real estate in Atlantic Canada is already on the rise, with upward pressure on prices. Similar trends along heavily developed coasts in the USA, southern Europe, and elsewhere have led to rapid growth in the value of buildings and other capital investment within the coastal zone (Carter, 1988). Under these circumstances, the financial risk associated with a given physical hazard (e.g. coastal erosion or flooding) is greatly increased. On a global scale, natural disasters have produced property losses averaging US$1 billion per week in recent years; this is two to three times the rate of loss in the 1980s (Carlowicz, 1996). The challenge of coastal management under more hazardous natural conditions is to minimise the risk to property, human safety, and environmental damage.

Three adaptive responses to sea-level rise have been distinguished in reports of the Intergovernmental Panel on Climate Change (IPCC, 1990, 1992). These are retreat, accommodation, and protection. Retreat may take the form of establishing setback requirements for new construction, allowing wetland migration, or relocating activities. Accommodation may involve modified building codes, acceptance of development compromises, and other adjustments to reduce vulnerability. Protection requires significant capital investment in seawalls, dykes, landfill, beach nourishment, or artificial wetlands, all of which will require ongoing maintenance and upgrading, as experience with the dyke system in the Bay of Fundy demonstrates. This option is only viable where the value of protected property justifies the cost (and protection may fail under extreme conditions). In most circumstances, costs and hazards can be reduced by appropriate planning strategies that favour retreat or accommodation.

SUMMARY

Relative sea level is rising now along most parts of the coast in Atlantic Canada. Accelerated sea-level rise over the past century may be a response to global climate change or it may represent medium-term (century-scale) natural variance in the rate of sea-level rise. There is evidence to suggest that global sea level has been rising at a rate between 0.1 and 0.2 m/century. The current IPCC consensus suggests a further increase of about 0.5 m by 2100. This will be added to vertical crustal movement (subsidence at rates as high as 0.2 to 0.3 m/century) in many parts of Atlantic Canada. The result will be an enhanced flood risk in some areas and accelerated coastal erosion in others. Appropriate zoning regulations and other adaptive measures that support strategies of retreat or accommodation will reduce the risk of property loss or damage by limiting vulnerability to flood and erosion hazards.

Variations in storminess, including possible increases in storm frequency or intensity, can be expected to cause enhanced erosion in some places and may affect the risk of storm-surge flooding and dyke overtopping in the Bay of Fundy. Changing winter ice conditions may also be important, increasing exposure to winter storm waves, among other effects. The impact of a given weather event is a function of storm characteristics and timing, coastal setting, and vulnerability of landforms or structures in the coastal zone. Differences in coastal response depend on the specific erosion processes, the coastal geology, and the morphological status of a site. The latter may reflect the impact of a previous storm and the time available for recovery since that event. Susceptible coastal landforms such as low gravel barriers may retreat as much as 20 m or more in single major storms, while higher barriers nearby remain stable. The high barriers may also be vulnerable if thresholds of stability are exceeded under changing climate conditions. Rapid cliff recession is also observed where protective boulder shoals are absent and where slumping or retrogressive flows and gullying occur. Long-term monitoring of the coast shows evidence for interdecadal variation in erosion rates, related to changes in the rate of relative sea-level rise and storm-surge frequency. Improved prediction of climate-change impacts in the coastal zone will require a better understanding of coastal response at storm-event scale and at longer time scales, both of which require sustained funding for long-term monitoring of water levels, waves, and coastal change.

ACKNOWLEDGEMENTS

This summary incorporates results of a GSC project on coastal impacts of climate change in eastern and northern Canada, funded under the Green Plan. We are grateful to colleagues Kimberley Edwardson (GSC) and Steven Solomon (GSC/SOPAC) for helpful and perceptive reviews.

REFERENCES

Airphoto Analysis Associates Consultants Ltd.
1975. Beach resources: eastern New Brunswick. Contract report prepared for New Brunswick Department of Natural Resources, 215 p. and supplementary maps.

Amin, S.M.N. and Davidson-Arnott, R.G.D.
1995. Toe erosion of glacial till bluffs: Lake Erie south shore. Canadian Journal of Earth Sciences, 32, 829-837.

Andrews, J.T.
1989. Postglacial emergence and submergence. In: Quaternary geology of Canada and Greenland (Fulton, R.J., editor). Geological Survey of Canada, Geology of Canada, 1 (also Geological Society of America, Geology of North America, K-1), 546-562.

Armon, J.W. and McCann, S.B.
1979. Morphology and landward sediment transfer in a transgressive barrier island system, southern Gulf of St. Lawrence, Canada. Marine Geology, 31, 333-344.

Atlantic Air Survey.
1976. Cliff height determination and cliff line recession, Nova Scotia, 1955-1974. Unpublished contract report to Department of Energy, Mines and Resources, Atlantic Geoscience Centre, Dartmouth, N.S., 9 p. and 3 maps.

Bacon, S. and Carter, D.J.T.
1993. A connection between mean wave height and atmospheric pressure gradient in the North Atlantic. International Journal of Climatology, 13, 423-436.

Bowen, A.J.
1980. Simple models of nearshore sedimentation; beach profiles and longshore bars. In: The coastline of Canada (McCann, S.B., editor). Geological Survey of Canada, Paper 80-10, 1-11.

Bowen, A.J., Edmond, D.P., Piper, D.J.W. and Welsh, D.A.
1975. The maintenance of beaches. Dalhousie University, Halifax; Institute of Environmental Studies, Technical Report, 582 p.

Boczar-Karakiewicz, B., Forbes, D.L. and Drapeau, G.
1995. Nearshore bars in the southern Gulf of St. Lawrence. Journal of Waterway, Port, Coastal,

Broccoli, A.J. and Manabe, S.
1990.Can existing climate models be used to study anthropogenic changes in tropical cyclone climate? Geophysical Research Letters, 17, 1917-1920.

Brown, R.D., Roebber, P. and Walsh, K.
1986. Climatology of severe storms affecting coastal areas of eastern Canada. Environmental Studies Revolving Funds, Ottawa, Report 20, 233 p.

Bruun, P.
1962. Sea-level rise as a cause of shore erosion. Journal of Waterways and Harbors Division, American Society of Civil Engineers, 88, 117-130.

Cant, D.J.

1991. Geometric modelling of facies migration: theoretical development of facies successions and local unconformities. Basin Research, 3, 51-62.

Carlowicz, M.
1996. Natural hazards need not lead to natural disasters. Eos, Transactions, American Geophysical Union, 77, 149 and 153.

Carrera, G. and Vanícek, P.
1988. A comparison of present sea level linear trends from the tide gauge data and radiocarbon curves in eastern Canada. Palaeogeography, Palaeoclimatology, Palaeoecology, 68, 127-134.

Carter, R.W.G.
1988. Coastal environments: an introduction to the physical, ecological and cultural systems of coastlines. Academic Press, London, 617 p.

Carter, R.W.G., Forbes, D.L., Jennings, S.C., Orford, J.D., Shaw, J. and Taylor, R.B.
1989. Barrier and lagoon coast evolution under differing relative sea-level regimes: examples from Ireland and Nova Scotia. Marine Geology, 88, 221-242.

Carter, R.W.G., Orford, J.D., Jennings, S.C., Shaw, J. and Smith, J.P.
1992. Recent evolution of a paraglacial estuary under conditions of rapid sea-level rise: Chezzetcook Inlet, Nova Scotia. Proceedings of the Geologists' Association, London, 103, 167-185.

Clarke, D.J. and Eliot, I.G.
1988.Low-frequency changes of sediment volume on the beachface at Warilla Beach, New South Wales, 1975-1985. Marine Geology, 79, 189-211.

Covill, R., Forbes, D.L., Taylor, R.B. and Shaw, J.
1995. Photogrammetric analysis of coastal erosion and barrier migration near Chezzetcook Inlet, Eastern Shore, Nova Scotia. Geological Survey of Canada, Open File 3027, 1 sheet (poster).

Delaney, G.
1997. Tides wreak havoc along Fundy coast. The Mail Star, Halifax, 49 (10) [Monday, January 13, 1997], A1-A2.

Desplanque, C.
1974. The Saros and the Saxby tide. Unpublished document, C.D.74.1.21, Maritime Resource Management Service, Amherst, N.S., 12 p.

Devoy, R.J.N., Delaney, C., Carter, R.W.G. and Jennings, S.C.
1996. Coastal stratigraphies as indicators of environmental changes upon European Atlantic coasts in the late Holocene. Journal of Coastal Research, 12, 564-588.

Diaz, H.F. and Pulwarty, R.
1993. A comparison of Southern Oscillation and El Niño signals in the tropics. In: El Niño: historical and paleoclimatic aspects of the Southern Oscillation (Diaz, H.F. and Markgraf, V., editors). Cambridge University Press, 175-192.

Dolan, R. and Davis, R.E.
1992. An intensity scale for Atlantic coast northeast storms. Journal of Coastal Research, 8, 840-853.

Dolan, R., Lins, H. and Hayden, B.
1988. Mid-Atlantic coastal storms. Journal of Coastal Research, 4, 417-433.

Emanuel, K.
1987.The dependence of hurricane intensity on climate. Nature, 326, 483-485.

Emanuel, K.
1995. Oral presentation on the physics of hurricane behaviour, summarised in Hurricane Workshop Summary, Risk Prediction Initiative, Bermuda Biological Station for Research, Bermuda, 30-31 March 1995 *[http://www.bbsr.edu/agcihome/rpi/0395HURRsumm.html]*.

Eyles, N., Eyles, C.H., Lau, K. and Clark, B.
1985. Applied sedimentology in an urban environment - the case of Scarborough Bluffs, Ontario; Canada's most intractable erosion problem. Geoscience Canada, 12, 91-104.

Flemming, N.C. and Woodworth, P.L.
1988. Monthly mean sea-levels in Greece 1969-1983 compared to relative vertical land movements measured over different timescales. Tectonophysics, 148, 59-72.

Forbes, D.L. and Liverman, D.G.E.
1996. Geological indicators in the coastal zone. In: Geoindicators: assessing rapid environmental changes in earth systems (Berger, A.R. and Iams, W.J., editors). Balkema, Rotterdam, 175-192.

Forbes, D.L. and Syvitski, J.P.M.
1995. Paraglacial coasts. In: Coastal evolution: Late Quaternary shoreline morphodynamics (Carter, R.W.G. and Woodroffe, C.D., editors). Cambridge University Press, chapter 10, 373-424.

Forbes, D.L. and Taylor, R.B.
1994.Ice in the shore zone and the geomorphology of cold coasts. Progress in Physical Geography, 18, 59-89.

Forbes, D.L., Covill, R.A., Feindel, R.D. and Batterson, M.J.
1995a. Preliminary assessment of coastal erosion between Port au Port and Stephenville, St. George's Bay, west Newfoundland. Geological Survey of Canada, Open File 3082, 10 p., 30 figs. and 4 appendices.

Forbes, D.L., Orford, J.D., Carter, R.W.G., Shaw, J. and Jennings, S.C.
1995b. Morphodynamic evolution, self-organisation, and instability of coarse-clastic barriers on paraglacial coasts. Marine Geology, 126, 63-85.

Forbes, D.L., Taylor, R.B. and Shaw, J.
1989. Shorelines and rising sea levels in eastern Canada. Episodes, 12, 23-28.

Forbes, D.L., Taylor, R.B. and Shaw, J.
1997. Interdecadal variability in coastal recession rates: climatic 'motor' and geological 'brakes' *[**this volume**]*.

Forward, C.N.
1960. Shoreline changes in Egmont Bay and Bedeque Bay, Prince Edward Island. Canada Department of Mines and Technical Surveys, Geographical Paper 26, 15 p.

Ganong, W.F.
1908. The physical geography of the north shore sand islands. Bulletin of the Natural History Society, Natural History and Physiography, New Brunswick, no. XVII, v. VI, pt. 1, 22-29.
Gehrels, W.R., Belknap, D.F., Pearce, B.R. and Gong, B.

1995. Modeling the contribution of M_2 tidal amplification to the Holocene rise of mean high water in the Gulf of Maine and the Bay of Fundy. Marine Geology, 124, 71-85.

Gornitz, V.
1995. Monitoring sea level changes. Climate Change, 31, 515-544.

Gornitz, V. and Seeber, L.
1990. Vertical crustal movements along the east coast, North America, from historical and Late Holocene sea level data. Tectonophysics, 178, 127-150.

Gornitz, V., Rosenzweig, C. and Hillel, D.
1994. Is sea level rising or falling? Nature, 371, 481.

Grant, D.R.
1975. Recent coastal submergence of the Maritime Provinces. Proceedings, Nova Scotian Institute of Science, 27, 83-102.

Haarsma, R.J., Mitchell, J.F.B. and Senior, C.A.
1992. Tropical disturbances in a GCM. Climate Dynamics, 8, 247-257.

Hale, P.B. and Greenwood, B.
1980. Storm wave climatology: a study of the magnitude and frequency of geomorphic process. In: The coastline of Canada (McCann, S.B., editor). Geological Survey of Canada, Paper 80-10, 73-88.

Hayden, B.P.
1981. Secular variations in Atlantic coast extratropical cyclones. Monthly Weather Review, 109, 159-167.

Hill, B.T. and Jones, S.J.
1990. The Newfoundland ice extent and the solar cycle from 1860 to 1988. Journal of Geophysical Research, 95, 5385-5394.

IPCC [Intergovernmental Panel on Climate Change]
1990. Climate change: the IPCC scientific assessment. Report prepared for IPCC by Working Group 1 (Houghton, J.T., Jenkins, G.J. and Ephraums, J.J., editors). Cambridge University Press, 365 p.

IPCC [Intergovernmental Panel on Climate Change]
1992.Global climate change and the rising challenge of the sea. Response Strategies Working Group, Coastal Zone Management Subgroup. Directorate General, Rijkswaterstaat, The Hague, 35 p. and 5 appendices.

IPCC [Intergovernmental Panel on Climate Change]
1995. IPCC second assessment synthesis of scientific-technical information relevant to interpreting Article 2 of the UN Framework Convention on Climate Change. IPCC Secretariat, WMO, Geneva, 28 p.

Jennings, S.C., Carter, R.W.G. and Orford, J.D.
1993. Late Holocene salt marsh development under a regime of rapid relative sea-level rise: Chezzetcook Inlet, Nova Scotia. Implications for the interpretation of palaeomarsh sequences. Canadian Journal of Earth Sciences, 30, 1374-1384.

Jónsson, T.
1994. Climatic changes and coastal processes. Proceedings Hornafjörður International Coastal Symposium, Höfn, 20-24 June 1994. Icelandic Harbour Authority, Kópavogur, 525-531.

Knight, R.J. and Dalrymple, R.W.

1976. Winter conditions in a macrotidal environment, Cobequid Bay, Nova Scotia. In: Le glaciel (Dionne, J.-C., editor). La Revue de Géographie de Montréal, 30, 65-85.

Kontopoulos, N. and Piper, D.J.W.
1982. Storm-graded sand at 200 m water depth, Scotian Shelf, eastern Canada. Geomarine Letters, 2, 77-81.

Lane, P. and Associates Limited.
1988. Preliminary study of the possible impacts of a one metre rise in sea level at Charlottetown, Prince Edward Island. Atmospheric Environment Service, Downsview. Climate Change Digest 88-02, 8 p.

Liu, K.-B. and Fearn, M.L.
1993. Lake-sediment record of late Holocene hurricane activity from coastal Alabama. Geology, 21, 793-796.

Liverman, D.G.E., Forbes, D.L. and Boger, R.A.
1994. Coastal monitoring on the Avalon Peninsula. In: Current Research. Newfoundland Department of Mines and Energy, St. John's. Geological Survey Branch, Report 94-1, 17-27.

LRIS [Land Registration Information Service]
1988. Air photo interpretation of coastal erosion on Prince Edward Island. Unpublished contract report to PEI Department of Community and Cultural Affairs, 15 p.

Maul, G.A. and Hanson, K.
1991. Interannual coherence between North Atlantic atmospheric surface pressure and composite southern USA sea level. Geophysical Research Letters, 18, 653-656.

Mikolajewicz, U., Santer, B.D. and Maier-Reimer, E.
1990. Ocean response to greenhouse warming. Nature, 345, 589-593.

Mysak, L.A., Manak, D.K. and Marsden, R.F.
1990. Sea-ice anomalies observed in the Greenland and Labrador Seas during 1901-1984 and their relation to an interdecadal arctic climate cycle. Climate Dynamics, 5, 111-133.

Neu, H.J.A.
1984. Interannual variations and longer-term changes in the sea state of the North Atlantic from 1970 to 1982. Journal of Geophysical Research, 89, 6397-6402.

Neumann, C.J., Cry, E.L., Caso, G.W. and Jarvinen, B.R.
1981. Tropical cyclones of the North Atlantic Ocean, 1871-1980. National Climatic Center, Asheville, NC and National Hurricane Center, Miami FL, 174 p. [inserts extend through later years].

Nichol, S.L. and Boyd, R.
1992. Morphostratigraphy and facies architecture of sandy barriers along the Eastern Shore of Nova Scotia. Marine Geology, 114, 59-80.

Nova Scotia Department of Agriculture and Marketing.
1987. Maritime dykelands: the 350 year struggle. Government of Nova Scotia, Halifax, 110 p.

Orford, J.D. and Carter, R.W.G.

1995. Examination of mesoscale forcing of a swash-aligned gravel barrier from Nova Scotia. Marine Geology, 126, 63-85.

Orford, J.D., Hinton, A.C., Carter, R.W.G. and Jennings, S.C.
1992. A tidal link between sea-level rise and coastal response of a gravel-dominated barrier in Nova Scotia. In: Sea level changes: determination and effects. International Union of Geodesy and Geophysics; American Geophysical Union, Geophysical Monograph 69, 71-79.

Owens, E.H.
1976. The effects of ice on the littoral zone at Richibucto Head, eastern New Brunswick. In: Le glaciel (Dionne, J.-C., editor). La Revue de Géographie de Montréal, 30, 95-104.

Owens, E.H. and Bowen, A.J.
1977. Coastal environments of the Maritime Provinces. Maritime Sediments, 13, 1-31.

Peltier, W.R. and Tushingham, A.M.
1989. Global sea level rise and the greenhouse effect: might they be connected? Science, 244, 806-810.

Piper, D.J.W., Letson, J.R.J., Delure, A.M. and Barrie, C.Q.
1983. Sediment accumulation in low-sedimentation, wave-dominated, glaciated inlets. Sedimentary Geology, 36, 195-215.

Reinson, G.E.
1980. Variations in tidal-inlet morphology and stability, northeast New Brunswick. In: The coastline of Canada (McCann, S.B., editor). Geological Survey of Canada, Paper 80-10, 23-39.

Robinson, L.A.
1977. Marine erosive processes at the cliff foot. Marine Geology, 23, 257-271.

Sahagian, D.L., Schwartz, F.W. and Jacobs, D.K.
1994. Direct anthropogenic contributions to sea level rise in the twentieth century. Nature, 367, 54-57.

Scott, D.B.
1980. Morphological changes in an estuary: a historical and stratigraphical comparison. In: The coastline of Canada (McCann, S.B., editor). Geological Survey of Canada, Paper 80-10, 199-205.

Scott, D.B. and Medioli, F.S.
1980. Post-glacial emergence curves in the Maritimes determined from marine sediments in raised basins. Proceedings, Canadian Coastal Conference 1980, Burlington. National Research Council Canada, Ottawa, 428-446.

Shaw, J. and Forbes, D.L.
1990. Short- and long-term relative sea-level trends in Atlantic Canada. Proceedings, Canadian Coastal Conference 1990, Kingston. National Research Council Canada, Ottawa, 291-305.

Shaw, J. and Forbes, D.L.
1992. Relative sea-level changes and coastal response, northeast Newfoundland. Journal of Coastal Research, 6, 641-660.

Shaw, J. and Forbes, D.L.
1995. The post-glacial relative sea-level lowstand in Newfoundland. Canadian Journal of Earth Sciences, 32, 1308-1330.

Shaw, J., Taylor, R.B. and Forbes, D.L.

1993. Impact of the Holocene transgression on the Atlantic coastline of Nova Scotia. Géographie physique et Quaternaire, 47, 221-238.

Shaw, J., Taylor, R.B. and Forbes, D.L.
1997. Impact of sea-level rise on the coasts of Atlantic Canada *[**this volume**].*

Shaw, J., Taylor, R.B., Forbes, D.L., Solomon, S.M. and Ruz, M.-H.
1994. Sensitivity of the coasts of Canada to sea-level rise. Geological Survey of Canada, Open File 2825, 114 p. and map.

ShawMont Martec Limited.
1985. Hydrotechnical study of the Placentia area flood plain. Contract report to Newfoundland Department of the Environment and Environment Canada under the Canada-Newfoundland Flood Damage Reduction Program, 2 volumes.

Short, A.D. and Hall, W.
1993. Long-term wave height and beach profile changes, Narrabeen Beach, Australia. Proceedings, Conference on Large-scale Coastal Behavior, St. Petersburg. United States Geological Survey, Open-File Report 93-381, 177-180.

Solomon, S.M. and Forbes, D.L.
1994. Impacts of climate change on the Beaufort Sea coastal zone. In: Conference Proceedings, Coastal Zone Canada 94, Halifax. Coastal Zone Canada Association, 1810-1823.

Stea, R.R., Forbes, D.L. and Mott, R.J.
1992. Quaternary geology and coastal evolution of Nova Scotia. Geological Association of Canada/ Mineralogical Association of Canada Joint Annual Meeting, Wolfville '92. Field excursion A-6 guidebook, 125 p.

Stea, R.R., Boyd, R., Fader, G.B.J., Courtney, R.C., Scott, D.B. and Pecore, S.S.
1994. Morphology and seismic stratigraphy of the inner continental shelf off Nova Scotia, Canada: evidence for a -65 m lowstand between 11,650 and 11,250 C^{14} yr BP. Marine Geology, 117, 135-154.

Sunamura, T.
1977. A relationship between wave-induced cliff erosion and erosive force of waves. Journal of Geology, 85, 613-618.

Tanner, W.F.
1995. Origin of beach ridges and swales. Marine Geology, 129, 149-161.

Taylor, R.B., Forbes, D.L., Frobel, D., Shaw, J. and Parkes, G.
1997. Shoreline response to major storm events in Nova Scotia *[**this volume**]*.

Taylor, R.B., Frobel, D., Forbes, D.L. and Parlee, K.
1995. Coastal stability and the monitoring of physical shoreline changes in Nova Scotia. Proceedings, Canadian Coastal Conference 1995, Dartmouth, N.S. Canadian Coastal Science and Engineering Association, 829-843.

Taylor, R.B., Wittmann, S.L., Milne, M.J. and Kober, S.M.
1985. Beach morphology and coastal changes at selected sites, mainland Nova Scotia. Geological Survey of Canada, Paper 85-12, 59 p.

van de Plassche, O.

1991. Late Holocene sea-level fluctuations on the shore of Connecticut inferred from transgressive and regressive overlap boundaries in salt-marsh deposits. Journal of Coastal Research, Special Issue 11, 159-179.

Varekamp, J.C., Thomas, E. and van de Plassche, O.
1992. Relative sea-level rise and climate change over the last 1500 years. Terra Nova, 4, 293-304.

Warrick, R. and Oerlemans, J.
1990. Sea level rise. Chapter 9 in: Climate change: the IPCC scientific assessment. Report prepared for IPCC by Working Group 1 (Houghton, J.T., Jenkins, G.J. and Ephraums, J.J., editors). Cambridge University Press, 260-281.

Wigley, T.M.L. and Raper, S.C.B.
1992. Implications for climate and sea level of revised IPCC emission scenarios. Nature, 357, 293-300.

Wijnberg, K.M.
1995. Morphologic behaviour of a barred coast over a period of decades. Ph.D. dissertation, KNAG, Faculteit Ruimtelijke Wetenschappen Universiteit Utrecht, 245 p.

Wright, L.D. and Short, A.D.
1984. Morphodynamic variability of beaches and surf zones: a synthesis. Marine Geology, 56, 93-118.

3.3 *Ecosystem Science and Water Resources*

Climate change sensitivities of Atlantic Canada's Hydrological and Ecological Systems

Thomas Clair[1], Spyros Beltaos[2], William Brimley[3], Anthony Diamond[4]

[1] Environment Conservation Branch, Environment Canada- Atlantic Region, P.O. Box 1590, Sackville, N.B., E0A 3C0
[2] Aquatic Ecosystem Conservation Branch, National Water Research Institute, Environment Canada, P.O. Box 5050, Burlington, Ontario, L7R 4A6
[3] Atmospheric Environment Branch, Environment Canada-Atlantic Region, 1496 Bedford Hwy, Bedford, N.S., B4A 1E5
[4] Depts. of Biology and Forestry, University of New Brunswick, Fredericton, N.B., E3B 6C2

Atlantic Canada ecosystems and hydrological regimes are defined by cool, wet, temperate conditions in New Brunswick, Nova Scotia, Prince Edward Island and the Island of Newfoundland, and by colder drier conditions in Labrador. The three Maritime Provinces are located in the Atlantic Maritime Ecozone and the Island of Newfoundland and southern Labrador are in the Boreal Ecozone. Central Labrador is in the Taiga and northern Labrador is in the southern Arctic and Arctic Cordillera Ecozones. The main characteristics of the zones are listed in Table 1.

Table 1. General description of Atlantic Canada ecozones (from Eaton *et al*. 1994).

Ecozone	Climate	Primary ground cover
Atlantic Maritime	moderate, cool-moist maritime influence	productive forests
Boreal Shield	cold arctic air masses, modified near the coast	poor forests
Taiga Shield	cold winters, cool summers, short summers	tundra, permafrost
Southern Arctic	cold year round, little precipitation	rolling plains
Arctic Cordillera	very cold, glaciers	coastal mountains

The work summarized in this section is the result of ongoing or recent hydrological , geochemical and ecological studies analyzing the impacts of climate on avian, freshwater and wetland systems in the region. There are a large number of relevant topics which are not dealt with in this report which is more an indication of the current state of knowledge than an indication of importance. Topics not covered due to insufficient information include freshwater fisheries, mammalian wildlife populations as well as non-commercial plant species. Forests and marine ecosystems are covered in other sections of this report.

WATER RESOURCES

General

Persistent change or increased variability in climate will affect the present characteristics of the water resource. Precipitation and temperature are the principal driving forces behind the hydrological cycle and anticipated changes in climate are expected to significantly alter Canada's water resources. To this end, it is important that the various climate/hydrologic mechanisms at play and their interdependent reactions be understood. Proper monitoring of key elements over the long term is vital to increasing our understanding of these processes so that preventative or adaptive measures may be taken to reduce the impact on society.

The amplification of the temperature trend signal through the hydrology cycle could be dramatic. The timing of the change could also be gradual or stepwise (Nuttle, 1993). Increased variation seen as seasonal time shifts or rapid swings in seasonal climate variables could change the normal characteristics of the water cycle, creating havoc for human or ecosystem users of the resource. For example, increased winter precipitation would impact both the winter and spring runoff depending on the temperatures. This could produce increased winter runoff if supplied as rain or increased spring runoff if stored in the winter snowpack. The timing of these precipitation/temperature combinations will dictate the severity of the runoff event. The result could include both beneficial and catastrophic impacts depending upon the sensitivity of individual species of the ecosystem to change, their interdependence and the ability of natural and anthropogenic systems to adapt or mitigate that change.

Habitat loss is a major concern especially in the Atlantic Region as there may be no alternatives for some species. Climate and hydrology play a major role in the health of freshwater ecosystems. The timing and magnitude of specific hydrologic events such as freeze-up/break-up, the severity of the spring freshet or the duration of the low flow period is vital to the life cycle of many species. Though little of these potential impacts are discussed in this report, a more thorough discussion of ecological impacts of freshwater ecosystems can be found in McKnight *et al*. (1996).

On the human side of the ecosystem, the accumulation of long term flow and climate data have been invaluable in aiding the safe and economical design of dams, bridges, water supplies and other infrastructure whose design and integrity are influenced by the extremes of the hydrologic cycle. Significant changes in the hydrologic cycle may impact on the safe and long term economic use of some capital projects. Without a clear indication of the size and timing of the trend it will be difficult to convince developers to justify additional design costs to mitigate the predicted change.

Ice in Rivers

In the Atlantic Region, the preliminary screening of existing data revealed an interesting source of information previously not included in normal hydrological analyses. A remark “Backwater due to ice” which is appended to the daily flow values, alerts the user that ice conditions existed and that data is estimated using different procedures than those used for open water conditions. In using the ice data, two approaches were initially examined. The first was to consider the period from the first day of ice to the last, while the second only considered the number of days with ice. In the more northerly regions of New Brunswick, Newfoundland and Labrador where the ice cover is established and generally remains consistent, the approaches were essentially the same. Most of Nova Scotia, PEI, southern New Brunswick and Newfoundland have streams which may or may not freeze over or which may have several freeze/break-up episodes each winter, particularly in watersheds near the coast with a southerly exposure to the ocean.

Preliminary analyses of these data showed that there were some definite trends over the last 40 years. Stations in Nova Scotia (Figure 1.) and on the Island of Newfoundland showed that the number of days with ice in the river has increased since 1952 (when the data became part of the record). Preliminary comparisons of ice data with winter season temperatures showed that there was a cause and effect relationship between the temperature and ice, but for whatever reason it did not explain it completely.

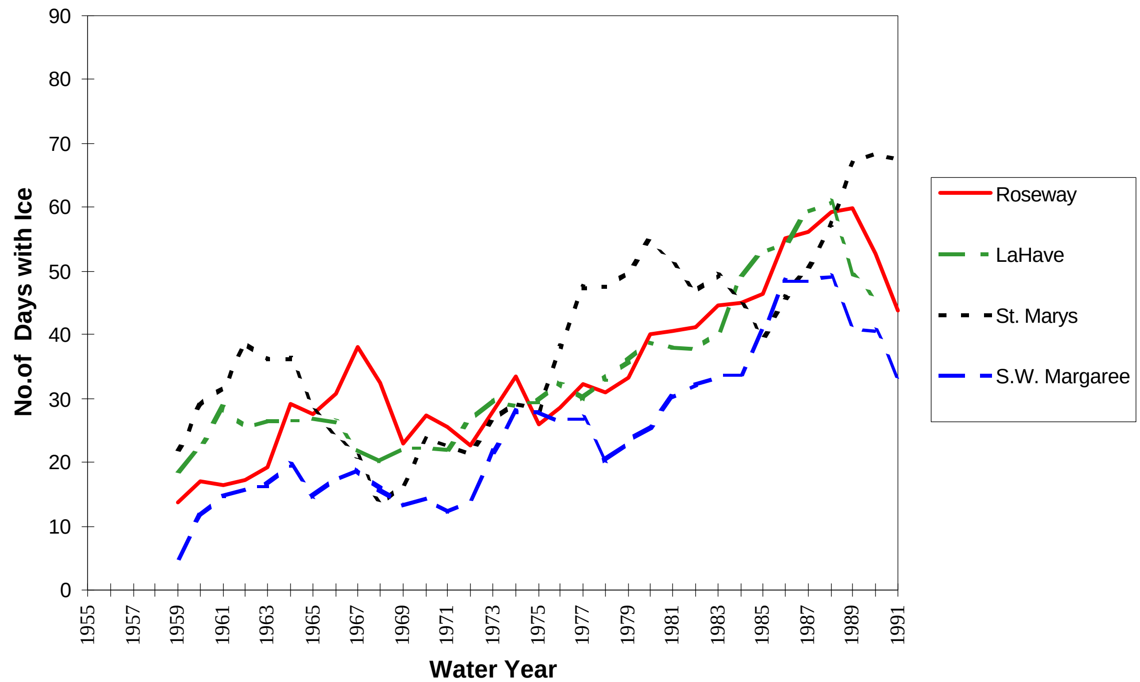


Figure 1. Ice Trends in Select Nova Scotia Rivers - 5 Year moving Averages

Runoff

Simplistically, runoff is a function of the watershed characteristics, which are essentially the physical structure of the watershed and the vegetation, in conjunction with the climate. The amount of runoff from a watershed is usually expressed as an average depth (i.e. millimeters) over the area of the watershed which enables us to make comparisons between watersheds as well as compare the output with the input (precipitation measured in the area). A given amount of precipitation will produce a different total runoff depending on the season, vegetation and the soil moisture condition.

By looking at the changes in runoff on an annual, seasonal, or shorter duration basis, it is possible to detect signals of change. Changes may include the magnitude and timing of seasonal events; trends in the number and severity of events per season and persistent trends or a change in the normal variability,

Trends may be the result of either a long term natural cyclic variation, climate change or a combination of both. To the ecosystem, the reason for the change may not be as important as the change itself. A more important fact is whether the anticipated effect of climate change will exacerbate or mitigate a cyclic trend, how long the trend will last and what are the implications for the entire ecosystem. Most of all, it is vital to apply this model to those susceptible species which may be on the edge of their habitat range. By understanding these systems there may be environmental management decisions that could reduce the impact on these species.

Preliminary analysis techniques have been used on the river ice data and on some annual and seasonal runoff data. In the case of the river ice data, trends were plotted for all existing data using a standard period from 1969-1992.

The results show three distinct hydrological areas: northern and eastern New Brunswick and Prince Edward Island, where there appears to be a mild signal showing less ice in the rivers; southern New Brunswick and central Nova Scotia where there appears to be no change; and southern, eastern and northern Cape Breton (Nova Scotia), as well as most of Newfoundland where there appears to be a significant trend towards more days with ice.

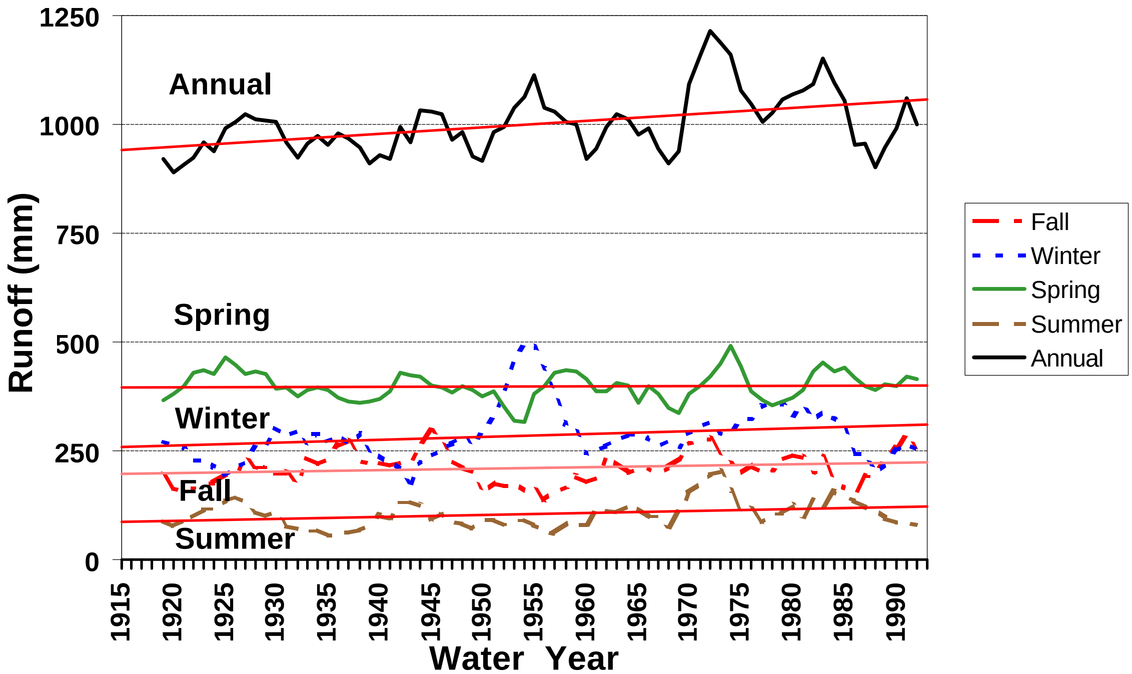


Figure 2. Seasonal and Annual Runoff as 5 - Year Moving Averages for the St. Marys River, N.S.

Using Figure 2 as an example, the runoff data shows a long period of level or slightly increased runoff in the St. Mary's River, Nova Scotia until 1970 when there is a dramatic increase in the runoff followed by increased variability. The pivotal point of 1970 appears to be a starting point for some sort of change (Karl, 1996). The effect of the 1952 warm winter anomaly (Richards and Russell, 1995), is also quite pronounced. When the last 25 years are viewed in isolation there appears to be a dramatic decrease in runoff in Nova Scotia streams especially during the winter. What appears to be a trend from 1970 toward lower winter runoff is also the same period of longer ice seasons in rivers and a full cause effect relationship is being determined.

EFFECTS OF CLIMATE ON RIVER ICE JAMS

General

Ice jamming in Canadian rivers has a multitude of socio-economic impacts such as flooding, damage to private property and infrastructure, interference with navigation, and inhibition of hydropower generation. When a jam is in place, the water level has to rise dramatically to enable conveyance of the river flow while accommodating the keel of the jam and the additional resistance produced by the very rough jam underside. The release of an ice jam is also a matter of concern. A large volume of water comes suddenly out of storage, creating a *surge*. Ice-jam surges are characterized by very rapid stage increases downstream (order of a metre in minutes) and very high flow velocities (5 m/s is not uncommon). Bank erosion, bed scour, and very high suspended sediment loads often accompany ice-jam surges.

The average tangible cost of ice jamming to the Canadian economy is estimated at $60 million per year (Gerard and Davar, 1995). A much greater amount is attributed to missed hydro-power generation opportunities due to inadequate understanding of river ice processes (Raban, 1995). Atlantic Canada is one of the most-seriously affected regions (Environment Canada, 1985; Kindervater, 1977, 1980, 1985). In New Brunswick, for example, ice jams cause a third of all flood events but are responsible for two-thirds of all flood damages (Humes and Dublin, 1988).

The strong relationship between river ice and aquatic ecosystems has only recently been emphasized (Prowse and Gridley, 1993). Ice jams and the surges that follow their release, have many detrimental impacts on aquatic life. Habitat loss due to bed and bank scour, fish mortality due to stranding on the floodplains, very high concentrations of fines, abrupt water quality changes, long range transport of pollutants, deposition of fine sediment and degradation of spawning habitat, are but a few examples. Ice jams also have positive ecological effects, such as the replenishment of floodplain habitat with nutrients and sediment for the sustenance of many aquatic, terrestrial and avian species, during the spring flood (e.g. see Peace-Athabasca Delta Project, 1973; Marsh and Hey, 1989).

Ice Processes and *their Links to Climate*

River ice studies show that the onset and severity of a breakup event, and the ensuing ice jams, are controlled by: the water levels during the preceding freeze-up; the thickness of the ice cover at the end of winter; the weather conditions during the breakup period; and the volume and rapidity of the spring runoff (Beltaos, 1995). The freeze-up level and the winter ice thickness determine threshold values of river flow for ice movement (onset of breakup) and ice clearing (end of breakup). If the runoff is slow, the onset of breakup will be delayed and the ice subjected to significant thermal deterioration. In extreme situations, the ice cover disintegrates in place and the breakup is *overmature* or *thermal*, characterized by minimal, if any, jamming. The opposite extreme is the *premature* or *mechanical* breakup which has the greatest potential for ice-jam damages. Here, the runoff is very rapid, usually due to rainfall combined with snowmelt. The breakup onset threshold is attained quickly, allowing little opportunity for ice deterioration.

Where the winter ice cover is set in motion, it rapidly breaks down into small floes that are eventually arrested by segments of still-intact ice cover. Major jams form, release, and re-form downstream, until the clearing threshold is reached and the breakup event is completed. Premature breakups are rare where the runoff is produced by snowmelt. They are most common in relatively temperate regions and often triggered by mid-winter thaws. Such *winter breakups* can be very dangerous, not only while they are in progress but even later on: when the cold winter weather resumes, ice jams that are still in place freeze over, resulting in higher freeze-up levels and thicker ice covers, thus enhancing the potential for more jamming during the next breakup event.

This brief discussion shows that the factors controlling the onset and severity of ice jams, viz. the flow hydrograph between fall and spring, and the thickness of the winter ice cover, are climate-related. Subtle changes in weather conditions can produce very different hydrographs, thus modifying the river ice regime. For instance, a slight temperature difference can produce a winter breakup by transforming a common snow storm into a rainfall event. Reduced ice thickness would imply easier ice clearance and lesser ice volumes that may be available to form ice jams, but the reduction would have to be more than subtle before noticeable moderation of ice jamming occurs.

Evidence of Changing River Ice Regimes and *Impacts of Various Scenarios*

The sensitivity of river ice processes to climate has been demonstrated by a limited number of studies in Canada and abroad. Zachrisson (1989) reported that earlier and more severe breakups are occurring in the river Torneälven (Sweden-Finland boundary), likely due to rising April temperatures. However, clear-cutting of forested areas and removal of numerous log-driving dams were also cited as factors. In rivers of Russia, Belorussia, and Ukraine, ice forms later than in the past, by as much as 21 days in 100 years (Ginzburg *et al*, 1992), in response to concomitant warming trends. Corresponding advances of up to 11 days in 100 years were reported for breakup dates by Soldatova (1993).

In Canada, Williams (1970) and Rannie (1983) reported earlier breakups in the Saint John River (NB) and the Red River (Man.), respectively, by about 15 days since the last century. These trends are consistent with Burn's (1994) findings, showing that the snowmelt peak flows generally arrive earlier, at an average rate of 0.25 days/year, in rivers of west-central Canada. Brimley (1996) considered the duration of the ice season in Atlantic Canada, as revealed by hydrometric gauge records (Water Survey of Canada) in the past 45 years or so. The results highlight the strong spatial variability of the Atlantic region's climate, and are consistent with, though not entirely explained by, local winter temperature trends.

The above studies deal with the length of the ice-cover season and do not specifically address ice-jam processes and their severity. This question could be investigated by examination and analysis of unpublished hydrometric gauge data, namely the continuously recorded time series of river stage. Beltaos *et al* (1990) provide guidelines for interpreting such data.

Considerable warming and changes in precipitation patterns are predicted by General Circulation Models (GCMs), under the well-known 2xCO_2 scenario. If these changes materialize, our understanding of river ice processes suggests that the ice regime may be modified in different ways over different parts of the country. In temperate regions such as SW Ontario, and parts of British Columbia and Atlantic Canada, the brief and capricious river ice cover may disappear completely, or become more intermittent. This should be good news on the socio-economic front, but could be disruptive to aquatic species that depend on the ice cover for winter survival.

A large part of Canada, on the other hand, including northern B.C., the Prairies, most of Ontario and Quebec, and northern parts of the Atlantic Region, experiences long river ice seasons, mostly devoid of winter breakups. This is certainly the case with west-central Canada. Ontario, Quebec, and northern New Brunswick do experience the occasional winter breakup, seemingly more often in recent years. [A case in point is the upper Saint John River (USGS gauge data, Fort Kent), where 3 of the 7 winter breakups of the past 70 years occurred during 1995 and 1996. A fourth event (December 1990) was followed by one of the most severe spring breakups on record (see also Beltaos and Ismail, 1996). No winter breakups have occurred between 1927 and 1957]. A common change that may occur in this part of Canada is the occurrence of winter breakups, either as a new phenomenon in some areas, or a more common one in other areas. Ice thickness will be reduced somewhat, though not enough to alleviate the risk of ice jamming.

In northern Canada, the winters are so cold that, even with the predicted warming, winter breakups should be very rare, if they appear at all. Less frequent jamming and flooding may occur in some areas, leading to long-term decline in floodplain habitat replenishment, as explained earlier. Longer open-water seasons in northern rivers could result in significantly increased exposure of aquatic species to UV-B radiation.

Beyond such broad predictions of possible changes, , it is not possible at present to identify specific areas and communities that may be vulnerable to climatic change, or to anticipate the magnitude of economic and ecological impacts. This is due to: (a) uncertainties introduced by the coarse grids of GCMs and their weakness in predicting amounts and types of precipitation; and (b) the relative "youth" of river ice science.

Research Needs

The preceding discussion has been a preliminary attempt to identify some of the changes in the ice-jam regime of Canadian rivers that may be expected under the global warming scenario. The emphasis should be on the word "preliminary" because neither GCMs nor river ice science are sufficiently advanced. However, GCM sophistication and computer power are increasing, and it is likely that many of the weaknesses of the GCMs will be rectified in the next decade. To take advantage of such progress, river ice science must also advance to the point that it can furnish quantitative predictions, given climatic inputs and channel morphology.

This cannot be accomplished satisfactorily at present because there is still considerable reliance on empirical formulae and methods. Such methods often assume that several climatic variables - except air temperature - do not change much from year to year, thus providing approximate relationships between ice-related parameters and simple thermal indices. This approach is not reliable in the climate-change context, and there is a need to develop physically-based models, by improving the basic understanding of river ice processes. A parallel effort needs to be made toward predicting what may happen to river ecosystems. Inter-disciplinary studies, combining biological, chemical, and physical expertise would have the best chance of success. At the same time, it is important to continue monitoring the status of the ice regime and assess how it may be changing. A comprehensive study of hydrometric station data to investigate hydrologic and ice-jam processes would be a starting point toward eventual identification of areas that may be of concern (see also Beltaos *et al*, 1990).

Summary

River ice jams have major social, economic and ecological impacts in the Atlantic Region. River ice processes in general, and ice breakup and jamming in particular, are highly sensitive to climatic inputs. The limited available evidence indicates that changes are taking place and they are consistent with concomitant temperature trends. A preliminary attempt to formulate future scenarios has indicated that there are several concerns pertaining to changing ice-jam regime, both of socio-economic and ecological nature. How serious the possible impacts might be, and exactly in what areas, cannot be determined at present, because neither the GCMs nor river ice science are sufficiently advanced. Research needs for the latter include assessment of current indicators of change using hydrometric gauge data, improved basic knowledge of breakup and ice jam phenomena to reduce empiricism, and inter-disciplinary studies of the links between river ice and stream ecology.

ATLANTIC CANADA WETLANDS AND CLIMATE

Introduction

Wetlands are areas where water tables are at or near the surface long enough to be noticeable to plants and animals. They can be very small, from a few hundred square meters or very large, covering hundreds of square kilometers as is the case in southern Labrador. They occupy 2% of the land area in New Brunswick, 17% of Newfoundland and Labrador, 3% of Nova Scotia and 1% of Prince Edward Island (National Wetlands Working Group, 1988). Despite the somewhat low coverage, they are very important in controlling water abundances and quality as well as are important ecosystems for waterfowl and plants.

There are a number of wetland classifications used in Canada and elsewhere, but what drives these classifications are three things: nutrients, temperature, and precipitation, the last two being modified by climate. Atlantic Canada wetlands fall in three general regions which overlap somewhat with the Ecozone classification. The Temperate wetland region is most important in the lower St. John River Valley and is defined by relatively warm summers, mild winters and moderately high amounts of precipitation. Most of the region has wetlands classified as Boreal which are influenced by cold winters, warm summers and in coastal regions, relatively high precipitation. Southern Newfoundland and northern Labrador wetlands are classified as Subarctic and are subjected to intensively cold winters and warm summers with relatively low precipitation levels. Each of these wetland groups has a well defined plant and animal assemblage which could be changed by changes in climate. They are important as waterfowl habitat and have an important role to play in landscape and geochemical cycles.

Wetlands are important to the global carbon cycle. The Northern Hemisphere with its large amount of wetlands is potentially one of the strong controls to the global atmospheric CO_2 cycling. CO_2 is taken up by the plants which eventually die, some of the organic matter is converted to peat, some of it goes back into the atmosphere as CO_2 and methane, and some of it leaves in drainage water in the form of dissolved organic carbon. The last sink is also an ecologically significant component of the water chemistry.

Consumptive uses of wetlands are varied. The peat industry for example drains wetlands and uses the dried organic matter for making horticultural products. Wetlands are also being used to clean up mining wastes because the organic acids that are generated in the wetland organic material, are good complexers of metals. Further, in small communities wetlands are used to purify municipal effluents.

Because they are defined by the location of seasonal and permanent water tables, wetlands are closely linked to climate. Balances between precipitation and temperature which control total water input and outputs are critical in determining the very existence of wetlands. Changes in the evapotranspiration balance leading to lower water tables may thus cause the disappearance of wetlands along with the ability of basins to absorb water and increase flood risks in certain areas. For examples, Clair and Ehrman (1996) used historical climate and hydrology information from 15 wetland influenced rivers in Atlantic Canada and developed predictions of water discharge from the region based on a number of climate scenarios. They found that a regional temperature increase of 3^o would lead to a decrease of 29% of regional discharge with a 20% decrease of precipitation, a 10% decrease with no change in precipitation and a 9.5% increase with a 20% increase in precipitation. These numbers suggest that water levels might change significantly with shifts in climate but how these translate into actual wetland distributions has not yet been determined and remains an important unknown in attempting to understand the implications of climate change.

Water levels and flows through wetlands also control their carbon content and fluxes (Gorham 1991). Clair and Ehrman (1996) show that aquatic dissolved organic carbon fluxes are closely linked to water flow through the basins. Moore (1994) also shows that water levels control the level of methane and CO_2 emissions from wetlands. Recent work (Dalva and Moore, unpub.) shows that gas fluxes from Nova Scotia wetlands fall within values measured elsewhere in Canada. These show that methane emissions under waterlogged conditions range from -23 to 1153 mg/m^2/day, while CO_2 fluxes are more important under drying conditions with values ranging from 0.2 to 23 g/m^2/day. Shifts in water tables due to a changing climate will change the relative importance of the gases and their impact on the global atmospheric carbon cycle.

EFFECTS OF CLIMATE ON MIGRATORY BIRDS IN ATLANTIC CANADA

Indirect Effects of Climate

Changes in habitat

Birds, like other organisms, live in habitats to which they are adapted and the distribution of these habitats is determined by interactions between climate (especially rainfall and temperature) and soils. Globally, continentally and regionally, the effects of changing climate on avifaunas will likely be mediated through changes in the distribution of ecoclimatic zones, which are reasonably predictable on a very broad scale. An important consequence of changes in distribution of ecoclimatic regions is that species will come into contact with other species from which they are currently separated geographically.

Biotic communities are not fixed associations, but shifting assemblages of species brought together by a common tolerance for combinations of environmental conditions (Pease *et al*. 1989). The most important changes to terrestrial habitats, however, are likely to be caused by changes in land-use by humans. Atlantic-region terrestrial ecosystems are dominated by forestry and agriculture which will respond to global changes of all kinds, especially economic and trade-related, in addition to climate, and these responses will likely dwarf any responses due directly to changing climate.

Changes in distribution

Boundaries of winter ranges of terrestrial birds will likely shift northwards with warmer winters; the northern boundaries of many species of songbird coincide with January isotherms reflecting daily energy requirements of about 2.5 times Basal Metabolic Rate (Root 1998 a, b). However, these direct effects of temperature are manifest only within the range of suitable habitat for any particular species, so that changes in habitat distribution will likely remain more important than temperature *per se* in determining winter distribution of most species. Equivalent relationships between climate and distribution presumably operate in summer as well as winter, but these relationships have not been described in Canada. The `energy theory' of species distributions developed by Brown (1981) and Wright (1983), which relates abundance and distribution of species to available solar energy (Turner *et al*. 1988), suggests that climatic changes could affect bird distributions directly, in addition to changes mediated through changes in distribution of habitat.

Among marine birds, changes in range will likely follow changes in the distribution of prey such as capelin, arctic cod, herring, sand-lance etc., which in turn will accompany changes in water-temperature and salinity (Brown 1991). Compression of the boreal marine ecozone can be expected as the cold Labrador current becomes cooler from increased inflow of glacial melt as the Greenland ice-caps melts, at the same time that warm waters of the Gulf Stream move further north (Brown 1991). Colonies of Thick-billed Murres and other arctic seabirds currently occur chiefly near polynyas and coasts where ice melts early, and are likely to change localities if these water-masses change in distribution.

Sea-level rises will likely cause abandonment of Funk Island, which currently supports enormous colonies but is only 15m above sea-level and already vulnerable to significant losses from summer storms (Brown 1991). Other shoreline habitats support breeding pairs of two endangered bird species - Roseate Terns and Piping Plovers - which will have to move to new locations as their present sites are inundated or washed away.

Migration routes

Habitat requirements on migration may be just as specific as those for breeding and wintering. Rising sea level is likely to inundate coastal staging grounds which are essential for shorebirds and waterfowl migrating between arctic breeding grounds and southern winter quarters. The most obvious examples in this region are the saltwater marshes connecting New Brunswick and Nova Scotia, and the mudflats at the head of the Bay of Fundy. The former are staging grounds for large numbers of migrating waterfowl, while the latter make up a critical stopover in July and August for shorebirds, especially most of the Semi-palmated Sandpipers *Calidris pusilla* in the world (Hicklin 1987). A rise is sea-level of 1 m will likely cause a 1.7% increase in tidal range in the Bay of Fundy (Greenberg 1986), with significant but unpredictable effects on these mudflats and marshes.

Direct Effects of Climate

Timing of breeding

Most birds breed as early as they can; accordingly, changes in the timing of warm spring temperatures are likely to bring breeding seasons forward. In many species, too, breeding success is correlated with the timing of breeding and early breeders do better than later breeders (Perrins and Birkhead 1983).

Understanding of effects of climate on breeding phenology is best developed for arctic-nesting waterfowl, whose breeding is normally initiated at or shortly after snow-melt; late melt delays breeding and often lowers breeding productivity as well, either for energetic reasons (e.g. Barry 1962, Davies and Cooke 1983, Ryder 1967) or through increased predation (Byrkjedal 1980). In extreme cases, it may lead geese to move to entirely new areas (McCormick 1988) or to abandon breeding altogether.

In Atlantic terrestrial ecosystems we know very little about the relation between climate and breeding phenology; in general at these latitudes breeding is probably initiated chiefly by changes in daylength (the 'proximate' factor in evolutionary terms) in such a way that the time of maximum energy demand coincides with increased food supplies (evolution's 'ultimate' factor) (Perrins and Birkhead 1983). In a changing climate the temporal relationship between daylength and food production will likely change, requiring adaptive changes by the bird populations.

Breeding success

Beyond general correlations between 'bad' (i.e. wet and cold) summer weather, and lower bird productivity, the influence of climate on breeding success has not been explored in Atlantic Canada. In many seabirds, both breeding distribution and the timing of breeding are related to sea-surface temperatures (Harris and Wanless 1989). Since these temperatures are likely to change as the climate warms, noticeable changes in distribution and breeding success of seabirds can be expected. Climate fluctuations in the north-west Atlantic over the last few hundred years, and their effects on fish and seabird populations, have been reviewed by Dunbar (1985), Dunbar and Thompson (1979), and Brown (1991).

Timing and success of migration

Migration is clearly timed to correlate closely with weather conditions; the departure of snow geese from winter quarters, for example, is triggered by temperatures above 18 C (Flickinger 1981), and the northward progress of Canada Geese on spring migration is correlated with the 35 F (17 C) isotherm (Lincoln 1979). In general, weather systems - rather than actual temperatures - probably govern the timing of migration. Peak waterfowl migration in fall usually follows shortly after the passage of a cold front (Hochbaum 1955) whereas in spring, migrants move north on the warm sector of low-pressure systems (Lincoln 1979). Thus, the distribution of air-masses is at least as important as temperatures and wind strengths (Blokpoel and Gauthier 1975).

The timing of many events in a bird's annual cycle, including migration, breeding and moult, is frequently triggered by changes in day length (Murton and Westwood 1977). This timing mechanism may prove maladaptive in a changing climate, when the linkage between day length and changing food supply, habitat availability, movement of air-masses, etc., becomes uncoupled as these climatic events change but day length does not.

Extreme Events

Storms at any time of year can have severe effects on birds. Cold snaps in late spring frequently cause large-scale mortality in small birds (e.g. Henny *et al*. 1982), and summer storms can kill shorebirds on their breeding grounds (e.g. Morrison 1975) and greatly reduce breeding success among bird groups as varied as songbirds and seabirds (pers. obs.). Observations of such extreme events are essentially anecdotal, and it is uncertain what role they may play in determining population persistence in the long term; however if, as is widely predicted, they become more frequent during climatic change, more attention will need to be paid to their possible impacts.

Discussion

The current state of knowledge of climate /wildlife interactions is fragmented and poorly understood; it is not yet organized as a coherent field of research. Currently we can estimate general sensitivities of birds to climate change, in the very broad fashion outlined here, but we have very limited knowledge of the sensitivities of particular species.

Examination of three General Circulation Models (GCM's) (Taylor and Taylor 1996) suggests that despite the last few decades cooling trend, the portion of Atlantic Canada most likely to be affected by climate warming is central and northern Labrador, especially during the winter and spring periods. Because of the moderating effect of the oceans, the remaining regions whose climate is likely to change slightly are not as likely to show large changes.

However, measures currently available (e.g. monthly temperature means, precipitation totals) in the climatological record are of limited value in assessing ecological impacts of climate change. Estimates of precipitation on finer geographic and temporal scales, are needed to predict effects of climate change on biodiversity in general, including birds.

For historical and geographical reasons, universities and research institutions, as well as most of the region's population, are located in the southern, more climatically hospitable part of the region. This has caused a situation where most of the knowledge of hydrological and ecological conditions and processes is concentrated on the one third of the region which is least likely to be affected by climate change. Future research on climate change or climate variability impacts should be initiated in Labrador as this is the area most likely impacted by a changing atmospheric energy balance.

REFERENCES

Barry,T.W.
1962. Effect of late seasons on Atlantic Brant reproduction. J. Wildl. Management 26:19-26.

Beltaos, S.
1995. Breakup of river ice. National Water Research Institute Contribution No. 95- 125. Prepared for IAHR book “River Ice Processes and Hydraulics”, Chapter 5.
Beltaos, S. (1997) Onset of river ice breakup. Cold Regions Science and Technology, in press.

Beltaos, S., Gerard, R., Petryk, S., and Prowse, T.D.
1990. (Working group on river ice jams): Field studies and research needs. NHRI Science Report #2, Saskatoon, Sask.

Beltaos, S. and Ismail, S.
1996. Saint John river ice and sedimentation study. Can. Civil Engineer, 13(8), 6-7.

Blokpoel,H. and Gauthier,M.
1975. Migration of lesser snow and blue geese. Part 2: influence of the weather and prediction of major flights. Can. Wildl. Serv. Report Ser. 32. 29pp.

Brimley, W.A.
1996 Hydrologic monitoring to detect climate change. Proc., Symposium on Climate Change and Variability in Atlantic Canada. Halifax, NS., in press.

Brown, J.H.
1981. Two decades of homage to Santa Rosalia: toward a general theory of diversity. Amer. Zool. 21:877-888.

Brown, R.G.
1991. Marine birds and climatic warming in the northwest Atlantic. Pp.49-54 in Montevecchi,W.A. and Gaston,A.J. (Eds.). Studies of high-latitude seabirds. I. Behavioural, energetic, and oceanographic aspects of seabird feeding ecology. Occ. Pap. No. 68, Can. Wildl. Serv., Ottawa.

Burn, D.H.
1994. Hydrologic effects of climatic change in west-central Canada. Journal of Hydrology, 160(1994), 53-70.

Byrkjedal,I.
1980. Nest predation in relation to snow cover - a possible factor influencing the starting of breeding in shorebirds. Ornis Scandinavica 11:249-252.

Clair, T.A. and J.M. Ehrman
1996. Variation in discharge, dissolved organic carbon and nitrogen export from terrestrial basins with changes in climate: a neural network approach. Limnology and Oceanography 41: 921-927.

Clair, T.A., T.L. Pollock, P. Collins, J. R. Kramer
1992. How brown waters are influenced by acidification: the HUMEX lake case study. Environ. Int. 18: 589-596.

Davies,J.C. and Cooke,F.
1983. Annual nesting productivity in snow geese: prairie droughts and arctic springs. J. Wildl. Manage. 47:291-296.

Dunbar,M.J.
1985. Sea ice and climatic change in the Canadian arctic since 1800. In: Harrington,C.R. (ed.). Climatic change in Canada - 5, Syllogeus 55, National Museum of Natural Sciences, Ottawa.

Dunbar,M.J. and Thompson,D.H.
1979. West Greenland salmon and climatic change. Meddeleser om Gronland 205:5-19.

Eaton, P.B., A.G. Gray, P.W. Johnson and E. Hundert
1994. State of the Environment in the Atlantic Region. Environment Canada, Atlantic Region, 457pp.

Environment Canada
1985. Flooding in New Brunswick: an overview 1696-1984. Inland Waters Directorate, Atlantic Region, Dartmouth, NS, 13 p.

Environment Canada
1995. The state of Canada’s climate: monitoring variability and change. SOE Report No. 95-1. Ottawa, Ont., 52 p.

Flickinger,E.L.
1981. Weather conditions associated with beginning of northward migration departures of snow geese. J. Wildl, Manage. 45:516-520.

Gerard, R. and Davar, K.
1995. Chapter 1, “River Ice Jams”, (editor: S. Beltaos) Water Resources Publications, Highlands Ranch, Colorado, USA.

Ginzburg, B.M., Polyakova, K.N., and Soldatova, I.I.
1992. Secular changes in dates of ice formation on rivers and their relationship with climate change. Soviet Meteorology and Hydrology, 12, 57-64.

Gorham, E.
1991. Northern peatlands: role in the carbon cycle and probable responses to climatic warming. Ecol. Appl. 1: 182-195.

Greenberg,D.A.
1986. Time and space variations of water levels in the Bay of Fundy and Gulf of Maine. Pp. 21-33 in Daborn,G.R. (ed.). Effects of changes in sea level and tidal range on the Gulf of Maine-Bay of Fundy system. Acadia Cent. Estuarine Res. Publ. No.1, Wolfville.

Harris,M.P. and Wanless, S.
1989. The breeding biology of Razorbills Alca torda on the Isle of May. Bird Study 36:105-114.

Henny,C.J., Blus,L.J. and Stafford,C.J.
1982. DDE not implicated in cliff swallow Petrochelidon pyrrhonata mortality during severe spring weather in Oregon. Can. Field Nat. 96:210-211.

Hicklin,P.W.
1987. The migration of shorebirds in the Bay of Fundy. Wilson Bulletin 99(4): 540-570.

Hochbaum,H.A.
1955. Travels and traditions of waterfowl. Minneapolis: University of Minnesota Press. 301pp.

Humes, T.M. and Dublin, J.

1988. A comparison of the 1976 and the 1987 St. John River ice jam flooding with emphasis on antecedent conditions. Proc. Workshop on Hydraulics of River Ice/Ice Jams, Winnipeg, Man., NRCC Associate Committee on Hydrology, Ottawa, Canada, 43-62.

Karl, T.R., *et al*
1996. Indices of Climate Change for the United States, Bull. Amer. Meteor. Soc., 77,279-292.

Kindervater, A.D.
1977. Flooding events in Nova Scotia: a historical perspective. Environment Canada, IWD Atlantic Region, Halifax, NS.

Kindervater, A.D.
1980. Flooding events in Newfoundland and Labrador: an historical perspective. Environment Canada, 80-WPMB-4, IWD Atlantic Region, Halifax, NS.

Kindervater, A.D.
1985. Flooding events in New Brunswick: an historical perspective. Environment Canada, IWD-AR-WPMB-84-65, IWD Atlantic Region, Dartmouth, NS.

Lettenmaier, D.P., *et al*.
1994. Hydro-Climatological Trends in the Continental United States, 1948-1988, J. Climate, 7, 586-607.

Lincoln,F.C.
1979. Migration of birds. U.S. Fish and Wildl. Serv. Circular 16. 119pp. (Rev Ed).

Marsh, P. and Hey, M.
1989. The flooding hydrology of Mackenzie delta lakes near Inuvik, N.W.T. Canada. Arctic, Vol. 42, No. 1, 41-49.

McCormick,K.J.
1988. Lesser snow goose colonies in the Pelly Lake area. C.W.S. Progr. Note No. 178. 3pp.

McKnight, D., D.F. Brakke, P.J. Mulholland (eds)
1996. Freshwater ecosystems and climate change in North America. Limnol. Oceanog. 41: no. 5.

Moore, T.R.
1994. Trace gas emissions from Canadian peatlands and the effects of climate change. Wetlands 14: 223-228.

Morrison,R.G.
1975. Migration and morphometrics of European Knot and Turnstone on Ellesmere Island, Canada. Bird-Banding 46:290-301.

Nuttle, W.K.
1993. Adaptation to Climate Change and Variability in Canadian Water Resources, Rawson Academy, Occasional Paper No. 7.

Peace-Athabasca Delta Project
1973. Technical Report, The Peace-Athabasca Delta Project Group, Information Canada, Ottawa, Canada, 176 p.

Pease,C.M., Lande,R. and Bull,J.J.

1989. A model of population growth, dispersal and evolution in a changing environment. Ecology 70:1657-1664.

Perrins,C.M. and Birkhead, T.R.
1983. Avian ecology. Blackie.

Prowse, T.D. and Gridley, N.C. (editors)
1993. Environmental aspects of river ice. NHRI Science Report No. 5., National Hydrology Research Institute, Saskatoon, Canada.

Raban, R.
1995. An ice engineering overview. Proceedings, 8th River Ice Workshop, Kamloops, BC, in press.

Rannie, W.F.
1983. Breakup and freeze-up of the Red River at Winnipeg, Manitoba, Canada, in the 19th century and some climatic implications. Climatic Change, 5, 283-296.

Richards, W.G. and M.P. Russell
1995. Socio-Economic Impacts of the Warm Winter of 1952/53 in New Brunswick, Internal Report: MAES 4-95, Environment Canada, Atlantic Region..

Root,T.
1988a. Energy constraints on avian distributions and abundances. Ecology 89:330-339.

Root,T.
1988b. Environmental factors associated with avian distributional boundaries. J. Biogeogr. 15:489-505.

Ryder,J.P.
1967. The breeding biology of Ross' Goose in the Perry River region. C.W.S. Report Ser. 3. 56pp.

Soldatova, I.I.
1993. Secular variations in river breakup dates and their relationship with climate variations. Soviet Meteorology and Hydrology, 9, 89-96 (in Russian).

Taylor, B and Taylor E.
1996. Climate change scenarios for Canada: a user's guide for climate change impact studies. Aquatic and Atmospheric Sciences Div., Environmental Conservation Br., Pacific and Yukon Region, Environment Canada, Vancouver, B.C.

Turner, J.R.G., Lennon, J.J. and Lawrenson, J.A.
1988. British bird distributions and the energy theory. Nature 335:539-541.

Williams, G.P.
1970. A note on the breakup of lakes and rivers as indicators of climate change. Atmosphere, 8, 23-24.

Woodward, W.A. and H.L. Gray
1995. Selecting a Model for Detecting the Presence of a Trend, . J. Climate, 8, 1929-1937
Wright,D.H. 1983. Species-energy theory: an extension of species-area theory. Oikos 41:495-506.

Zachrisson, G.
1989. Climate variation and ice conditions in the river Torneälven. Proc., WMO Conf. on Climate and Water, Publications of the Academy of Finland, Vol. **I**, 353-364.

3.4 *Agriculture*

A Review of Impacts of Climate Variability and Change on Agriculture in Atlantic Canada

Andrew Bootsma

Agriculture and Agri-Food Canada, Research Branch
Eastern Cereal and Oilseed Research Centre
Central Experimental Farm, Ottawa, Ontario K1A 0C6

Climate is one of the most fundamental natural resources needed for agricultural production. Along with soils, climate to a large extent determines the types of crops that can be successfully produced in the Atlantic region, where these crops can best be grown and the management practices that are used. A review of existing literature will be presented to highlight climate variability and change and the various impacts these have on agricultural production and management practices in the region.

Spatial variation in climate ranging from the micro-scale (on-farm) level to the broader meso- to macro-scale has a significant influence on crop selection and management. Temporal variability has greatest impact on the yield and quality of crops being produced in a given year and hence also directly impacts on farm profits. Relative to these factors, long term climatic change over the last 100 years or more has had much lesser impact on agriculture, although projected changes in future climate could become a significant factor in agricultural production in the region.

INTRODUCTION

The agricultural sector is particularly sensitive to climate change and variability because of its direct dependence on the weather/climate. Along with soils, climate, to a large extent, determines the types of crops that can be grown in the Atlantic region, where these are best produced, the yield and quality that is achievable with present-day technology and the types of management practices used. Some crops, such as grain corn, soybeans, winter wheat, tree fruits and grapes are presently marginal in many parts of the region but can be successfully produced where the climate is favourable. These types of crops are likely to be particularly sensitive to any climate change that may occur. Yearly variability in climate is large and has a very significant impact on crop yields and quality, and on the losses that are experienced due to such hazards as drought, frost, excess moisture and wind. The agricultural industry is continually challenged to minimize the negative impacts of climatic extremes that periodically occur. However, agriculture in the region may be considered as a ‘success’ story, achieving impressive gains in production over the years under what is often an inhospitable climate. In 1994, the region produced over 1.5 million metric tonnes of potatoes with a farm value of over $275 million (Statistics Canada, 1995). Farm cash receipts for all agricultural commodities totalled close to $1 billion in 1995 (Statistics Canada, 1996).

Climatic change could have a significant impact (either positive or negative) on the ability of the agricultural industry to compete with other regions, particularly if the frequency of occurrence of extreme conditions such as droughts, early fall frosts and excess moisture increases. Any impacts on the agricultural sector could have important spin-offs, since agriculture is a significant part of the regional economic activity. However, it is generally felt that the industry can adapt to gradual changes in climate that may occur over the next few decades or more.

This presentation will examine some of the current variability (both spatial and temporal) and long term trends in climate in the region, and highlight some of the impacts of these on agriculture. Other factors that could overwhelm climatic impacts plus mitigation measures to lessen negative effects and take advantage of potential positive changes will also be considered briefly.

CURRENT CLIMATE VARIABILITY AND IMPACTS

Spatial Variability and Impacts

Spatial climatic variations in the Atlantic region have considerable impact on agriculture, affecting such things as yield, quality, maturity and winter survival of crops and influencing management practices such as seeding and harvesting dates, pest and disease control measures, drainage and irrigation, crop selection and fertilizer inputs. Numerous descriptions of variations at the macro- to meso-scale level have been made, but interpretations of how these variations impact on agricultural production and management are frequently lacking. At this scale, the influence of large water bodies, major changes in relief (elevation) and latitude are fairly well identified.

Classification schemes developed in the early 1900's by Koppen and by Thornthwaite tended to be too broad (global) to be of practical use to agriculture in the region. Putnam (1940) published a detailed description of climate in the region, dividing the three Maritime provinces into eleven climatic zones. Other agroclimatic studies followed, including the Canada Land Inventory report by Chapman and Brown (1966) and the Agroclimatic Atlas of Canada (Agriculture Canada, 1976). Banfield (1981) provided a detailed description of the climate of Newfoundland relevant to agriculture. Dzikowski, *et al*. (1984) also prepared a detailed description of climate specifically for agriculture. These publications present spatial variations in average climatic variables of importance to agriculture such as heat units, frost-free period, growing season length, moisture deficits, potential evapotranspiration and precipitation. Other studies have focused on variations in a single variable such as annual water surpluses (Sanderson and Phillips (1967) or growing degree-days (Gordon and Bootsma, 1993). Some have focused on specific impacts of spatial differences in climate on crop production/management practices, such as cutting management of forage crops (Bootsma, 1984), optimum seeding period of winter wheat (Bootsma and Suzuki, 1986), field workdays available for spring and fall tillage (Baier, *et al*., 1978: Dyer, 1980) and for harvesting small grains cereals (Dyer and Bootsma, 1979).

It is beyond the scope of this presentation to describe all of the spatial variations in climate that exist and their impact on agriculture. Some of the most important differences are related to temperature (heat units), soil moisture, growing season length, frost occurrence and severity of winter conditions. A few examples follow.

Spatial differences in heat units (CHU) available for corn and soybean production (Bootsma *et al*., 1992) have significant impact on the production potential of these crops. Average CHU in the three Maritime provinces range from a high of about 2800 in the Annapolis valley to less than 1700 in northern New Brunswick. With present-day available hybrids, grain corn has good potential in areas with >2500 CHU, is marginal in 2300-2500 heat unit areas, and is generally not feasible in areas with <2300 CHU. Silage corn is generally not feasible in areas with <2100 CHU. These limits may be stretched as improved early-maturing corn becomes available through breeding. Thus the availability of heat units has very significant impact on which crop species, varieties and/or hybrids producers choose to grow and on the productivity of their farms.

Growing degree-days above 5°C (GDD) vary from less than 1000 to over 1800 in parts of the Annapolis and lower Saint John River valleys (Gordon and Bootsma, 1993: Dzikowski *et al*. 1984). Differences in GDD particularly impact the potential on long season crops such as spring wheat, potatoes and forages. GDD in combination with growing season length affects the number of cuts that can be taken of various forage crops (Bootsma, 1984), thereby impacting on their productivity. Providing that adequate winter survival is achievable, areas with less than 1300 GDD generally have potential for only one cut of alfalfa, while up to three cuts may be possible in regions with more than 1800 GDD. Spatial variation in autumn temperatures result in differences in the time of the optimum period for seeding winter wheat. This period ranges from Sep. 10-25 in the Annapolis valley to the latter part of August in northern New Brunswick (Bootsma and Suzuki, 1986).

Spatial variations in winter climates have significant impact on survival (and hence the suitability) of overwintering crops such as winter wheat, clover, alfalfa, strawberries, tree fruits and ornamental trees and shrubs. Blackburn (1984) rated the susceptibility of winter injury to apples from low in the Annapolis valley to high in many areas of New Brunswick. The Annapolis valley probably has one of the most favourable climates for tree fruits in the region because of a combination of low susceptibility to winter damage and a long warm growing season (relative to other areas in the region) promoting good maturity and yield, while many other areas of the region which lack these characteristics are either marginally or not at all suited for tree fruit production. Significant differences exist in winter hardiness zones for ornamental trees and shrubs, with the area least susceptible to damage being the southwest tip of Nova Scotia and the severest region in north-central New Brunswick (Ouellet and Sherk, 1967).

Significant climate-induced differences in soil moisture deficits and spring field workdays occur in the region. Estimates for well-drained sandy loam soils at St. John's, Charlottetown and Kentville, respectively, indicate there are on average about 16, 24 and 31 days suitable for tillage and planting between April 1 and June 2, and 35, 75 and 110 mm of seasonal water deficits (Coligado *et al*., 1968; Bootsma and Boisvert, 1987). These differences impact farm management decisions such as machinery size, labour requirements, irrigation and drainage system design. Regional differences in climate impact the need for and potential benefit of irrigation. Bootsma *et al*. (1996), using a crop growth model, estimated that average alfalfa yields would only increase by 0.5 t/ha at St. John's, but as much as 4 t/ha at Charlottetown using irrigation.

Significant variations in climate also can occur over short distances or the topo or farm scale. Nighttime minimum temperature and wind are particularly affected by topography and shelter. Surveys conducted in P.E.I. indicated that on-farm minimum temperatures during clear calm nights can vary by 6°C or more between hilltops and valley bottoms with elevation differences of as little as 35 m (Bootsma, 1976, 1980). As a result, the average date of the first fall frost can differ by 4 weeks or more on the same farm. This has important implications for a variety of frost sensitive crops such as tender fruits and vegetables, corn, potatoes, tobacco, blueberries and tree fruits, affecting field suitability for these crops and impacting on management decisions such as planting dates, harvesting dates and whether or not active frost prevention methods are needed. Crop damage inflicted by unusually early fall frost is generally greatest in low-lying fields which experience lower nighttime minimum temperatures than surrounding areas. Significant gradients in minimum temperature during some freeze situations may also be experienced on land influenced by large bodies of water such as the Northumberland Strait and the Bay of Fundy.

Temporal Variability and Impacts

Temporal variability in climate exerts perhaps even greater impact on agriculture than the spatial differences that are encountered in the Atlantic region. Variations that likely have the greatest impact on agriculture include excess moisture, unusually late spring or early fall frosts, drought, unusually severe storms, unfavourable overwintering conditions and exceptionally cool growing season weather. Yearly variability is perhaps the most difficult attribute of the climate that producers must cope with, having very significant impacts on crop yield, quality, field losses and on cost of production and economic returns.

Treidl (1978) provided statistics on variability (e.g. coefficient of variation, standard deviation, extremes) for a number of climatic variables of importance to agriculture. Information on spring and fall frost dates is generally presented for a range of probability levels, indicating the variability (Hornstein, 1961; Coligado *et al*., 1968; Environment Canada, 1982). We evaluated variability in dates of last spring and first fall frost (0°C), GDD above 5°C, and May to September total precipitation (P) at four locations (Table 1). If variables are normally distributed, then about 5% of years will be more than $\pm$ 2 standard deviations from the mean value. Thus variations in spring and fall frost dates of 5 or 6 weeks are not uncommon. Heat units vary by more than 450 GDD and precipitation fluctuations of 350 mm are fairly common (extreme differences in growing season precipitation at Kentville is 477 mm!).

Excessively wet spring conditions can result in delayed planting dates, reduce yields, increase susceptibility to disease and increased risk of frost damage in the fall due to later maturity. The number of days suitable for field work between April 1 and June 2 can vary by more than 200% from year to year, ranging, for example, from less than 16 to over 35 days at Charlottetown (Table 2). This variability makes it difficult for growers to schedule field work activity and labour requirements and make the most appropriate machinery size selection for their operation. Excess moisture during the growing season can result in significantly increased disease pressure, particularly of foliar type fungal diseases such as potato blight. Quality of hay is particularly sensitive to weather conditions during field curing and losses in quality can be high during abnormally wet years. Wet conditions during the fall can result in serious field losses of crops by delaying the harvest, particularly when accompanied by early frosts. In 1974, such conditions resulted in losses in potatoes estimated to exceed $4 million in P.E.I. alone (The Guardian, Nov. 8, 1994). Unusually severe storms with heavy rain and wind can result in severe lodging of cereals and too much humidity at harvest can cause grain to sprout. Other negative impacts of excessive rainfall include leaching of soil nutrients (especially nitrogen) and chemicals into the ground water and increased erosion.

Unusually late spring or early fall frosts can have severe impact on agriculture, with the effects ranging from a partial loss of crop yield and/or quality to total loss of the crop. Crop insurance statistics from New Brunswick indicate that for the 1975-1984 period, 19% of indemnities for apples and 22.4% for strawberries were due to frost (Smith, 1987). In 1980 it was estimated that approximately 450 metric tonnes of tobacco with a farm value of over $1 million were lost because of frost on a single night (Province of P.E.I., 1981).

Although problems of drought are possibly less frequent than those associated with too much moisture, periods of drought stress that significantly impact crop yields do occur. From 1980-1985, over 44% of crop insurance payouts (exceeding $4.4 million) to potato growers in New Brunswick were drought related (Smith, 1987). In 1975, exceptionally dry weather reduced average potato yields by about 15% on P.E.I. (Statistics Canada). At prices and acreages of the ’90's, a drought of this severity could reduce the total farm value of the crop in P.E.I. alone by over $20 million (although in real life the situation is more complex since price may be influenced by supply).

Yearly variability in available moisture affects the amount of irrigation water needed and how the crop responds. Water supply is adequate in many years, but seasonal deficits typically exceed 120 to 150 mm at 5% probability (1 year in 20) on well-drained loam soils at many locations (Coligado *et al*., 1968). Irrigation increased potato yields in field trials on P.E.I. by more than 8 t/ha in 3 out of 7 years from 1988-1994, while in the other 4 years there was no significant increase (White and Sanderson, 1995). Yields were increased by more than 60% in 1994, an exceptionally dry year.

Variability in overwintering conditions can have severe impact on the survival of crops such as alfalfa, clover, winter wheat, strawberries and tree fruits. Frequent freeze/thaw cycles and extreme cold during periods with little or no snow cover can be particularly hard on these crops. In 1972 almost the entire strawberry crop was wiped out in P.E.I. and severe damage was inflicted on alfalfa, clover, orchard grass and winter wheat (Suzuki, 1972). Total strawberry production in the Maritimes was reduced by about 60% from the previous year, or by a farm value of almost $1 million (Statistics Canada). Surveys from historical records (Suzuki *et al*., 1975) indicate that climate variability results in winter injury ranging from little to none in some years to severe in others (Table 3).

From these examples it is clear that large temporal variability in climate has a very significant impact on agriculture in the region, influencing crop production, final yield and economic returns to producers. These impacts have spin-off effects on service industries and on the economy of the region as a whole, since agriculture is a very significant part of the regional economy.

CLIMATE CHANGE AND IMPACTS

Past Changes in Climate

For this presentation we will primarily consider climatic changes over the last 100 years or so, since changes over a longer time are generally beyond the planning time frame that is useful for agriculture. There is evidence that the climate has changed significantly since the period of the 'little ice age' from around 1400-1900 A.D. (Environment Canada, 1995). The year 1816 has been labelled as 'the year without a summer', and personal diaries indicate occurrences in the 1800's when buckwheat was frozen in the middle of July on P.E.I. However, it is debatable whether the warming which has occurred since then was due to the enhanced greenhouse effect or due to other causes.

Changes in both average climate and in variability can occur. The Atlantic region has apparently not followed the national warming trend of about 1°C during the last 100 years. Trends indicate that there was slight gradual warming from around 1900 to the 1950's, cooling from the '50's to the 1970's and a levelling off in the '80's (Phillips, 1990; Berry, 1991; Gullett and Skinner, 1992; Bootsma, 1994). Morgan *et al*. (1993) observed a remarkable similarity between air temperature trends and sea surface temperatures in the North Atlantic, but indicated that definite cause and effect relationships had not yet been established. Lack of increase in daily minimum temperature may be partly due to lack of change in cloud cover in the region, since there seems to be evidence that increased cloud in other parts of north America has raised nighttime minimum temperatures and reduced day/night temperature range (Karl *et al*., 1993; Environment Canada, 1995). Overall, the temperature changes are relatively insignificant and likely have had little or no impact on agriculture compared to that of climatic variability.

Precipitation seems to have increased and become more variable over the past 100 years (Danard, 1990; Phillips, 1990; Bootsma, 1994). This may have impacted agriculture through reduced drought stress but may have increased problems in coping with excess moisture. Increased variability may have resulted in greater fluctuations in crop yields in recent decades, although no data are presented to support this. While long term changes in precipitation are statistically significant, they are still relatively small in comparison to the yearly variability that growers must contend with.

We recently examined long term trends in selected climatic variables at 8 locations (Table 4) in the region, using linear regression and correlation analyses. No attempt was made to test for or remove inhomogeneities in the data, although in a few cases stations were relocated to another site or alternate nearby stations were used for part of the period of record. Missing data were estimated using adjusted values from nearby stations. Results indicate that May to September precipitation increased significantly at most locations (Table 5), confirming the trends observed by others. GDD showed no positive correlation with time at six locations, confirming the lack of overall warming trend. Several locations had significant trends in frost-free period, although this variable is quite sensitive to minor changes in station elevation or exposure.

Correlations between 5-year moving standard deviations and time indicate significant increases in variability in precipitation but not in GDD at most locations (Table 6). Spring and fall frosts appear to have become more variable over time at some locations, but less at others.

Long term trends in yearly values of May-Sept. precipitation and GDD, and their standard deviations, are shown for four locations in Figures 1 and 2. Linear regression trends are shown where these are statistically significant. These figures clearly show the extent to which climate variability overwhelms any long term gradual changes.

Impacts of Climate Change

From the foregoing analyses, we can conclude that climate change over the past 100 years has had relatively little impact on agriculture compared to the variability, with the possible exception of precipitation which appears to have increased and become more variable. Changes over the longer term (centuries) likely have had significant impact, but these are beyond the planning time frame of agriculture.

Few studies have investigated the potential impacts of possible future changes in climate in the Atlantic region. Bootsma *et al*. (1984) examined the possible effects of warmer/cooler and wetter/drier conditions on crop yields by processing hypothetical scenarios through a crop growth model. Results for the Annapolis valley suggested that a rise in temperature with no change in precipitation would tend to reduce yields due to higher moisture stress. Estimated yields tended to increase slightly if precipitation increased and decrease with lower precipitation with no temperature change. The study had several weaknesses common to many studies of this nature: i) the direct effects of rising CO_2 concentrations on crop growth, although likely to be quite significant, were not considered; ii) no attempts were made to consider adaptation to change using different or new crop species or varieties; iii) there was no indication of which scenario is most likely to occur (predictions of this are still very uncertain in our opinion); iv) reliability of the model for predicting impacts of change on yield was uncertain.

Stewart and Muma (1990) looked at the possible impacts of climate change under a $2XCO_2$ scenario, based partly on outputs from three General Circulation Models (GCM's). They concluded that the potential for corn, soybeans and winter wheat would increase significantly in the region mostly as a result of warming, and expected that the P/PE ratio would reduce slightly towards more optimum conditions for crop production. However, higher temperatures would tend to shorten the growth period of many crops which could reduce yields unless there was a shift to longer season varieties. They also concluded that a 1 to 2°C cooling would eliminate many crops from the region, including corn, soybeans, spring wheat, many specialty crops and tree fruits.

The sensitivity of potato yields in P.E.I. to climatic variables was studied by Gordon and Asiedu (1990) by using a multiple linear regression model developed from yield data from the 1911-1987 period. Results indicated that above normal temperatures in spring were associated with higher yields, while yields tended to decrease with departures in summer temperatures either above or below normal values. Cautions must be exercised in interpreting the results, however, as regression coefficients do not necessarily explain cause and effect relationships. Their model also contained time trends which indicated that the impact of technological improvements on potato yields was far greater than that of climate over that period.

While the above studies may give some general indications of agriculture's sensitivity to a warmer and a wetter or drier climate, none of them consider the direct effects that continually rising concentrations of CO_2 in the earth's atmosphere may have. CO_2 is one of the principal ‘greenhouse’ gases in the atmosphere which is expected to cause global warming. Concentrations have increased by more than 25% since the start of the industrial revolution (Environment Canada, 1996). While often looked at as a pollutant, it should be noted that additional CO_2 acts as fertilizer to the plant and a doubling of its concentration is likely to have a beneficial effect on growth and yield. Increased concentrations of CO_2 particularly promote more rapid photosynthetic rates in what are known as C_3 plants (‘inefficient’ species), such as soybeans, small grains cereals, most grass species and alfalfa, but less so in C_4 plants (‘efficient’ species) such as corn (Warrick, 1988). In both types of crops the extra CO_2 is also expected to increase water use efficiency by reducing plant transpiration rates. Some studies have suggested that yields of some crops could be enhanced by as much as 50% with a doubling of CO_2 concentrations.

Climatic changes that may occur in the future could have significant impact on agriculture in the Atlantic region. Rising CO_2 concentrations accompanied by a warming trend would be beneficial to agriculture, particularly if new crop varieties that are better adapted to any changed conditions are selected. Warming could be expected to improve the competitiveness of the agricultural industry by expansion of production in corn, soybeans, tree fruits and specialty crops. Change to wetter or drier conditions could have both positive and negative impacts. Increased moisture supply would reduce yield reductions due to drought, but likely result in increased disease pressure (particularly from foliar-type fungal diseases such as potato blight, which thrive in wet weather), increase the leaching of nutrients and chemicals to the ground water, reduce the number of days suitable for field work and result in greater soil erosion. A change to drier conditions would have the opposite effect. Milder winters could significantly impact the survival of many crops such as alfalfa, clover, winter wheat, strawberries, tree fruits and grapes, and improve the potential of these crops in many areas. However, negative effects on survival could be experienced in some areas where warming results in less reliable snow cover.

The agricultural industry should, in general, be able to adjust relatively well to any long term gradual changes in climate that may occur, taking advantage of any improvement in conditions while minimizing the negative impacts of less favourable climate. Variability and extremes in climate that will occur will likely have greater impact and be more difficult for producers to cope with. In general, any progress that can be made in reduce the negative impacts of climatic extremes should help the industry to cope with any long term climate changes that may occur.

Some Possible Overriding Factors

Because of the expected gradual nature of any climatic change, it is quite likely that a number of other factors will have overriding impact on agriculture and on people's lives in the future. It is not our intent to predict which factors will be most important. However, some of the following are likely candidates (not necessarily in order of importance):

i) Soil degradation and its impacts on long term sustainability of agricultural production.
ii) Environmental and food safety issues are becoming increasingly important public concerns.
iii) Impacts of global economy, interest rates, etc.
iv) Supply/demand for food and their impact on prices.
v) Changes in costs of production (e.g. energy, fertilizer, chemicals, labour).
vi) Further developments in farm mechanization (in the past this has drastically reduced the percentage of the population involved in primary agricultural production).
vii) Consolidation of farms into larger units.
viii) Political changes, free trade (e.g. NAFTA).
ix) Appearance of new weeds, pests and/or diseases or mutated strains of present diseases (e.g. potato blight) for which present control measures are less effective.
x) Government stabilization and subsidy programs, crop insurance.

Climate change could influence the extent that some of these factors impact on the agricultural industry. For example, the impact of unfavourable commodity prices, interest rates and energy costs would likely be greater if these were combined with climatic conditions less favourable to agriculture, putting additional strain on the economic well-being of individual farm units.

Mitigating Factors

There are measures that could be implemented that would reduce the negative impacts of climate change and take advantage of any improvements in the climate that may occur. A few examples follow:
i) Increased use of irrigation and wider adoption of soil management practices and crop rotations which build up soil organic matter levels would make agriculture more resilient to the effects of drought.
ii) Wider adoption of drainage practices and erosion control methods such as cover crops, grassed waterways, contour plowing and reduced tillage would help to offset negative effects of higher rainfall.
iii) Increased adoption of active and passive frost prevention methods. (Active methods include those used at the time frost occurs, such as sprinkling irrigation, covering, wind machines or helicopters; passive methods are taken well before frost occurs, such as crop selection, field selection, planting/harvesting schedules and windbreak management).
iv) Increased efficiency in field tillage, planting and harvesting operations through improvements in machinery, adoption of minimum or zero tillage, appropriate machinery size selection. Negative effects

of reductions in available field work caused by climate change could be offset by some of these measures.

v) Develop new crop varieties that are better adapted to existing or changed climate or climatic extremes and improved agro-chemicals and/or management practices to control weeds, pests and diseases. Probably the bulk of present day research efforts by both industry and government are focused on these areas.

CONCLUSIONS

The agricultural sector of the economy is heavily dependent on climatic conditions for successful crop production and is therefore highly vulnerable to climate change. Nevertheless, it is generally felt that agriculture can readily adapt to the kinds of changes that have occurred over the last 100 years or so. If continued rise in ‘greenhouse gas’ concentrations in the earth’s atmosphere lead to some warming without drastic change in precipitation, the region would likely stand to benefit through increased agricultural productivity. Spatial and temporal variability in the climate have greater impact on agriculture than is likely to be experienced as a result of climate change in the next few decades. The continual challenge is for agriculture to become more resilient to climatic extremes that periodically occur and, in so doing, should be in a good position to cope with climatic changes that may be experienced in the Atlantic region in the future.

REFERENCES

Agriculture Canada.
1976. Agroclimatic Atlas Canada. Agriculture Canada, Research Branch, Chemistry and Biology Research Institute, Agrometeorology Research and Service Section, Ottawa. 17 maps.

Baier, W., Dyer, J., Hayhoe, H.N. and Bootsma, A.
1978. Spring field workdays in the Atlantic Provinces. Atlantic Committee on Agrometeorology, ACA No. 1, Agdex 075. 43 pp.

Banfield, C.E.
1981. The climatic environment of Newfoundland. In: The natural environment of Newfoundland, past and present. Edit: Macpherson, A.G. and Macpherson, J.B., Dept. of Geography, Memorial University of Newfoundland, St. John's. p. 83-153.

Berry, M.O.
1991. Recent temperature trends in Canada. The Operational Geographer 19: 9-13.

Blackburn, W.J.
1984. Apple tree losses in Canada due to winter injury - a climatic perspective. Agriculture Canada, Regional Development Branch, Resource and Environment Section, Report No. 84-3. 27 pp.

Bootsma, A.
1976. Estimating minimum temperature and climatological freeze risk in hilly terrain. Agricultural Meteorology 16:425-443.

Bootsma, A.
1980. Frost risk survey of Prince Edward Island. P.E.I. Dept. of Agriculture and Forestry and Agriculture Canada, Land Resource Research Institute, Ottawa. 35pp.

Bootsma, A.
1984. Climatic zonation for forage crops in the Atlantic region. Agriculture Canada, Research Branch, LRRI Contribution No. 83-01, 43 pp.

Bootsma, A.
1994. Long term (100 yr) climatic trends for agriculture at selected locations in Canada. Climatic Change 26: 65-88.

Bootsma, A., Blackburn, W.J., Stewart, R.B., Muma, R.W. and Dumanski, J.
1984. Possible effects of climatic change on estimated crop yields in Canada. Agriculture Canada, Research Branch Technical Bulletin 1984-9E. 26 pp.

Bootsma, A. and Boisvert, J.
1987. Climatic variability and change now and in the future, and its impact on soil moisture problems in Atlantic Canada. In: Soil Moisture Workshop Technical Session Proceedings, Oct. 16, 1987, Fredericton, N.B., sponsored by the Atlantic Committee on Soil and Climate. p. 1-24.

Bootsma, A., Boisvert, J.B., de Jong, R. and Baier, W.
1996. La sécheresse et l'agriculture canadienne: une revue des moyens d'acton. Sécheresse 4 (7), 9 pp. (in press).

Bootsma, A. and Dwyer, L.M.
1990. Soil climate classification and winter risk assessment for the Atlantic region based on estimated soil temperatures. Agriculture Canada, Research Branch, Tech. Bull. 1990-1E. 44 pp.

Bootsma, A., Gordon, R., Read, G. and Richards, W.G.
1992. Heat units for corn in the Maritime Provinces. Atlantic Committee on Agrometeorology, Publ. No. ACA 92-1, Agdex No. 111.31. 8pp.

Bootsma, A. and Suzuki, M.
1986. Zonation of optimum seeding period of winter wheat based on autumn temperatures. Canadian Journal of Plant Science 66: 789-793.

Chapman, L.J. and Brown, D.M.
1966. The climates of Canada for agriculture. Canada Land Inventory Report #3, Environment Canada, Lands Directorate, Ottawa, 24 pp.

Coligado, M.C., Baier, W. and Sly, W.K.
1968. Risk analyses of weekly climatic data for agricultural and irrigation planning. Canada Department of Agriculture, Research Branch, Plant Research Institute, Ottawa, Technical Bulletin No's 17-24 and 61. 8 pp. + tables.

Dyer, J.A.
1980. Fall field workdays in Canada. Agriculture Canada, Research Branch, Land Resource Research Institute, Ottawa, Technical Bulletin 92. 14 pp. + tables.

Dyer, J.A. and Bootsma, A.
1979. Harvesting hours for small grain cereals in the Atlantic provinces. Agriculture Canada, Research Branch, Land Resource Research Institute, Ottawa, Misc. Bull. 12. 33 pp.

Danard, M.B., El-Sabh, M.I. and Murty, T.S.
1990. Recent trends in precipitation in eastern Canada. Atmosphere-Ocean 28:140-145.

Dzikowski, P.A., Kirby, G., Read, G. and Richards, W.G.
1984. The climate for agriculture in Atlantic Canada. Atlantic Advisory Committee on Agrometeorology, Publ. No. ACA 84-2-500, 19pp. + 33 maps.

Environment Canada.
1982. Canadian Climate Normals Volume 6, Frost 1951-1980. Atmospheric Environment Service, Downsview, Ont. 276 pp.

Environment Canada.
1995. The state of Canada's climate: monitoring variability and change. Environment Canada, SOE Report No. 95-1. 52 pp.

Environment Canada.
1996. Climate change indicator: Global atmospheric concentrations of greenhouse gases. State of Environment Bulletin 96-4. 1 pp.

Gordon, R. and Asiedu, S.
1990. Weather variability and crop production in the Maritimes: a case study. In: Preprints of workshop on the application of climate and weather information to the farm. Edit: Gordon, R.J. Nova Scotia Agricultural College, Truro, N.S., Jan. 25, 1990. p. 136-161.

Gordon, R. and Bootsma, A.

1993. Analyses of growing degree-days for agriculture in Atlantic Canada. Climate Research 3: 169-176.

Gullett, D.W. and Skinner,W.R.
1992. The state of Canada's climate: temperature change in Canada 1895-1991. Environment Canada, Atmospheric Environment Service, Downsview, Ont., SOE Report No. 92-2. 36 pp.

Hornstein, RA.
1961. Probabilities of freezing temperatures at Fredericton, N.B., Charlottetown, P.E.I., Kentville, N.S. and Nappan, N.S. Canada Dept. of Agriculture, Research Branch and Dept. of Transport, Meteorological Branch, Catalogue No. A53-1111. 13 pp.

Karl, T.R., Jones, P.D., Knight, R.W., Kukla, G., Plummer, N., Razuvayev, V., Gallo, K.P., Lindseay, J., Charlson, R.J. and Peterson, T.C.
1993. A new perspective on recent global warming: asymmetric trends of daily maximum and minimum temperature. Bulletin of the American Meteorological Society 74: 1007-1023.

Morgan, M.R., Drinkwater, K.F. and Pocklington, R.
1993. Temperature trends at coastal stations in eastern Canada. Climatological Bulletin 27: 135-153.

Ouellet, C.E. and Sherk, L.C.
1967. Woody ornamental plant zonation III. Suitability map for the probable winter survival of ornamental trees and shrubs. Canadian Journal of Plant Science 47: 351-358.

Phillips, D.
1990. Atlantic farming weather: Is it more or less variable today than in the past? In: Preprints of workshop on the application of climate and weather information to the farm. Edit: Gordon, R.J. Nova Scotia Agricultural College, Truro, N.S., Jan. 25, 1990. p. 64-85.

Putnam, D.F.
1940. The climate of the Maritime provinces. Canadian Geographical Journal 21:135-147.

Sanderson, M.E. and Phillips, D.W.
1967. Average annual water surplus in Canada. Dept. of Transport, Meteorological Branch, Toronto, Climatological Studies Number 9, 76 pp.

Smith, P.J.
1987. A crop insurance perspective on soil moisture and its management. In: Soil Moisture Workshop Technical Session Proceedings, Oct. 16, 1987, Fredericton, N.B., sponsored by Atlantic Committee on Soil and Climate. p. 60-63.

Statistics Canada.
1995. Fruit and vegetable production. Statistics Canada Catalogue No. 22-003, Ottawa. Periodic reports.

Statistics Canada.
1996. Agricultural economic statistics. Statistics Canada Catalogue No. 21-603E.

Stewart, R.B. and Muma, R.
1990. Climatic change: some implications for agriculture in the Atlantic region. In: Preprints of workshop on the application of climate and weather information to the farm. Edit: Gordon, R.J. Nova Scotia Agricultural College, Truro, N.S., Jan. 25, 1990. p. 136-161.

Suzuki, M. 1972.
Winterkill patterns of forage crops and winter wheat in P.E.I. in 1972. Canadian Plant Disease Survey 52: 156-159.

Suzuki, M., Black, W.N., Cutcliffe, J.A. and Sterling, J.D.E.
1975. Frequency of occurrence of winter injury to forage legume, winter cereal and strawberry plants in Prince Edward Island, 1901-1975. Canadian Journal of Plant Science 55:1085-1088.

Treidl, RA.
1978, Handbook on agricultural and forest meteorology. Fisheries and Environment Canada, Atmospheric Environment, Downsview, Ont. 74 pp. + 14 tables.

Warrick, RA.
1988. Carbon dioxide, climatic change and agriculture. The Geographical Journal 154: 221-233.

White, P.R. and Sanderson, J.B.
1995. Irrigation studies on potatoes at Charlottetown. In: Proceedings of the First Atlantic Canada Agricultural Science and Technology Workshop, Truro, N.S., Apr. 19-20, 1995, Edit: Eastern Canada Soil and Water Conservation Centre, Grand Falls, N.B. p. 59-68.

Table 1. Statistics on selected agroclimatic variables at four locations in the Atlantic region.

Station/Province/ Period of record	Variable*	Mean value	Standard deviation	Extreme values low/earliest	Extreme values high/latest
Fredericton CDA, N.B.	SF	May 17	9.3	Apr. 25	June 14
1921-1994	FF	Sep. 28	8.4	Sep. 11	Oct. 21
	GDD	1714	112	1451	1930
	PREC	439	91	230	648
Kentville CDA, N.S.	SF	May 20	10.8	Apr. 25	June 15
1914-1994	FF	Oct. 2	11.8	Sep. 9	Nov. 2
	GDD	1781	119	1459	1999
	PREC	402	94	219	696
Charlottetown CDA,	SF	May 15	9.7	Apr. 26	June 10
P.E.I.	FF	Oct. 15	9.7	Sep. 12	Nov. 11
1889-1991	GDD	1680	121	1412	1955
	PREC	416	84	212	640
Deer Lake, Nfld.	SF	June 9	12.3	May 8	July 9
1934-1994	FF	Sep. 15	16.7	July 19	Oct. 20
	GDD	1222	124	954	1482
	PREC	434	84	264	671

* SF =Date of last occurrence of 0°C or lower in spring; FF =Date of first occurrence of 0°C or lower in fall; GDD = Growing degree-days above 5°C accumulated over the length of the growing season; PREC =Total precipitation, May-Sept. (mm).

Table 2. Estimated minimum number of field work-days from April 1 - June 2 for well-drained sandy loam soil at three probability levels and four locations (from Baier et al., 1978).

Location	Probability level 10 %	50 %	90%
Fredericton, N.B.	42	32	24
Kentville, N.S.	38	31	22
Charlottetown, P.E.I.	35	24	16
St. John’s, Nfld.	34	16	9

Table 3. Frequencies of winter injury to clover, alfalfa, winter wheat and strawberry plants in P.E.I. (from Suzuki et al., 1975).

Crop	Little or no injury	Considerable to severe injury	No. of years surveyed
Clover	1/1.9	1/4.7	75
Alfalfa	1/2.2	1/4.7	28
Winter wheat	1/3.3	1/3.3	10
Strawberries	1/3.1	1/4.9	34

Table 4. Climatic stations used in long term trend analyses.

Location	Station name	AES #	Elevation (m)	Period of record used
Grand Falls, N.B.	Grand Falls	8101900	152	1921-1965
	Grand Falls Drummond	8101904	229	1965-1992
Fredericton, N.B.	Fredericton CDA	8101600	40	1921-1994
Sussex, N.B.	Sussex	8105200	21	1900-1994
Nappan, N.S.	Nappan CDA	8203700	20	1916-1994
Kentville, N.S.	Kentville CDA	8202800	49*	1914-1994
Charlottetown, P.E.I.	Charlottetown	8300298	12	1889-1910
	Charlottetown, CDA	8300400	23	1910-1991
Deer Lake, Nfld.	Deer Lake	8401500	11	1934-1994
St. John's, Nfld.	St. John's	8403500	38	1935-1941
	St. John's Torbay A	8403900	140	1942-1950
	St. John's West CDA	8403600	114	1951-1994

* Kentville CDA was at 30 m elevation prior to April, 1960.

Table 5. Correlation coefficients (r) between selected agroclimatic variables and year at eight locations in the Atlantic region.

Variable	Location and period of record							
	Grand Falls N.B. 1921-1992	Fredericton N.B. 1921-1994	Sussex N.B. 1900-1994	Kentville N.S. 1914-1994	Nappan N.S. 1916-1994	Charlottetown P.E.I. 1889-1991	Deer Lake Nfld. 1934-1994	St. John's Nfld. 1935-1994
FAI	-.38**	-.27*	-.18	-.19	-.24*			
SF	-.45**			-.32**				
SF-2	-.26**					.17		
FF			.21*	.31**		-.22*		
FF-2						-.32**		
FFP	.39**		.24*	.42**		-.18		
FFP-2	.23			.23*	-.25*	-.33**		
GDD			.20*	.39**				
CHU			.30**	.41**				
GSS				-.24*				
GSE	-.26*							
GSL				.26*				
PE	-.36**	-.25*		-.26*			-.35**	
PREC	.47**	.23*	.28**	.21	.36**	.24*	.27*	
JAN								
JUL								
SNOW	.19		.32*	.35**		.21*	.58**	-.32*

**Significant at *P*=.01; *Significant at *P*=.05; Coefficients without asterisks significant at *P*=.10; Coefficients not shown were not significant at *P*=.10. FAI =Forage aridity index; SF =Last spring frost, 0°C; FF =Fisrt fall frost, 0°C; SF-2 =Last spring frost, -2°C; FF-2 =First fall frost, -2°C; FFP =Frost free period, 0°C; FFP-2 =Frost free period, -2°C; GDD = Growing degree-days >5°C: CHU =Corn heat units; GSS =Growing season start; GSE =Growing season end; GSL =Growing season length; PE = Potential evapotraspiration; PREC = May to Sept. precipitation; JAN = January mean air temperature; JUL=July mean air temperature; SNOW = Total snowfall, Oct. to March. (For more detailed explanation of variables, see Bootsma, 1994).

Table 6. Correlation coefficients (r) between 5-year moving standard deviations of selected agroclimatic variables and year at eight locations in the Atlantic region.

Location	SF	FF	GDD	PREC
Grand Falls	-.30*		-.35**	
Fredericton	.42**	.53**		
Sussex	.25*	-.46**		.25*
Kentville		.35**		
Nappan	.43**	.43**	.31**	.25*
Charlottetown	.30**	-.56**		.52**
Deer Lake	-.35**			.52**
St. John's		-.36**		-.44**

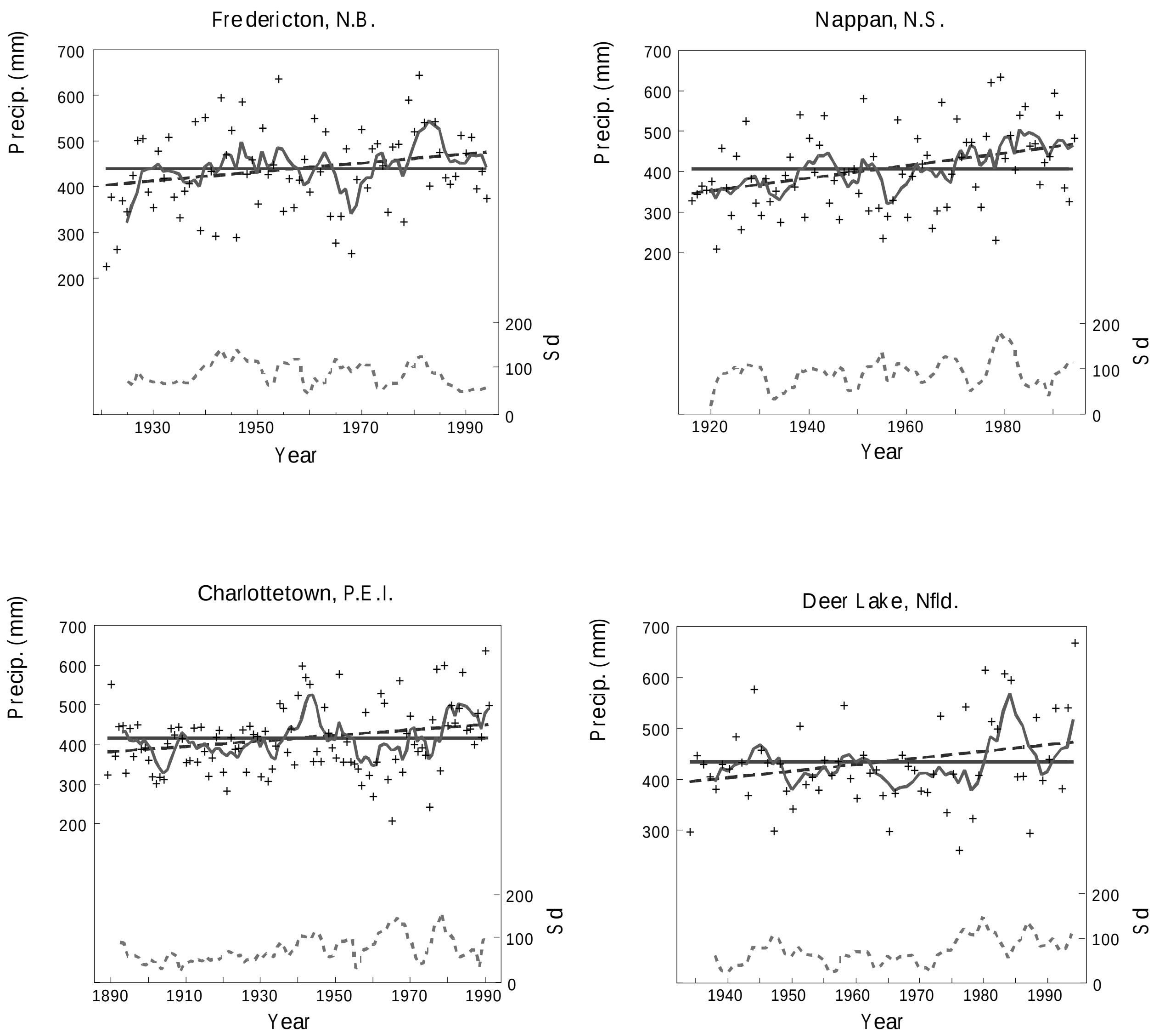


Figure 1. Long term trends in precipitation (May-Sept.) at four locations in the Atlantic region.

+ yearly values; --- regression line; —— mean value; moving 5-yr mean; standard deviation (Sd).

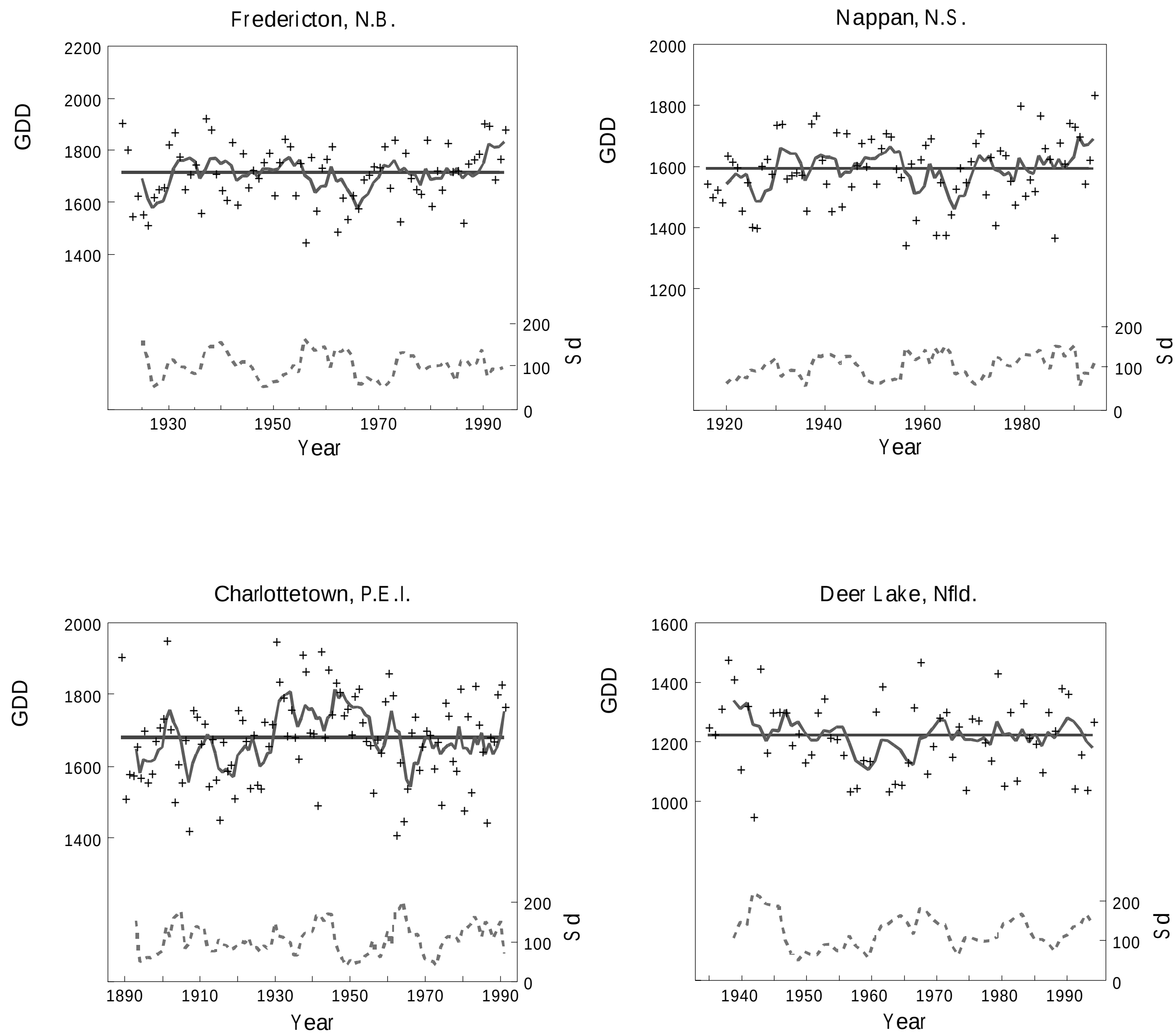


Figure 2. Long term trends in Growing Degree-days >5°C (GDD) at four locations in the Atlantic region.

+ yearly values; mean value; moving 5-yr mean; standard deviation (Sd).

3.5 *Forestry*

Climate Change, Potential Impacts and Forestry Research in the Atlantic Region of Canada: A Synthesis

R.M. Cox

Natural Resources Canada, Canadian Forest Service - Atlantic
Fredericton, New Brunswick E3B 5P7

Increasing levels of carbon dioxide (30% since 1750) and other greenhouse gasses (Methane 145% and NO_2 15% since 1750) are expected to alter climate (Houghton, *et al,* 1990). Doubling CO_2 concentrations in the atmosphere may be achieved by the year 2056 (Jenkins and Derwint 1990). Mean annual global increases of air temperature of 0.5 ^oC in the last century are evident. Mean temperature in Canada has risen 1.1 ^oC nationally and 1.7 ^oC regionally in the past century (Gullett and Skinner 1992) and temperature increases are expected to be greater in winter than in summer (McElroy 1994). These temperature increases are also expected to be greater at higher latitudes and are expected to approach 3-4 ^oC in parts of Canada (Hansen, *et al,* 1988) with some projections for doubled CO_2 concentrations as high as +8-12 ^oC in the winter (Hengeveld, 1991). Recent modelling results (Santer, *et al* 1996, work cited in Kerr 1995) have tentatively implicated greenhouse effect in climate warming since 1950, using both climate forcing by greenhouse gasses and aerosol cooling by the reflective haze in the northern hemisphere. Of relevance to Atlantic Canada, is the significant increasing trends in mean annual temperatures of the North Eastern forest region (Ontario to Labrador coast) over the last 100 years (increase of 0.5 ^oC). The Maritimes (PEI, NFL, NB and NS), however, shows no significant trend with a small rise of 0.4 ^oC (Gullett and Skinner 1992), with most of the warming projected for the winter and spring and a cooling influence in the autumn (Hengeveld, 1991). With these competing influences together with the effects of aerosol cooling, it may not be unreasonable to postulate changes in seasonality, increased climate variability and more extreme weather events. This scenario is likely to have more serious consequences to forest health than a small rise in mean temperature both in terms of wide spread tree decline phenomena (Auclair, 1987: Cox and Malcolm, 1997) and insect outbreaks (Flemming and Volney, 1995). In addition if this climatic instability leads to increased incidence and severity of storms due to increased vigour of the hydrological cycle we may expect more large scale blowdown in the forests of Atlantic Canada.

FOREST RESPONSES

The forest of Atlantic Canada can respond to these changes in climate by alterations in: 1) growth rates; 2) forest extent; 3) carbon sink-source relationships; 4) species composition; and 5) disturbance regimes.

Growth rates

Climatic factors may influence growth rates and carbon sinks: predicted temperature changes indicate warmer winters and springs but cooler summers for most of the Maritimes (Hengeveld, 1991). This may increase growth rates of conifers if the length of growing season significantly increases due to the warmer springs. Warmer soils also means faster nutrient cycle and more nutrients. Modelled responses (Joyce *et al,* 1995) suggests mean increase in productivity in the northeast US of 33.4% for spruce-fir and 25.2% for Maple-beech-birch. These results however, were highly variable for the projected period of 75 years. Certainly, earlier springs would have to be accompanied by an extension of frost free days here in Atlantic Canada, as late frosts or early extended thaws would be more damaging to the hardwood species with early phenology if refreezing occurred after dehardening of buds and roots. Such early species would be those of birch, aspen and maple (Auclair 1987, Cox and Malcolm 1997).

The amount of light or photosynthetically active radiation (PAR) would be dependent on cloud cover, fog, and haze. Cloud cover is likely to increase generally due to increased energy in the hydrological cycle, however, it is at present uncertain what the changes will be in the Atlantic region. Enhanced UV-B exposure due to the depletion of the stratospheric ozone layer may also be a factor affecting tree growth. Although the majority of plant species that have been tested to date were agricultural plants, trees appear to run a higher risk of accumulating UV-B damage over their far longer lifetimes (De Gruijl 1995). More subtle changes, such as a delay in flowering, changes in leaf structure and metabolism, as verified in field studies (SCOPE, 1993), and in laboratory studies (Gordon 1995: Gordon *et al* 1995), may have far-reaching consequences as these may change competitive relationships, which can in turn, cause shifts in plant populations and in biodiversity.

Projected changes in precipitation indicate little change for the Maritimes perhaps a little dryer towards northern Newfoundland (Bergeron and Flannigan, 1995). Better water use efficiency due to increased CO_2 concentrations will aid in offsetting this deficit.

Forest extent

Changes in forest extent due to melting permafrost is not an issue in the Maritimes but changes in tree line at altitude may occur. Extensions of agricultural land in the central and northern New Brunswick and southern Nova Scotia may be a factor (Hengeveld, 1991)..

Carbon sink-source relationships

Gains in carbon storage due to higher productivity will be offset in some part by increased decomposition rates in the soils and peat. Transient losses in the mature forest due to disturbances may account for additional loss in carbon storage. Sink strength of the young forest could be negated by other stresses such as air pollution, especially tropospheric ozone (Cox and Malcolm 1996), acid rain and acid fog (Cox *et al* 1996). The importance of a more accurate assessment of the carbon cycle of temperate deciduous and mixed forests present in the Atlantic region is given by Lavigne *et al* (1996).

Forest sector response is driven by market forces and competition for exports. Higher inventories due to higher biomass production, at least in some conifers, may lead to lower stumpage rates and higher harvest here. Strategies should be developed both nationally and internationally that allow maximization of carbon storage from our mature forest either as biomass or forest products in the light of possible increasing forest disturbances and a need for salvage operations. These activities, however, should not detract from efforts that maximize the growth and production of our carbon sink, our young forest.

Species composition

Changes in species composition in the long term may be affected by slow changes in biome distributions in the Maritimes. There is some expectation, for a move to a more temperate mixed forest, with some loss of boreal characteristics (Rizzo 1990 cited in Hengeveld 1991). In the short term, transient behaviour of our forests will depend on the adaptability of each species population in the current forest and the regional manifestation of climatic change. Current research in the region is underway to determine the limits of adaptation of black spruce to drought (Major and Johnsen 1996) and to photoperiod and CO_2 enrichment (Johnsen and Seiler 1996). The response of sugar maple to snow removal and frost penetration of soil and roots have been investigated (Bertrand *et al* 1994) together with the responses of birches to winter thaw duration and frequency (Cox and Malcolm 1997). Responses of two birch species to marine fog frequencies have also been investigated (Cox *et al* 1995: Hughes and Cox 1994).

Rate of migration from refugia can be estimated and modelled from pollen records. The conservation of refugia and habitats of rare species assemblages is necessary to maintain species diversity and the provision of potential pre-adapted populations. The environment for seedling establishment can be projected using GCMs using climate surfaces of specific variables (Flannigan and Woodward 1993). There is a need to interpolate the GCM's output on to the three dimensional landscape to determine spatial shifts in habitat requirements of specific species (Bourque, 1996). Changes in succession due to changed competition under higher CO_2 and nutrients needs to be incorporated within gap dynamics models used at present to predict species composition.

Disturbance regimes

Forest disturbances usually refer to catastrophic events which trigger a change from a renewal phase to a release phase of a successional cycle. Li and Apps (1995) have suggested that understanding disturbance regimes in the forest is a prerequisite to modelling and understanding forest dynamics, and that this requires spatial models, without which no realistic simulation can match the natural species abundance and composition.

The main types of disturbance in the Atlantic Region likely to respond to climate change are fire, insect outbreaks, climate related decline phenomena, storm damage (blow downs), browser population (deer) and human population migration (associated forest harvesting).

Fire: Fire burns an average 1-2 Million ha each year in Canada. Mean annual burns in New Brunswick's Acadia forest up to 1975 were 1200 ha. Relevance of this to the Maritimes under climatic change is indicated in Changes in the simulated Fire Weather Index (FWI) using the AES General circulation model under 1 times CO_2 and 2 times CO_2 scenarios, carried out by Bergeron and Flannigan (1995). This computer simulation indicated that changes in FWI are variable over eastern Canada. The predicted changes in FWI would vary from being reduced in the southeast boreal in southern Quebec, with only slight increases in the southern Maritimes, increasing slightly more over Cape Breton and east Newfoundland. The uncertainty in these predictions, however, are increased by other disturbances such as blowdown, insect outbreaks, and declines, which affect fuel quality and fire risk.

Insect outbreaks: Major contributors to disturbance regimes in the Maritime forests are insects, outbreaks of which exert a large influence on forest productivity. In Canada, on average 51 million m^3 of wood are lost per year to insect damage which represents one third of the harvest volume (Hall and Moody 1994).

The Balsam Woolly Adelgid was introduced from Europe just prior to 1900 by 1930 was found in Nova Scotia, PEI, Fundy Coast by 1934 had spread south to New Brunswick, Maine and most of Vermont. By 1950 it was in New Hampshire and had moved more slowly north into parts of Cape Breton and Newfoundland. There was a serious outbreak in Nova Scotia from 1970-71; 67% of the fir were affected from Barrington to Shelburne. This insect seems to be controlled in its northward extension due to intolerance of dormant adelgids of temperatures <-34 ^oC. (Bryant 1995; Johnson 1986). It is likely that this insect would present a serious problem if the winter temperature of the Boreal forest increased.

Another introduced insect vector of beech bark disease (parasitic bark fungus *Nectria coccineea*) the beech scale insect was introduced to Halifax in 1890. This insect carried the disease slowly into Nova Scotia's hardwood forests, west to New Brunswick, Quebec, New England and to New York by 1970 and is responsible for the removal of beech as a dominant tree in the Eastern North American forest. By 1970 there was evidence that beech escaped the disease at altitude and in the northern parts of their range, indicating that this insect too, may be limited by climate (Johnson 1986) and thus, may respond to a warmer winters under climatic warming.

It has also been suggested (Flemming and Volney, 1995) that, in the northern limits of the spruce budworm, that ends of outbreaks may be associated with late spring frosts that destroy the early foliage.

As climate warms, fewer late frosts may increase the length and severity of outbreaks in these northern areas. Defoliators populations such as the spruce budworm may also respond to climate change in another way, as their population cycle may be controlled by two univoltine parasitoids (Royama, 1992). This control which is reliant on the synchrony between the host larval stage and the parasites adult stage may be broken in warm springs if larval development outpaces that of its parasitoids' (Flemming and Volney, 1995)

Climate related decline phenomena: An important example of a decline phenomenon linked to climate was the birch decline of the 1930's in eastern North America. This resulted in an estimated stem volume loss of 1400 Million m^3 of yellow and white birch over an area of 490,000 km^2 (Pomerleau 1991). Winter thaws have been implicated in this decline (Braathe 1957 and 1995: Cox and Malcolm 1997). Auclair (1987) has discussed the role of winter thaw in the other hardwood species. Thaws have also been proposed as the cause of dieback in all but a few hardy commercial apple cultivars in New Brunswick (Coleman 1992). Studies by Pomerleau (1991) have linked root depth of birch to degree of decline. In addition, using snow removal studies, he was able to link thaws and deep soil frosts with decline. This effect of soil freezing was also noted by Bertrand *et al* (1994) using snow exclusion from the ground under sugar maples.

Freeze induced damage was noted by Sperry *et al* (1988) who observed seasonal occurrence of xylem embolisms in sugar maple, which reached a maximum of 84% in February. The authors also suggested that recovery from this injury was driven by spring-time root pressure.

Extensive xylem cavitation was also documented in birches showing crown dieback in New Brunswick (Greenidge 1951) but at the time, was not attributed to winter thaw freeze cycles. Auclair (1993) has noted that the long time between winter cavitation and the development of symptoms has made it more difficult to recognize the cause of the injury. Results from winter thaw simulations, using paper birch and yellow birch, (Cox and Malcolm 1997 and in Appendix J, Page 289) indicate that combinations of accumulated winter cavitation and root damage caused by thaw duration that allow dehardening of roots prior to refreeze are key factors in birch dieback. In addition it was shown that yellow birch was more sensitive to thaw durations than paper birch.

Storms and large scale blow-downs: The Atlantic Region lies exposed to ocean storms and hurricanes which cause large amounts of damage and influence cutting practices (Johnson 1986). Major events causing forest damage which influenced cutting practices are shown in Table 1. This table shows an increasing effort in the salvage of blowdown in recent times, due to a shortage of wood supply, and jobs. Government subsidies for salvage and the fast and organized response of the forest industries to the large Christmas Mountain blowdown in 1994 proved responsible for maintaining the carbon storage of this forest as forest products. Good forest management of the salvaged areas will insure sustainability of the forest and return the areas to a strong carbon sink. Storm damage (blowdowns) may possibly increase in severity and frequency with global warming due to a more intense hydrological cycle. The effects of increased forest disturbances as described above serve to open the canopy and may exacerbate blowdown situations, as will the move towards more softwood plantations.

Browser populations: Warmer winters, less snow accumulation may lead to extensions of overwintering areas for deer which means more available food and decreased predation. These effects can, in turn, lead to higher population levels which can impact regeneration and lower species diversity.

Uncertainties

There is little research and much uncertainty concerning multiple effects of climatic factors and other stresses such as air pollution i.e. SO_2, NH_4, NO_x and O_3, together with deposition of acidifying substances and heavy metals. The effects of enhanced UV-B exposure needs consideration. There is a need to determine which of these stressors may predispose trees to climatic effects. For example ozone is known to change carbon allocation in forest trees favouring above ground biomass at the expense of roots. This effect may leave trees more vulnerable to drought, nutrient deficiency, blowdown and reduce capabilities of some hardwoods to recover from winter cavitation injury. The long term effects of population migration (associated forest clearing and harvesting) due to extension of farmable land and industrial development are also uncertain. These will be added to by movements of people due to sea level rise .

REFERENCES

Auclair, A. N. D.,
1993: Extreme Climatic Fluctuations as a cause of Forest Dieback in the Pacific Rim. Water, Air and Soil Pollution **66**:207-229.

Auclair, A. N. D
1987: The distribution of forest declines in eastern Canada. In: Forest Decline and Reproduction: Regional and Global Consequences; Proceedings of a workshop held in Krakow, Poland, 23-27 March 1987. (Eds: Corrects, L.; Nelson, S.; Straszak, A.) International Institute for Applied Systems Analysis, Laxenburg, Austria, 307-320.

Bergeron, Y., and Flannigan, M. D
1995: Predicting the effect of climate change on the fire frequency in the southeastern Canadian Boreal Forest. Water, Air, and Soil Pollution 82: 437-444.

Bertrand, A.; Rebuttal, G.; Nadeau, P.; Boutin, R.
1994: Effects of soil freezing and drought stress on abscisic acid content of sugar maple sap and leaves. Tree Physiology 14, 413-425.

Bourque, C.P.A.
1996: Accounting for Variable Terrain in Landscape Scale Forest-Climate Models: Outline of a Report. Environment Canada - Atlantic Region Occasional Report No. 9: 281-288.

Braathe, P.
1957: Is there a connection between the birch dieback and the and the march thaw of 1936? For. Chron **33**:358-363.

Braathe, P.
1995: Birch dieback caused by prolonged early spring thaws and subsequent frost. Norwegian Journal of Agricultural Sciences Supplement No. 20 59pp.

Bryant, D. G.
1975: Balsam Wooly Aphid *Adelges piceae* (Ratz.). In: *Aerial Control of Forest Insects in Canada*. Dept. Of the Environment, Ottawa, Canada, Information Canada, Ottawa, K1A 0S9, 250-253.

Coleman, W. K.
1992: A proposed winter-injury classification for apple trees on the northern fringe of commercial production. Can. J. Plant Sci. 72: 507-516.

Cox, R. M. and J. W. Malcolm
1997: Winter Thaw Duration on Birch Die-back and Xylem Conductivity: An Experimental Approach with *Betula papyrifera* L. Tree physiol (in press).

Cox, R. M., Meng, F-R., Charland, M., Helleur, R. and Malcolm, J. W.
1997: Response of Mature Wite pine Foliage to Tropospheric Ozone. Proc. OCAC Workshop on Atmospheric ozone: issues, science, impacts, policy and programs. Downsview Sept. 30-Oct. 1, 1996 (in press)

Cox, R. M. Lemieux, G. and Lodin, M.
1996: The assessment and condition of Fundy white birches in relation to ambient exposure to acid marine fogs. Can. J. For. Res. 26: 682-688.

De Gruijl, F. R.

1996: Impacts of a Projected Depletion of the Ozone Layer. Available from http://www.gcrio.org/CONSEQUENCES/summer95/impacts.html: INTERNET

Flannigan, M. D. and Woodward, F. I.,
1993: Red pine abundance: current climatic control and responses to future warming. Can. J. For. Res. 24: 1166-1175.

Fleming, R. A. and Volney, J. A.
1995: Effects of Climate Change on Insect Defoliator Populations Processes in Canada’s Boreal Forest: Some Plausible Scenarios. Water, Air and Soil Pollution 82: 445-454.

Gordon, D. C.
1995: Effects of UV-B exposure on cuticular characteristics, leaf ultrastructure and leaf pigment content. M.Sc thesis University of New Brunswick, Dept of Biology, pp. 164.

Gordon, D. C., Percy, K. E. and Riding, R.T.
1996: effects of UV-B radiation on cutiular characteristics in four spruce species. Abstract NATO Advanced Study Institute, *Solar Ultraviolet Radiation: Modelling and Measurement.* Oct. 2-11, 1995 Haldiki, Greece.

Greenidge, K. N. H.
1951: 'Dieback: A Disease of Yellow Birch (*Betula lutea* Michx.) in Eastern Canada' Ph.D. Thesis Department of Biology, Harvard University, Boston, Massachusetts, U.S.A., 300 P

Gullett, D. W. and W. R. Skinner
1992: The State of Canada’s Climate: Temperature Change In Canada 1895-1991. A state of the Environment Report, SOE Rep. No. 92-2, Atmos. Environ. Serv. Environment Canada. pp 36.

Hall, J. P. and Moody, B. H.
1994: *Forest Depletions Caused by insects and diseases in Canada*, 1982-1987, Information Report ST-x-8, Canadian forest service, Ottawa, Canada 14 pp.

Hansen, J.; Fung, I.; Rind, A.; Lebedeef, S.; Ruedy, R; Russel, G.
1988: Global climate changes as forecast by Goddard Institute for Space Studies three dimensional model. J. Geophys. Res. 93:(D8),9341-9364.

Hengeveld, H.
1991: *Understanding Atmospheric Change: A Survey of the background Science and Implications of Climate Change and Ozone Depletion,* A state of the Environment Report SOE Rep. No. 91-2, Atmos. Environ. Service, Environment Canada, pp68.

Houghton, J. T., Jenkins G., and Ephraums, J. J. (Eds.)
1990: *Climate Change: The IPPC Scientific Assessment*, Cambridge University Press, Cambridge, UK, 403 pp.

Hughes, R.N. and Cox, R.M.
1994: Acid fog and temperature effects on stigmatic receptivity in two birch species. J. Environ. Quality 23:686-692

Jenkins, G. J. and Derwint, R. G.
1990: Climate consequences of emissions. In *Climate change. The IPPC scientific assessment.* (ed. By J. T. Houghton, G. J. Jenkins and J. J. Ephraums) World Meteorological Organization, United Nations Environment Programme, Cambridge University Press, Cambridge.

Johnsen, K. H.; Seiler, J. R.
1996: Growth, shoot phenology and physiology of diverse seed sources of black spruce: I. Seedling responses to varied atmospheric CO_2 concentrations and photoperiods. Tree Physiology 16, 367-373.

Johnson, Ralph S.
1986: *Forests of Nova Scotia: a history*. Province of Nova Scotia and Four East Publications, Nova Scotia pp 406.

Joyce, L. A., Mills, J. R., Heath, L. S., McGuire, A. D., Haynes, R. W. and Birdsey, R. A.
1995: Forest sector impacts from changes in forest productivity under climate change. Journal of Biogeography 22: 703-713.

Kerr, R. A.
1995: Studies Say - Tentatively- That Green house Warming Is Here. *Science* 286: 1567-8

Lavigne, M.B., Robitaille, G. and Bernier, P. Y.
1996: Carbon Cycling in Atlantic Canadian forests in Relation to Climate Change: Outline of a Report. Environment Canada - Atlantic Region Occasional Report No. 9: 309.

Li, C. and Apps, M. J.,
1995: Disturbance Impacts on Forest Temporal Dynamics. Water, Air, and Soil Pollution 82: 429-436.

Major, J. E. and Johnsen, K. H.
1996: Family variation in Photosynthesis of 22-year-old black spruce: a test of two models of physiological response to water stress. Can. J. For. Res. 26:1922-1933.

McElroy, M. B.
1994: Climate of the Earth: An Overview. Environ. Pollut. 83:3-21

Pomerleau R.
1991: Experiments on the causal mechanisms of dieback on deciduous forests in Quebec. Information Report LAU-X-96, 1991, Forestry Canada, Quebec Region pp. 47.

Royama, T.
1992 *Analytical Population Dynamics, Routledge*, Chapman and Hall, New York, USA, 387 pp.

Santer, B. D., Tayler K. E., Wigley, T. M. L., Penner, J. E., Jones, P.D. and Cubasch, U.
1996:Towards the Detection and Attribution of an Anthropogenic Effect on Climate. *Climate Dynamics* 12:77-100.

SCOPE
1993: Effects of Increased Ultraviolet Radiation on Global Ecosystems, edited by E. De Fabo. Scientific Committee on Problems of the Environment (SCOPE). Paris, 1993.

Sperry, J. S., Donnelly, J. R. and Tyree, M. T.
1988: Seasonal occurrence of xylem embolism in sugar maple (*Acer Saccharum*). Amer. J. Bot. 75(8):1212-1218.

TABLE 1.

MAJOR STORM BLOW-DOWN IN THE MARITIMES FOREST

Year	Date	Name	Location of Maximum Impact	Forest Losses	Notes
1869	Oct 5	Saxby Gale	South NB - North NS	Whole tracks of forest were uprooted	Large tidal wave covered Tantramar marsh
1873	Aug 24	August Gale	North NS - Cape Breton	extensive forest damage	
1953	Sept 7	Carol	North Shore NS	Blow down in patches Halifax - Yarmouth	Most blowdown in partially cut stands within 30 miles from ocean coast
1953	Dec 1	Unnamed storm	North Shore NS	Moderate damage to trees	Most damage accounted for with Edna
1954	Sept 11	Edna	Central NB Woodstock-Chatham	Massive blowdown of forest. 700 million board feet in NS. 300,000 cords salvaged	Bark beetle outbreak followed this disturbance
1974	Oct 20	Unnamed storm	Annapolis Valley, NS	Heavy forest damage reported	No salvage reported
1976	Feb 2-3	Ground Hog Day Storm	NS Bay of Fundy, South NB	Heavy losses due to tree breakage Some forest damage	Extensive flooding $4M paid by NS Gov. for salvage operations (first known assistance for salvage).
1976	Mar 2-3	Unnamed Storm			
1994	Nov 7	Christmas Mountains Blow Down	Central East NB	>30 million trees blown down = $100M. 2,015,000 m^3 of wood salvaged	44% rebate on stumpage as incentive to salvage by NB Gov. Most fir >80y old.

3.6 *Socio-Economic Dimensions*

Dave Sawyer

EnviroEconomics
Halifax, Nova Scotia

1 Introduction

The objective of this chapter will be to identify economic sensitivities in the Atlantic Region with respect to climate change. These sensitivities will reflect the current consensus in the literature with respect to the socioeconomic responses to climate change. The chapter will first provide a brief overview of how climate change can result in socioeconomic impacts. Then, existing literature will be reviewed with the aim of identifying climate-sensitive activities within the Atlantic Region. Finally, recommendations for further research will be provided.

2 Assessing Socioeconomic Responses to Climate Change

Individuals derive economic benefit from the environment stemming from direct use, such as using natural resources in production, to "passive-use" associated with the intrinsic value people place on the maintenance of existing environmental attributes. When shifts in environmental quantity or quality occur, such as those predicted under climate change, then changes in the level of benefits humans derive from the environment can also occur. Physical changes in the environment, such as sea level rise, the increased frequency of extreme events and habitat loss can therefore lead to social and economic changes and disruptions.

A central climate change question is how large will these impacts be, and how will they be distributed? To answer these questions, predictions must be available about the size and direction of shifts in key climactic variables such as precipitation, temperature and the frequency and intensity of extreme events. These shifts must then be translated into social and economic impacts, and then the relative winners and losers assessed. This is done by comparing the level and composition of human activity in the absence of climate change, with the predicted level and composition of human activity with climate change. The difference between the two scenarios is the socioeconomic impact attributable to climate change. The larger the shift in the level and composition of human activities with climate change when compared to the level without, the greater the impact of climate change and the more climate-sensitive the activity or economy. Climate change damages include both market (i.e. shifts in the level of economic activity or value such as changes in agricultural output), and non-market impacts (i.e. damage to ecosystems and human health impacts). Although there is uncertainty with market based damage estimates, the estimates of non-market damages are a source of major uncertainty, are highly speculative, and are not comprehensive (IPCC WGIII 1996).

From a socioeconomic perspective, identifying climate-sensitive sectors is a necessary first step in assessing the socioeconomic impacts of climate change. If we can identify those activities that are climate-sensitive, and which are important to Atlantic Canada, in terms of economic activity or social welfare, then we have also identified activities that need further investigation.

3 Identification of Climate-Sensitive Activities

In this section, existing information on which sectors and human activities are most at risk to climate change and variability will be identified. Socioeconomic research will be reviewed, and background information on why certain sectors are climate-sensitive will be presented. This information will then be compared to the structure of the Atlantic Canadian economy and climate-sensitive activities identified and discussed.

3.1 Selected Socioeconomic Responses to Climate Change

The IPCC WGII (1996) concludes that natural ecological systems, socioeconomic systems, and human health are all sensitive to both the magnitude and the rate of climate change. Given that climate change is anticipated to have different effects on a wide range of terrestrial and aquatic ecological systems, the socioeconomic impacts of climate change are believed to touch every segment of society. For example, Cline (1992) investigates a list of 17 areas of economic effects and believes the list to be incomplete. Despite an increasing body of literature on the comprehensive socioeconomic impacts of climate change, however, most of the climate change socioeconomic research has focused on impacts to agriculture, forestry, and coastal zone resources. By far the best-studied areas are agricultural impacts and the costs of sea level rise (Fankhauser, 1996).

This focus has occurred for two reasons: (1) the physical responses of crop primary productivity to changes in precipitation, CO_2, and temperature are well established; and, (2) low lying coastal areas susceptible to sea-level rise can be easily identified and the value of the land and defensive expenditures estimated. This focus, is however, well placed given that impacts on coastal zones and agricultural production are considered among the most serious effects and therefore these sectors are regarded to be highly climate-sensitive (Fankhauser, 1996).

Other significant impacts could include changes in:

- forestry;
- recreational demand;
- human health and safety;
- water supply;
- transportation;
- energy demand;
- habitat/species loss;
- construction;
- fisheries; and,
- extreme events.

Due to time and data limitations, selected socioeconomic impacts will be discussed below including agriculture, forestry, fisheries, transportation, energy, sea-level rise, and, extreme atmospheric events.

3.2 Agricultural

The potential impacts of climate change on agriculture are well established. Investigations have focused on changes in the primary productivity of major world food crops in response to a doubling of CO_2 to predict changes in the yield of crops. Socioeconomic damage attributable to climate change is then estimated by comparing the before and after value of world or regional food crops.

The basic linkages between climate change and agricultural impact include:

1. Climate change alters existing patterns in precipitation and temperature which leads to a change in the length of the growing season;
2. Length of growing season may alter the long term mix of crops (crop migration);
3. Change in precipitation has short run (near future) impacts. Increases in precipitation may lead to increases in disease, such as fungus, whereas decreases in precipitation may require increased irrigation costs to maintain productivity;
4. CO_2 levels increase crop productivity. Literature concludes that under ideal (laboratory) conditions, a doubling of CO_2 can increase yields in most crops by 20-35%. Some crops like maize would experience much smaller increases (Wolfe 1996);
5. Changes in these variables can lead to changes in productivity (weather-crop yield relationship) and the mix of crops over time;
6. Different crops, changes in growing seasons and changes in crop productivity all alter the value of agriculture within an area. Increases in pesticides, to combat disease, or increases in irrigation costs will increase operating costs and decrease the value of the crop. Formally, changes in value are determined by the equation ((price*yield)-variable costs) (Mooney and Arthur, 1990).

Most studies in Canada and the US predict changes in crop yields to be negative. For example, Mooney and Arthur (1990) investigating climate change in Manitoba state that it is apparent that large reductions in yields (mostly in the range of 20% to 30%) are predicted for virtually all crops. This finding holds today, however, more recent studies incorporate the beneficial impact of CO_2 fertilization. For example, Wolfe (1996), after reviewing the most recent information on agricultural impacts, concludes it is clear that regardless of the global climate model (i.e. general circulation model) used, climate change had a substantial negative effect on cereal crop yield unless a beneficial effect of elevated CO_2 is assumed. A major uncertainty therefore exists as to the possible mitigating impact of increased CO_2 on crop productivity. Wolfe (1996) also notes that considerable regional variations in yield responses to climate change exist, with yield increases in the highest latitudes, including Canada, attributable to an extension of the frost-free growing season and improved temperatures for productivity.

Bootsma (1997) concludes that the agricultural industry in Atlantic Canada should be able to adapt to any long term gradual climate change, taking advantage of improvements in conditions while minimizing the impact of less favorable climate. However, it is argued that changes in climate variability have the potential to have a greater impact on producers than any gradual shift in variables such as precipitation, CO_2 and temperature. It is subsequently believed that the sector is sufficiently flexible to adapt to, and therefore mitigate, the impacts on agriculture of climate change in the long term (Wolfe 1996, Bootsma 1997). This is not to say that adaptation will not result in increased costs to the agricultural sector. Transition costs at the farm level will likely include , costs associated with irrigation, pesticide and fertilizer use, crop switching, and investments in new farm equipment, and costs to governments such as increased expenditures on new areas of focus and other infrastructure to support the changing mix of agriculture (Wolfe, 1996).

Fankhauser and Pearce (1994) provide a range of impacts to Canada's agricultural sector. Based on a review of the literature, a range of annual impact is estimated to be in the order of -0.047% to -0.2% of GDP associated with a $2xCO^2$. Given that more detailed estimates are not available for the Atlantic Region, we will assume, for illustrative purposes, that the same level of impact can be expected in the Atlantic Region. Note, this is done to provide an indication of the size of the potential impact to the agricultural sector. Using these ranges and recognizing a high degree of uncertainty inherent in transferring these values to Atlantic Canada, annual damages to agriculture are estimated to be in the order of -$20 to -$88 million. This damage represents a range of 2% to 10% of current agricultural GDP.

Based on a review of the literature, it can be reasonably argued that agriculture in Atlantic Canada will be significantly impacted with climate change. The magnitude of the change in economic value will be highly dependent upon the yield response of crops to climate change, including CO_2 fertilization, the size of transition costs and the adaptability of farmers to climate change (Wolfe 1996). However, at this time, a high degree of uncertainty exists with respect to these variables. On-going research should decrease uncertainty about the impacts.

3.3 Forestry

The approach to determine the impacts of climate change on the forestry sector is similar to that of agriculture. Changes in the primary productivity of forests are estimated based on anticipated changes in precipitation, CO_2 and temperature. Three factors influencing primary productivity are altered by changes in climactic variables: the length of the growing season; the amount of productive forestland; and, the growth rate of trees. In the short run, there is also a link between changes in precipitation and temperature, and forest fire occurrence. In the long run, forests will migrate and the mix of forests, i.e. softwood vs. hardwood, is expected to change. Changes in economic value result from changes in the productive yield of forests often measured in yield per cubic meter (m^3). As yield changes, the revenue generated by an area of forest also changes. As yields increase, for example, more trees can be harvested per area of forest and therefore more revenue and value is generated. Decreases in yield would have the opposite effect.

When investigating the economic issues of climate change for forestry in Canada under a doubling of CO_2 ($2xCO_2$), van Kooten (1990) found that Canada's potential harvest would, as a result of less but more productive forest land, increase by a total amount of 7.5%. For forests in Atlantic Canada, forest productivity is anticipated to increase by an average of 15-16%. Another published figure argues that Quebec forests could increase annual yields by anywhere from 50% to 100% (Hengeveld 1995). To calculate the economic value of increased forest yields, van Kooten (1990) assumes three scenarios with yield changes of 5% and 7.5% and 15% and then calculates a socioeconomic benefit for Canada based on these multipliers.

By assuming these yield changes, we can provide very crude order of magnitude estimates of changes in forest production in Atlantic Canada under a 2xCO_2 scenario. This would assume that both precipitation and temperature would increase in Atlantic Canada. Note, this is done purely to demonstrate how socioeconomic impacts are estimated and is not intended as an estimate of potential climate change impact to forestry in Atlantic Canada. Using the information in Table 1, and applying the simple multipliers to existing yield, we can estimate a range of potential changes in forest value with a 2xCO_2. To estimate the socioeconomic impact, we multiply the range of yield changes by the existing yield and then multiply this by the average value added per cubic meter harvested. For example, for Newfoundland, we multiply 3,131 by 5%, 7.5% and 15%, and then by $20.86 (Table 1).

Table 1

Selected Forestry Statistics, 1993

	Productive Area millions Ha	Primary Forest Production 000m^3 (1)	Value Added Logging millions $ (2)	Value Added $/$m^3$ Harvested (2)/(1)
Newfoundland	10.3	3,131	$65.3	$20.86
PEI	0.3	534	$3.4	$6.37
Nova Scotia	3.3	4,585	$76.9	$16.77
New Brunswick	5.9	8,959	$145.6	$16.25

Source: Statistics Canada - Cat. No. 25-202-XPB

Table 2

Illustrative Example: Change in Yearly Harvest Value under a 2xCO_2 Scenario
Millions 1996$[1]

	Assumed Yield Change		
	5%	7.5%	15%
Newfoundland	$3.75	$5.62	$11.24
PEI	$0.20	$0.29	$0.59
Nova Scotia	$4.41	$6.62	$13.23
New Brunswick	$8.35	$12.53	$25.05
Total Yearly	$16.70	$25.05	$50.11

[1]Adjusted to 1996 dollars using the Statistics Canada Industrial Product Price Index, Cat. No. 62-011.

In Table 2, an estimate of the yearly change in harvesting value attributable to a range of productivity changes resulting from a doubling of CO_2 is presented. These findings highlight the importance of knowing the linkage between changes in climactic variables and the socioeconomic response. As can be seen, the greater the yield response to climate change, the larger the shift in socioeconomic response or value. Given the size of the forestry sector, and that forestry is climate-sensitive, significant socioeconomic impacts can be expected with climate change. Further research in this area is clearly required.

3.4 Fisheries

Climate change fisheries impacts are not often included in assessments. For example, comprehensive assessments by Cline (1992) and Fankhauser (1992) do not estimate socioeconomic impacts for the fishery. The complexity of the factors leading to changes in fish populations, notably climate fluctuations, changes in their biological environment and fishing pressures (Drinkwater, 1997), are likely the reason for this omission. However, while this complexity makes it difficult to establish unequivocal linkages between changes in the physical environment and the response of fish or shellfish stocks, some effect are clear (Drinkwater, 1997). Notably, five main categories of climate-fisheries linkages for Atlantic Canadian fish and shellfish stocks can be identified:

1. Growth - environmental conditions have a marked effect on the growth rate of many species;
2. Spawning and reproduction - the age of sexual maturity of certain fish species is determined by ambient water temperatures as well as spawning times and egg incubation time;
3. Distribution and migration - temperature is one of the primary factors, together with food availability and suitable spawning grounds, in determining the large large-scale distribution pattern of fish and shellfish;
4. Abundance and recruitment - evidence of changes in fish abundance in the absence of fishing effort suggests the possibility of environmental causes; and,
5. Catchability and availability - the ease with which fish are caught (Drinkwater, 1997).

For salmonid populations, Minns *et. al*. (1995) argue that climate change will also adversely impact the quantity and quality of available productive habitat. This stress is in addition to other environmental variables such as those identified by Drinkwater (1997). Minns *et. al*. (1995) conclude that the potential impacts of climate change on Atlantic Salmon populations are significant, and therefore require further study. If populations are adversely impacted, then socioeconomic impacts are certain. For salmonids, changes in economic value of the recreational fishery are associated with changes in the value fishers place on a rod day and the number of rod days. Their satisfaction, as measured by their willingness-to-pay for a rod day and angler effort are highly correlated to the catchability of fish (DPA Group, 1990).[1] If fish catches decline, then the value of the recreational fishery also declines. The difference between the two values, before and after climate change, is a measure of the socioeconomic impact to the recreational fishery.

A study by the DPA Group (1990) modeled the potential impacts of acid deposition in Eastern Canada (including Ontario and Quebec) on the recreational fishery. The study concluded that if SO_2 controls were put in place in the late 1980s, the net economic value to Canada due to increased angler activity would be larger by $4.2 billion (1985$) for the period 1986-2021 (Net Present Value of $925 million in 1986). Based on these findings, we can see that the recreational fishery is important, and that it is susceptible to changes in ambient environmental quality, similar to those envisioned with climate change.

Aquaculture is also anticipated to experience change. Specifically, changes in the number of ice free days could change the suitability of locations to aquaculture operations. In addition, changes in water temperature can impact the incidence of bacterial contamination and the growth rate of finfish and bivalves (*pers. com.* Shawn Robinson, DFO, St. Andrews).

From a socioeconomic perspective, it is clear that impacts to the fishery sector, including both the recreational and commercial fisheries, will occur and that they will likely be significant. However, it is not possible to determine the size of this impact at this time. Given the importance of the fishery to the Atlantic Canadian economy, as discussed in Chapter 2, the high degree of uncertainty about the potential climate change impacts on the fishery is an area of concern. Additional research in this area is clearly required.

---

[1] For example, this study argues that a 1% increase in the availability of preferred species will result in a 0.97% increase in angler days, and therefore economic value.

3.5 Transportation

Although transportation is often not identified as an important climate-sensitive sector, transportation could be significantly impacted by climate change in the Atlantic Region. Marine transportation sectors which could be impacted by changes in climate, and the number of ice free days in particular, include sub-sectors such as the coast guard, with major ice breaking expenditures (in 1986 they were 22 million 1996$), ferry service, ports and harbors, and shipping (Stokoe, 1988). A recent study on transportation in the Northwest Territories found that changes in the number of ice free days would result in measurable economic impacts. It was found that increases in ice free days would result in decreased operating costs for marine transportation as well as a lengthening of the shipping season (Difrancesco and Lonergan, 1994). Given the reliance of ferry service and marine shipping in the Atlantic Region, changes in the number of ice free days can be expected to result in socioeconomic changes. Increases in the number of ice free days will benefit the region, whereas decreases in the number of days would result in increased costs.

3.6 Energy

Energy is universally accepted as being climate sensitive. The components of the energy sector that are climate-sensitive are offshore oil and gas, hydroelectric production, and demand changes (Stokoe 1988).

3.6.1 Off-Shore Oil and Gas Development

Off-shore oil and gas exploration and development could experience socioeconomic change if the number of ice free days changes with climate change. Stokoe (1988) determined that downtime for exploration activities in the Atlantic Region due to ice delays cost approximately $130,000 (1996$) per 24 hours of downtime. A loss of $52 million in the extreme ice year of 1984-5 occurred. Other costs would be related to operating and maintenance costs associated with changes in the number of ice free days.

3.6.2 Hydropower

Climate change would alter the ability of the Utilities in the Atlantic Provinces to generate hydroelectric power due to changes in precipitation and therefore annual run-off. The generation of hydroelectric power by province is presented in Table 3. Of the Newfoundland hydroelectric total, 75% is exported to Quebec, which in turn exports the power to the United States (Stat. Can. 57-202-XPB). Therefore, the largest ultimate customer of hydroelectricity from the Atlantic Region is the United States.

For illustrative purposes, we can demonstrate that changes in economic value can be estimated based on changes in run-off assumed to occur under climate change. Given the economic importance of the exported hydropower from Labrador, we will choose to concentrate on the potential socioeconomic changes in value that could result from changes in exported power due to climate change. Although a change in run-off could alter a power utility's ability to substitute hydroelectric power with other sources for domestic customers, this impact is not included in the analysis. We can assume, however, that an increase in run-off would allow for more costly power sources to the phased out and for cheaper hydroelectric power to be used. The proportion of hydropower as a percentage of total electric power would therefore be positively correlated to precipitation and run-off relative to existing levels and the cost differences between energy alternatives.

Table 3 Electric Power Production Million MW Hours - 1994			
	Hydroelectric	Total	Proportion Hydro of Total Electric Power
Newfoundland	36.2	37.9	95.5%
PEI	0	0.04	0.0%
Nova Scotia	0.916	9.55	9.6%
New Brunswick	2.65	12.66	20.9%

Source: Statistics Canada - Cat. No. 57-001-XPB

Using various Statistics Canada data, we calculated the price per energy unit of hydroelectric power exported to Quebec and then to the United States. The quantity and price of power sold to the US market by Quebec was used to estimate the value of the Labrador power, on a per unit of energy basis, given that the current price paid by Quebec is not a good indicator of the market value of the hydroelectric power. We then used the annual flow of water employed to generate the hydropower as the basis for estimating increased power generation capacity due to changes in run-off (i.e. estimate energy/flow ratio). Simple multipliers ranging from 10-30% were used to simulate increased run-off in Labrador resulting from climate change. This range is conservative given that Stokoe (1988) assumed an increase of 35% in run-off when estimating potential benefits from an increase in precipitation due to climate change in Labrador. This range can easily be changed to reflect the most current predictions of run-off change in Labrador.

The multipliers were then applied to the existing quantity of water (flow) used to generate export power. This provides a range of potential increases in flow that could be used to increase energy production. Note, this approach assumes that surplus generating capacity exists and that additional capital outlays would not be required to increase power generation with increased water flow. To determine changes in the value of generated power with precipitation and run-off changes, we simply multiplied the range of flow changes by the energy/flow ratio and then by the value of the exported power. Based on these estimates, for every +/-10% change in annual run-off in Labrador, economic value changes by +/-$73 million. Clearly, hydroelectric power generation is highly sensitive to changes in precipitation and run-off and this sector is highly climate-sensitive in the Atlantic Region.

3.6.3 Energy Demand

Changes in the mean annual temperature are widely believed to result in changes in space heating and cooling requirements (Cline 1992, Fankhauser and Pearce 1994). Energy demand can therefore be expected to change as the climate and mean annual temperature change. To determine the climate-sensitivity of energy demand to temperature change, a relationship between temperature, degree days and the value of a degree day, in terms of energy requirements, is often used (Cline 1992).

Based on available information, we can estimate changes in energy demand and therefore economic value for the Atlantic Region. We will use an approach similar to that outlined by Cline (1992). First, it is necessary to determine how degree-days change in response to annual temperature. Electric utility forecasters are required to understand this relationship between the mean annual temperature and degree-days. As an approximation, a 1 ^{o}C change in mean annual temperature results in a corresponding 5% change in degree-days in Atlantic Canada (*pers. com.* B. Boutilier, Senior Forecaster, NS Power). Note that changes in space heating energy demand is being investigated and not changes in space cooling energy demand (air conditioning).

Using Environment Canada information, the average number of degree-days for the Atlantic Provinces for the period 1993-1995 was used to estimate the average number of degree days per year. Then provincial energy use and cost statistics for electrical power and home heating oil were divided by the number of degree-days to provide an estimate of the quantity and cost of energy demanded per degree day. Careful attention was paid to ensuring that the existing mix of electrical and heating oil energy demand was reflected in the estimates. Results indicate that for every 1 ^{o}C change in the mean annual temperature, energy demand changes by $46 million.

Although electrical space heating supplies approximately 35% of the region's space heating demand, larger impacts are experienced in the electrical sector given that electrical power is more costly than home heating oil. These results indicate that the space heating energy sector is highly sensitive to changes in temperature and climate change, and that the electric utilities and consumers are particularly sensitive.

3.7 Sea-Level Rise

As discussed above, climate change related sea-level rise has been vigorously investigated. Economic costs associated with sea-level rise divide into two types: (a) capital costs of protective constructions; and, the recurrent annual cost of foregone land services (Cline 1992). In response to sea-level rise, defensive structures would likely be constructed to protect valuable lands and property, such as cities and ports, whereas less valuable lands, such as coastal wetlands, would not be protected (Fankhauser and Pearce 1994). A Charlottetown, PEI, study found that a 1 metre sea-level rise would cause significant social and economic impacts and threaten the city's waterfront developments, including over 250 buildings, streets, sewer systems and parks (CCD 88-02). Given the value of this property and infrastructure, it is reasonable to assume that defensive measures would be implemented. A study for Saint John, NB, found similar potential impacts in addition to the increased probability of storm surge flooding of agricultural land. The authors state that the richest farmland in the area is presently subject to flooding and the impacts can only be expected to increase as the frequency and duration of the flooding increases in response to sea-level rise (CCD 87-04).

Given the body of literature on the damages associated with sea-level rise, preliminary estimates for Atlantic Canada can be made. For example, annual defensive expenditures associated with sea-level rise have been estimated for Canada to be approximately 0.03% of GDP (Rijsberman 1991). Applying this number to Atlantic Canada's GDP in 1996, damages are estimated the be in the order of $117 million. This does not include damages such as loss of habitat, salt intrusion into groundwater, and income loss from dryland inundation. Three studies investigated by Fankhauser and Pearce (1994) found sea-level rise to account for 11%-20% of the total climate change impacts on the United States which puts them in the range of 0.012% to 0.02% of GDP. Applying this range to Atlantic Canada's GDP in 1995 provides estimates of total sea-level rise damages in the order of $49 to $86 million ($1996).

It is interesting to note that one of the early studies on sea-level rise (Table 1.3, Rijsberman 1991), used coastal length figures very similar to those of the Maritime Provinces (13,660 reported for Canada vs. 11,200 for the Maritime provinces reported by Eaton *et. al.* (1994)). Subsequent studies, including all of the studies cited here, report the exact figures. Although it is unclear what data was used, it is possible that the Canadian damages for sea-level rise reported in the literature is for the three Maritime Provinces only.

Adopting a wetland valuation and loss approach used in most of the above-mentioned studies, we can estimate wetland damages for Atlantic Canada. This is done simply by multiplying the wetlands area by the assumed loss with climate change by the value of the wetland. After reviewing a number of studies, Fankhauser and Pearce (1994) assume a 50% loss of wetlands associated with a 1 metre sea-level rise resulting from a 2xCO_2 and a temperature increase of at least 3^{o}C. In the Maritime Provinces (PEI, NS and NB), total wetland area is 3,600 km^2 (Eaton *et. al.* 1994). A more difficult assumption is the value of an area of wetland. Much of the literature assumes a value of US$5 million/km^2, a figure that is extremely high for Atlantic Canada. Eaton *et. al.* (1994) report estimates in the $21,000/km^2 (adjusted to 1996 dollars) range. Using this estimate, wetland damages are estimated to be in the order $77 million annually for the Maritime Provinces.

Based on the literature and the above calculations, it is clear that Atlantic Canada is highly sensitive to sea-level rise from a socioeconomic perspective. Damages from sea-level rise are likely to be one of the largest damage categories. Further investigation is therefore required.

3.7.1 Extreme Events

The economic effects of extreme events have two significant dimensions, which include:

1. Direct Event Effects: these include all actual effects occurring as a direct result of the impact of an extreme natural event on a human settlement (i.e. destruction, damage, injuries and death). These can also be referred to as stock effects; and,

2. Indirect Event Effects: these are all potential and actual effects resulting from the disruption of social frameworks. These are also known as flow effects (Albala-Bertrand 1993).

Direct event effects stem from extreme event impacts on human, natural and human-made capital stocks. Examples of direct effects would include deaths (human stock), standing timber losses (natural stock) and building damages (human-made stock). After the event, and depending on the distribution of impact on the three capital stocks, the size of each of these stocks would change as a result of the event. The difference in the level of capital stock before and after the event could be used to measure the direct economic effect of the event. The resulting decrease in the capital stock translates into a decrease in regional wealth and is therefore a cost of a extreme event.

Indirect effects stem from alterations in the flow of goods and services in an economy as a result of a extreme event. These would include income and employment losses due to business disruptions during and immediately after the event. Income and employment gains would result from emergency response and storm damage repair expenditures.

To date, there has been no comprehensive study of the costs associated with extreme events in the Atlantic Region. Although the Insurance Bureau of Canada (1996) has recorded the value and number of claims associated with significant property damages resulting from atmospheric hazards in Canada. During the period from July 1987 to 1995, for example, there were 43 “natural disasters” resulting in major multiple-payment occurrences. 21% of the storms occurred in the period from September to March. The median value of claims is reported at $12 million with 3,300 claims registered. Of the 43 events, two were exclusive to the Atlantic Region: the wind event in October 1992 in Avalon, Newfoundland, with $8.2 million in claimed damages and 4,100 claims; and, the 1995 summer storm (Hortense) in Nova Scotia with 1,200 claims and $3 million in claimed damages.

Given the lack of existing information, there is a clear need to gain a better understanding of how climate change induced changes in the frequency and intensity of extreme atmospheric events could impact the socioeconomics of the Atlantic Region.

4 Summary

Climate change is expected to impact all sectors of society and the economy through impacts on the physical environment. Based on predictions in the literature about the order of magnitude of socioeconomic impacts, annual damages for developed countries and regions could be between 1% and 1.5% of GDP or $417 to $625 million (1996$) of Atlantic Canada’s 1995 GDP. Given the high reliance on primary industries in the Atlantic Region, damages are likely to be in the upper range.

While climate change is difficult to assess from a regional perspective, consensus exists as to which human activities are climate-sensitive. In Atlantic Canada, the most significant impacts can be expected in agriculture, forestry, fisheries, energy including hydroelectric generation and space heating final demand. Other effects would stem from extreme events and sea-level rise including loss of coastal habitat, other productive lands and defensive expenditures to protect the built environment. Although the direction of impact for many of these sectors will depend on the heating or cooling effect in the

Atlantic Region, the change in precipitation and frequency and intensity of extreme events, it is clear that the above noted sectors are climate-sensitive. Further investigation is therefore required.

5 Conclusions and Recommendations

Two recommendations from a Climate Change Digest (CCD) summary report on economic perspectives of climate change in 1988 are still of relevance today:

"Although expected changes in climate and their consequent impacts will profoundly affect social and economic structures, most research efforts have focused on biophysical aspects of climate change. These studies now need to be set within the framework of social understanding and economic analysis." (CCD 88-04)

When the literature on climate change and socioeconomic impacts is reviewed, there is a lack of information specific to Atlantic Canada in particular. For the most part, information is presented at the national or international level and recent regional work concentrates on physical responses to climate change. Certainly most of the recent socioeconomic assessment of climate change and variability is conducted at the international level. While this provides a solid understanding of the economic sectors at risk from climate change, preliminary socioeconomic investigations within the Atlantic Canadian context are not available. This is not surprising given that little is agreed upon regarding the climactic implications of climate change and variability at the regional level in Canada. However, this lack of biophysical information at the regional level should not preclude preliminary socioeconomic investigations.

Which leads to the second recommendation:

"Climate change could trigger considerable adjustments in regional patterns of agriculture…at the farm, regional and provincial levels. These and other impacts need to be assessed and linked to more general approaches (e.g. scenario modelling) in developing optimal future research activities." (CCD 88-04)

This recommendation argues for the use of scenario based approaches to investigating the economic implications of climate change. Scenario based approaches are similar to dose-response investigations where a relationship is established between changes in key variables, in this case climactic, and the subsequent response, in this case economic activities. The scenario approach is already used in agriculture where climactic variables are known to have an impact on yield and therefore the profitability of the agricultural sector.

Presently, scenarios can be created for agriculture, which match changes in climatic variables to changes in crop yield. Yield changes can then be matched with economic information so that a relationship between climatic variables and economic activity is developed. Although this approach would provide crude estimates, these estimates would likely be sufficient for the purposes of climate change economic research at this time: that of identifying sensitive sectors and the order of magnitude of socioeconomic response to climactic change and variability. Once climate-sensitive sectors are identified, and the likely impacts determined, mitigation strategies can be formulated. Options can then be assessed for dealing with climate change induced biophysical, social and economic effects.

The scenario approach also circumvents a current stumbling block in research: determining the magnitude and direction of change in climactic variables. By using scenarios, economic response relationships associated with different levels of climactic variable change can be established. This could, of course, include positive and negative changes in climactic variables. As more information becomes available on climactic variable change, the basic relationships with the economy will be established.

Therefore, future research in Atlantic Canada should seek to develop workable relationships between changes in climactic variables and economic responses. Key sectors where this opportunity presents itself have been identified in this paper and include agriculture, forestry, fisheries, space heating, hydroelectric power, and losses stemming from sea-level rise and extreme events.

Bibliography

Albala-Bertrand, J.. 1993*. Natural Disaster Situations and Growth: A Macroeconomic Model for Sudden Disaster Impacts*. World Development, Vol. 21, No. 9, pp. 1417-1434.

Climate Change Digest (CCD) CCD 87-04. *Effects of a One Metre Rise in the Mean Sea-Level at Saint John, NB*. Environment Canada.

CCD 88-02. *Preliminary Study of the Possible Impacts of a One Metre Rise in the Sea Level at Charlottetown, PEI*. Environment Canada.

CCD 88-04. *Economic Perspectives on the Impact of Climate Variability and Change: A Summary Report*. Environment Canada.

CCD 88-07, (Stokoe 1988). *Socioeconomic assessment of the of the Physical and Ecological Impacts of Climate Change on the Marine Environment of the Atlantic Region in Canada. - Phase 1.* Environment Canada.

CCD 90-?. *Assessing the Socioeconomic Impacts of Climate Change in Marine Environments.* Environment Canada.

Cline, W., 1992. *Global Warming: Estimating the Economic Benefits of Abatement*. OECD Environment Committee. Paris.

Difrancesco, R., and Lonergan, S.. 1994. *Examining Regional Sensitivities to Climate Change Using Aggregate Input-Output Data: the Case of Transportation in the Northwest Territories*. Canadian Journal of Regional Science. Summer 1994, 233-257.

DPA Group, 1990. *Assessing Future Economic Impacts of Acid Deposition on the Recreational Fishery in Eastern Canada*. Economic and Commercial Analysis Report No. 49. Department of Fisheries and Oceans. Ottawa, On.

Drinkwater, K., 1997. *Impacts of Climate Variability on Atlantic Canadian Fish and Shellfish Stocks*. *In* Proceedings of the Symposium on Climate Change and Variability in Atlantic Canada, December 1996, In press. Environment Canada, Atlantic Region.

Eaton, Gray, Johnson, and Hundert, 1994. *State of the Environment in the Atlantic Region.* Environment Canada*.* Dartmouth, NS.

Environment Canada, 1994. *The Canadian Economy, Energy and Greenhouse Gas Emissions: A Sectoral and Regional Analysis 1988-1992*. Environment Canada. Hull, P.Q..

Fankhauser, S., 1992. *Global Warming Damage: Some Monetary Estimates*. CSERGE Global Environmental Change Working Paper. GEC 92-29. Cited in Fankhauser, S., and Pearce, D., (1994). *The Social Costs of Greenhouse Gas Emissions*. *In* The Economic of Climate Change: Proceedings of An OECD/IEA Conference. OECD Paris.

Fankhauser, S., 1996. *Economic Estimates of Climate Change Impacts*. *In* Sustainable Development and Global Climate Change: Conflicts and Connections. Conference Proceedings, December 4-5, 1995. Center for Environmental Information Inc..

Hengeveld, H., 1995. *Understanding Atmospheric Change: A Survey of the Background Science and Implications of Climate Change and Ozone Depletion*. Atmospheric Environment Service, Environment Canada, SOE Report No. 95-2.

Insurance Bureau of Canada. 1996. Fact Book. URL:<http://www.ibc.ca/>

Minns, Randal, Chadwick, Moore and Green, 1995. *Potential Impacts of Climate Change on the Habitat and Population Dynamics of Juvenile Atlantic Salmon in Eastern Canada*. *In* R.J. Beamish (ed.) Climate Change and Northern Fish Populations. Can. Spec. Publ. Fish. Aquatic Science. 121.

Mooney, S., and Arthur, M., 1990. *The Impacts of Climate Change on Agriculture in Manitoba*. *In* Canadian Journal of Agricultural Economics. 38. 685-694.

Rijsberman, J., 1991. *Responding to Climate Change: Selected Economic Issues*. OECD. Paris.

Stokoe, P., 1988. *Socio-economic Assessment of the Physical and Ecological Impacts of Climate Change on the Marine Environment of the Atlantic Region Phase 1.* Environment Canada, Climate Change Digest, CCD 88-07.

OECD, 1991. *Climate Change: Evaluating the Socioeconomic Impacts*. Paris.

IPCC, 1996. *The Economic and Social Dimensions of Climate Change, IPCC Working Group II and III*.

van Kooten, G.C., 1995. *Climate Change and Canada's Boreal Forest: Socioeconomic Issues and Implications for Land Use*. *In* Canadian Journal of Agricultural Economics. 43. 133-148.

Wolfe. D. 1996. *Potential Impact of Climate Change on Agriculture and Food Supply*. *In* Sustainable Development and Global Climate Change: Conflicts and Connections. Conference Proceedings, December 4-5, 1995. Center for Environmental Information Inc..

4.0 ADAPTATION

R.W. Shaw
Meteorological and Environmental Consultant
Box 2C5, 177 Mason's Point Road
Head of St. Margaret's Bay, Nova Scotia B0J 1R0

4.1 *General*

Research will in all likelihood result in improved estimates of the impact on climate caused by increasing concentrations of greenhouse gases, but reliable predictions of climatic change on a regional scale are still some time away. In addition, even if large reductions in the emissions of greenhouse gases were to take place now, there might still be changes in climatic means and variability because of the inertia of the ocean-earth-atmosphere system. Therefore, it would be prudent to assume that adaptive management and use within the next several decades of natural and man-made resources such as forests, agriculture and coastal structures may have to be carried out in the face of climatic uncertainty.

While the development of climate models with better regional resolution needs to proceed, the vulnerability of ecosystems to climate change, and the exploration of adaptive measures, should be a priority for the Canada Country Study in Atlantic Canada. At the symposium *Science and Policy Implications of Atmospheric Issues in Atlantic Canada*, held in Halifax, Nova Scotia in December 1995 (Shaw, 1996), the following response was given to the question: "What aspects of climatic change are of greatest importance in the Atlantic Region?":

> **Despite the uncertainty in the projections of climatic change in the Atlantic Region, it is important to have an estimate of the sensitivity of Atlantic Canada resources to climatic changes in either direction. Such resources include agriculture, forests, wildlife, the fishery, coastal infrastructure, transportation, tourism and the human population.**

Many insights on sensitivity in the Atlantic Region to climate change have been described in Section 3 of this Report although, as outlined in Section 5, there are many gaps in our knowledge which need to be filled.

To the question: " What activities are needed to asses the sensitivity of the Atlantic Region to climate change?", the 1995 workshop replied:

> **Formation of an interdisciplinary and multisectoral (public, private, academia) group to develop a matrix of sensitivity of various components of the environment of the Atlantic Region to climatic change. One dimension of the matrix would be the aspect of the resource (using indicators such as freshwater availability or forest biodiversity); the other would be climatic variables such as temperature, precipitation, frequency of sea level rise or storm surges. This activity would make use of existing information, ecosystem studies and modelling results.**

Adaptation would be most appropriate in sectors in which there is a large degree of human activity or investment in human infrastructure, such as fishing (including aquaculture), forestry, agriculture and the coastal zone, and where there is great sensitivity to climate change.

4.2 *Fishing*

The report of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 1996) suggests adaptation measures for the fishing industry, including aquaculture. Following are a few examples, modified slightly to apply to this region, with the first two applying regardless of further changes in climate:

- modify and strengthen fisheries management policies (this would require the ability to forecast shifts in fish stocks due to climate change (see Section 5), and the ability to reach international agreements).

- promote fisheries conservation and environmental education among fishermen on an international basis

- preserve and restore wetlands, estuaries, floodplains and bottom lands - essential habitats for most fisheries

- adjust to possible changes in relative abundance of species (more warm water species, fewer cold water species) and distributional shifts in fish stocks (i.e., northward shifts and changes in timing and location of migratory patterns)

- for aquaculture, expanding the number of species and increasing the area in which operations could be located.

4.3 *Coastal Zone*

Concerns affecting the coastal zone associated with climate change could include greater storm variability, changes in wave climatology and increased sea-level rise.

- Environmental monitoring networks (now rapidly declining) provide the basis for assessing vulnerability to climate change, evaluating impacts and planning adaptation.

- Coping with global sea-level rise:

    - Given the low population density and large, mostly natural coastline, the recommended strategy for adapting to sea-level rise is to allow the coastline to retreat and avoid costly engineering solutions.

    - In some areas, such as Argentia, Newfoundland and parts of the Bay of Fundy marshlands, protection of the coastline is warranted.

    - A Canada-wide approach to coastal zone management could be developed.

- Increased erosion and overtopping of beaches and other structures are serious consequences of sea-level rise.

- With regard to flooding, for example in the Bay of Fundy, an important objective must be to determine the probability of the dykes being overwhelmed by the coincidence of a storm surge and high tides. Consideration should be given to the extent of potential flooding, and the infrastructure at risk.

4.4 *Agriculture*

- The agricultural industry should, in general, be able to adjust relatively well to any *long term gradual* changes in climate that may occur, taking advantage of any improvement in conditions while minimizing the negative impacts of a less favourable climate. However, *variability and extremes* in climate that will occur will likely have greater impact and be more difficult for producers to cope with. In general, any progress that can be made in estimating and reducing the negative impacts of variability and extremes in climate should help the industry to cope with any long term climate changes that may occur.

- There are measures that could be implemented that would reduce the negative impacts of climate change and take advantage of any improvements in the climate that may occur. A few examples follow:

  i) Increased use of irrigation and wider adoption of soil management practices and crop rotations which build up soil organic matter levels would make agriculture more resilient to the effects of drought.
  ii) Wider adoption of drainage practices and erosion control methods such as cover crops, grassed waterways, contour plowing and reduced tillage would help to offset negative effects of higher rainfall.
  iii) Increased adoption of active and passive frost prevention methods. (Active methods include those used at the time frost occurs, such as sprinkling irrigation, covering, wind machines or helicopters; passive methods are taken well before frost occurs, such as crop selection, field selection, planting/harvesting schedules and windbreak management).
  iv) Increased efficiency in field tillage, planting and harvesting operations through improvements in machinery, adoption of minimum or zero tillage, appropriate machinery size selection. Negative effects of reductions in available field work caused by climate change could be offset by some of these measures.
  v) Development of new crop varieties that are better adapted to existing or changed climate or climatic extremes and improved agro-chemicals and/or management practices to control weeds, pests and diseases. Probably the bulk of present day research efforts by both industry and government are focused on these areas.

4.5 *Forestry*

A likely scenario for this region is a cooling down in the summer due to the southerly movement of arctic melt water and warmer in the winter due to greenhouse effect. Expectations may lead to large swings in seasonality (late frosts or extended thaws) and increases in extreme weather events (tropical storms and hurricanes). This scenario may lead to increased mortality and salvage operations and a glut of wood on the market. This would require:

a) imaginative substitution of non-timber products with forest products to maintain carbon storage.

b) rapid reforestation with tree species and genotypes better adapted to climatic variability (swings in seasonality) would be required for the transition period to a warmer climate and is the deliverable of ongoing research by the Canadian Forest Service.

c) improved forestry practices that reduce the impacts of harvesting especially selective or partial cuts that open up the canopy to wind and design of appropriate methods to protect plantations.

d) a flexible, responsive and cooperative forest industry to respond to all aspects of rapid changes in salvage, production of goods and marketing.

e) a strategic approach to research for the selection of appropriate species and provenances, together with management techniques that will maximise forest ecosystem production and biodiversity, as well as carbon storage in a warming environment while providing required wildlife habitat and recreation objectives.

f) increased management of deer populations which under reduced snow pack and forest disturbance may increase and threaten regeneration and biodiversity necessary to maintain long term carbon sequestration.

g) extensive monitoring of forest health to provide early warning of changes and provide through research cause effect relationships to feed into models to better predict future changes in forest species composition.

REFERENCES

IPCC
1992. *Global Climate Change and the Challenge of the Sea*; Report of the Coastal Zone Management Subgroup of the Intergovernmental Panel on Climate Change, 35 p. & appendices.

1996: *Climate Change 1995 - Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses.* Cambridge University Press, Cambridge, UK. x + 887 pp.

Shaw, R.W., (Ed.)
1996: *Science and Policy Implications of Atmospheric Issues in Atlantic Canada: Workshop Proceedings*. Environment Canada - Atlantic Region Occasional Report No. 6, 143 pp. Available from Environmental Conservation Branch, Environment Canada - Atlantic Region, P.O. Box 1590, Sackville, New Brunswick E0A 3C0, Canada.

5.0 Knowledge Gaps

R.W. Shaw
Meteorological and Environmental Consultant
Box 2C5, 177 Mason's Point Road
Head of St. Margaret's Bay, Nova Scotia B0J 1R0

Although much excellent research has been carried out to date in the Atlantic Region on various aspects of climate change, it is obvious that gaps remain in our knowledge. Future work must endeavour to fill these gaps to increase our capacity to understand and reduce the effects of climate change in the Region, and to adapt to those effects which are unavoidable. Furthermore, to avoid knowledge gaps in the future, monitoring systems must continue to operate and to improve in order to provide the environmental record that will allow us to observe climate change, and our efforts to forestall and adapt to it.

Following are highlights of knowledge gaps that have been revealed by research in the Region. They are organized according to the sensitivities discussed elsewhere in this Report.

5.1 *Climatological Monitoring, Analyses and Modelling*

- Climate researchers require access to long temporal datasets, updated continuously and collected on a broad regional or global scale. These data must have well documented quality standards and, in some cases, be limited by programme objectives to specific datasets and derived products.

- The Climate Change Network is sparse and declining. Stations have decreased steadily from a peak of 2915 stations in 1991 to 2483 stations in 1996. A similar trend has occurred with the Supplementation Observation Networks (which monitor snow depth and ice coverage), but over a shorter period of time. Another problem is a lack of northern stations.

- Like most countries, Canada essentially lacks offshore observing systems. Needed are regular, long-term, systematic, and cost-effective ocean measurements that are relevant to global climate systems and are subject to continuous examination. Canada has a tradition of offshore measurements for research (e.g. Labrador Sea and Grand Banks) that could be continued as part of an oceans monitoring system.

- Traditional statistics cannot incorporate the temporal-spatial chaos inherent in climate datasets, rapid short-term changes or intermittent events. Use of other techniques, such as circular statistics, fractal geometry and chaos theory should be considered. Chaotic change is governed by the initial conditions that trigger movement towards one state or the next and their following pattern of change and development; i.e., the initial state plays a key role in the future of a system.

- A new statistical approach is needed for climate modelling. The short length of time and the short cycles we are often dealing with means that traditional statistics are often of little use. It is recommended that paleoclimatology be used for looking back and discovering long-term cycles.

- More accurate climate models are needed. Global models are improving but there is much work to be done. The oceanographic community is starting to model the coastal shelf, but as yet this is not well-coupled to the deep oceans. More accurate regional models are also needed.

- Some climatic process needs to be identified linking environmental signals such as crop yields and fish catches in Europe, Atlantic Canada and the Black Sea, areas which lie between the positive and negative phases of the North Atlantic Oscillation (NAO) correlation.

- It is essential that we maintain (or enhance) the moored buoy network and validate offshore platforms for long term wind/wave monitoring

- Wave hindcast models (including wind aspects) still need work in relation to extreme conditions; mesoscale effects may be important.

5.2 *Extreme Events*

- Little or no work examining the implications of a changing climate has been done in Atlantic Canada on:
    - the frequency or severity of extreme events
    - storms in transition from tropical to extra-tropical
    - trends in summer severe weather

5.3 *Fisheries and Plankton*

- Quantitative predictions of the consequences of climate change on the fish resources of Atlantic Canada will require good regional atmospheric and oceanic models of the response of the ocean to climate change, improved knowledge of the life histories of those species for which predictions are required and further understanding of the role of environment, species interactions and fishing play in determining the variability of growth, reproduction, distribution and abundance of fish stocks. This multi-forcing and numerous past examples of "failed" environment-fish relationships indicate the difficulty fisheries scientists face in providing reliable predictions of the fish response to climate change.

- As the marine aquaculture industry grows and diversifies, the role of climate will become more important. It will be more and more useful to define and predict local climate variability and the critical values of environment conditions, since these are still poorly defined.

- To understand the impact of climate variations on the marine ecosystem, it is essential to monitor not only the quantity (biomass), but also the quality (i.e., species composition) of the organic production.

- A good knowledge of the food chains in the ocean is essential for a better understanding of the efficiency of transfer from primary production to fish stocks

5.4 *Coastal Zone*

The impact of a given weather event is a function of storm characteristics and timing, coastal setting, and vulnerability of landforms or structures in the coastal zone. Differences in coastal response depend on the specific erosion processes, the coastal geology, and the morphological status of a site. The latter may reflect the impact of a previous storm and the time available for recovery since that event. Improved prediction of climate-change impacts in the coastal zone will require a better understanding of coastal response at storm-event scale and at longer time scales, both of which require sustained funding for long-term monitoring of water levels, waves, and coastal change.

- We need to enhance our ability to predict the changes that would occur on wave-dominated coasts in the next century if accelerated sea-level rise were to occur.

- Long-term tide gauges for monitoring rates of relative sea-level rise must be maintained, perhaps in combination with satellite altimetry, absolute gravity, and other techniques. Tide gauges are required for detection and analysis of storm surges.

- Long-term coastal wave instruments must also be maintained for analysis of wave climate, detection of trends, improvement of wave prediction, and documentation of storm waves.

- A regular schedule of repetitive, large-scale, vertical aerial photography should be carried out to observe changes in the coastline.

- An analysis of historical data should be carried out to derive reliable estimates of coastal retreat, sea-level rise, storm-surge climatology, and wave climate.

- Regular surveys of representative "indicator" sites along the coast should be continued.

- Closer links need to be established between shoreline monitoring crews and storm surge forecasters who have access to real time marine measurements. The forecasters could provide storm alerts to the survey crews who could measure shoreline changes sooner, obtain better-post storm observations which could be used to develop a better relationship between wave heights, water levels and beach response. Once the beach response to specific storms is established, storm warnings could be developed for specific shore types along Atlantic Nova Scotia.

- It is critical that the network of wave buoys, especially inshore buoys (e.g., MEDS 037), and the network of tide gauges along our coasts, be maintained, not abandoned. These observing tools allow forecasters to monitor the movement of storm surges along shore and allow a better documentation of the marine conditions responsible for the physical changes observed onshore.

5.5 *Ecosystem Sciences and Water Resources*

Water Resources

- Precipitation and temperature are the principal driving forces behind the hydrological cycle and anticipated changes in climate are expected to significantly alter Canada's water resources. To this end, it is important that the various climate/hydrologic mechanisms at play and their interdependent reactions be understood. Proper monitoring of key elements over the long term is vital to increasing our understanding of these processes so that preventative or adaptive measures may be taken to reduce the impact on society.

- Preliminary comparisons of ice data on ice cover in rivers with winter season temperatures showed that there was a cause and effect relationship between the temperature and ice. However, there is a need to explain this relationship, and how it might change with a shift in climate.

- Trends in watershed runoff may be the result of either a long term natural cyclic variation, climate change or a combination of both. An important question is whether the anticipated effect of climate change will exacerbate or mitigate a cyclic trend, how long the trend will last and what are the implications for the entire ecosystem. It is vital to apply models to those susceptible species in the watershed which are susceptible to changes in runoff and which may be on the edge of their habitat range. By better understanding these systems there could be environmental management decisions that might reduce the impact on these susceptible species.

River Ice Jams

- Neither Global Circulation Models (GCMs) nor river ice science is sufficiently advanced to identify some of the changes in the ice-jam regime of Canadian rivers that may be expected under the global warming scenario. However, GCM sophistication and computer power are increasing, and it is likely that many of the weaknesses of the GCMs will be rectified in the next decade. To take advantage of such progress, river ice science must also advance to the point that it can furnish quantitative predictions, given climatic inputs and channel morphology.

Wetlands in Atlantic Canada

- Because they are defined by the location of seasonal and permanent water tables, wetlands are closely linked to climate. Balances between precipitation and temperature which control total water input and outputs are critical in determining the very existence of wetlands. Changes in the evapotranspiration balance leading to lower water tables may thus cause the disappearance of wetlands along with the ability of basins to absorb water and increase flood risks in certain areas. Research thus far suggests that water levels might change significantly with shifts in climate but how these translate into actual wetland distributions has not yet been determined and remains an important unknown in attempting to understand the implications of climate change.

Migratory Birds

- Understanding of the effects of climate on the timing of breeding is best developed for arctic-nesting waterfowl. In Atlantic terrestrial ecosystems we know very little about the relation between climate and the timing of breeding; in general at these latitudes breeding is probably initiated chiefly by changes in daylength in such a way that the time of maximum energy demand coincides with increased food supplies. In a changing climate the temporal relationship between daylength and food production will likely change, requiring adaptive changes by the bird populations.

- Extreme events at any time of year can have severe effects on birds. Cold snaps in late spring frequently cause large-scale mortality in small birds, and summer storms can kill shorebirds on their breeding grounds and greatly reduce breeding success among bird groups as varied as songbirds and seabirds. Observations of such extreme events are essentially anecdotal, and it is uncertain what role they may play in determining population persistence in the long term; however if, as is widely predicted, they become more frequent during climatic change, more attention will need to be paid to their possible impacts.

General

- Data currently available (e.g. monthly temperature means, precipitation totals) in the climatological record are of limited value in assessing ecological impacts of climate change. Estimates of precipitation on finer geographic and temporal scales, are needed to predict effects of climate change on biodiversity in general, including birds.

- Efforts should continue to be made to exploit proxy climate records archived in the terrestrial and marine sediments in the Atlantic Region to examine ecosystem response to climate change. Many of the fossil sites are vulnerable to natural erosion or are only temporarily exposed through construction activity. While protecting the sites may not be practical, sharing information and samples is important. Some sites might deserve protection as reference sections. Rare specimens of less studied groups are often found in museums, where decades of collecting have accumulated significant records. Use of these collections will help fill in knowledge gaps.

- For historical and geographical reasons, universities and research institutions, as well as most of the region's population, are located in the southern, more climatically hospitable part of the region. This has caused a situation where most of the knowledge of hydrological and ecological conditions and processes is concentrated on the one-third of the region which is least likely to be affected by climate change. Future research on climate change or climate variability impacts should be initiated in Labrador as this is the area most likely to be affected by a changing atmospheric energy balance.

5.6 *Agriculture*

- The agricultural industry should, in general, be able to adjust relatively well to any *long term gradual* changes in climate that may occur, taking advantage of any improvement in conditions while minimizing the negative impacts of less favourable climate. However, *variability and extremes* in climate that will occur will likely have greater impact and be more difficult for producers to cope with. In general, any progress that can be made in estimating and reducing the negative impacts of variability and extremes in climate should help the industry to cope with any long term climate changes that may occur.

5.7 *Forestry*

- There is little research and much uncertainty concerning multiple effects of climatic factors and other stresses such as air pollution i.e. SO_2, NH_4, NO_x and O_3, together with the deposition from the atmosphere of acidifying substances and heavy metals. The effects of enhanced UV-B exposure also needs consideration. There is a need to determine which of these stressors may predispose trees to the effects of climate change. For example, ozone is known to change carbon allocation in forest trees favouring above ground biomass at the expense of roots. This effect may leave trees more vulnerable to drought, nutrient deficiency, blowdown and reduce capabilities of some hardwoods to recover from winter cavitation injury.

- The long term effects of population migration (associated forest clearing and harvesting) due to extension of farmable land and industrial development are also uncertain. These will be exacerbated by movements of people due sea level rise .

- Forest responses to climate warming are predicted to differ among regions of the country. For example, forests are predicted to disappear from much of the area currently covered by dry, boreal forests, causing northern parts of the Prairie provinces and northwestern Ontario to become sources of carbon dioxide to the atmosphere, whereas the Atlantic provinces are predicted to become stronger sinks of atmospheric carbon dioxide. All predictions of source/sink activity are subject to much uncertainty, and the regional disparities in predicted responses argues strongly for reducing uncertainties on a regional basis.

- There is much uncertainty globally about how processes involved in primary forest production in Atlantic Canada will respond to increasing atmospheric CO_2 concentrations, in combination with rising temperature, changes in precipitation, and uncertain nitrogen deposition rates. It is very uncertain how patterns of allocation of growth to foliage, fine roots, and woody-tissues will change, but it is clear that the potential of the forests to act as a sink for atmospheric carbon dioxide depends on these patterns. Uncertainty exists concerning whether carbon storage in soils will increase of decrease as climate changes, and whether more nitrogen or less nitrogen will be made available to roots.

5.8 *Socio-economic Aspects of Climate Change*

- A Climate Change Digest summary report on economic perspectives of climate change in 1988 states that, although expected changes in climate and their consequent impacts will profoundly affect social and economic structures, most research efforts have focused on biophysical aspects of climate change. These studies now need to be set within the framework of social understanding and economic analysis. When the literature on climate change and socioeconomic impacts is reviewed, there is a lack of information specific to Atlantic Canada in particular. For the most part, information is presented at the national or international level and recent regional work concentrates on physical responses to climate change. While this provides a solid understanding of the economic sectors at risk from climate change, preliminary socioeconomic investigations within the Atlantic Canadian context are not available. However, this lack of information at the regional level should not preclude preliminary socioeconomic investigations.