Climate Scenarios
Results of the Oct 24-25, 2001 CCAF Workshop

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Context

Potential impacts of climate change cannot be assessed unless there is some scientifically justified understanding of what changes in climate are likely, globally and for Canada. Changes in climate affect many variables, including precipitation, temperature, soil moisture, cloudiness, winds, oceanic circulation, ice cover, sea level, etc. No one variable or index can be a surrogate to assess the complete effects of climate change. The best way to relay projections of climate change to the research community, for their use in assessing climate change impacts on human health, ecosystems, natural resources, infrastructures, economies and society, is through the production of climate scenarios for the future.

Global Climate Models, and Regional Climate Models applicable to specific geographic regions, have developed to the point that the broad scale features of the anticipated climate can be produced, under various assumptions of future greenhouse gas emissions. While these models are our best guess at defining future projections of a changed climate, they have an ongoing need for further improvements in their parameterizations, processes, feedbacks, etc. Furthermore, because of the high cost (in time, people and dollars) of model integrations, the higher resolution models necessary for understanding system sensitivities and impacts must be generated by less satisfactory forms of statistical/dynamical downscaling. Finally, if we wish to provide policy makers with credible information needed for mitigation, adaptation and/or economic and social decisions affecting Canada and Canadians, we must attempt to identify and limit the uncertainty inherent to the simulation in the future.

The CCAF has taken several initiatives to bring climate modelers and impact researchers together to assess the needs and problems of climate scenario development.

- Workshops have been held to define the research agenda.
- Funds have been provided to support needed infrastructure to engage the scientific community in scenario building and usage.
- Proposals were called to quick-start development of national scale climate scenarios from climate model simulations, and other scenarios in resource dependent sectors (fisheries, forestry, agriculture) to assess possible impacts. The CCAF has funded eleven climate scenario related projects in 1999/00 and 2000/01.
- A workshop was held on October 24-25, 2001 to evaluate successes, program gaps and possible next steps.

The following is a report of the CCAF Evaluation Team on the Oct. 24-25, 2001 Climate Scenarios Workshop.

Overview of Projects and Specific Recommendations

S99-15-03 Climate Scenarios – Identifying the Needs. An earlier Canadian workshop (L'Estérel, April 1998) on climate change scenarios identified the pressing requirement for a consistent and comprehensive source of climate data, and GCM output, for use by the impacts research community. CCAF provided funding to take the next step at "identifying the needs" through a follow-on workshop (Sainte-Adèle, May 1999). The workshop focused on identifying climate scenario outputs needed by the impacts community, and the "means" to efficiently deliver advice, products and services to impacts researchers.

The primary conclusion of the workshop was that an intermediary service was immediately required to link the climate modelling and the impacts research community. This conclusion directly resulted in the establishment of the CCAF funded Canadian Climate Impacts Scenarios (CCIS) Project; see S99-15-05.

S99-15-05 Canadian Climate Impacts Scenarios (CCIS) Project - Pilot. One objective of this project, funded for two years, was to encourage the use of a consistent set of scenarios by the Vulnerability, Impact and Adaptation scientific community. Without consistency and without reference to the emission scenarios and guidelines of the IPCC, the resulting assessments cannot be inter-compared and risk losing scientific credibility. This project created a scenario service centre which provides data for scenarios as well as guidance and training to users on scenario development. A key achievement of the project is a very user-friendly web site http://www.cics.uvic.ca/scenarios/ used by at least 300 registered users, and receiving 4 to 10 thousand visits per month. The site provides access or links to analysed data and modeled data for the recommended IPCC periods (1961-90, the 2020's, 50's and 80's), including monthly, seasonal and annual averages for a minimum set of climate variables from some six Global Circulation Models (GCM). In total, twenty-nine scenarios of climate change are currently available from the CCIS Project web site. The data set from the Canadian GCM is the most detailed and has been accessed directly from the Canadian Centre for Climate Modelling and Analysis (CCCma) web site, rather than through the IPCC Data Distribution Centre.

The CCIS project also provides tools, such as temperature-precipitation scatter plots, to facilitate the selection of the model simulations most relevant for the particular impacts research, and statistical tools for simulating realistic detailed climate scenarios at selected points or daily climate scenarios (e.g., weather generators). Finally, the CCIS project provides training through regional workshops, on-line guidance, handbooks and a video.

The activities of the CCIS project are guided by an advisory committee consisting of representatives from federal government departments and the university and impacts community. Judging from the comments of the users present, CCIS does an excellent job. CCAF has already committed funds, including enough to support a second person, to continue this project for the 2001-04 period, during which they hope to address issues

such as significance of climatic changes and identification of extreme events. Research will also be conducted on how to improve scenario construction, selection of scenarios for regions instead of simply points, and improved weather generators. There will be continued emphasis on training and on updating the information on the web site. Since contacts with users are very time consuming, **it is recommended that a *Frequently Asked Questions* section, a User Forum and lists of people involved, projects ongoing and publications released, be added to the web site**. Overall, it would appear that this project meets or exceeds user needs, within the possibilities of the observed and simulated information available. **It is recommended that a higher profile be provided (communications outreach) to this activity, and that users be encouraged to express their views on the continuing need for CCIS.** In the longer term, stable funding will be required. **Finally, the partitioning of the research and operational effort must be carefully monitored in order to maintain a reasonable balance.**

S99-15-02 Production of Regional Climate Change Scenarios over Regions of Canada with the Canadian Regional Climate Model (CRCM). CCAF funding for this two-year project served mainly to acquire a massive data handling system and to cover the salaries of operational personnel who direct and monitor the validation, preparation and delivery of model simulation data produced by the CRCM research group. Equipment purchases allowed for significant reductions in the time-consuming data handling procedures that had been previously handled by the CRCM core group. Three 10-year regional climate change simulations for western Canada were processed and made available to users through the CCCma web site. A fourth simulation was also made to test a new more efficient system of grid nesting. Compatible observed climatologies were also computed for model validation and made available. **It is recommended that in the future, CRCM simulations be made for more of the IPCC recommended periods/scenarios.**

S99-15-01 Modelling Regional Climate Changes in the Canadian Inland Seas: The Gulf of Saint Lawrence and Hudson Bay. This project, funded for two years, focused on developing sensitive ice-ocean models that best describe the observed variability and processes of water circulation in the Gulf and Hudson Bay. It resulted in regional models suitable for downscaling climate change scenarios, and that reflect reality in comparison to measured data sets. Emphasis on developing these improved regional models was in the areas of tidal dissipation and mixing, turbulence modelling, realistic atmospheric forcing fields, and coupling of the ice-ocean model with atmospheric models (CRCM and GEM). The project was highly successful in meeting its scientific objectives, communicating scientific findings in the published literature and at conferences, entraining collaboration and funding support from others, and training PDFs, research assistants and graduate students.

Additional work is recommended to bring the model to equilibrium, to account for water residence times of 3-5 years, by running several annual cycles until convergence occurs. Next steps in assessing the effects of climate change on the oceanographic conditions of the Gulf and Hudson Bay are to examine a number of GCM simulations and undertake research in a number of climate scenario sensitive

areas, including air temperature, water properties of the Labrador shelf, St. Lawrence and Hudson Bay runoff cycles, frequency and intensity of extreme events such as extratropical cyclones, and the effects of sea level rise.

S00-15-11 Canadian Climate Change Scenarios - Historical Data. This project, funded for one year, aims at providing quality controlled daily temperature (210 stations) and precipitation (485 stations) from the long term climate archives (up to 100 years) adjusted for changes in observational procedures. Adjustment for instrument relocation is included. The project also calculated the statistical properties of the time series, revealing serious skewness for temperature over most of the country. **It is recommended that users take steps to account for skewness when using weather generators to interpolate.** A user survey was conducted, but elicited few responses. **It was recommended by the participants that, if the project were to be expanded to cover additional variables in the future, "radiation" should be considered as a priority.** (note: see additional comments on data availability under "Data Policies" at the end of this report.)

S99-15-04 Current and Future Forest Fire Occurrence and Severity in Canada: Creation and Validation of Scenarios Developed Using the Regional Climate Model. CCAF funds over two years allowed significant acceleration of this ongoing project, including early communication of project results to the impacts community. RCM data from the boreal forest of western Canada were used to develop daily fire danger scenarios for time periods 1975-1985, 2040-2049 and 2080-2089. The model output from the time period 1975-1985 was found to be in reasonable agreement with known fire weather danger. Future values of fire weather severity using RCM outputs indicate a projected increase in seasonal fire severity of 50 to 100% by the decade of the 2080s (note: less than 1% of the boreal forest is burned annually).

An initial model of cloud to ground lightning has been developed as a PhD thesis project. Preliminary results were compared with data in Ontario and Quebec. **The model requires further enhancement and testing in the coming months, with a final version to be completed by the winter of 2001.** Scenarios of RCM projections of people-caused fires were studied. Results indicate possible increases in people-caused fires of 50% by the end of the 21st century.

Spin-off research from this project is in progress, with the BC Forest Service in improving RCM predictions in mountainous valleys, with OMNR in studies of levels of fire protection and evaluation of fire management scenarios, and with CFS in examining strategic forest management schemes to limit future areas burned.

S00-15-03 Transient Climate Change Scenarios for High Resolution Assessment of Impacts on Canada's Forest Ecosystems. This project was funded for one year. The main result is a set of national monthly maps (and manipulation software tools) of several basic variables gridded at 10km for the 120 year period 1950 to 2070. This impressive data set will be placed on the CCIS web site. The data are interpolated from a single CGCM2 run

for one IPCC scenario. Some of the details expected for such a high spatial resolution have been preserved by working with the simulated climatic change fields and applying the change fields to the higher resolution 1961-1990 normals. However, the influence of orography is not reflected very well in the data output. Simulated data from the CRCM were tested, but since the available runs cover only part of the country and only a few periods of time, they could not be used. Also, since, no other GCM offers a continuous time series as the CGCM does, no independent estimate of model uncertainty can be made. So, users will have to obtain such measures by other means. Concerning use of a single emission scenario, it is felt by the authors that when dealing with monthly averages, it is more important to have a consistent relationship between variables than to have a spread of estimates. Despite limitations, ecosystem assessment modelers, in forestry and other fields will be eager to use this data set.

S00-15-02 Climate Change Scenarios for Sockeye and Coho Salmon Stocks. This project was also funded for one year. Project objectives addressed included: retrospective studies of Fraser River flows and temperatures; prediction of Fraser River flows and temperatures under a changed climate scenario for the 2020s, 2050s and 2080s; examination of open ocean mixed layer depth (where salmon generally spend up to two years of their lives); monitoring changes in zooplankton (critical to support the salmon food chain); and, development of a bioenergetic model of salmon growth and distribution in the northeast Pacific.

Project results indicate a number of likely significant trends affecting salmon under a changing climate: (i) further shallowing of the mixed layer depth resulting from predicted global warming, and concurrent decreases in salinity; (ii) peak flows in the Fraser River are likely to decline, and occur earlier in time; and, (iii) river temperatures, in time frames critical to salmon spawning, are predicted to increase thereby having adverse effects on the viability of certain stocks, particularly those migrating in early summer. It was noted that by the 2080s, every second year would be worse (for the fish) than the worst year in the historical record. **It is recommended that the project be carried out again with simulations from other GCM's and emission scenarios, when they become available.**

S00-15-01 Increased Flood Risk in the Bay of Fundy in Scenarios for Climate Change. This project, funded for one year, used a finite element ocean model, with relevant data sets and sea level change scenario, to examine a number of factors that relate to flood risks from increasing water levels in the Bay of Fundy. These were: land subsidence due to geological effects, sea level rise under climate change, and the changing resonance frequency of the Bay with increasing water depth.

Study results indicate a sea-level rise of 0.5 metres at the head of Bay of Fundy over the next 50 years, and of the order of 1 metre by the end of the century. These would have significant impacts on coastal communities in the Bay of Fundy and Gulf of Maine. When combined with different processes, such as storm surges or melting of polar ice caps, effects could be catastrophic. **It is recommended that future work include model**

improvements using high resolution topography, incorporation of storm surge and wave interaction into the model, and development of flood risk maps for present day and future climate change scenarios.

S00-15-10 Development of Climate Change Scenarios for the Agricultural Sector. This project, initially funded for only a few months, has already been approved for continued support under the renewed CCAF. The project goals are to develop gridded daily climate data (0.5 degree) of temperature, precipitation and radiation for a historical baseline period (1961-1990) and for future scenarios (2040-2069 period) for the major agricultural areas of Canada. This is to meet the needs of modellers who wish to assess climatic impact on agricultural aspects such as crop growth, soil moisture, nutrients, GHG balance, erosion, leaching, etc. Many such models integrate over the growing season or annual cycle using daily time steps. Several interpolation procedures will be compared to generate the historical gridded data. To date, interpolated surfaces of daily temperature and precipitation have been constructed using thin plate smoothing splines. This procedure produced daily temperatures mostly within an error of ± 2°C, but also some large outliers in excess of ± 6°C. Results for precipitation were even more variable. Other approaches to be utilized are inverse distance weighting and weather generator techniques. An historical gridded database of daily climate will be constructed based on the most appropriate method. Future climate scenarios of daily data for the same variables as the historical data will be generated for the 2040-2069 period based on two or more GCM models using weather generator and statistical downscaling methods. For reasons of ensuring credible temperature and precipitation fields, **it is recommended that the project continue to maintain close relations with the CCIS and the climatic research unit of MSC.** It is intended that some of the generated data would eventually be made available through the CCIS web site. In the future**, it is recommended that this project benefit from an eventual high resolution reanalysis of historical data.**

Discussion of Related Ongoing Issues

CCAF has been extended for an additional three years, with a climate Science, Impacts and Adaptation (SIA) component. The SIA has elements related modelling, processes and scenarios. The scenarios theme will allow for continuing support to the CCIS facility, extend a few of the earlier funded CCAF scenarios projects, and allow for the initiation of a few new projects.

There is, and will continue to be, uncertainty in the simulated future climate and its regional and local impacts, and it cannot be expected that research in these fields will come to an end. Senior managers have already recognized that global circulation modelling (GCM) is a basic responsibility of the government, as is weather forecasting. A permanent organisation has been set up (the Canadian Centre for Climate Modelling and Analysis, CCCma) to simulate the future climate on an operational basis, including the necessary research. This is a very successful enterprise, but its global models operate, of necessity, at a resolution that limits the amount of detail available on the scales required for regional and sectoral climate impact assessments.

To fill the gap, regional climate modelling (RCM) was developed initially as a university-based research program, but has now reached the stage where users need it to become an ongoing activity. There is a very high interest from the climate assessment community for the high resolution data of the CRCM. However, a major problem remains in that there is currently no organisation with the base funding and the mandate to provide high resolution simulation data on an operational basis. A UQAM partnership arrangement with CFCAS and the Ouranos consortium appears to secure this function at UQAM for the 2001-04 period. **It is recommended to expand the mandate and funding of the CCCma to include RCM operations, while at the same time ensure the continuation of university-based RCM research.** In this way, RCM outputs could be developed for more of the time periods and emissions scenarios that are recommended by the IPCC.

There is however a problem with the recommended IPCC climate simulation periods, as they relate to RCM's. First, since the current CRCM is much more costly (an order of magnitude higher) to run than GCM's, it is not possible to make runs for **all** the periods/scenarios recommended. Secondly, whereas the GCM outputs can, in principle provide continuous time series over very long periods, this is not realistic for RCMs. Thus, **it is recommended that the IPCC be asked to provide guidance as to which subset of the gas emission scenarios and time periods recommended for GCM's should be selected for RCM simulations**. Also, **it is recommended that more research be directed at methods to generate higher resolution simulation results without requiring the running of complete RCMs in every instance; e.g. linearisations, correlations, interpolations, statistical downscaling, or more complex dynamical adjustments based on a limited set of GCM/RCM simulations.**

For the purposes of several impact assessments, even the 45 km resolution of the Canadian RCM is insufficient to represent the scale and the natural variables of the phenomena or processes studied, e.g. hydrology, agriculture, forestry, coastal phenomena, urban effects, etc. Climatic scenarios downscaled or interpolated from the GCM/RCM simulations are required. To meet this need, CCAF funding has been very successful in establishing the Canadian Climate Impact Scenario (CCIS) group, to carry out research in scenario development and provide, through its web site, a few high resolution scenarios to be used by a number of users. As manifestations of climate change are making themselves more and more likely or evident, the community of impact assessment researchers is growing rapidly, and demanding ever more services from the CCIS. The CCAF has therefore seen it fit to extend its funding for this group for another three years. However, **it is recommended that permanent funding for this activity be placed high on the list of priorities addressed to senior EC management.** Also, **it is recommended that specific impact assessment research continue to be funded on a short term basis by special programs such as the CCAF, since it does not fit well within the regular mandates of government agencies nor of granting agencies such as NSERC. Finally, CCIS should continue to keep abreast of advances in such areas as downscaling techniques, weather typing, weather generators, etc., and provide advice on best, cost effective, practices to the Canadian research community.**

A reason for hesitating to take actions in relation to climate change, that is often cited by decision makers, is uncertainty in the scientific assessments of the magnitude and timing of the impacts of climate change. Uncertainty arises at each step in the scientific analysis, and it is not possible to eliminate it. Decision makers can be assisted if the sources of uncertainty are elucidated, even if not eliminated. To facilitate a fuller exploration of the uncertainty associated with climate impact assessments the IPCC has developed a set of 6 illustrative scenarios, complete with population and income data and guidelines on how to use them. **It is recommended that these IPCC scenarios, which are designed to span the range of uncertainty in climate prediction, be utilised as a tool to bracket error bars in scenarios used for climate impact assessments in Canada.**

Another use of CCAF funding that has been very successful and appreciated by the community is workshops. Workshops are a particularly effective means of starting new fields of climate change research by offering opportunity to receive guidance on the IPCC guidelines and to exchange techniques and early results before formal publications appear. Training of newcomers is also an effective way of bringing them rapidly into the main stream. **It is recommended that the CCAF continue to support these activities in the next round of funding. In particular, a major workshop should be held near the end of the next CCAF funding cycle, to summarize the progress achieved on the question of the generation and use of impact scenarios and plan for the future.**

Continuation of CCAF Projects

A number of projects described above need to be completed or extended through MSc/PhD theses, with or without additional funding; this has been noted under each project description.

Four projects have developed or are developing higher temporal and/or spatial resolution gridded data sets, suitable for regional climate modelling, process modelling and impact analysis, based on the past climatology (and the future climate simulations from the GCM/RCM), namely the Gulf of St-Lawrence and Hudson Bay Ocean Model (S99-15-01), Scenarios for Forest Ecosystems (S00-15-03), and Scenarios for the Agriculture Sector (S00-15-10). The fourth project is the RCM itself (S00-15-06). These projects, and doubtless many others, would benefit from a high resolution re-analysis of 3-dimensional archived data using a high quality dynamical analysis/forecasting model. Several of the scientists present at the workshop indicated confidence in the GEM results, and indicated they would like to use a Canadian re-analysis generated by GEM. Such analyses would considerably reduce the spatial and temporal interpolation errors and ensure full consistency between the weather variables in the past climate. For many applications, the structure functions found in the analysed data could be utilized to add the required high resolution to the various climate simulations of the coarser GCM/RCM models. In this way, more realistic (less uncertain) scenarios could be developed for climate impact assessment. **It is recommended that Environment Canada/MSC examine the possibility of obtaining a high quality high-resolution re-analysis**

suitable for Canadian climate change scenarios, through purchase from the European Centre for Medium Range Weather Forecasts or in-house integration, and that CCAF consider providing funding for that undertaking.

Finally, there are several other areas of research that could not be funded in the first round of CCAF funding and which should be reconsidered in the second round. In particular, the energy, tourism and health sectors and the northern and coastal regions should be the topics of future studies.

Communications

To help avoid duplication and false starts, it is important to communicate research progress rapidly and effectively within the community, as well as to convey progress to decision makers and the public. The need for workshops and training were noted continually throughout the Workshop. University short or regular courses (e.g. a course given at Laval U.) are a good training method. Scientific society meetings, such as CMOS, would also be good occasions for scenarios experts to inform and involve a greater number of scientists in climate change vulnerability, impact and adaptation research. Some specific ideas include:

- while a full suite of 3-d ocean data is now available on the web for all of the CCCma runs, the time-resolution is not as fine as some people would like. Results from the simulations are archived in greater detail, and it is generally possible to extract more fields, if the demand can be justified. While CCCma encourages individual users to communicate their unique needs directly to them, **in the case of ocean data, which could be used by several people, it is recommended that CCCma consult with the users to determine what more should be offered on the web.**

- **occasional authoritative assessments on specific topics such as scenarios research should be released by scientific bodies** (such as the Canadian Meteorological and Oceanographic Society). This is not meant to duplicate international assessments, but rather to validate international scientific consensus within a Canadian context and highlight unique circumstances important to Canada.

- **carefully validated presentations and newsletter articles of sectoral or regional climate change assessment studies, using outputs of scenarios research, should be offered to business or other officials of the sector or region. A senior level presentation on climate change adaptation should be proposed as a topic for a "Bacon and Eggheads" breakfast meeting of the Partnership Group on Science and Engineering (PAGSE) with federal members of Parliament**.

In summary, in order to assist managers at all levels in reaching appropriate mitigation or adaptation decisions, it is essential to reach them in different ways, but always with carefully reviewed and substantiated analyses.

Data Policies

The provision of observed climate data to users is currently hindered by the cost recovery policies of the MSC. However, data that has been processed for research, such the data sets provided by project S00-15-11, can be provided free of charge. Currently monthly averaged data are available from the web to users after registering on-line. Gridded (50 x 50 km) monthly, seasonal and annual time series are available unofficially on request. Daily time-series are also available on request. **It is recommended that MSC be as forthcoming as possible in providing the research community with free access to data sets, including model outputs, so as to ensure climate scenario and impacts research is continued in an unfettered manner.**

During the discussion the need for adjusted station data was questioned; that is, s**ome users would prefer to use the raw data in their studies.** A related concern of the Evaluation Team has to do with **the relatively small number of stations included in the adjusted data set compared to the total number of stations in the archives, which will limit the number of applications**. Scenarios work requires data from long term stations of consistently high quality so that trends and other changes can be evaluated reliably.

CCAF Process Procedures

There is essentially unanimous agreement that the CCAF procedures are simple, efficient and fair. The modest requirements for reporting were praised by a few, but that did not prevent several reports from arriving at the last moment, or even after the deadline! The only complaint was that funding was approved only in the last year for several projects, making it almost impossible to complete the objectives in time. Several participants commented on the friendliness and ease of access of secretariat personnel.

Final Thought

The overall success of the suite of projects funded under the climate scenarios theme is very impressive, given the very short time available. Valuable foresights on sector specific future climate change scenarios have been provided to the impacts community. Additionally the community has received timely and valuable advice from experts via a "service centre"; e.g. the Canadian Climate Impacts Scenarios (CCIS) project. The success of these projects, in no small measure, facilitated recognition of the need to continue the CCAF into a second phase, with particular regard for targeted resources related to climate change scenario research.