



# Adapting to Climate Change

## Canada's First National

### Engineering

### Vulnerability Assessment

of

### Public Infrastructure



APRIL 2008



Appendix E  
Ouranos Climate Change  
Summary Report



Canada



## Appendix E

### OURANOS Climate Change Summary Report

## Production of Climate Scenarios for Pilot Project and Case Studies

The protocol developed for assessing the vulnerability of infrastructure requires data on a variety of climatic elements that are used as input towards evaluating the degree of exposure of the infrastructure to climate events or conditions. Estimates of these variables enable quantitative assessments of a given infrastructure's exposure and help identify which changes in climatic conditions will have the most impact on its vulnerability.

It was deemed essential, in order to provide coherent and comparable results for all of the case studies, that the vulnerability analyses be based on plausible and equi-probable scenarios of climate change for the various regions of the country where the studies were being conducted. OURANOS was mandated to provide this data.

OURANOS is a research and development consortium specialized in climate change. The multi-disciplinary and multi-institutional organization's mission is to acquire and develop knowledge on regional-scale climate change as well as socio-economic and environmental impacts and vulnerabilities. Its mission also includes transferring knowledge and advising users and decision-makers to identify, promote, implement and evaluate local and regional adaptation strategies.

This document describes the methodology used to produce the climate scenarios and discusses the limitations and elements to consider when interpreting the data. Recommendations concerning the use of climate scenarios for future assessments of this nature are also proposed in conclusion.

### *Methodology*

Impacts and adaptation projects should be based on projections of multiple climatic simulations in order to ensure that uncertainty of future climate projections is fully explored and incorporated in the decision-making process. Furthermore, for projects at regional or local scales, such as in the PIEVC case studies, downscaling of coarse resolution Global Circulation Model (GCM) output is desirable in order to capture local characteristics that can affect climate conditions (topography, large bodies of water, etc.).

Regional climate modelling employing the dynamical downscaling approach is one area of expertise covered by the OURANOS consortium and its research partners. OURANOS has contributed to the development of the Canadian Regional Climate Model (CRCM; Caya and Laprise, 1999), which, like other regional climate models (RCMs), uses principles of conservation on energy, mass and movement to generate temporal series of *physically coherent climatic variables*. Developed using the same physical principles as GCMs, RCMs concentrate on a portion of the globe and allow production of simulations at higher spatial resolution (approximately 45km for the CRCM compared to the several hundred km seen with typical GCMs).

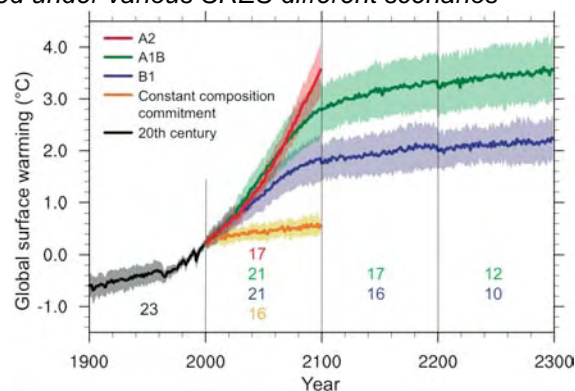
Dynamical downscaling can have a particular advantage in simulating meso-scale weather events when compared with global models. As such, extreme events (particularly precipitation events) are typically better reproduced by regional modelling efforts. Plummer *et al.* (2006) showed that general observed patterns of precipitation and

temperature are relatively well reproduced over North America by the CRCM (version 3.7.1). Regional comparison of CRCM precipitation output (again version 3.7.1) and corresponding intensity-duration-frequency curves by Mailhot *et al.* (2007) showed favourable results versus observed values for southern Quebec. Mailhot *et al.* also state that there is good indication that CRCM results are statistically consistent with observations in terms of extreme rainfall estimates.

In general the majority of CRCM simulations produced by OURANOS for impacts and adaptation purposes focus on the future period of 2041-2070 (termed horizon 2050). However, due to increasing demand for climatic scenarios for different future periods a small number of continuous simulations have been produced for the period 1961-2100. At least two of these simulations were selected for use in each of the case studies. Most simulations were produced using the CRCM, version 4.1.1 (Music and Caya, 2007; Brochu and Laprise, 2007). This selection was based on the advantages of having increased spatial resolution (compared to GCMs) and the availability of continuous future daily series for the period 1961-2100 (the future horizons of interest in the pilot study being horizons 2020, 2050 and 2080). The choice was also due to the time constraints imposed for completion of the projects.

The simulations (which differed slightly for the case studies because of data availability considerations) were carried out for a domain centred over Québec and covering an area of approximately 5,050 km by 4,000 km with a horizontal grid-size mesh of 45 km (true at 60 degrees north latitude) for the period 1961-2100. The simulations were driven at their boundaries by atmospheric fields taken from simulation output of the 4<sup>th</sup> and 5<sup>th</sup> members of the third generation coupled Canadian Global Climate Model (CGCM3). Both global and regional simulations were performed using the IPCC SRES A2 greenhouse gas (GHG) and aerosol projected evolution<sup>1</sup>. Figure 1 shows the simulated mean global temperature evolution according to the multiple GCM output grouped under various SRES different scenarios. It is interesting to note that the emissions scenarios diverge very little before approximately 2050.

Figure 1 Mean global temperature evolution according to the multiple GCM output grouped under various SRES different scenarios



The choice to use given runs of the Canadian Global Climate Model (CGCM3) for the Canadian Regional Climate Model (CRCM) runs was based on temporal resolution considerations as the CGCM3 runs were archived specifically for OURANOS with a 6-hour time-step, as opposed to 12-hour time-steps for runs 1 to 3 of the same model.

RCM results are not necessarily "biased" by the GCM used. Despite an obviously direct connection between the driving GCM and the RCM results, there is still a fair amount of control exerted by the RCM because it has a far more detailed topography than the GCM. The RCM is driven at its boundaries by GCM upper atmospheric conditions (pressure, convection, etc.) but ***is not dependent*** on the GCM surface fields of surface temperature, precipitation, etc. These are generated solely by the RCM.

Climate indices for the case studies were calculated for each climate station and each RCM grid cell individually. A regional value for each index was then determined by taking the average of all stations (grid points) within each study area. These regional values appear in the "results" section of each report.

Changes (or deltas) in indices were calculated as either the difference or ratio between simulated future conditions and simulated present day conditions.

The following table summarizes the climate indices that were examined in each case study and the number of weather stations that were included to calculate the observed data.

<i>location</i>	<i>infrastructure</i>	<i>climate indices</i>					
		<i>TMAX</i>	<i>TMIN</i>	<i>RAIN</i>	<i>SNOWFALL</i>	<i>SNOW ON GROUND</i>	<i>WIND</i>
Portage-la-Prairie (MB)	water resources	13	13	12	12	3	10
Metro Vancouver (BC)	wastewater and stormwater	4	4	9	9	n/a	n/a
Sudbury (ON)	roads	2	2	2	2	1	1
Placentia (NFLD)	water resources (coastal)	n/a	n/a	n/a	n/a	n/a	1
Edmonton (AB)	roads (bridge)	9	9	8		5	
Ottawa (ON)	buildings						
Inuvik (TNO)	buildings	no climate scenarios requested					

The choice and priority of climate indices was made in consultation with each client in terms of specific project needs as well as in terms of the limitations of the climate model simulations. Calculated indices were chosen from those having been known and used in the climate literature in the past. A review of the literature for climate indices for which scenario results were not as reliable was also provided for in each report.

The climate elements examined were defined as follows:

***Temperature indices***

- a. Monthly average maximum temperature (Monthly AVG TMAX):  
- Average daily maximum temperature for a given month over the time period
- b. Monthly average minimum temperature (Monthly AVG TMIN):  
- Average daily minimum temperature for a given month over the time period
- c. Average annual daily maximum temperature (annual\_max):

$$annual\_max = \left( \sum_{i=1}^I (t \max 365i) \right) / I$$

Calculated as the sum of  $t \max 365i$  for years  $i$  through  $I$  divided by the number of years. Where  $t \max 365i$  is the highest daily temperature for a given year  $i$

- d. Average annual daily minimum temperature (annual\_min):

$$annual\_min = \left( \sum_{i=1}^I (t \min 365i) \right) / I$$

Calculated as the sum of  $t \min 365i$  for years  $i$  through  $I$  divided by the number of years. Where  $t \min 365i$  is the lowest daily temperature for a given year  $i$

### **Rain indices**

*\*Rain indices refer in all cases to precipitation in **liquid form***

- a. Rainfall frequency 6 hour (6h\_frequency)  
- cutoff values of 5, 10 and 20 mm  
- frequency of events that are greater than cutoff(s)
- b. Rainfall frequency 1 day (1day\_frequency)  
- cutoff values of 5, 10 and 20 mm  
- frequency of events that are greater than cutoff(s)
- c. Yearly Max. Rainfall (annual\_max\_rain):  
- average maximum yearly rainfall event for 1, 2 and 5-day periods

$$annual\_max\_rain = \left( \sum_{i=1}^I (rain365ix) \right) / I$$

Calculated as the sum of  $rain365ix$  for years  $i$  through  $I$  divided by the number of years. Where  $rain365ix$  is the highest rainfall amount for a given year  $i$  summed over period of  $x$  days.

- d. Average total annual / seasonal rainfall (Avg\_total\_rain)  
- average sum of liquid precipitation for the year and 4 seasons (DJF, MAM, JJA, SON)

- e. Simple Daily Intensity Index (SDII)  
- Mean rainfall amount per wet day (wet day > 1mm)
- f. Drought : Average maximum annual dryspell length (Avg\_max\_dryspell)  
- average yearly maximum number of consecutive 'no rain days' (< 1mm) for the season April 1 – Oct. 31<sup>st</sup>.

$$Avg\_MAX\_dryspell = \left( \sum_{i=1}^I (dSPELLi) \right) / I$$

Calculated as the sum of  $dSPELLi$  for years  $i$  through  $I$  divided by the number of years. Where  $dSPELLi$  is the maximum dryspell length for a given year  $i$ .

- g. Average maximum annual wetspell length (Avg\_max\_wetspell)  
- Average yearly maximum number of consecutive 'rain days' (> 1 mm) for the season April 1 – Oct. 31<sup>st</sup>.

$$Avg\_MAX\_wetspell = \left( \sum_{i=1}^I (wSPELLi) \right) / I$$

Calculated as the sum of  $wSPELLi$  for years  $i$  through  $I$  divided by the number of years. Where  $wSPELLi$  is the maximum wetspell length for a given year  $i$ .

### **Snow indices**

\*Snow index values in mm indicate values of Snow Water Equivalent (SWE) in all cases.

\*\*Observed snowfall values from EC stations had units of cm of snow and were converted to SWE using an assumed conversion ratio of 10:1 (i.e. 10 mm of fresh snow = 1mm SWE)

- a. Snowfall frequency 1 day (1-day\_frequency)  
- cutoff values of 5, 10 and 20 mm  
- frequency of events that are greater than cutoff(s)
- b. Yearly maximum snowfall (annual\_max\_snow):  
- average maximum yearly snowfall event for 1, 2 and 5-day periods

$$annual\_max\_snow = \left( \sum_{i=1}^I (snow365ix) \right) / I$$

Calculated as the sum of  $snow365ix$  for years  $i$  through  $I$  divided by the number of years. Where  $snow365ix$  is the highest snowfall amount for a given year  $i$  summed over period of  $x$  days.

- c. Average total annual / seasonal snowfall (Avg\_total)
  - average sum of solid precipitation for the year and 4 seasons (DJF, MAM, JJA, SON)
- d. Simple Daily Intensity Index (SDII)
  - mean snowfall amount per wet day (wet day > 1mm)
- e. Rain on snow events
  - occurrence defined as presence liquid precipitation > 1mm combined with presence of snow on ground (> 0)
  - cutoff values of 1, 5 and 10 mm
  - frequency of events that are greater than cutoff(s) over 1-day period

### **Wind indices**

\*Wind index values in m/s indicate values of average wind speed over a 6h period.

\*\*NB – A 6hour timestep was used as this is the minimum timestep available for analysis for the CRCM4 data.

- a. Monthly average 6h windspeed (Monthly AVG WIND6h):
  - average 6h windspeed for a given month over the time period
- b. Yearly maximum 6hour Wind (Avg annual MAX6h):
  - average maximum yearly 6h Wind

$$Avg\_annual\_MAX6h = \left( \sum_{i=1}^I (wind365i) \right) / I$$

Calculated as the sum of  $wind365i$  for years  $i$  through  $I$  divided by the number of years. Where  $wind365i$  is the highest 6h mean windspeed for a given year  $i$ .

### **Frost indices**

- a. Frost Season (fr\_seas\_dys)
  - average annual maximum length in days that the 30-day moving average of daily average temperature remains consecutively below 0°C
- b. Freeze-Thaw cycles (frz\_thw\_freq)
  - frequency of days where  $T_{max} > 0^{\circ}C$  and  $T_{min} < 0^{\circ}C$

### **Limitations**

The production of climate scenarios for the PIEVC case studies was limited to the use of only 2 simulations. Furthermore, these simulations were produced by the same regional climate model (CRCM 4.2.0), driven by two runs of the same GCM (CGCM3) and the same GHG emissions scenario (SRES A2). In short, the predicted changes cover only a small portion of the spectrum or envelope of changes that would be produced via the

use of multiple SRES scenarios and multiple driving models (or even multiple RCMs). Use of only two simulations is sufficient for sensitivity analyses but lacks the robustness provided by the use of a large ensemble of simulations, recommended for decision-making or policy planning.

A large number of RCM runs would help to gain a better understanding of the uncertainties associated with the RCM runs and a more reliable idea of the range of possible change. At present, only two such runs are available with the CRCM and, as a consequence, this range is not covered as well.

As well, despite the fact that RCMs perform better than GCMs at representing more localized or meso-scale weather events, much research is still needed to project reliable results for changes in extreme events.

For these reasons, it is recommended that any decision or policy making activities be based on an expanded version of the climate scenario reports for the case studies.

### *Recommendations*

1) Future vulnerability assessments using the PIEVC protocol should provide for more time to produce climate scenarios that would be based on two approaches.

The first approach would follow the methodology used in this report with as many runs possible of the regional climate model. This allows for a better representation of the local/regional characteristics (topography, land cover, etc.) and finer spatial and temporal resolution than the global circulation models, providing results more applicable for such impacts and adaptation assessments.

The second approach would be based on a wide array of GCM outputs that scan the range of possible outcomes. Although the GCM's lower resolution does not well reproduce more localized phenomena such as precipitation episodes or other extreme events, it does help illustrate the uncertainties or range of possibilities associated with different scenarios of green-house gas emissions.

At present, large ensemble analyses using strictly RCM output are not possible over North America. However, OURANOS continues to produce RCM simulations, and is also actively involved in the North American Regional Climate Change Assessment Program (NARCCAP <http://www.narccap.ucar.edu/>), an international program that will serve the high resolution climate scenario needs of the United States, Canada, and northern Mexico, using regional climate model, coupled global climate model, and time-slice experiments. The needs of the PIEVC (i.e. simulations with a fine spatial resolution, and inclusion of a number of extreme indices) would be best addressed using an ensemble of multiple RCM driven by multiple pilot GCMs such as will be produced with NARCCAP project. This approach would allow a large inclusion of possible futures and thus better cover the envelope of uncertainty. Further research continues to be needed in climate modelling and climate scenarios in order to provide reliable data for climate change vulnerability and impacts assessments.

2) It is also recommended to work more closely with climate specialists. This helps to identify climate scenario needs more accurately for such impacts and vulnerability assessments. It also helps to understand the climate scenarios better, including the uncertainties associated with them, as well as how to interpret the data.

3) In cases where weather events are difficult to model and predict in future climate conditions (for example ice storms), it is recommended to use “what if” scenarios to determine vulnerability thresholds and increase “safety” margins when designing and building infrastructure.

4) As well, it is recommended to continue to collect weather data and monitor the infrastructure closely to keep improving on the vulnerability assessments.

5) Finally, it is important to pursue research in the field of climate science, namely concerning climate variability and extreme events. Work towards improving the resolution of the climate models could help improve projections for extreme weather events. As well, continued research in the field of climate change, which includes regional climatology as well as impacts and adaptation to climate change, would help in improving our understanding of the potential vulnerabilities to climate change and develop effective adaptation strategies that help mitigate the anticipated impacts.

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