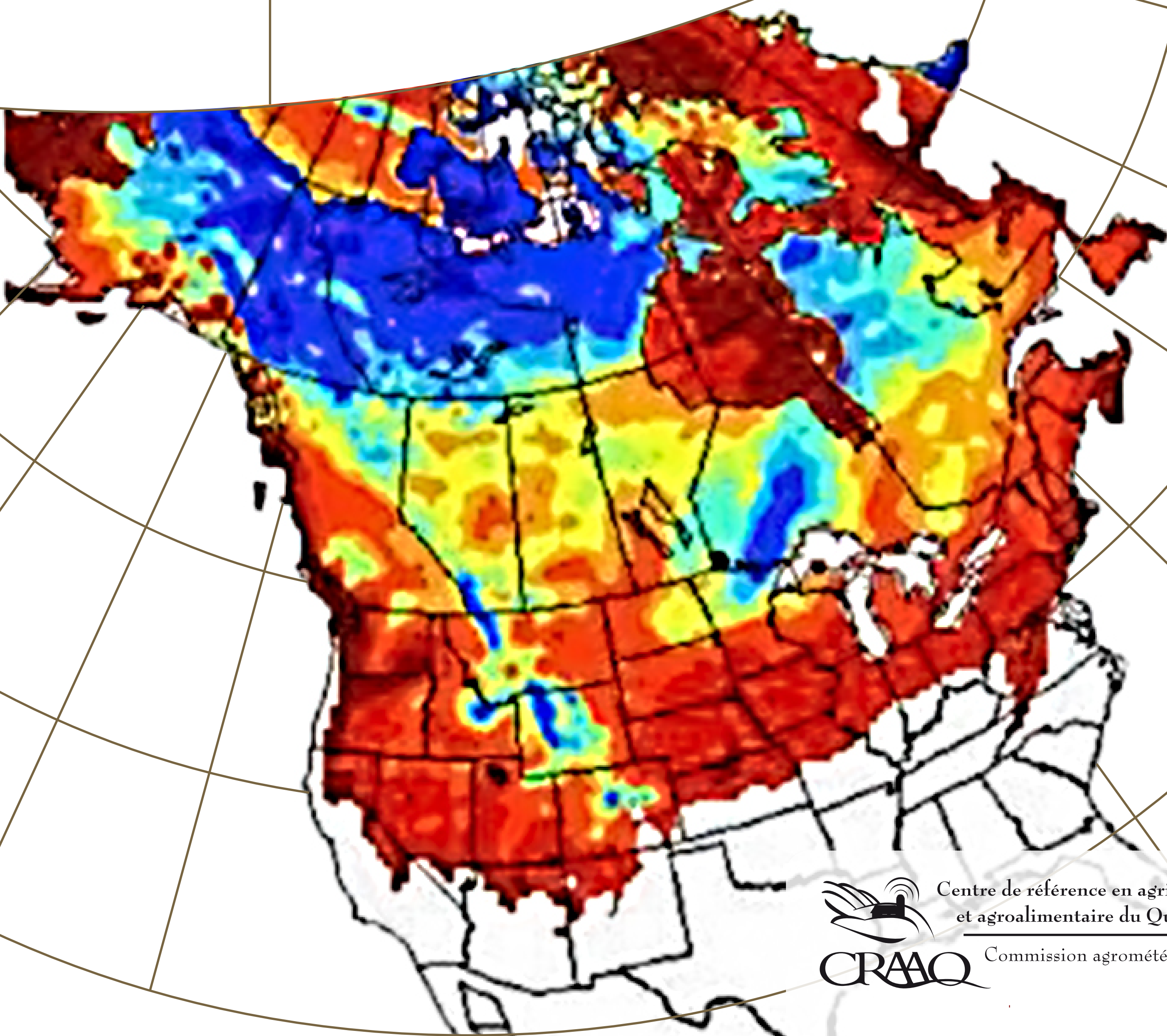
Interpretation of Climate Change Scenarios

in order to Improve Agricultural Risk Management

Marie-Pier Lepage, M.Sc.
Line Bourdages, M.Sc.
Gaétan Bourgeois, Ph.D.



Centre de référence en agriculture et agroalimentaire du Québec
CRAAQ
Commission agrométéorologie

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The original version of this document was published with funding provided by Ouranos in partnership with Natural Resources Canada.

Thanks to Agriculture and Agri-Food Canada, CRAAQ and Ouranos for the publication of the English version.

FOR MORE INFORMATION

Centre de référence en agriculture et agroalimentaire du Québec (CRAAQ)
Édifice Delta 1
2875, boulevard Laurier, 9e étage
Québec (Québec) G1V 2M2
Telephone: 418 523-5411
Fax: 418 644-5944
Email: client@craaq.qc.ca
Internet site: www.craaq.qc.ca

Publication nº PAGR0107
ISBN 978-2-7649-0313-1
Legal Deposit
Library and Archives Canada, 2012
Bibliothèque et Archives nationales du Québec, 2012

WRITING

Marie-Pier Lepage, M.Sc., Biologist, Saint-Jean-sur-Richelieu, QC, Canada

Line Bourdages, M.Sc., Climate Scenarios Specialist, Ouranos, Montréal, QC, Canada

Gaétan Bourgeois, Ph.D., Bioclimatology and Modelling, Agriculture and Agri-Food Canada, Saint-Jean-sur-Richelieu, QC, Canada

COLLABORATION AND REVISION

Diane Chaumont, M.Sc., Group Leader, Climate Scenarios, Ouranos, Montréal, QC, Canada

Patrice Mullier, M.Sc., Research Agent, La Financière agricole du Québec, Saint-Romuald, QC, Canada

Dominique Plouffe, B.Sc., Research Assistant, Agriculture and Agri-Food Canada, Saint-Jean-sur-Richelieu, QC, Canada

Myriam Renauld, B.Sc., Agronomist and Climate Change Analyst, ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, Québec, QC, Canada

COORDINATION

Lyne Lauzon, Biologist and Publication Coordinator, CRAAQ, Québec, QC, Canada

Denise Bachand, M.Sc., Project Supervisor, CRAAQ, Québec, QC, Canada

EDITING

Danielle Jacques, M.Sc., Agronomist, CRAAQ, Québec, QC, Canada

GRAPHIC DESIGN AND LAYOUT

Nathalie Nadeau, Computer Graphics Technician, CRAAQ, Québec, QC, Canada

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INTRODUCTION

General declaration on climate change from the Intergovernmental Panel on Climate Change (IPCC)

Throughout its history, climate has undergone many natural changes (IPCC 2007b). Volcanic activity and variations in solar radiation are known natural causes of climate variations. In spite of that, it is very unlikely that the climate warming of the last century was of a natural origin. Increased human activity has a strong impact on the radiation balance in the atmosphere. Greenhouse gas emissions from various sources, both natural and industrial, contribute to changing the composition of the atmosphere, thereby affecting its interactions with the various types of radiation (solar, terrestrial, etc.). The effect of climate change is felt worldwide: increased atmosphere and ocean temperatures, massive snow and ice melt, and average sea level rise (IPCC 2007a). Many natural, physical and biological systems are already affected by these changes on a terrestrial and oceanic level.

Climate change in Quebec in the recent past

Several changes in the Quebec climate have been observed in the recent past (i.e., in the past 30 to 40 years). Overall, daily temperature increases of 0.2 to 0.4ºC per decade are observed in southern Quebec (Yagouti et al. 2008). This increase causes, among other things, a higher number of accumulated degree-days in a season and a shorter frost period. With regards to precipitation, an increase in the number of days of light rain has also been noted (Vincent and Mekis 2006). Snowfall amounts increased in northern Quebec and decreased in the south (Brown 2010). Regarding the frequency of extreme weather events, some of them (e.g. stifling heat waves) increased somewhat in number whereas other events (e.g. bitterly cold nights) decreased. It is difficult to determine whether or not these events are due to climate change or to other factors, although some studies lead one to believe that these events were caused by warming attributable to the greenhouse effect (IPCC 2007b).

The main objective of this technical document is to define some concepts related to climate change, in particular the interpretation and use of climate scenarios. Links will then be made with the agriculture sector to obtain an overall vision of the effects and risks associated with this issue.

CLIMATE CHANGE TERMINOLOGY

Greenhouse gases and aerosols

Greenhouse gases (GHG) are those gaseous constituents, both natural and anthropogenic (human), that by their very nature interact with terrestrial infrared radiation. These gases accumulate in the atmosphere and help to retain the planet's heat by absorbing the infrared radiation emitted by the Earth and re-emitting it in all directions. Atmospheric radiation attributable to the greenhouse effect is therefore added to the direct solar radiation to warm the Earth's surface. There are several types of GHGs, but the primary ones are water vapour (H_2O), light hydrocarbons such as carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone (O_3), fluorocarbons such as hydrofluorocarbons (HFCs) , and other inert gases such as sulfur hexafluoride (SF_6) (IPCC 2007a).

Aerosols are important factors to consider in the Earth's radiation balance. Also of natural or anthropogenic origin, they consist of very fine solid or liquid particles that are suspended in a gaseous environment. Their emission sources vary: volcanoes, sea spray, industrial combustion and dust, agricultural emissions, etc. They can have an impact on the climate in two ways: directly, by disseminating and absorbing rays, and indirectly, by serving as a central point for water vapour formation, thereby modifying cloud dynamics (IPCC 2007a).

Model, simulation, projection, forecast or climate scenario?

The terms model, simulation, projection, forecast and climate scenario are quite often used in climate change studies. The following descriptions, taken and adapted from the Fourth Assessment Report of the IPCC, present and differentiate each of these terms (IPCC 2007a).

Climate model and simulation

A climate model is a numerical representation of the climate system based on mathematical equations concerning fluid dynamics and the conservation of mass, energy, and quantity of movement. It can evoke the Earth's entire climate system, which includes the atmosphere, hydrosphere, cryosphere, the planet's surface, the biosphere and their interactions (IPCC 2007a). The result of the use of the climate model - the climate simulation - is a set of data representing a large quantity of variables such as surface and air temperature, humidity and wind. Simulations are produced on a given territory (the spatial domain) going from extended global coverage for global climate models to a more limited domain such as Quebec for regional climate models. The simulated period can represent both the past and the future.

Climate projection and forecasts

A climate projection represents the climate system response, as simulated by a climate model, to certain hypotheses postulated on the future evolution of aerosol and GHG emissions. Climate forecasts are the result of an attempt to produce an estimate on the actual future evolution of the climate.

Climate scenario

A climate scenario is considered a plausible representation of the future climate based on one or more climate projections. When the information is sent in the form of climate change with regard to a given reference period, this is called a climate change scenario. Scenarios are typically established to determine the potential consequences of climate change caused by humans (IPCC 2007a) and they constitute information that can be used in impact studies as input in a bioclimatic model. For example, in a future climate impact study on the phenology of an agricultural crop, one climate scenario may be used as input in the phenological model of this crop.

CLIMATE MODELLING

Global climate models (GCM)

Global Climate Models (GCM) are climate models that can simulate a response from the climate system to the variation in GHG concentrations. Their spatial resolution is generally between 250 and 600 km. GCMs have about 30 vertical levels that could be virtually represented by a set of cubes piled one on top of the other from the Earth's surface to the outer reaches of the atmosphere. This pile would hold the equations and features that are specific to each. These cubes react and have an impact on each other in such a way that they virtually recreate the dynamics of the climate system. There are several models from all over the world; some of these models are listed in Table 1.

Downscaling methods

GCM climate data downscaling methods are ranked under two major categories: dynamical and statistical. Dynamical downscaling consists in extracting high-resolution climate data from lower-resolution GCMs (CCCSNc). This technique, associated with Regional Climate Models (RCM), which are introduced in the next section, enables results to be obtained in the form of variables that are physically consistent in time and space, as well as among themselves. Statistical downscaling relates to the quantitative development of relations between large-scale and local variables. In other words, statistical relationships between climate variables are established and climate data are then adjusted. This method, although less costly, is used less than the preceding because it requires a large quantity of regional observations from the recent past (Beaumont et al. 2008) and does not necessarily yield physically consistent results.

Regional climate models (RCM)

Some studies require climate information on a finer scale than the information provided by the GCMs. In such cases, Regional Climate Models (RCM) can be used. RCMs are similar to GCMs in that they also include vertical levels but they generally have higher horizontal resolution, generally about 50 km (CCCSNb). Modelling at such a resolution is much more costly in terms of time and requires high-performance computer resources. Consequently, this type of model is used for simulating the climate in a more restricted spatial domain by using GCM data as boundary data. In this context, the GCM is called the pilot model because it places a restriction on the RCM simulation domain boundaries. The increased RCM resolution enables a better representation of some physical elements that are too small in scale for GCMs. For example, they could allow or improve the representation of geographic features such as topography and the presence of large bodies of water that could have an impact on the local climate, of some local weather phenomena such as convective precipitation (heavy precipitation lasting a short time over a small spatial extension) and heat islands. It is partly for these reasons that the scenarios obtained from RCMs are more realistic for representing climate change at the local level (CCCSNc).

TABLE 1. LIST AND COUNTRY OF ORIGIN OF SOME GLOBAL CLIMATE MODELS (GCM) AVAILABLE IN THE WORLD [TAKEN FROM THE WORLD CLIMATE RESEARCH PROGRAMME (WCRP) COUPLED MODEL INTERCOMPARISON PROJECT, PHASE 3 (CMIP3) MULTIMODEL DATASET]

Name of model	Country of origin
BCC-CM1	China
BCCR-BCM2.0	Norway
CCSM3	United States
CGCM3.1 (T47) and (T63)	Canada
CNRM-CM3	France
CSIRO-Mk3.0	Australia
ECHAM5/MP1-OM	Germany
ECHO-G	Great Britain and Korea
FGOALS-g1.0	China
GFDL-CM2.0; GFDL-CM2.1	United States
GISS-AOM; GISS-EH; GISS-ER	United States
INGV-SXG	Italy
INM-CM3.0	Russia
IPSL-CM4	France
MIROC3.2(medres); MIROC3.2(hires)	Japan
MR1-CGCM2.3.2	Japan
PCM	United States
UKMO-HadCM3; UKMO-HadGEM1	Great Britain

Source: Meehl et al. 2007

Aerosol and greenhouse gas emissions scenarios

Aerosol and GHG concentrations in the atmosphere have a direct impact on the planet's radiation balance. It is difficult to establish a consensus on their probable evolution in time, because this evolution depends on several factors such as the economy, human demographics, industry and technology. IPCC researchers therefore developed a set of aerosol and GHG emission scenarios by varying these different elements. These emission scenarios are known under the initials SRES (Special Report on Emissions Scenarios) (Nakićenović and Swart 2000) and fall under the four major categories listed in Figure 1.

The scenarios associated with the A1 family focus on rapid economic growth and technological development of energy systems. There is also a social and cultural convergence in various territories, which serves to decrease the differences between them. The A2 scenarios specifically represent economic growth focused on local self-sufficiency. The B1 scenarios lean towards an economy focused on equity and effective resource management. Their production activities are of less importance. Lastly, the B2 category focuses on local solutions and environmental protection. New technology does not develop as quickly in that family. Regarding the human population, the A1 and B1 families describe a rapid increase followed by a decrease; for the A2 and B2 families, the population increase is slower but consistent (IPCC 2000). The choice of an emissions scenario will therefore have an impact on the desired study results. Some GHG evolution studies mention that the most extreme scenarios (the A1 and A2 families) would be more likely than the more conservative scenarios (the B1 and B2 families) (Beaumont et al. 2008).

CLIMATE SCENARIOS

Impact studies require precise and often simplified information on the expected future climate. This section gives a brief description of the method and choices related to producing climate scenarios.

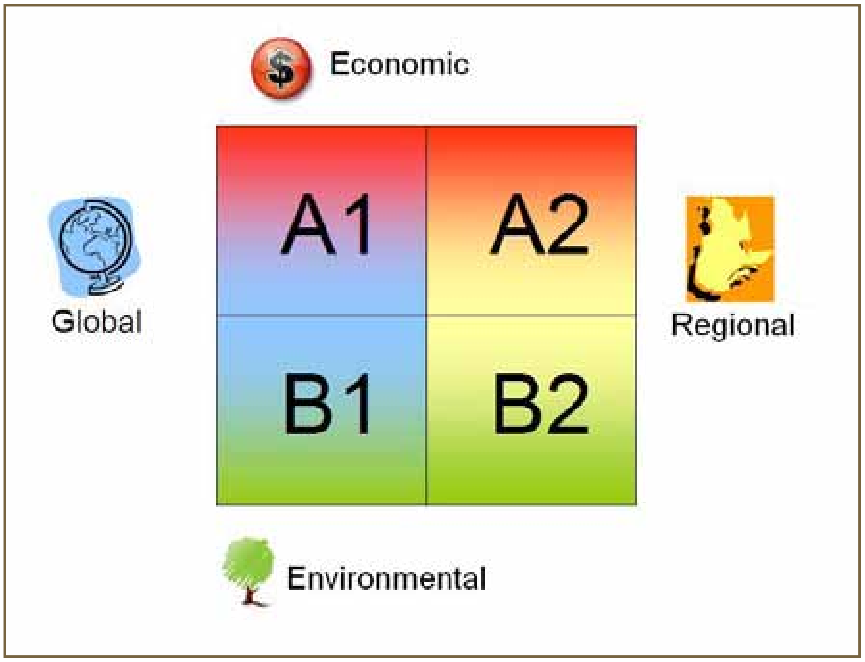

FIGURE 1. SCHEMATIC REPRESENTATION OF THE FOUR MAJOR AEROSOL AND GREENHOUSE GAS EMISSIONS SCENARIOS FROM SRES BASED ON THEIR ASSOCIATION WITH GLOBAL OR REGIONAL ECONOMIC OR ENVIRONMENTAL FACTORS

Adapted from Nakićenović and Swart 2000.

Choice of climate indices and of a climate scenario

In the development of a climate scenario, a set of variables can be selected based on the required climate indices such as precipitation intensity or the temperature of the territory and the period studied. For example, during a study on the impact of climate change on a set of crops in the Bas-Saint-Laurent region by 2050, simulated surface temperature and precipitation data, which have an impact on the crops in this region in particular, will be used. In a project studying projected precipitation change in a location where the landscape and geography are complex, such as the Canadian Rockies or the Maritime coastlines, use of RCMs will be required. For a study concerning a variable with a smooth spatial distribution, a variable such as the temperature in southern Quebec, GCMs can also be used to prepare the climate scenario.

Available information sources

As mentioned earlier, several climate models have been developed worldwide. GCMs and RCMs cover different spatial domains and go from one specific territory in the case of a RCM to the entire planet in the case of a GCM, and at variable resolutions. Each of these two categories of model has specific use restrictions as well as advantages and disadvantages that must be considered from the outset. According to the study objectives, a set of GCMs and/or RCMs can be selected. In addition, the simulations produced by these models depend on several factors such as aerosol and GHG emissions scenario and initial conditions. In the case of a RCM, simulations also depend on the GCM pilot data used as a constraint at the domain boundaries. Typically, GCM data are more accessible and cover a wider variety of SRES scenarios and of range of uncertainty than with RCMs, because many scientists develop models of this type worldwide and these models represent the entire planet. However, GCMs have a very coarse resolution (between 250 and 600 km) that does not include precise features on the sector; it might not be possible for some phenomena to be represented adequately.

RCM simulations are produced on a higher-resolution spatial grid. Figure 2 illustrates the change in the snow water equivalent, represented by a GCM with a course resolution of 350 km (left) and a RCM with a finer resolution of 45 km (right). In some areas (e.g., northern Quebec and the west-central United States), the regional particularities of the sector are not well represented by GCMs; this generates information that is not sufficiently precise.

A fast growing amount of simulations is available for producing climate scenarios and some choices have to be made. The most relevant elements to consider in choosing the simulations to be used to produce a scenario are availability of study variables, appropriate resolution to represent the studied phenomena and the coverage of the climate change uncertainty. This last point represents a crucial element in climate scenario production and is dealt with in the next section. In addition, some studies require simulations in which some specific processes are represented. For example, for a study of the ice melt in the Canadian Arctic, the selected simulations should give a proper representation of the cryosphere in the region concerned.

Climate change uncertainties

There are several sources of uncertainty in the climate modelling process, whether related to GCM or RCM imperfections, aerosol and GHG emissions scenarios or natural climate variability. GCMs are based on various mathematical equations and parameters that are chosen by developers to represent the physics of the terrestrial system. Each of these models has some uncertainties depending on the choices made and the limitations of the computer capacity.

As mentioned previously, emission scenarios represent a source of uncertainty. Figure 3 illustrates the degree of uncertainty in connection with the SRES. The A1F1, A1T and A1B scenarios come from the A1 family. They describe alternative directions of technological change: fossil intensive (A1F1), non-fossil energy sources (A1T) and a balance across all energy sources (A1B) (CCCSNa).

Natural climate variability is also a source of uncertainty. According to Murphy et al. 2009:

> **"Climate, at a global scale and even more at a local scale, can vary substantially from one period (for example, a decade or more) to the next, even in the absence of any human influences. (…) Natural internal variability will continue in future, and be superimposed on longer-term changes due to man's activities."**

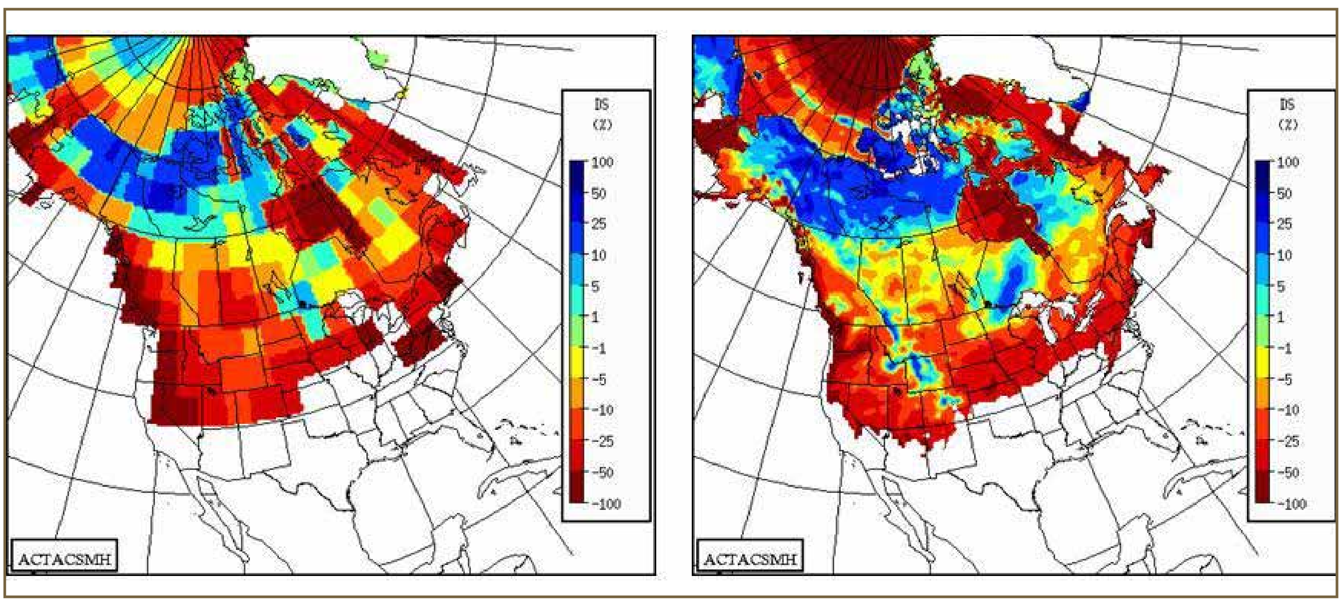

FIGURE 2. RELATIVE CHANGE (%) IN SNOW WATER EQUIVALENT (DECEMBER–FEBRUARY), 2041–2070 IN COMPARISON WITH THE RECENT PAST (1961–1990) FOR THE A2-SRES SCENARIO AT A RESOLUTION OF ABOUT 350 KM (LEFT), FROM THE SIMULATION OF THE THIRD-GENERATION CANADIAN GLOBAL CLIMATE MODEL (CGCM3), AND AT A RESOLUTION OF ABOUT 45 KM (RIGHT), FROM THE SIMULATION OF THE CANADIAN REGIONAL CLIMATE MODEL (CRCM)

Source: Brown and Mote 2009. ©American Meteorological Society. Used with permission.

This source of uncertainty is related to the chaotic nature of the climate system and is therefore irreducible.

Climate change uncertainty is crucial information related to climate scenarios. Contributions from various sources of uncertainty can be quantified by using an ensemble of climate simulations. For example, uncertainty about the future evolution of aerosol and GHG emissions is quantified by using several simulations that were forced by different SRES scenarios. The uncertainty related to natural climate variability can be determined by producing a set of climate simulations from the same model and SRES scenario and by slightly modifying the initial conditions. The simulations produced will represent a set of possible future climates, their differences being due exclusively to natural climate variability.

An example of uncertainty quantification

An example of using an ensemble of climate simulations is presented in Figure 4 (Ouranos 2010a). The figure shows the evolution of summer and winter temperature and precipitation anomalies in southern Quebec from 1990 to 2080 in comparison with the 1900–1969 average as projected by an ensemble of 130 GCM simulations. The ensemble median (solid line), the 25th and 75th percentiles (dotted lines) and the 5th and 95th percentiles (shaded area) describe the distribution of the ensemble and therefore quantify the projected climate change uncertainty. One observation is that despite the extent of the uncertainty on the significance of summer temperature changes in southern Quebec, all the simulations used project an increase in this variable. The ensemble median suggests no change in summer precipitation. Here,

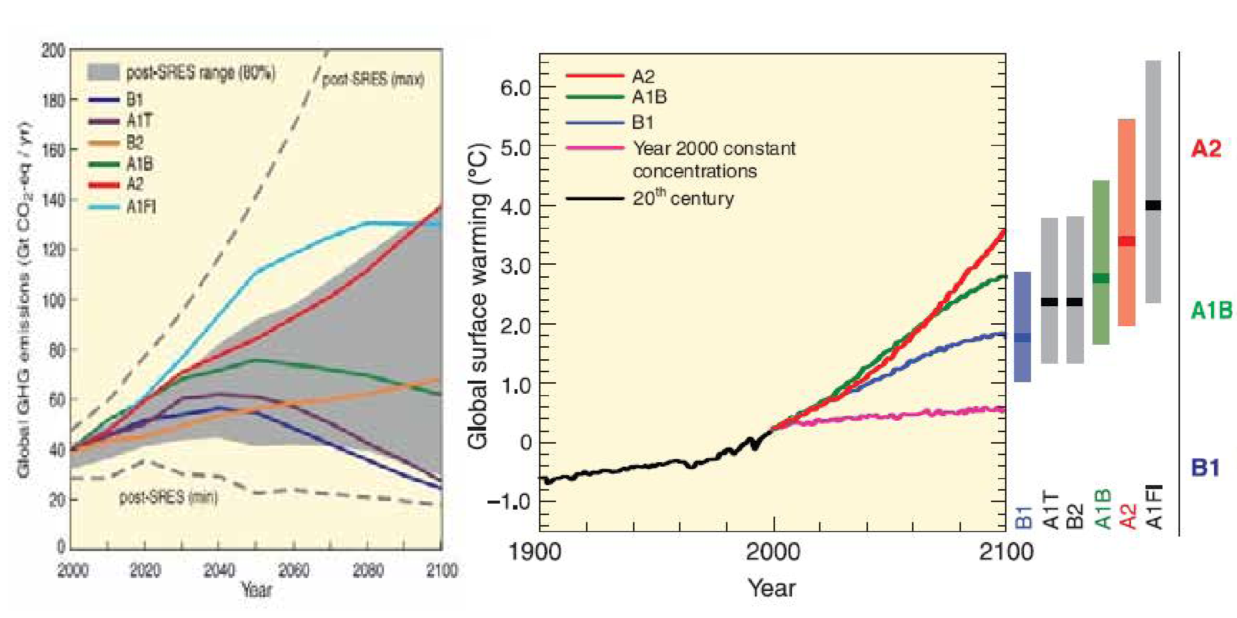

FIGURE 3. LEFT: GLOBAL GHG EMISSIONS BASED ON SIX ILLUSTRATIVE MARKER SCENARIOS AND THE 80TH PERCENTILE RANGE OF THE SCENARIOS PUBLISHED IN THE SRES (POST-SRES, SHADED AREA). RIGHT: GLOBAL AVERAGES OF SURFACE WARMING SHOWN AS CONTINUATIONS OF THE 20TH-CENTURY SIMULATIONS. THE VERTICAL BARS ON THE RIGHT INDICATE THE BEST ESTIMATE (DARKENED AREA) AND THE LIKELY RANGE ASSESSED FOR THE SIX SRES MARKER SCENARIOS AT 2090–2099. ALL TEMPERATURE DIFFERENCES ARE CALCULATED RELATIVE TO 1980–1999.

Source: GIEC 2007a, Figure RiD.5., p. 7

although the ensemble climate simulations sometimes differ with regard to the direction of the change (positive or negative), all change values projected by the ensemble are low. With the development of climate modelling knowledge, available future climate information will become clearer. However, climate change uncertainty is partly irreducible. It is therefore important to learn how to interpret the information related to this and to understand its implications.

EXPECTED CLIMATE CHANGE IN QUEBEC

According to the Ouranos, Consortium on Regional Climatology and Adaptation to Climate Change, temperatures are projected to rise in Quebec by 2050. There will be a greater warming in the winter than in the summer (Ouranos 2010b). Figure 5 shows estimated temperatures taken from 1961–1990 observations; it also shows estimations obtained for 2041–2070 based on an ensemble average of climate projections. During the winter, an average temperature increase of 2.5 to 3.8ºC is shown in southern Quebec and an increase of 4.5 to 6.5ºC is shown in northern Quebec. Conversely, in the summer, the expected increase is around 1.9 to 3.0ºC in the south and 1.6 to 2.8ºC in the north.

An increase in precipitation is also expected throughout Quebec (Figure 6). In the winter, the isohyets (imaginary lines connecting points of equal rainfall) are expected to move northwestward. This would cause greater snow cover in the north but lesser snow cover in the south. During the warm season, additional rainfall is projected in the north whereas in the south, there is no projected change. Changes in the intensity, frequency and magnitude of some weather events could also be felt throughout Quebec (IPCC 2007a).

POTENTIAL IMPACT ON THE QUEBEC AGRICULTURAL SECTOR

Several studies have been conducted on the potential impact of climate change on agricultural production. By and large, the results depend on the studied region, crops, the significance of extreme events, and changes in temperature, CO_2 concentration and precipitation.

The climate scenarios show that projected climate conditions could be favorable for some crops but not for others (Ouranos 2010b). A rise in temperatures in a given region can increase the agronomic

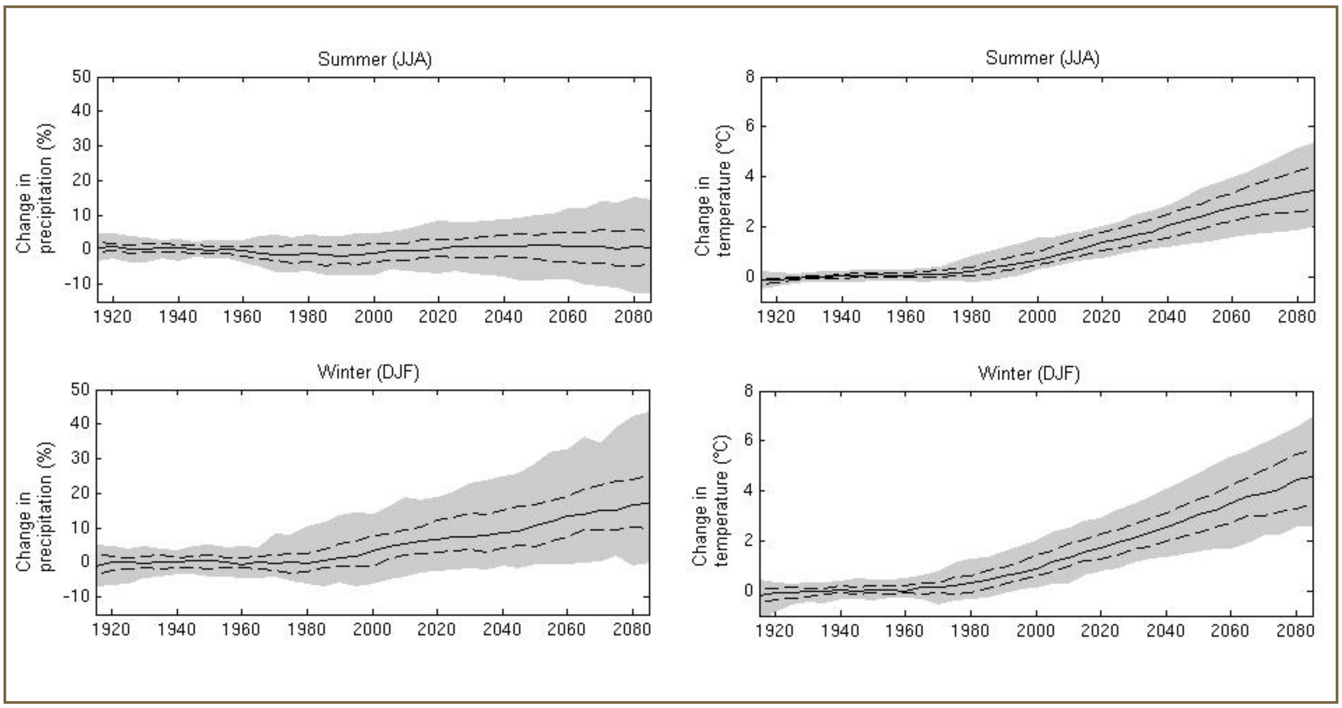

FIGURE 4. ANOMALIES IN SEASONAL PRECIPITATION (%) AND TEMPERATURE (°C) AVERAGES FROM 1990 TO 2080 BASED ON THE 1900–1969 AVERAGE (SUMMER AND WINTER, SOUTHERN QUEBEC)

Source: Ouranos 2010a

potential of a crop that requires a long growing season (e.g., corn or soybean) or enable a new crop to be developed that was previously inappropriate for the conditions in this region. Conversely, crops that are adapted to cooler conditions (e.g., small grains such as wheat, barley, oats and rye) could be put at a disadvantage (Ouranos 2010b). Most studies mention that plant ability to acclimatize to higher CO_2 concentrations or temperatures will essentially depend on the quickness and intensity of the change to which the plants will be exposed. Extreme temperatures during the summer could cause losses in animal production, especially poultry production which is most vulnerable.

According to the projected scenarios, change in terms of summer precipitation remains uncertain. However, an increase in evapotranspiration owing to a rise in temperatures, combined with a lack of rainfall, could cause water stress. It is difficult to predict whether or not this phenomenon will be an issue in Quebec given the presence of irrigated and non-irrigated land. Drainage modification and soil structure improvement are foreseen solutions for counteracting possible water shortage problems. An increase in the frequency of extreme events such as drought or flooding could possibly have substantial consequences on water supply, plant productivity and soil erosion. In addition, many crop pests, such as insects and pathogenic agents, might be affected by climate conditions, which could cause an exotic specie to establish itself in Quebec.

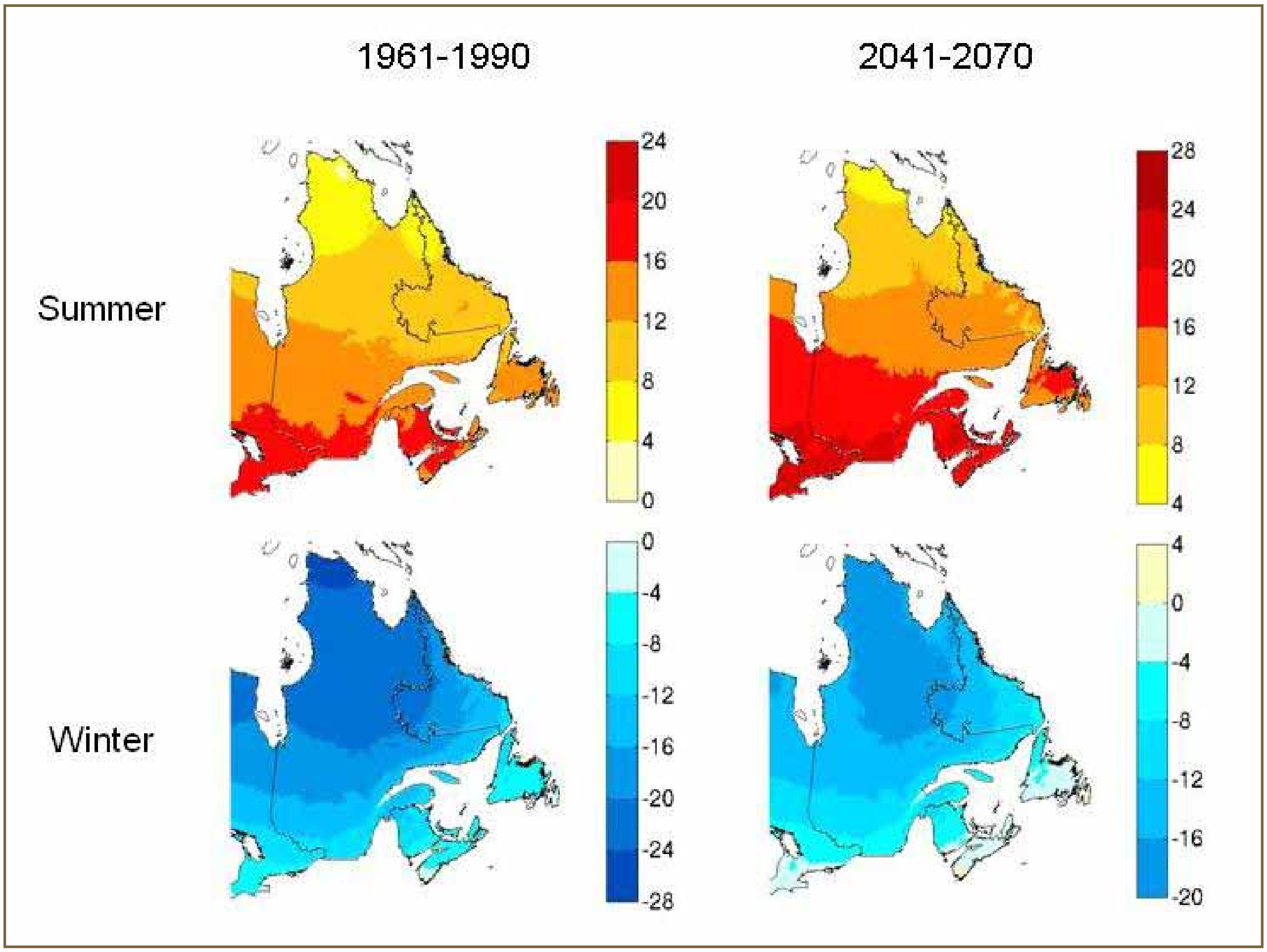

FIGURE 5. MEAN SUMMER AND WINTER TEMPERATURES (°C) 1961–1990, OBTAINED FROM NATURAL RESOURCES CANADA (NRCAN) (HUTCHINSON ET AL. 2009), AND 2041–2070, OBTAINED FROM A CLIMATE CHANGE SCENARIO PRODUCED WITH AN ENSEMBLE OF 17 SIMULATIONS USING THE CANADIAN REGIONAL CLIMATE MODEL (CRCM) (FROM DE ELIA AND CÔTÉ 2010)

Source: Ouranos 2010b

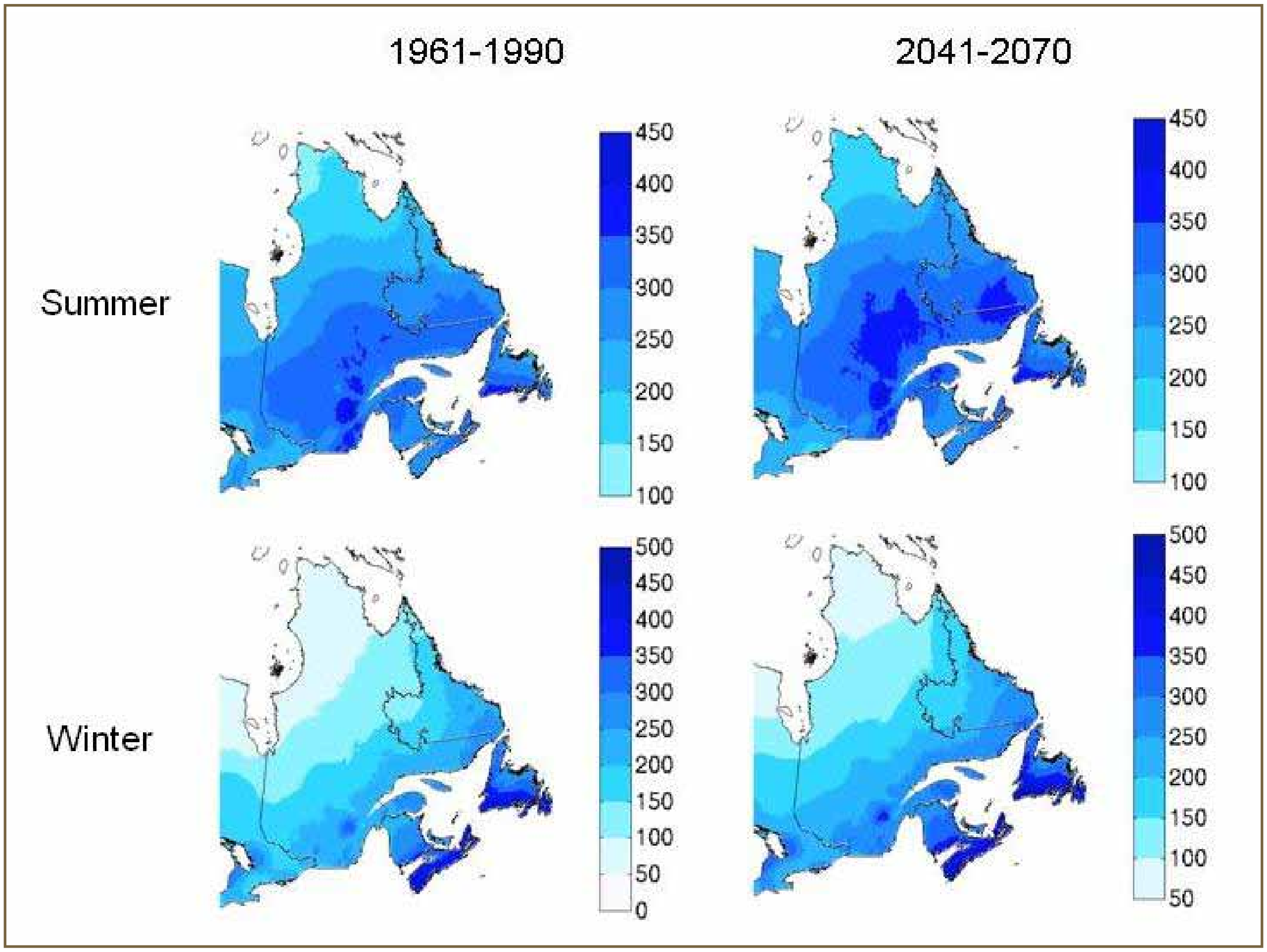

FIGURE 6. MEAN SUMMER AND WINTER PRECIPITATIONS (MM PER SEASON) FOR 1961–1990, OBTAINED FROM NATURAL RESOURCES CANADA (NRCAN) (HUTCHINSON ET AL. 2009), AND FOR 2041–2070, OBTAINED FROM A CLIMATE CHANGE SCENARIO PRODUCED WITH AN ENSEMBLE OF 17 SIMULATIONS USING THE CANADIAN REGIONAL CLIMATE MODEL (CRCM) (FROM DE ELIA AND CÔTÉ 2010)

Source: Ouranos 2010b

ADAPTATION STRATEGIES FOR QUEBEC AGRICULTURE

Several strategies are planned for the agriculture sector to counteract the negative impact of climate change.

Regarding plant production, selecting a well-adapted cultivar is a good choice. Selecting hybrids or cultivars with higher thermal-based indices (e.g., corn heat units, degree-days) than those recommended on current maps will help in counteracting possible issues caused by high temperatures. Diversifying cultivated species remains an effective way of reducing the magnitude of agricultural losses (Ouranos 2010b). To obtain the best yield possible, adapted management and planning are essential. Producers can adjust planting, seeding, and harvest seasons based on current and projected climate conditions by using available tools such as bioclimatic models (Bourgeois et al. 2004). They can also mitigate and prevent damage caused by pests by keeping up to date through newsletters or maps made available to them by agricultural sector stakeholders. It is therefore very important for these stakeholders to regularly update their publications about climate information and the associated risks.

Regarding animal production, farmers must be watchful during periods of extreme heat and modify, as needed, the environment of animals inside buildings in order to mitigate the associated risks. With the tools available to them and given stakeholders ongoing involvement in the agricultural sector, producers can make short-, medium- and long-term decisions based on more or less rapid climate development.

REFERENCES

Documents

Beaumont, L.J., L. Hughes, and A.J. Pitman. 2008. *Why is the choice of future climate scenarios for species distribution modelling important?* Ecology Letter 11: 1135–1146.

Bourgeois, G., A. Bourque, and G. Deaudelin. 2004. *Modelling the impact of climate change on disease incidence: A bioclimatic challenge*. Canadian Journal of Plant Pathology 26: 284–290.

Brown, R.D. and P.W. Mote. 2009. *The response of Northern Hemisphere snow cover to a changing climate*. Journal of Climate 22: 2124–2145.

Brown, R.D. 2010. *Analysis of snow cover variability and change in Quebec, 1948–2005*. Hydrological Processes 24: 1929–1954.

de Elia, R. and H. Côté. 2010. *Climate and climate change sensitivity to model configuration in the Canadian RCM over North America*. Meteorol. Zeit. 19 (4): 325-339.

Hutchinson, M.F., D.W. McKenney, K. Lawrence, J.H. Pedlar, R.F. Hopkinson, E. Milewska, and P. Papadopol. 2009. *Development and testing of Canada-wide interpolated spatial models of daily minimum-maximum temperature and precipitation for 1961–2003*. Journal of Applied Meteorology and Climatology 48: 725–741.

IPCC. 2007a. *Climate Change 2007 Synthesis Report*. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Core writing team supervised by Pachauri, R. K. and A. Reisinger). Intergovernmental Panel on Climate Change, Geneva, Switzerland. 103 pp.

IPCC. 2007b. *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller, eds.). Cambridge University Press, Cambridge, UK and New York, NY, USA. 80 pp.

IPCC. 2000. *Special report on emissions scenarios*. Summary for Policymakers. A Special Report of IPCC Working Group III. Based on a project written by Nakićenović, N., O. Davidson, G. Davis, A. Grübler, T. Kram, E. Lebre La Rovere, B. Metz, T. Morita, W. Pepper, H. Pitcher, A. Sankovski, P. Shukla, R. Swart, R. Watson and Z. Dadi. 27 pp.

Meehl, G.A., C. Covey, T. Delworth, M. Latif, B. McAvaney, J.F.B. Mitchell, R.J. Stouffer, and K.E. Taylor. 2007. *The WCRP CMIP3 multimodel dataset: A new era in climate change research*. Bulletin of the American Meteorological Society 88: 1383–1394.

Murphy, J.M., D.M.H. Sexton, G.J. Jenkins, B.B.B. Booth, C.C. Brown, R.T. Clark, M. Collins, G.R. Harris, E.J. Kendon, R.A. Betts, S.J. Brown, K.A. Humphrey, M.P. McCarthy, R.E. McDonald, A. Stephens, C. Wallace, R. Warren, R. Wilby, and R.A. Wood. 2009. *UK Climate Projections Science Report: Climate Change Projections*. Exeter, UK. Meteorological Office Hadley Centre. 192 pp.

Nakićenović, N. and R. Swart. 2000. *Special Report on Emissions Scenarios: A special report of working group III of the intergovernmental panel on climate change*. Cambridge University Press. 612 pp.

Ouranos. 2010a. *Élaborer un plan d'adaptation aux changements climatiques : Guide destiné au milieu municipal québécois*. Written by: C. Larrivée, V. Moffet, P. Robitaille, P. Blais, M. Marceau, C. Dupuis, C. DesJarlais, and A. Bourque. Ouranos, Consortium on Regional Climatology and Adaptation to Climate Change, Montreal, QC. 48 pp.

Ouranos. 2010b. *Learning to Adapt to Climate Change*. Written by: C. DesJarlais, M. Allard, D. Bélanger, A. Blondlot, A. Bouffard, A. Bourque, D. Chaumont, P. Gosselin, D. Houle, C. Larrivée, N. Lease, A.T. Pham, R. Roy, J.P. Savard, R. Turcotte, and C. Villeneuve. Ouranos, Consortium on Regional Climatology and Adaptation to Climate Change, Montreal, QC. 128 pp.

Vincent, L.A. and É. Mekis. 2006. *Changes in daily and extreme temperature and precipitation indices for Canada over the twentieth century*. Atmosphere Ocean 44: 177–193.

Yagouti, A., G. Boulet, L.A. Vincent, L. Vescovi, and É. Mekis. 2008. *Observed changes in daily temperature and precipitation indices for Southern Quebec, 1960–2005*. Atmosphere Ocean 46: 243–256.

Web sites

Agri-Réseau. *Réseau d'avertissements phytosanitaires*. http://www.agrireseau.qc.ca/rap/ (consulted on October 31, 2010).

CCCSNa. *Emissions Information*. Canadian Climate Change Scenarios Network. http://cccsn.ec.gc.ca/?page=emissions-info (consulted on October 17, 2012).

CCCSNb. *Regional Climate Models*. Canadian Climate Change Scenarios Network. http://cccsn.ec.gc.ca/?page=rcm (consulted on October 17, 2012).

CCCSNc. *Downscaling*. Canadian Climate Change Scenarios Network. . http://cccsn.ec.gc.ca/?page=downscaling (consulted on October 17, 2012).