PAPER

8

CLIMATE CHANGE ADAPTATION THROUGH LEARNING (ATL): USING PAST AND FUTURE CLIMATE EXTREMES SCIENCE FOR POLICY AND DECISION-MAKING

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ABSTRACT: Climate can be thought of as an average of the weather over a period of years or decades. It describes the characteristic weather conditions to be expected in a region at a given time of year, based on long-term experience. By international convention, weather observations are commonly averaged over a period of 30 years to produce the statistics that describe the climate "normals". These averages are helpful for providing "average" temperatures and precipitation, or when comparing one location to another, but they do not provide the necessary information to assist communities in planning for climate change adaptation. Communities need climate information on extremes of climate so that they can determine how they have adapted in the past to these extremes, and how to best plan for these in the future. By showing the community how the climate has changed in the past, the question can be asked as to how they have adapted to these changes. Years of climate extremes may have required intervention from the community to save agricultural crops, preserve endangered species habitat, or ensure the quality of groundwater. This knowledge, taken together with scenarios of future climate change showing similar extreme hot or dry years in the future (that is, changed return periods), can identify some adaptation measures that might be taken to ensure that an adaptation infrastructure is in place, or that alternative management of the biosphere reserve occurs. In other words, what lessons did the community learn from the last event that can be drawn on with advanced knowledge about the future to minimize the negative impacts and maximize the benefits from climate change? The authors title this approach Adaptation Through Learning (ATL), and the paper provides an example from Canada.

Keywords: climate, climate change, adaptation, extremes, learning, Biosphere Reserves

1. Introduction

Climate can be thought of as an average of the weather over a period of years or decades. It describes the characteristic weather conditions to be expected in a region at a given time of year, based on long-term experience. By international convention, weather observations are commonly averaged over a period of 30 years to produce the statistics that describe the climate "normals" (see Phillips and McCulloch, 1972; Gates, 1973; Watson, 1974; Janz and Storr, 1977; Wahl *et al,* 1987; Auld *et al,* 1990). These averages are helpful for providing "average" temperatures and precipitation, or when comparing one location to another, but they do not provide the necessary information to assist communities in planning for climate change adaptation.

For example, as part of the Canadian Biosphere Reserves Association (CBRA) Climate Change Initiative (CCI) designed to present climate change information to Biosphere Reserve communities to allow local organizations to understand climate change and adapt to potential impacts, Hamilton *et al.* (2001) examined instrumental climate records from Biosphere Reserves across Canada including Waterton Lakes, Riding Mountain, Niagara Escarpment, Long Point, and Kejimkujik (a candidate Biosphere Reserve that was designated as the Southwest Nova Biosphere Reserve in 2001). Annual average temperature and precipitation series were generated from daily temperature and precipitation values. Long term trends were identified over the period of the instrumental record leading to the following results.

In general, data from the interval 1900 to 1998 show cooler temperatures in the 1920's, warming from the early 1940's into the early 1950's, cooling into the 1970's, and subsequent warming. At many stations, 1998 was the warmest in the instrumental record. The 20th century warming was shown as approximately 1.0 degree Celsius in the Riding Mountain area and 0.6 degrees Celsius at Long Point, Niagara Escarpment (see Figure 1 for example), and Waterton Lakes. There was a slight cooling in the Kejimkujik area over the past half century. Precipitation data showed increasing trends in the Kejimkujik. Long Point, Niagara Escarpment, and Waterton Lakes areas with no long term trend in the Riding Mountain area.

Managers at the Biosphere Reserves in Canada were perplexed when presented with this data and information. How, they asked, was such information on climate normals and trends supposed to assist them in preparing for future climate change, and the necessary adaptations that might follow?

This paper presents how the needs of environmental managers at Canada's Biosphere Reserves have dictated the development of an approach to community-based adaptation strategies to climate change that the authors title *adaptation through learning: using past and future climate extremes science for policy and decision-making.*

2. Biosphere Reserves in Canada

Biosphere Reserves are ecosystems around the world, regionally representative of the biosphere, and recognized internationally by UNESCO's Man and the Biosphere (MAB) Programme as part of a global network of 459 Biosphere Reserves in 97 countries (UNESCO, 2007). Biosphere Reserves are used to share

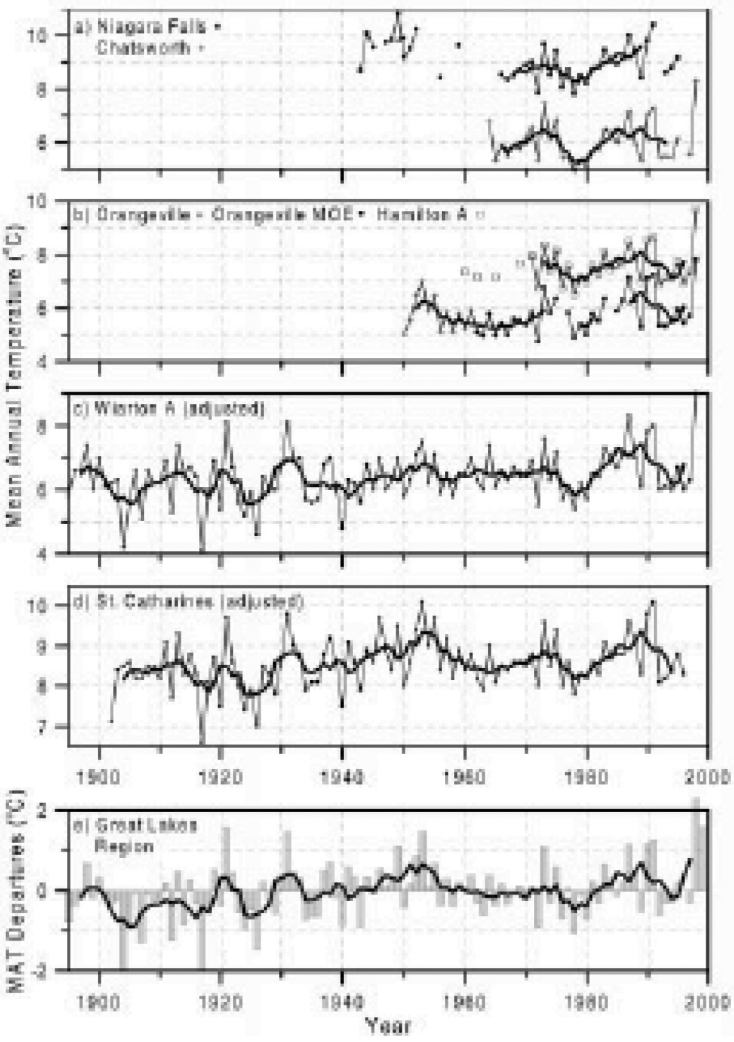


FIGURE 1

Mean annual temperature for stations representing Niagara Escarpment Biosphere Reserve, and departures for the Great Lakes Region. (Source: Hamilton *et al.*, 2001).

knowledge on how to manage natural resources in a sustainable way; to co-operate in solving natural resource issues; to conserve biological diversity; to maintain healthy ecosystems; to learn about natural systems and how they are changing; and to learn about traditional forms of land-use. Biosphere reserves are test areas for demonstrating ideas, tools, concepts, knowledge, etc. of resource conservation, sustainable development as well as climate change. It is the role of the biosphere reserve to serve as a mechanism for enhancing local, regional, and multi-jurisdictional cooperation that is most needed in the area (Ravindra, 2001).

These objectives are met through each Biosphere Reserve's management structure, or "round table" of local communities (ranging from local indigenous communities to rural societies), farmers, foresters, fishermen, research scientists, government decision-makers, and other agency representatives. What make these "round tables" unique are their connection to a national network of Biosphere Reserve communities and the links to the World Network promoting areas where sustainable development is an applied concept.

Since 1972, UNESCO has designated 15 biosphere reserves in Canada (see Figure 2): Mont St. Hilaire (Quebec, 1978); Waterton (Alberta, 1979); Long Point (Ontario, 1986); Riding Mountain (Manitoba, 1986); Charlevoix (Quebec, 1989); Niagara Escarpment (Ontario, 1990); Clayoquot Sound (British Columbia, 2000); Redberry Lake (Saskatchewan, 2000); Lac St. Pierre (Quebec, 2000); Mount Arrowsmith (British Columbia, 2000); South West Nova (Nova Scotia, 2001); Thousand Islands – Frontenac Arch (Ontario, 2002).

3. Adaptation to Climate Change

According to Smit *et al.* (2000), adaptation to climate change is the process of adjusting in response to, or in anticipation of, changed conditions. In the climate change context, more specifically, it is adjustment in ecological, social or economic systems in response to actual or expected climate stimuli and their effects or impacts. Adaptation is not a new concept (Burton, 2004) as it has been employed traditionally by ecologists to refer to the evolutionary process by which living organisms mould into a new environment. Observers have broadened the scale of reference by using the concept of adaptation to describe how systems, both natural and human, evolve over time when faced with environmental changes.

Adaptation can take the form of autonomous, reactive, or anticipatory action (Abramovitz *et al.*, 2002). *Autonomous adaptation* to climate change is

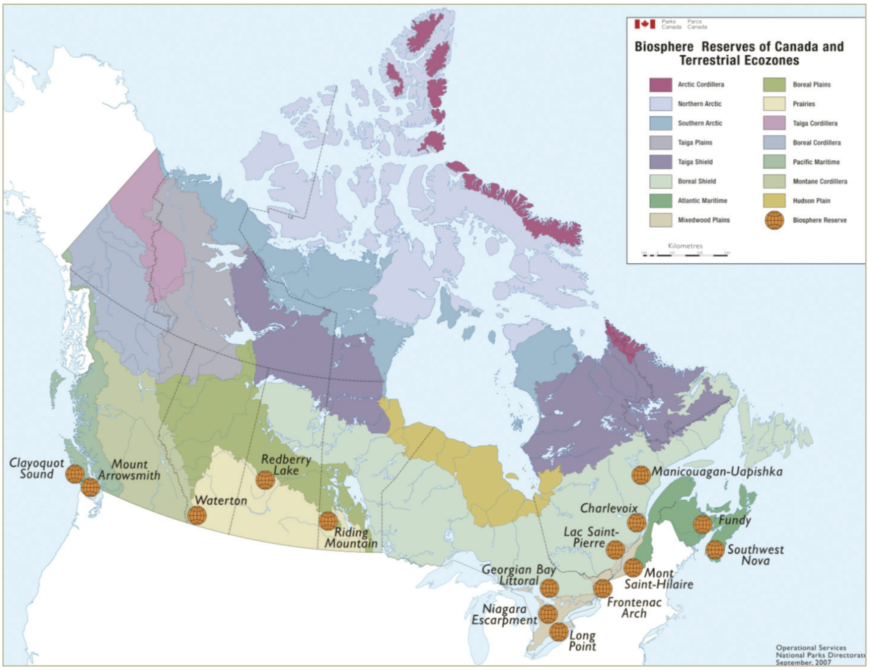


FIGURE 2
Map of Canada's Biosphere Reserves
Source: Canadian Biosphere Reserve Association, 2007.

essentially an unconscious process of system-wide coping, most commonly understood in terms of ecosystem adjustments. *Reactive adaptation*, as the name implies, involves a deliberate response to a climatic shock or impact, in order to recover and prevent similar impacts in the future. *Anticipatory adaptation* involves planned action, in advance of climate change, to prepare for and minimize its potential impacts. Such actions can aim at enhancing the buffering capacities of natural systems in the face of climate extremes.

The most recent literature in the climate change adaptation field revolves around concepts of building adaptive capacity (see Fenech *et al.*, 2004), adaptive capacity and development (Smith *et al.*, 2003), the adaptation deficit (Burton, 2004), and knowledge translation (Fenech and Murphy, 2006). Most relevant to this paper is the concept of knowledge translation – a concept used in the health care field that can be applied to climate change adaptation. Knowledge translation can be defined as the effective and timely incorporation of evidence-based information into the practices of health professionals in such a way as to affect optimal health care outcomes and maximize the potential of the health system. This same concept can be applied to the climate change adaptation field. Traditional methods of reading printed educational materials and attending didactic educational meetings are often not very effective in changing behavior (Grimshaw, 1998). To change behaviour and sustain a willingness to adapt to climate change will require, at a minimum, a catalyst for change, an understanding of the barriers to change, ongoing activities and communications to reinforce new behaviours, and recognition for taking the action (Fenech *et al.*, 2005). This paper presents an approach to providing past and future climate information, merged with experience and understanding of changes required, as a means of attempting to bring about climate change adaptation.

4. The Approach

Informal discussions were conducted with environmental managers at Biosphere Reserves in Canada and China – these being those responsible for local agriculture, local tourism, park management, or biodiversity conservation. The question was asked: "How do you make preparations about the threats from future climate (climate change)?" Most viewed the threat of climate change, or their own vulnerability, was to climate extremes – extreme hot, cold, wet and dry. They also felt that they had good experience with extreme weather over the past decades that they could learn from how they adapted in the past (if reminded of the specific years). The unknown was when and how often extreme weather was going to occur. The authors leave the answer to "when" to the *Farmer's Almanac*, but there is some science available to provide guidance on answering the question of "how often." It was clear from the discussions that communities such as Biosphere Reserves need climate information on extremes of climate so that they can determine how they have adapted in the past to these extremes, and how to best plan for these in the future.

4.1 Indices of Climate Extremes

An index of climate extremes summarizes and presents a complex set of multivariate and multidimensional climate changes so that the results can be easily understood and used in policy decisions made by nonspecialists in the field. Many have developed their own indices of climate extremes (see World Meteorological Organization (WMO) Commission on Climatology (CCl) (Karl *et al.*, 1999); European Climate Assessment, 2006; Stardex, 2006; *et al.)* totaling over 400, yet for the application of indices of climate extremes to Canada, the authors considered Gachon (2005) who identified 18 indices for extreme temperature and precipitation for Canadian regions.

Gachon considered four criteria in choosing indices: the indices must represent Nordic climate conditions such as found in Canada; the indices must be relevant to climate change impact studies; extreme indices are relatively moderate (for example, using 10th and 90th percentiles as opposed to the 5th and 95th); and indices are adapted to the main characteristics of climate conditions at the regional scale. Gachon (2005) concludes that the 18 indices presented in Table 1 "provide a good mix of information – precipitation indices characterize the frequency, intensity, length of dry spells, magnitude and occurrence of wet

TABLE 1

Gachon Indices of Climate Extremes for Impact Studies of Climate

DEFINITION		UNIT	TIME SCALE
Precipitation *Indices*			
Frequency	Percentage of wet days (Threshold=1 mm)	% days	Season
Intensity	Simple daily intensity index : sum of daily precip/ number of wet days	mm/wet d	Season
Extremes Magnitude and Occurrence	Maximum number of consecutive dry days (<1 mm)	days	Season
	Maximum 3-days precipitation total	mm	Season
	90th percentile of rainday amount (Threshold=1 mm)	mm/days	Season
	Percentage of days Prec>90th percentile (61-90 based period)	% days	Season
Temperature *Indices*			
Daily variability	Mean of diurnal temperature range	°C	Season
	Percentage of days with freeze and thaw cycle (Tmax>0°C, Tmin<0°C)	% days	Month
Season length	Frost season length :Tday<0°C more than 5 d.and Tday>0°C more than 5 d.	days	Year
	Growing season length :Tday>5°C more than 5 d.and Tday<5°C more than 5 d.	days	Year
Extremes Cold & Hot	Sum of sequences > 3 days where Tmin< daily Tmin normal - 5°C	days	Winter
	Sum of sequences > 3 days where Tmax> daily Tmax normal + 3°C	days	Summer
Extremes Magnitude and Occurrence	10th percentile of daily Tmax	°C	Season
	90th percentile of daily Tmax	°C	Season
	10th percentile of daily Tmin	°C	Season
	90th percentile of daily Tmin	°C	Season
	Percentage of days Tmax>90th percentile (61-90 based period)	% days	Season
	Percentage of days Tmin<10th percentile (61-90 based period)	% days	Season

extremes while temperature indices refer to variability, season lengths and cold and warm extremes in terms of magnitude, occurrence and duration."

These indices provide climate information as "easily understood and used in policy decisions made by nonspecialists in the field."

4.2 Climate Observational Data for Past Climate Extremes

The Gachon Indices of Climate Extremes (GICE), used to present to communities across temperate regions on understanding climate changes, are based on the two most common meteorological observations - temperature and precipitation. For the indices to be useful in understanding extremes, observations of the maximum and minimum temperatures as well as precipitation should be available on a daily basis, with a record length of at least thirty years of data. Basic climate observations of temperature and precipitation are taken around the world using common methodologies and standards established by the World Meteorological Organization (WMO). Temperature and precipitation observations are recorded across Canada by automatic weather stations, and volunteer climate observers.

An automatic weather station is a cluster of climate sensors connected to a data logger. Sensors are usually positioned by international standards and protocols on a two meter mast, and the station powered by a solar panel and battery. Sensors often used on automatic weather stations include: air temperature; relative humidity; rainfall; solar radiation; wind speed and direction; and barometric pressure. These stations can be designed as automated bioclimate monitoring stations (see Figure 3) adding sensors to measure meterological variables throughout the forest canopy and into the soil.

A network of more than two thousand volunteer climate observers from every province and territory in Canada records maximum and minimum temperature readings and precipitation readings twice daily. Every morning before eight o'clock, and every evening after five, these dedicated individuals head out into their backyards, schoolyards, churchyards or farmyards to observe using a rain gauge, a ruler and a thermometer housed in a louvred wooden box called a Stephenson screen. These measurements are reported to Environment Canada using an automated telephone entry system, and since 2000, via the Internet. The new system has resulted in a reduction in expenses (for manual data entry, postage and handling), automated quality assurance and data availability from observation to archive in minutes rather than months. The Canadian National Climate Archive in Toronto, Ontario, now houses more than seven billion

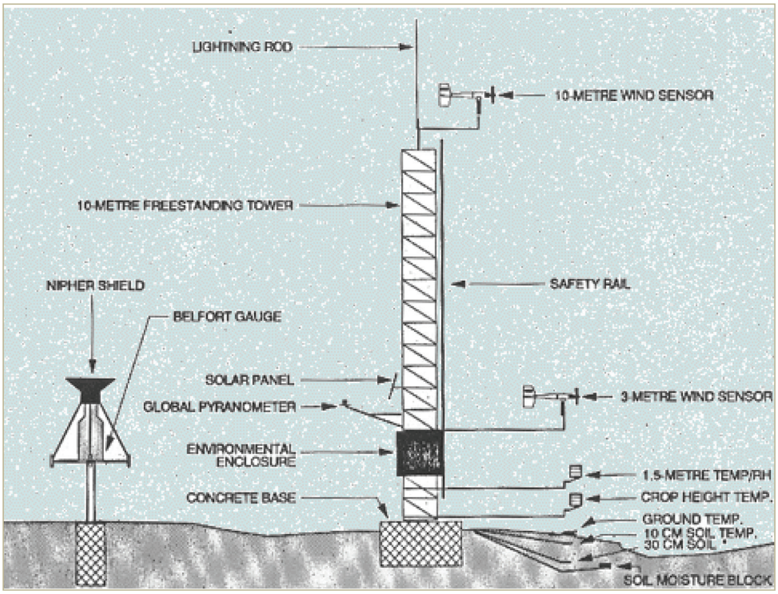


FIGURE 3
Bioclimate instrumentation to measure a profile of temperature, humidity, wind, precipitation and solar radiation throughout the forest canopy and temperature into the soil. (Source: Fenech *et al.*, 1995).

observations collected across Canada over the past century and a half, many of which are from volunteer climate observers.

To monitor and detect climate change reliably, the indices should contain variations that are caused by climate processes only. There are two aspects to consider when constructing these indices (Zhang, 2004). First, the original daily data should be homogeneous, that is, be free of not-climate-related variation. Secondly, the method for constructing the indices should not introduce any additional variation (function of use of calendar years that need to be overcome – see Zhang *et al.,* 2005). A climate dataset contains climate information at the observation sites, as well as other non-climate related factors such as the environment of the observation station, and information about the instruments and observation procedures under which the records were taken. An assumption is made that the station records are representative of climate conditions over a region when the data are used in climate analysis. This is, unfortunately, not always the case. Zhang (2004) provides two excellent examples:

For example, if an observing station is moved from a hill top location to the valley floor 300 meters lower in elevation, analysis of its temperature data will likely show an abrupt warming at the time of the station relocation. This artificial jump would not be representative of temperature change in the region. Also, consider a station located in the garden of a competent and conscientious observer for 50 years, and suppose a tree was planted west of the garden at the time the observation station was established. The instruments are maintained in good condition and the observer accurately records the temperature in the garden. The tree slowly grows up and shades the observing site during the late afternoon when the daily maximum temperature is observed. As a result, the recorded daily maximum temperature would gradually become lower than that over the surrounding area not shaded by the tree. Thus the station would gradually become less representative of the surrounding area.

A real life example of a Canadian site being moved has been shown by Vincent (1998). It is therefore important to remove the non-climate factors from the data as much as possible, before the climate data can be used reliably for climate change studies. A great deal of effort has been made to develop methods to identify and remove non-climatic inhomogeneities (see Peterson *et al.*, 1998) and the WMO has developed a set of practical guidelines on how to deal with inhomogeneity problems depending on the circumstances under which inhomogeneity occurs (see WMO, 2007).

4.3 Modeling Future Scenarios of Climate Extremes

Our present understanding of the climate system and how it is likely to respond to increasing concentrations of greenhouse gases in the atmosphere would be impossible without the use of global climate models (GCMs). GCMs are powerful computer programs that use physical processes to replicate, as accurately as possible, the functioning of the global climate system (Environment Canada, 2002).

GCMs use mathematical models to simulate the functioning of the global climate system in three spatial dimensions and in time. Modern climate models, such as Canada's GCM, include coupled atmosphere, ocean, sea-ice and land-surface components. Constraints on the availability of computing resources dictate that coupled models, such as Canada's GCM, must operate at modest resolutions.

For example, the atmospheric component of the Canadian model is a 3-dimensional grid with a horizontal spacing of about 300 km and 10 layers in the vertical. The model simulates atmospheric temperature, pressure, winds and humidity at each grid point. The ocean has considerably higher resolution, using 29 layers of grid points with a horizontal resolution of about 150 km. The model simulates the density, salinity and velocity of the ocean water at each grid point. The land-surface component has one layer, uses the same horizontal grid as the atmosphere, and simulates the temperature and moisture content of the soil. The sea-ice component, which also has one layer, uses the horizontal grid of the atmosphere and simulates the temperature and thickness of the ice pack.

Detailed projections of local climate impacts cannot be made with modest resolution GCMs. Climate impact studies usually require detailed information on present and future climate with high resolution and accuracy. In most cases, detailed information is needed with spatial resolutions of the order of 100 km or less, and with high accuracy concerning the tails of statistical distributions (in particular the frequency and intensity of rare events). At the lowest end of the spatial resolution, with scales of one or a few grid distances, the global climate models have little or no skill.

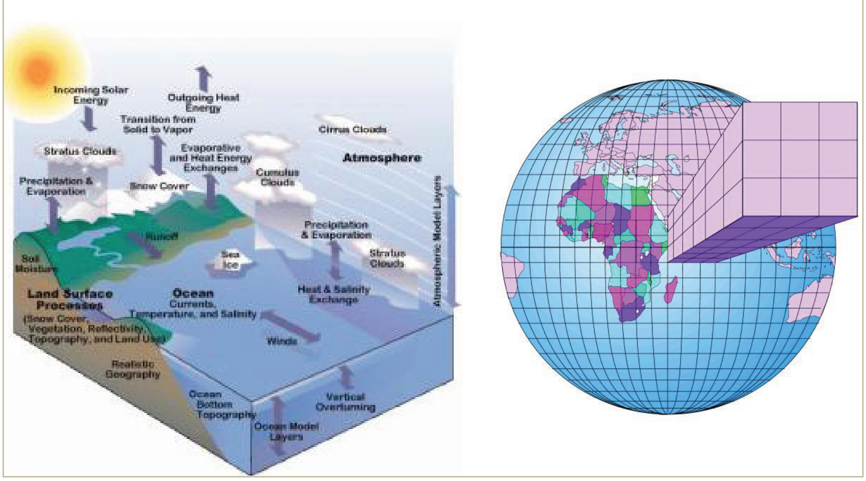


FIGURE 4

On left, climate system to be modeled by Global Climate Model (GCM); on right, gridded horizontal and vertical layers of a GCM.

A method often used to refine results from global models is to nest a regional climate model (RCM) within a GCM. In this approach, information from the global model is used to drive a higher resolution limited area model at its boundaries. The RCM in turn simulates climate features and physical processes in much greater detail within its limited area domain. The success of the nested approach depends on the accuracy of the large scale model (at the scales that it represents) and on the quality of the regional model. Scenarios of future climate change have become available from the Canadian Regional Climate Model (Caya *et al.*, 1995) recently (see CRCM website), yet no assessments have been made of their usefulness in local climate impact studies.

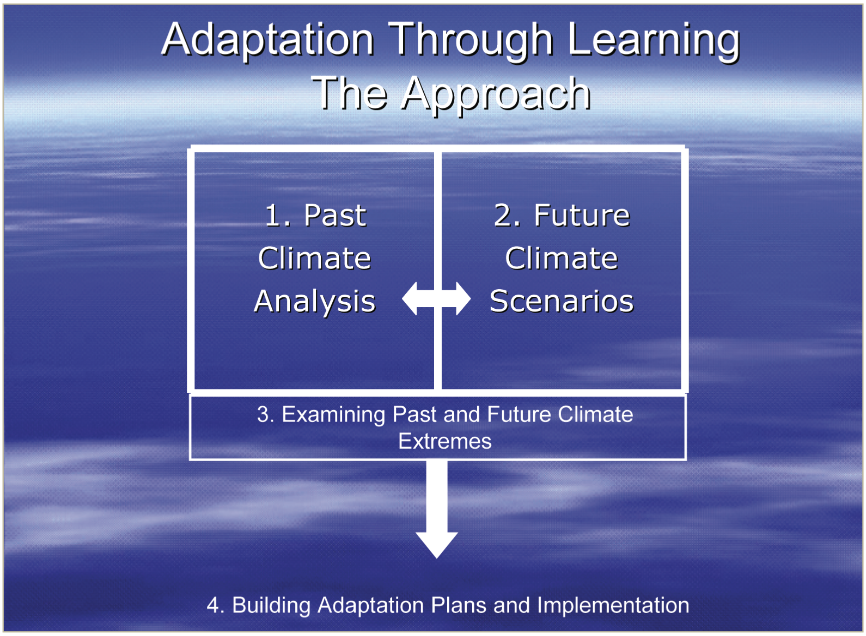
A number of methodologies have been developed for deriving more detailed regional and site scenarios of climate change for impacts studies. These downscaling techniques are generally based on GCM output and have been designed to bridge the gap between the information that the climate modelling community can currently provide and that required by the impacts research community (Wilby and Wigley, 1997). The literature presents downscaling techniques as generally divided into spatial (deriving local scenarios from regional scenarios) and temporal (deriving daily data scenarios from monthly or seasonal information) classes (Giorgi and Mearns, 1991).

Spatial downscaling refers to the techniques used to derive finer resolution climate information from coarser resolution GCM output. The fundamental bases of spatial downscaling are the assumptions that it will be possible to determine significant relationships between local and large-scale climate (thus allowing meaningful site-scale information to be determined from large-scale information alone) and that these relationships will remain valid under future climate conditions. There are three main classes of spatial downscaling:

- Transfer functions - statistical relationships are calculated between large-area and site-specific surface climate, or between large-scale upper air data and local surface climate.
- Weather typing - statistical relationships are determined between particular atmospheric circulation types (for example, anticyclonic or cyclonic conditions) and local weather.
- Stochastic weather generators - these statistical models may be conditioned on the large-scale state in order to derive site-specific weather.

Each has its own advantages and disadvantages, but what is most important is which method is able to most accurately take CGCM or CRCM data and statistically downscale it to areas the size of Canadian communities such as

Biosphere Reserves. No evaluation has been made as to the accuracy and appropriateness of the various methods – CGCM, CRCM, transfer downscale, weather typing, stochastic weather generator – for providing future climate scenarios for areas the size of Canadian communities.



Adaptation Through Learning
The Approach

1. Past Climate Analysis

2. Future Climate Scenarios

3. Examining Past and Future Climate Extremes

4. Building Adaptation Plans and Implementation

FIGURE 5
The Approach of Adaptation through Learning: Using Past and Future Climate Extremes Science for Policy and Decision-Making.

5. Applying the Approach as an Example

As shown above, in order to provide for community-based climate change adaptation planning, a history of climate extremes (hot-cold, wet-dry) should be built for the community – in this example, the Southwest Nova Biosphere Reserve located in Nova Scotia, Canada. Observational data from several climate stations are available for this Biosphere Reserve (see Figure 6 for example of climate stations around Southwest Nova Biosphere Reserve). However, a station from Canada's Climate Reference Network close to Southwest Nova Biosphere Reserves was selected to ensure the length and completeness of climate records

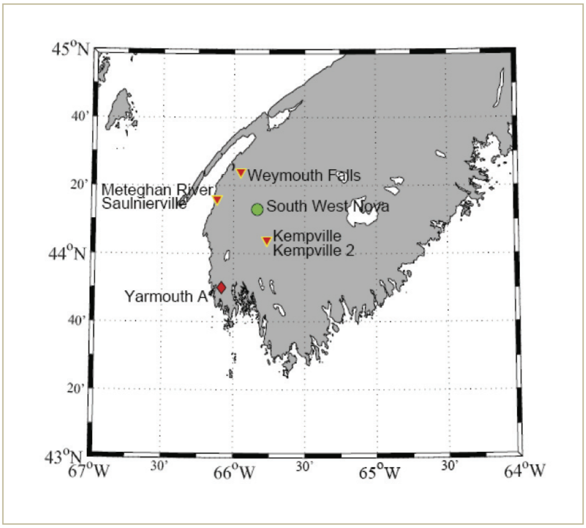


FIGURE 6
Climate Stations around Southwest Nova Biosphere Reserve in Nova Scotia, Canada.

available. There are 302 Reference Climate Stations in Canada for climate change studies, as well as other climate research (Plummer *et al.*, 2003).

At least seventy years of climate data are available for each of Canada's stations in the Climate Reference Network used in this study. The daily maximum, minimum and mean temperatures and precipitation amounts were checked for homogeneity using an R-based toolkit RHTest that uses a two-phase regression technique (Wang, 2003) for the detection and adjustment of inhomogeneity. The homogenized climate data for Southwest Nova Biosphere Reserve was then run through the 18 indices for climate change detection as identified by Gachon (2005). Based on seasonal reporting of indices, this produced a series of over 100 graphs and charts. A history is now being built that selects the most informative of the graphs to tell a story of when (year and/or season) the Biosphere Reserve experienced climate extremes. The process of graph selection is being documented for each of the 13 Biosphere Reserves, and an overall "approach" to building a history will be formulated.

Using the Southwest Nova Biosphere Reserve as an example, Figure 7 shows the mean temperature from 1941 to 2002 where no discernable trend of increasing or decreasing temperature is apparent.

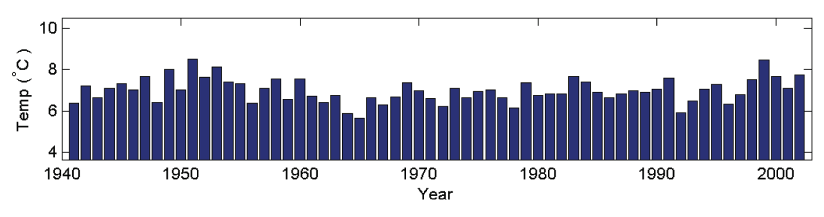


FIGURE 7
Mean Daily Temperature of Yarmouth Station A (8206500) from 1941-2002.

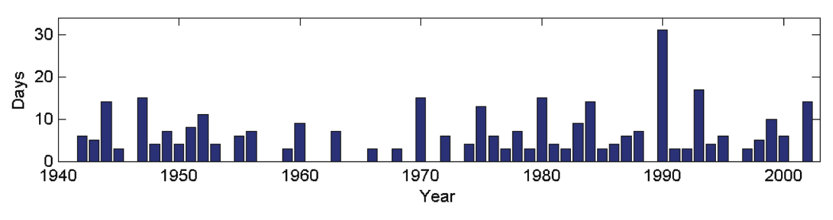


FIGURE 8
Annual Extreme Hot Days at Yarmouth Station A (8206500) from 1941-2002.

Examining extremes, however, provides an opportunity to focus on particular years. Figure 8 shows the extreme hot days (3 consecutive days where maximum temperature is greater than the daily normal maximum temperature plus 3 degrees Celsius) at Southwest Nova Biosphere Reserve. It is obvious that 1990 was a year of extreme hot days doubling any other year prior or following over the observation period.

Figure 9 shows a similar graph for precipitation – the number of consecutive dry days in the autumn when precipitation was less than 1 millimeter. The autumn of 1979 stands out as a particularly dry season, similar only to the autumns of 1964 or 1947.

The community's experience and natural knowledge bases are built using a participatory integrated assessment, a collaborative interdisciplinary research effort which is based on developing a partnership between researchers and stakeholders (Cohen, 2004). This is meant to create an exercise in shared

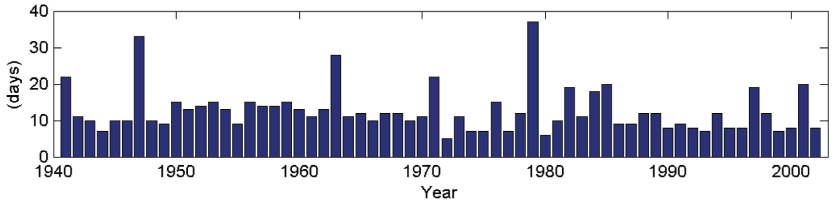


FIGURE 9

Consecutive Dry Days (precipitation less than 1 mm) in Autumn at Yarmouth Station A (8206500) from 1941-2002.

learning. Dialogue processes are critical to this process, extending beyond simply performing an outreach function. In this approach, dialogue contributes important information on how adaptation options may be considered by governments, private enterprises, and community groups.

By showing the community how the climate has changed in the past, the question can be asked as to how they have adapted to these changes. In this example, the past climate highlights a year of extreme hot days just 15 years ago, and 25 years ago for an extremely dry season, within the memory of many Biosphere Reserve managers. This extreme year may have required intervention from Biosphere Reserve managers to save agricultural crops, preserve endangered species habitat, or ensure the quality of groundwater. For example, the year 1990 was followed at Southwest Nova Biosphere Reserve by significant increases in the growth rates of the Blanding's Turtle, one of Nova Scotia's endangered species (see Drysdale, this volume). This knowledge, taken together with scenarios of future climate change showing similar extreme hot or dry years in the future (that is, changed return periods), can identify some adaptation measures that might be taken to ensure that an adaptation infrastructure is in place, or that alternative management of the biosphere reserve occurs. In other words, what lessons did the community learn from the last event that can be drawn on with advanced knowledge about the future to minimize the negative impacts and maximize the benefits from climate change?

6. Conclusions

Human communities, such as those in Biosphere Reserves, cannot gain much direction for future climate change adaptation planning using common methods of climate data presentation such as "climate normals" or "climate averages."

What is needed, and asked for by the community, is information on climate extremes, how these have been dealt with by the community in the past, and the expected frequency and increase in magnitudes expected to be dealt with in the future. This paper has presented an approach to feeding these needs; what the authors title Adaptation Through Learning. Adaptation Through Learning can be described as providing communities with information on past and future extremes of climate so that they can determine how they themselves have adapted in the past to these extremes, and how to best plan for these in the future. The tools available from climatologists for this approach include the Gachon Indices of Climate Extremes (GICE) to provide results from climate changes over time that can be easily understood and used in policy decisions made by nonspecialists in the field; observational climate data on temperature and precipitation from automated and volunteer weather stations to feed the indices for past climate; and climate data on temperature and precipitation from models of future climate scenarios, including Global Climate Models, Regional Climate Models, and several downscaling techniques for understanding future climate extremes.

References

Abramovitz, J., T. Banuri, P. Girot, B. Orlando, N. Schneider, E. Spanger-Siegfried, J. Switzer and A. Hammill. 2002. *Adapting to Climate Change: Natural Resource management and Vulnerability Reduction.* International Institute fro Sustainable Development. pp. 37.

Auld, H., M. Loiselle, B. Smith and T. Allsop. 1990. The Climate of Metropolitan Toronto. Environment Canada.

Burton, I. 2004. "Climate Change and the Adaptation Deficit" in Fenech, A., D. MacIver, H. Auld, R. Bing Rong and Y. Yin (eds). 2004. *Climate Change: Building the Adaptive Capacity*. Meteorological Service of Canada, Environment Canada. Toronto, Ontario, Canada. 413p.

Canadian Biosphere Reserve Association. 2007. **www.biosphere-canada.ca/home.asp**.

Caya, D., R. Laprise, M. Giguere, G. Bergeron, J.P. Blanchet, B.J. Stocks, G.J. Boer and N.A. McFarlane. 1995. Description of the Canadian regional climate model. *Water, Air and Soil Pollution.* 82: 477-482.

Cohen, S. 2004. "Regional Assessment of Climate Change Impacts in Canada: Okanagan Case Study" in Fenech, A., D. MacIver, H. Auld, R. Bing Rong and Y. Yin (eds). 2004. Climate Change: Building the Adaptive Capacity. Meteorological Service of Canada, Environment Canada. Toronto, Ontario, Canada. 413p.

Environment Canada. 2002. Poster 5: Climate Modelling: Predicting Global Climate Change in series *Science for Sustainable Development* presented at the 2002 World Summit on Sustainable Development.

European Climate Assessment **www.knmi.nl/samenw/eca**.

Fenech, A. and M. Murphy. 2006. *Applying the Concept of Knowledge Translation to Climate Change Adaptation*. Adaptation and Impacts Research Group Occasional Paper 14. Environment Canada.

Fenech, A., M. Murphy, D. MacIver, H. Auld and R. Bing Rong. 2005. *The Americas: Building the Adaptive Capacity to Global Environmental Change*. Adaptation and Impacts Research Group Occasional Paper 5. Environment Canada.

Fenech, A., D. MacIver, H. Auld, R. Bing Rong and Y. Yin. 2004. "Climate Change: Building the Adaptive Capacity" in Fenech, A., D. MacIver, H. Auld, R. Bing Rong and Y. Yin (eds). 2004. *Climate Change: Building the Adaptive Capacity*. Meteorological Service of Canada, Environment Canada. Toronto, Ontario, Canada. p. 3-18.

Fenech, A., R. Roberts-Pichette and D. MacIver. 1995. Canadian Biodiversity Monitoring: Terrestrial (Forest) Plots as part of the Ecological Monitoring and Assessment Network (EMAN). Presented at **http://www.eman-rese.ca/eman/research/bioclimate-monitoring.html**.

Gachon, P. 2005. A first evaluation of the strength and weaknesses of statistical downscaling methods for simulating extremes over various regions of eastern Canada. Environment Canada.

Gates, A. 1975. The Tourism and Outdoor Recreation Climate of the Maritime Provinces. Environment Canada.

Giorgi, F. and Mearns, L.O. (1991): Approaches to the simulation of regional climate change: a review. *Reviews of Geophysics* 29, 191-216.

Grimshaw, JM, What have new efforts to change professional practice achieved? *Journal of the Royal Society of Medicine*. 1998; 91(35): 20-25.

Hamilton, J.P., G. Whitelaw and A. Fenech. 2001. "Mean annual temperature and total annual precipitation trends at Canadian Biosphere Reserves" in Environmental Monitoring and Assessment. Volume 67, Issue 1/2, February 2001.

IPCC (Intergovernmental Panel on Climate Change). 2001. Working Group II. Cambridge University Press. Cambridge, United Kingdom.

Janz, B. and D. Storr. 1977. The Climate of the Contiguous Mountain Parks. Environment Canada.

Karl, T.R., N. Nicholls, and A. Ghazi, 1999: CLIVAR/GCOS/WMO workshop on indices and indicators for climate extremes: Workshop summary. Climatic Change, 42, 3-7

Peterson, T.C., Easterling, D.R., Karl, T.R., Groisman, P., Nicholls, N., Plummer, N., Torok, S., Auer, I., Bohm, R., Gullett, D., Vincent, L., Heino, R., Tuomenvirta, H., Mestre, O., Szentimrey, T., Salinger, J., Foland, E.J., Hanssen-Bauer, I., Alexandersson, H., Jones, P. and Parker, D., 1998: Homogeneity adjustments of in situ atmospheric climate data: a review. *International Journal of Climatology*, 18,1493-1517.

Phillips, D. and J. McCulloch. 1972. The Climate of the Great Lakes Basin. Environment Canada.

Plummer, N., D. Collins, P. Della-Marta, T. Allsop, Y. Durocher, T. Yucyk, R. helm, M. helfert, R. Heino, E. Rudel, P. Stasney, I. Zahumensky, and S. Zhou. 2003. Progress of Automatic Weather Stations in Meeting the Needs of Climate. Presented at 3a Conferencia Internacional sobre Experiencias con Estaciones Meteologicas Automaticas.

Ravindra,M. 2001. Opportunites and challenges for protecting, restoring and enhancing coastal habitats in the Bay of Fundy in Chopin, T (ed); Wells, PG (ed.s). Proceedings of the 4th Bay of Fundy Science Workshop, Saint John, New Brunswick, September 19-21, 2000. no. 17, pp. 148-160.

Smit, B., I. Burton, R.J.T. Klein and J. Wandel. 2000. An anatomy of adaptation to climate change and variability. *Climatic Change* 45(1):223-251.

Smith, J., R. Klein and S. Huq (ed.s). 2003. Climate Change, Adaptive Capacity and Development. Imperial College Press. 356pp.

Stardex **www.cru.uea.ac.uk/projects/stardex**.

UNESCO. 2007. **http://www.unesco.org/mab/BRs.shtml**.

Vincent, L.A., 1998: A technique for the identification of inhomogeneities in Canadian temperature series. *Journal of Climate*, 11, 1094-1104

Wahl, H., D. Fraser, R. Harvey and J. Maxwell. 1987. Climate of Yukon. Environment Canada.

Wang, X.L., 2003: Comments on "Detection of undocumented changepoints: A revision of the two-phase regression model". *Journal of Climate,*16,3383-3385.

Watson, W. 1974. The Climate of Kejimkujik National Park. Environment Canada.

Wilby, R.L. and Wigley, T.M.L. (1997): Downscaling general circulation model output: a review of methods and limitations. *Progress in Physical Geography* 21, 530-548.

WMO (World Meteorological Organization). 1983. *Guide to Climatological Practices*, 2nd Edition. WMO 100. Geneva, Switzerland.

Zhang, X., G. Hegerl, F.W. Zwiers, and J. Kenyon, 2005. Avoiding inhomogeneity in percentile-based indices of temperature extremes. *J. Climate,* 18, 1641-1651.

Zhang, X. 2004. Climate Change Indices. **http://cccma.seos.uvic.ca/ETCCDMI/**.