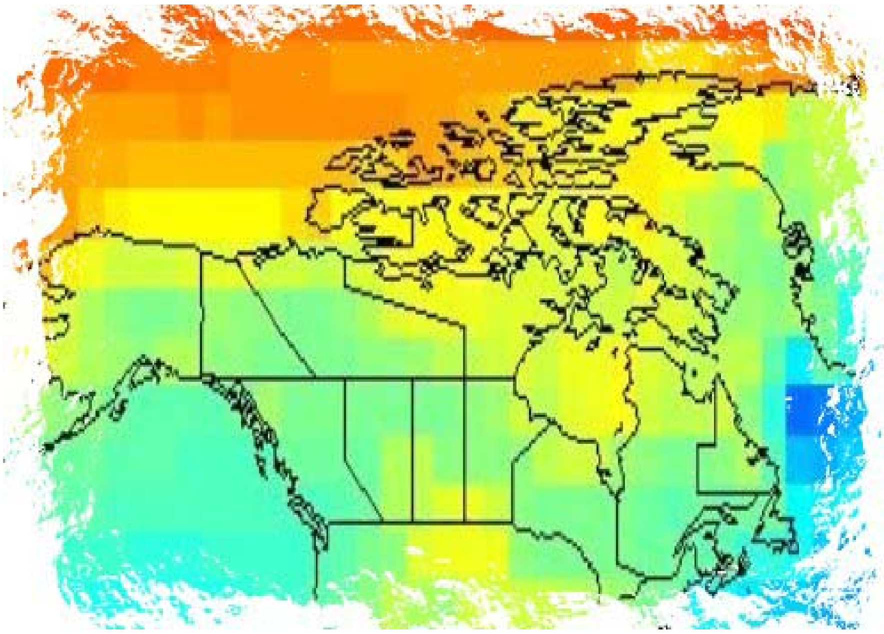
Climate Change and Canada's National Parks





A USERS MANUAL

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Environment Canada Environnement Canada
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Climate Change Scenarios for Canada's National Parks

Scénarios de changement climatique pour les parcs nationaux du Canada

This users manual was prepared for Parks Canada by the Adaptation & Impacts Research Group (AIRG), Environment Canada and the Faculty of Environmental Studies (FES), University of Waterloo. This manual is the second in a series of collaborative technical reports on climate change and Canada's national park system.

This manual refers to climate change scenario data for existing and proposed* national parks contained on the CD-ROM entitled **Scenarios & Impacts: Climate Change and Canada's National Park System.**

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** The proposed national parks in the study were those in public discussion at the time the analysis was done, but at the time of final editing only Bathurst Island, East Arm of Great Slave Lake, Gulf Islands, Manitoba Lowlands, Mealy Mountains, Torngat Mountains and Ukkusiksalik remain under consideration. Wolf Lake results are included for information only and do not reflect the pursuit of this area by Parks Canada for a potential national park.*

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List of Acronyms

CCIS	Canadian Climate Impacts and Scenarios
CCSR	Centre for Climate System Research
CGCM	Coupled General Circulation Model
CSIRO	Commonwealth Scientific & Industrial Research Organization Model
GCM	Global Climate Model
GHG	Greenhouse Gases
GFDL	Geophysical Fluid Dynamics Laboratory
ECHAM	European Centre Hamburg Model
HadCM	Hadley Centre Coupled Ocean-Atmosphere Climate Model
IPCC	Intergovernmental Panel on Climate Change
LARS	Long Ashton Research Station
TAR	Third Assessment Report
VIA	Vulnerability, Impact and Assessment

Executive Summary

Nearly a century after the link between increasing concentrations of greenhouse gases from industrial emissions and a changing global climate system was first theorized, the United Nations Intergovernmental Panel on Climate Change (IPCC) declared that 'the balance of scientific evidence indicates a discernable human influence on the global climate' (1995). The magnitude of climate change is expected to be similar to that of the transition from the last glacial to interglacial period (about 5°C), yet occur during a single century, rather than over a few thousand years. A screening level impact assessment (Scott and Suffling, 2002) concluded that the implications of climate change for Canada's national parks are considerable.

An important component of any response by park officials to climate change will be the use of climate change scenarios to examine the potential climate change impacts and the implications of adaptation strategies. Most climate change scenarios used by the vulnerability, impact and adaptation (VIA) researchers are computer-generated descriptions of plausible scientific future climates, which describe possibilities rather than provide predictions. There are many climate change scenarios. This report describes the development of three types of climate change scenarios (scenarios from global climate models (GCMs), bioclimate scenarios and daily scenarios) for use by Parks Canada.

Understanding the differences between the three types of scenarios and interpretability of their output data is often difficult for first-time users. **Climate Change Scenarios for Canada's National Parks** is a plain-language manual designed to guide people through the selection and interpretation of the three types of climate change scenarios listed above. Prepared for Parks Canada, by the Adaptation & Impacts Research Group (Environment Canada) and the Faculty of Environmental Studies (University of Waterloo), this manual is the second in a series of collaborative technical reports on climate change and Canada's national park system. The manual addresses the theoretical and practical foundations of each climate change scenario, outlines how to retrieve output data from each scenario from the CD-ROM, and includes hands-on exercises to assist in their interpretation.

Chapter one provides an introduction to the manual. Some of the ecological and tourism-related challenges posed by climate change for management of Canada's system of national parks in the 21st Century are explored in its first section. The three types of climate change scenarios (GCM, bioclimate and daily scenarios) are introduced in the second half of Chapter one. Each type of climate change scenario is defined here, and the spatial and temporal characteristics that distinguish each type are described. For example, GCM scenarios operate at the global scale because climate change impacts are examined at regional and local levels. GCM scenarios are often downscaled (spatially and temporally) for use in impact assessments. Two approaches used to downscale GCM-based climate change scenarios to local climate stations are described in this manual (bioclimate and daily scenarios with the LARS weather generator). An indication of the intrinsic relationship between the three types of climate change scenarios is also included in this chapter.

The development, characteristics and use of GCM-based climate change scenarios are the focal points of Chapter two. GCM scenarios are the most commonly employed type of climate change scenario and provide the basis for all three climate change scenario types. They are widely accepted as the primary means for making plausible projections about the magnitude of future climate change. The first part of Chapter two distinguishes between GCMs and GCM scenarios. The two are in fact different, although the terms are often used interchangeably. General circulation models, or global climate models, are three-dimensional models of the earth's climatic system in which the physical processes governing climate are represented in mathematical terms. GCM-based climate change scenarios simulate how climate may change in the future in response to changing levels of greenhouse gases in the atmosphere, based largely on assumptions about such factors as global population and economic growth and energy use. These factors are integrated into different *emissions scenarios,* which are used to drive, or 'force' a GCM to determine the climate response. IS92 and SRES are the two families of emissions scenarios currently employed by the IPCC for climate change impact assessments. The assumptions for both families are summarized in this chapter.

A great deal of uncertainty surrounds the selection of specific scenarios for use in a climate change impact assessments. In the second part of Chapter two, this uncertainty is addressed. Government agencies and research organizations around the world that are actively involved in the development of GCMs; there were eight GCMs available through the IPP as the time this manual was prepared: Coupled General Circulation Model (CGCM - Canada); Hadley Centre Coupled Ocean-Atmopshere Model (HadCM – United Kingdom); European Centre/Hamburg Model (ECHAM – Germany); Centre for Climate System Research (CCSR-98 – Japan); Commonwealth Scientific and Industrial Research Organizational Model (CSIRO – Australia); and Geophysical Fluid Dynamics Laboratory Model (GFDL – United States). However, each of these general circulation models has different spatial characteristics and includes numerous IS92 and SRES emissions scenarios, which amounts to more than 100 climate change scenarios for researchers to choose from for use in an impact assessment. As a general rule of thumb, the IPCC recommends that multiple climate change scenarios, spanning a range of possible future conditions, be used in impact assessments. Scatter plots are commonly used to determine which scenarios to select. Scatter plots represent annual mean temperature change and annual precipitation change, and are graphical tools used to illustrate the range of future climate scenarios. A series of scatter plots are presented in this chapter to help clarify the range of future climate scenarios projected by different climate change scenarios.

The final section of Chapter two takes the reader through a hands-on exercise. The step-by-step instructions provide guidance in the selection of climate change scenarios for a hypothetical climate change impact assessment of Riding Mountain National Park. The exercise uses data contained in a series of Microsoft Excel worksheets provided on the accompanying CD-ROM. GCM scenario data for each of Canada's existing and proposed national parks is also provided on the CD-ROM.

Chapter three describes the second type of climate change scenario provided by this manual – bioclimate scenarios. Similar to the previous chapter, the first part of this chapter describes the characteristics of bioclimate scenarios, focusing on the use of GCM output data to transform bioclimate profile data. Profiles are comprised of individual climate variables and related indices that are derived from a 30-year average of site-specific daily climate observations from across Canada. To provide future projections of different aspects of the bioclimate, GCM-derived climate change scenario output is applied to it. Since this type of climate change scenario has an advantage over the GCMs in that it provides a finer spatial resolution for impact assessments, a reference list of climate stations near each existing and proposed national park is provided in the report. The proximity of each national park to one of the Canadian reference climate stations varies considerably. Also described in this section are the four categories of bioclimate data that are available for use by Parks Canada in impact assessments – temperature, precipitation, degree-days and water availability.

The latter part of Chapter three describes the method for using bioclimate data. The step-by-step instructions provide guidance in accessing bioclimate data from the Canadian Climate Impacts and Scenarios (CCIS) Project website. Using the Dauphin, Manitoba climate station as an illustrative example, the exercise depicts projected changes in temperature, precipitation and degree days for Riding Mountain National Park in the 2050s (2040-69) with respect to the 1961-90 normal.

The last chapter in the manual examines daily scenarios. Daily scenarios are a temporally downscaled version of the GCM-derived scenario output data. Daily scenario data is derived by applying climate change scenarios at the monthly time scale to a statistical representation of observed climate data in stochastic weather generator. Stochastic weather generators are statistical tools that simulate daily weather data for a suite of climate variables at a given site. They are a means to generate 'synthetic' (simulated) weather that is statistically similar to observed climate data from climate stations and can also be used to derive daily scenario data from climate change scenarios at the monthly time scale.

They are inexpensive computational tools that can provide site-specific multi-year climate change scenarios at a daily temporal level. The technical process of generating synthetic weather with the Long Ashton Research Station (LARS) weather generator, a specially designed software program from the University of Bristol (UK) is described in section one. A hands-on exercise completes this chapter. This type of scenario data is useful in situations that rely on climatic thresholds at a very small temporal scale, such as forest fire season, berry producing season, recreational season length and drought conditions. A sample data set of temperature, precipitation and frost and growing degree days are provided again for Riding Mountain national Park, although data for Prince Edward Island and Simirlik National Parks are also provided for comparison. Daily scenario data for other national parks can be generated by running the GCM scenario output data through the LARS weather generator program; this program is available for downloading from the CCIS Project website.

An appendix of additional resources is provided at the end of the manual. A number of journal publication, government report and Internet website citations about the three types of climate change scenarios are provided in the report. However, it is important to note that these resources are generally more technical in nature than the manual.

Sommaire

Pratiquement un siècle après l'établissement d'un lien entre l'augmentation des concentrations de gaz à effet de serre provenant des émissions industrielles et le changement du système climatique de la planète, le Groupe intergouvernemental d'experts sur l'évolution du climat (GIEC) des Nations Unies a déclaré que « la prépondérance de la preuve indique qu'il existe une influence humaine évidente sur le climat du globe » (1995). On s'attend à ce que le changement climatique atteigne une ampleur similaire à celle de la transition de la dernière époque glaciaire à l'époque interglaciaire, le tout concentré sur un siècle plutôt que sur quelques milliers d'années. Une évaluation préliminaire a permis de conclure que les conséquences du changement climatique pour les parcs nationaux du Canada sont énormes.

Un élément important de la réaction des responsables des parcs face au changement climatique sera l'utilisation des scénarios de changement climatique pour examiner les répercussions potentielles et les conséquences des stratégies d'adaptation. La plupart des scénarios de changement climatique utilisés par les chercheurs spécialisés en vulnérabilité, impacts et adaptation (VIA) sont des descriptions créées par ordinateur de climats futurs reposant sur des données scientifiques plausibles, qui sont des possibilités plutôt que des prévisions. Il existe de nombreux scénarios de changement climatique. Le présent rapport décrit l'élaboration de trois types de scénario (modèles de circulation générale (MCG), scénarios bioclimatiques et scénarios quotidiens) qu'utilisera Parcs Canada.

Il est parfois difficile pour les personnes qui utilisent les scénarios pour la première fois de comprendre la différence entre les trois types et d'interpréter les données qui en découlent. **Scénarios de changement climatique pour les parcs nationaux du Canada : guide de l'utilisateur** est un document de vulgarisation visant à guider les personnes dans le choix et l'interprétation des trois types de scénario de changement climatique énumérés ci-dessus. Le guide traite des fondements théoriques et pratiques de chaque scénario, explique comment tirer des données de chaque scénario figurant sur le CD-ROM et comprend des exercices pratiques pour en faciliter l'interprétation.

Le chapitre 1 renferme une introduction. La première partie examine certains des défis liés à l'écologie et au tourisme que pose le changement climatique pour la gestion du réseau des parcs nationaux du Canada au XXI^e siècle. La deuxième partie du chapitre 1 présente les trois types de scénario de changement climatique (MCG, scénarios bioclimatiques et scénarios quotidiens). On y trouve une définition de chaque type ainsi que les caractéristiques spatiales et temporelles de chacun. Par exemple, les scénarios de MCG sont utilisés à l'échelle mondiale parce que les répercussions du changement climatique sont examinées aux niveaux régional et local. L'échelle de ces scénarios est souvent réduite (spatialement et temporellement) aux fins de l'évaluation des répercussions. Le guide décrit deux approches utilisées pour réduire l'échelle des scénarios de changement climatique fondés sur les MCG à des stations climatiques locales (scénarios bioclimatiques et quotidiens avec le générateur de données météorologiques de la Long Ashton Research Station (LARS)). Le premier chapitre du guide explique également le lien intrinsèque entre les trois types de scénario de changement climatique.

L'élaboration, les caractéristiques et l'utilisation des scénarios de changement climatique fondés sur les MCG sont décrites au chapitre 2. Les scénarios de MCG sont les plus couramment utilisés et servent de fondement aux trois types de scénario. Ils sont largement reconnus comme étant le principal moyen de faire des projections plausibles quant à l'importance du changement climatique à venir. La première partie du chapitre 2 fait la distinction entre les MCG et les scénarios de MCG. Ces deux notions sont bel et bien différentes même si on les utilise souvent l'une pour l'autre. Les modèles de circulation générale sont des modèles tridimensionnels du système climatique de la planète où les processus physiques qui régissent le climat sont représentés en termes mathématiques. Les modèles de climat du globe sont des scénarios de changement climatique fondés sur les MCG qui simulent les changements climatiques possibles en fonction de l'évolution du niveau des gaz à effet de serre dans l'atmosphère, en partant surtout d'hypothèses concernant des facteurs comme l'augmentation de la population mondiale, le développement économique et la consommation d'énergie. Ces facteurs sont

intégrés dans différents *scénarios d'émissions* qui sont utilisés pour inciter ou « forcer » un MCG à déterminer la réaction climatique. IS92 et SRES sont les deux types de scénarios d'émissions actuellement utilisés par le GIEC pour évaluer les répercussions du changement climatique. Les hypothèses concernant les deux types sont résumées au chapitre 2.

Le choix de scénarios particuliers pour évaluer les répercussions du changement climatique s'accompagne de beaucoup d'incertitude. Dans la deuxième partie du chapitre 2, il est question de cette incertitude. Un certain nombre d'agences gouvernementales et d'organismes de recherche de par le monde s'emploient activement à élaborer des MCG. Au moment où le guide a été rédigé, le GIEC offrait huit MCG : le modèle couplé de circulation générale (MCCG – Canada); le modèle couplé océan-atmosphère du Hadley Centre (HadCM – Royaume-Uni); le modèle du Centre de recherches climatiques de l'Allemagne/Hambourg (ECHAM – Allemagne); le modèle du Centre japonais de la recherche sur les systèmes climatiques (CCSR-9 – Japon); le modèle de la Commonwealth Scientific and Industrial Research Organization (CSIRO – Australie); et le modèle du Geophysical Fluid Dynamics Laboratory (GFDL – États-Unis). Toutefois, chacun de ces modèles de circulation générale a des caractéristiques spatiales différentes et comprend de nombreux scénarios d'émissions IS92 et SRES, ce qui oblige les chercheurs à choisir parmi plus de 100 scénarios de changement climatique pour faire une évaluation des répercussions. En règle générale, le GIEC recommande d'utiliser pour l'évaluation des répercussions de nombreux scénarios de changement climatique présentant un éventail de conditions futures possibles. Les diagrammes de dispersion sont couramment utilisés pour déterminer les scénarios qu'il convient de choisir. Ces diagrammes représentent le changement de la température moyenne annuelle et la variation des précipitations annuelles, et sont des outils graphiques qui permettent d'illustrer l'éventail des scénarios climatiques futurs. Le chapitre 2 renferme une série de diagrammes de dispersion qui permettront de préciser l'éventail de scénarios climatiques futurs prévus par différents scénarios de changement climatique.

La dernière partie du chapitre 2 propose un exercice pratique au lecteur. Les directives étape par étape aident à choisir les scénarios de changement climatique pour une évaluation hypothétique des répercussions du changement climatique au parc national du Mont-Riding. L'exercice utilise les données qui figurent sur une série de feuilles de travail Microsoft Excel qu'on trouvera sur le CD-ROM. Les données du scénario de MCG pour chaque parc national proposé et existant du Canada figurent également sur le CD-ROM.

Le chapitre 3 décrit le deuxième type de scénario de changement climatique qui figure dans le guide : les scénarios bioclimatiques. Comme pour le chapitre 2, la première partie du chapitre 3 décrit les caractéristiques des scénarios bioclimatiques en mettant l'accent sur l'utilisation des données des MCG pour transformer les données du profil bioclimatique. Les profils se composent de différentes variables climatiques et d'indices connexes tirés d'observations climatiques quotidiennes propres à un lieu et échelonnés sur une moyenne de 30 ans dans l'ensemble du pays. Pour obtenir des projections de différents aspects du bioclimat, on lui applique des données des scénarios de changement climatique tirés des MCG. Comme ce type de scénario de changement climatique a un avantage par rapport aux MCG en ce qu'il fournit une résolution spatiale plus fine pour les évaluations des répercussions, le rapport renferme une liste des stations climatiques proches de chaque parc national existant et proposé. La proximité de chaque parc national par rapport à une station climatique canadienne varie considérablement. Cette partie du chapitre 3 décrit également les quatre catégories de données bioclimatiques que Parcs Canada peut utiliser pour évaluer les répercussions – températures, précipitations, degrés-jours et hydraulicité.

La dernière partie du chapitre 3 décrit la méthode d'utilisation des données bioclimatiques. Les directives étape par étape expliquent comment consulter les données bioclimatiques du site Web du Projet canadien des scénarios de répercussions climatiques (PCSRC). En utilisant la station climatique de Dauphin (Manitoba) à titre d'exemple, l'exercice décrit les changements prévus de température, de précipitation et de degré-jour au parc national du Mont-Riding dans les années 2050 (2040 à 2069) par rapport à la période de référence (1961-1990).

Le dernier chapitre du guide porte sur les scénarios quotidiens. Ces derniers sont une version à échelle réduite dans le temps des données des scénarios tirés des MCG. Les données des scénarios quotidiens sont obtenues par l'application des scénarios de changement climatique établis au mois à une représentation statistique des données climatologiques observées dans un générateur de données météorologiques stochastiques. Ce dernier est un outil statistique qui simule des données météorologiques quotidiennes pour une série de variables climatiques à un endroit donné. C'est une façon de produire des données météorologiques « synthétiques » (simulées) qui sont statistiquement semblables aux données observées aux stations climatiques et d'obtenir des données de scénarios quotidiens à partir des scénarios de changement climatique produits mensuellement. Il s'agit d'un outil de calcul peu coûteux qui peut fournir quotidiennement des scénarios de changement climatique propres à un lieu sur plusieurs années. Le processus technique de production de données météorologiques synthétiques au moyen du générateur de données météorologiques de la Long Ashton Research Station (LARS), programme logiciel expressément conçu par l'Université de Bristol (Royaume-Uni), est décrit dans la première partie du chapitre. Celui-ci se termine par un exercice pratique. Ce type de données tirées de scénarios est utile dans des situations qui reposent sur des seuils climatiques à une très petite échelle temporelle comme la saison des feux de forêt, la saison des petits fruits, la saison des activités récréatives et les conditions de sécheresse. Des données-échantillons de température, de précipitation et de gel et des données correspondant à l'augmentation des degrés-jours sont fournies pour le parc national du Mont-Riding en plus de données pour les parcs nationaux de l'Île-du-Prince-Édouard et Simirlik qui sont fournies à des fins de comparaison. Les données des scénarios quotidiens pour d'autres parcs nationaux peuvent être obtenues par l'application des données du scénario de MCG au programme de générateur de données météorologiques de la LARS; ce programme peut être téléchargé à partir du site Web du PCSRC.

Une annexe renfermant des ressources additionnelles se trouve à la fin du guide. Un certain nombre de publications, de rapports gouvernementaux et d'extraits de sites Web sur les trois types de scénario de changement climatique sont également mentionnés dans le rapport. Toutefois, il importe de noter que ces ressources sont en général plus techniques que le guide lui-même.

1.0 Introduction to the Manual

Naturally-occurring, radiatively-active gases, the so-called *greenhouse gases (GHG*), in the Earth's atmosphere (*e.g.,* water vapour, carbon dioxide, methane, nitrous oxide) trap long wave energy radiated from the surface and atmosphere, which results in the global mean near-surface temperature being about 33°C warmer than it would otherwise be. Life as we currently known it would not be possible without the warming influence of this natural 'greenhouse effect.'

The theory that industrial emissions of these greenhouse gases would influence the global climate system was first formulated by the Swedish chemist Svante Arrhenius over 100 years ago. Arrhenius (1896) concluded that the world's supply of coal and other fossil fuel resources would be exhausted before there would be an appreciable human influence on global climate. However, this is not the case. In 1995, nearly a century later, the United Nations Intergovernmental Panel on Climate Change (IPCC) declared that 'the balance of scientific evidence indicates a discernible human influence on the global climate' (IPCC, 1996) The magnitude of climate change is expected to be similar to that of the transition from the last glacial to interglacial period (about 5°C), yet to occur during a single century, rather than over a few thousand years. The implications for human and environmental systems in park management are considerable.

1.1 Climate Change and National Parks

Climate change was identified as a significant stressor by seven national parks in Canada's *The State of the National Parks Report* (1997). A screening level impact assessment (Scott and Suffling, 2000), conducted by the Adaptation & Impacts Research Group (Environment Canada) and the University of Waterloo (Faculty of Environmental Studies) in collaboration with Parks Canada, further examined the implications of climate change for Canada's 38 national parks. The results of this assessment are summarized by region in Figure 1.

Climate change will pose a number of ecological and tourism-related challenges for park management in Canada. The first challenge relates to conservation. Climate change embodies a simultaneous threat and opportunity to different species and ecological communities within the national parks system. It is projected that as individual species respond to climate change, current ecological communities will begin to disassemble and 're-sort' into new assemblages. The dynamic biogeography brought about by global climate change will effectively alter the 'rules' of ecological conservation. The current system of conservation lands in Canada was established, however, to protect ecosystems and species according to their current distributions. The mandate of Parks Canada is to conserve representative examples of Canada's biodiversity for perpetuity. The spatial displacement of ecosystems and species over varying time scales, will pose a serious challenge to maintaining the ecological integrity of a representative sample of the nation's biodiversity.

The second challenge for park management is related to tourism in national parks. It is expected that climate change will alter the recreational opportunities and visitation patterns within and among national parks. Changes in these factors will significantly influence the viability of tourism and recreational activities in parks and the stability of local economies dependent on park-based tourism. As it is, Canada's system of national parks represents a major tourism resource. Tourism expenditures attributable to national park visits exceeded $1.2 billion in 1994/95 (Parks Canada, 1998).

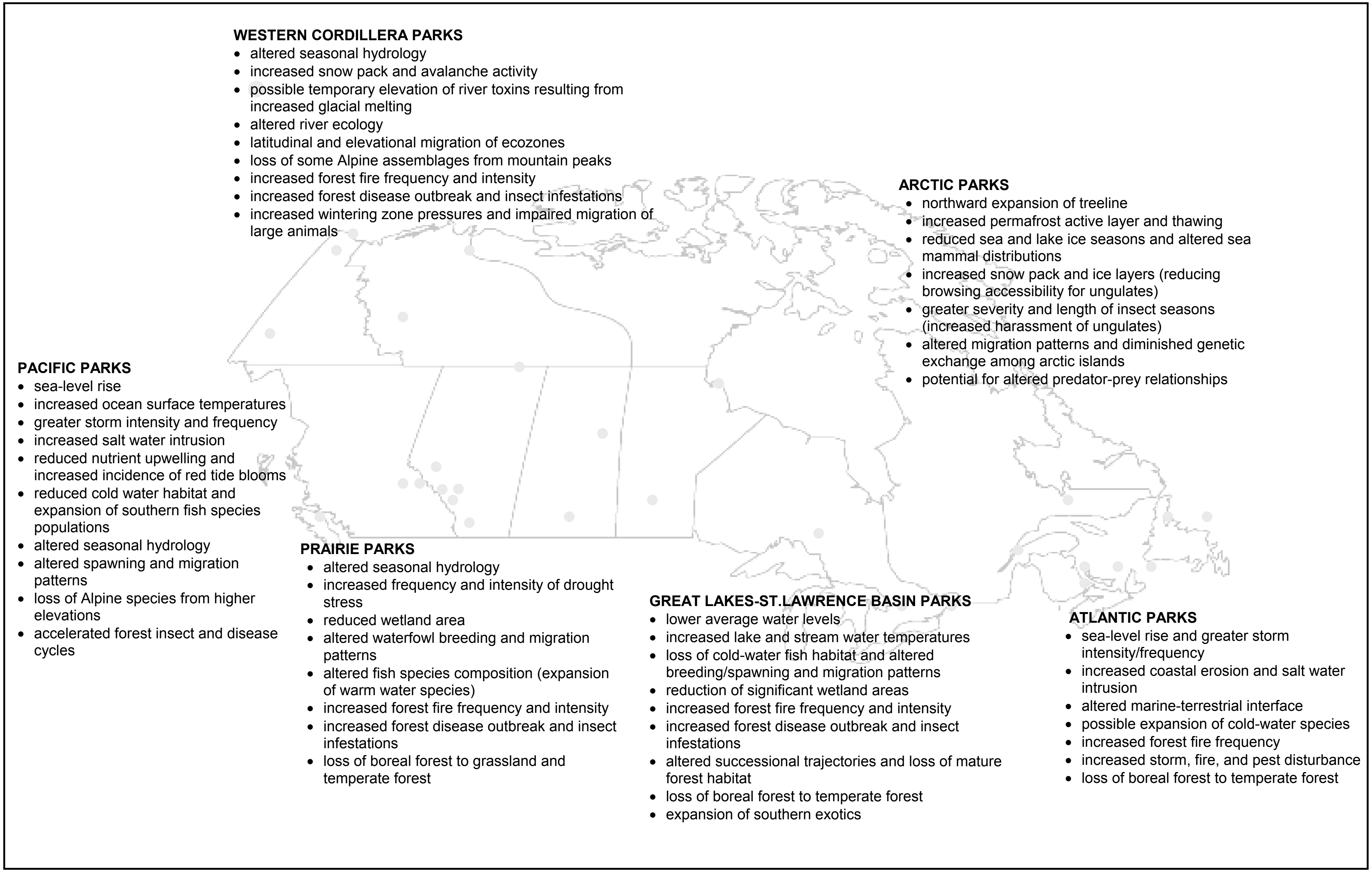


Figure 1. Regional Cross-Cutting Climate Change Impacts in Canada's National Parks
Source: Summarized from Scott and Suffling, 2000

Two recreation dimensions highly sensitive to climatic changes are the length of operating seasons and the quality of tourism experiences. Any changes in season length would have considerable implications for both the short-term and long-term viability of tourism and recreation activities. Winter activities, such as cross-country skiing and snowmobiling, as well as the businesses and destination areas associated with them are likely to be negatively impacted. Recent assessments (Scott *et al*., 2002) of the tourism industry in central Ontario suggest that the ski seasons could be reduced by 50% as early as the 2020s. Alternatively, warmer temperatures could also be beneficial. Season lengths of certain recreational activities (*e.g.,* camping) could be extended and the occurrence of other activities could be possible in parks where the activities are currently not as common. However, locally important tourism resources, such as Athabasca Glacier in Banff National Park or polar bears in Wapusk National Park will likely be at risk. The possibility of economic benefits may occur at the expense of increased environmental deterioration, as destinations will likely host more visitors for longer periods of time, the quality of recreation resources (*e.g.,* water quality) and experiences may decline, and increased inter-sectoral resource conflicts may become more pronounced.

1.2 Climate Change Scenarios

An important component of any response by park officials to climate change will be the use of climate change scenarios to examine the potential climate change impacts and the implications of adaptation strategies. Most climate change scenarios are computer-generated descriptions of scientifically plausible future climates that describe ***possibilities*** rather than ***predictions***, which suggest a degree of certainty. There are three types of climate change scenarios for use by Parks Canada: 1) scenarios from global climate models (GCMs), 2) bioclimate scenarios, and 3) daily scenarios.

Scenarios from global climate models

GCMs are three-dimensional computer models that represent mathematically, as far as is possible, the physical processes of the atmosphere, oceans, cryosphere and land surface and the relationships and feedbacks between them. Changes in atmospheric composition (*e.g.,* changes in the concentration of the greenhouse gases) affect the radiation balance of the Earth-atmosphere system and result in changes in climate, such as altered temperature and precipitation patterns. It is possible to simulate how climate may change in the future by running experiments in which atmospheric composition changes in response to different greenhouse gas emissions scenarios. GCMs generally work well at the global, hemispheric and continental scales and at seasonal timescales or longer, but in general, the finer the spatial and temporal resolutions the less confidence there is in their output. This means that instead of using GCM output directly to represent current or future climate conditions, it is necessary to construct climate change scenarios from this output by calculating the changes between the model's representation of the baseline period (currently 1961-1990) and a future time period. The climate change scenarios are then applied to observed climate data in order to obtain a representation of future climate conditions. Climate change scenarios for Canada can be obtained from the Canadian Climate Impacts and Scenarios (CCIS) Project website (http://www.cics.uvic.ca/scenarios), whilst the IPCC Data Distribution Centre (http://ipcc-ddc.cru.uea.ac.uk) provides climate change scenarios at the global scale.

Bioclimate scenarios

Bioclimate scenarios, which provide projections of different aspects of the bioclimate (*e.g.,* growing degree days, water deficits) at individual sites, are also available from the CCIS Project website for a number of sites across Canada. Whilst they provide site-specific future climate information, the bioclimate scenarios have been obtained using the standard scenario practice of applying coarse-scale GCM-derived climate change scenarios to observed climate data, rather than developing statistical relationships between the large-scale (*i.e.,* GCM) climate and local weather in the process known as downscaling.

Daily scenarios

Although GCMs operate and provide information at the daily time scale they are considered to be less reliable at this temporal resolution. One way of obtaining daily data for a particular climate scenario is to use a statistical model known as a stochastic weather generator. These models can be used to generate synthetic daily weather data for a particular climate scenario by combining the projected monthly or seasonal changes in temperature and precipitation, for example, with the statistical characteristics of the current climate at the site in question.

GCMs provide output for the entire globe on a grid box basis, with the grid boxes varying in size depending on which GCM being used. The bioclimate scenarios and daily scenarios have been obtained by taking the information from the grid box within which the site is located (or information averaged over a number of grid boxes) and applying it to observed weather data. So although the bioclimate and daily scenarios appear to be at fine spatial resolution, this is because the observed weather data is providing the local detail.

1.3 Objectives and Outline

This manual is a plain-language document designed to guide people through the selection and interpretation of the three types of climate change scenarios listed above. The manual has three objectives:

1) it addresses the theoretical and practical foundations of each climate change scenario type,
2) it outlines how to retrieve output data from each type of climate change scenario, and
3) it includes hands-on exercises to assist in the interpretation of output data for each type of climate change scenario.

This manual is divided into four chapters. Chapters two through four, respectively, are devoted to the three types of climate change scenarios. Background information on the characteristics of each scenario are provided, along with a hands-on exercise demonstrating how to obtain and interpret associated data. For the purposes of simplicity, climate change scenarios for Riding Mountain National Park are used in the hands-on exercises. The appendix of additional, yet slightly more technical, information about climate change scenarios is provided at the end of this manual.

2.0 GCM Scenarios

Climate change scenarios derived from GCMs are by far the most commonly employed type of climate change scenario and provide the basis for all three of the climate change scenario types introduced in Chapter one of this manual. They are widely accepted as the primary means for making scientifically plausible projections about the magnitude of future climate change and for exploring the consequences of different greenhouse gas and aerosol emissions scenarios. They have been and are routinely used in climate change vulnerability, impacts and adaptation assessments.

2.1 What are GCMs?

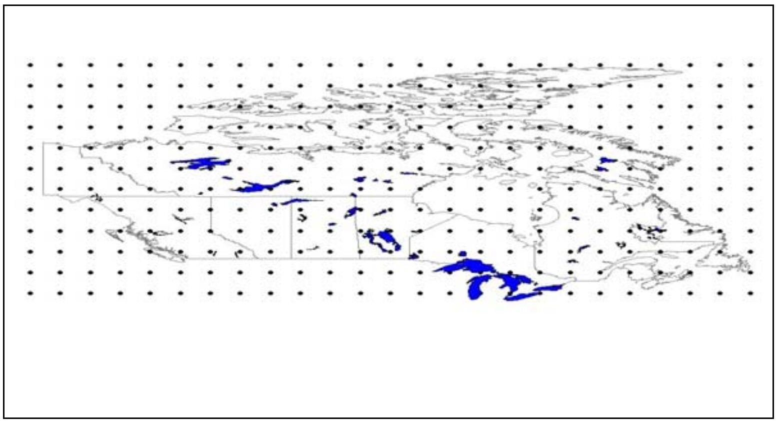
Global climate models (GCMs), also referred to as general circulation models, are three-dimensional models of the earth's climatic system in which the physical processes governing climate are represented in mathematical terms. The most recent generation of GCMs is able to simulate historical (from about 1850 onwards) as well as future climate conditions by modelling the climate response to changes in atmospheric composition, which affect the energy balance of the Earth-atmosphere system.

The degree to which a GCM can simulate the observed climatic records hinges on the level of understanding of the processes that govern the climate system and also on available computing resources. Over the last three decades, improvements in the understanding of the individual atmospheric, oceanic and associated processes and the tremendous increase in the power of computer technology have advanced the development of climate models. In the early 1970s and 1980s, the representation of complex atmospheric and oceanic processes was limited to a certain extent by computing power; three-dimensional models of the atmosphere and ocean were developed separately. By the late 1990s, scientific and computer advances enabled atmospheric and oceanic models to be integrated in a process known as coupling. GCMs now include a range of atmospheric (*e.g.,* radiation absorption, cloud formation, aerosols), oceanic (*e.g.,* heat and salt transportation, formation of sea ice) and related (*e.g.,* water and carbon cycle, vegetation evapotranspiration) processes and feedbacks. A GCM, operating at a spatial resolution of about 3° latitude by 3° longitude (roughly 300 km by 300 km), will take about 260 days of CPU time on a CRAY X-MP computer to simulate 200 years of output for a particular climate change experiment.

2.2 What are GCM Scenarios?

Despite advances in model complexity, the output from GCM simulations does not have a sufficient spatial resolution to be used directly in climate change studies. Instead it is necessary to construct climate change scenarios based on the output. Scenarios derived from GCM output provide estimates of projected changes (with respect to a baseline or reference period) for a range of climate variables at a set of global grid points. Figure 2 illustrates the location of these grid points over Canada, as modelled by the first version of the Canadian coupled GCM, CGCM1.

Figure 2 - GCM grid points (CGCM1)



Earlier generations of GCMs were run in what is known as '*equilibrium'* mode. These GCMs were basically three-dimensional models of the atmosphere coupled to a very simple representation of the ocean. This meant that it was not possible to simulate time-dependent, or *'transient'*, climate change, since the complex role of the oceans, particularly in heat transport, was not represented. Instead these GCMs were used in climate change experiments examining the effect on climate of an instantaneous doubling (or quadrupling) of atmospheric CO_2 concentrations. These experiments, termed 'equilibrium' since the models were run until a stable, or equilibrium, climate was obtained, were run for $1\times CO_2$ and $2\times CO_2$ conditions and the difference between these two runs (known as the 'control' and 'perturbed' experiments, respectively) represented the magnitude of the climate response to the imposed forcing (*i.e.,* the climate change in response to a doubling of CO_2).

The most recent generation of GCMs is much more complex, with three-dimensional atmospheric models coupled to three-dimensional models of the ocean. In addition there are representations of sea ice, of the individual greenhouse gases, of the role of atmospheric aerosols and the land surface is much more complex than in earlier GCM generations. These 'warm start' transient GCMs are able to simulate climate over both the historical and future time periods and generally operate at a higher spatial resolution than the earlier equilibrium GCM experiments. Atmospheric composition can change on a year-by-year basis and so much more realistic experiments investigating the climate response to different greenhouse gas and aerosol emissions scenarios can be undertaken. Since the reliability and resolution of these GCMs are still generally insufficient for most applications, climate change scenarios are still constructed by calculating the change between a future time period and the baseline (currently 1961-1990) period, although these two time periods are taken from the climate change experiment of the GCM. This experiment simulates the change in climate over the historical as well as the future time period. For this generation of GCMs a control simulation also exists, but it has no role in climate change scenario construction since it represents conditions in which there is no change in atmospheric composition and so is used solely to determine the GCM's representation of 'natural' climate variability. All of the GCMs used in the IPCC Third Assessment Report were of the 'warm start' transient variety. The climate change scenarios discussed in this manual represent three future time periods, the 2020s (2010-2039), the 2050s (2040-2069) and the 2080s (2070-2099).

GCMs produce output on a grid box by grid box basis, but a model's ability to simulate current climate conditions is measured over a larger area. GCM-derived climate change scenario data for each national park are therefore based on an average of the grid boxes surrounding each reference climate station.

2.2.1 What are emissions scenarios?

In order to simulate how climate may change in the future in response to changing levels of greenhouse gases, we need to know how the emission of greenhouse gases will change. This will obviously depend on such factors as global population and economic growth and energy use. Scientific assumptions are made about the future state of these factors and integrated into a number of proposed different *emissions scenarios,* which are used to drive, or 'force' a GCM to determine an associated climatic response. In addition to the global warming effect of the greenhouse gases, atmospheric aerosols (*e.g.,* sulphate aerosols resulting from fossil-fuel combustion) generally result in regional cooling through their direct effects on radiation scattering and their indirect effects on clouds.

IS92 Scenarios

The first comprehensive set of emissions scenarios was proposed by Leggett *et al*. (1992) in the 1992 Supplement to the IPCC's First Assessment Report (IPCC, 1990). These six IS92 scenarios (IS92a to IS92f) made assumptions concerning future social, economic and technological conditions and thus the emissions of anthropogenic greenhouse gases into the atmosphere. The IS92a scenario is considered to be a *'business-as-usual'* scenario and was widely adopted by the climate modelling and impacts/ adaptation communities. The assumptions underlying this and the two other main IS92 scenarios are outlined in Table 1. At about the same time, the regional cooling role of atmospheric aerosols was recognised and incorporated into GCMs. Since this regional cooling effect is short-lived (these aerosols are washed out relatively quickly), two types of climate change experiments were undertaken with the IS92 emissions scenarios, namely one which considered greenhouse gases alone, and one which incorporated the aerosol effects in conjunction with greenhouse gas emissions. These are generally referred to as GG (or GHG) only experiments and as GA (or GHG+A) experiments, respectively. The GHG only experiments are considered by some scientists to better represent the magnitude climate change in the longer-term.

Table 1 - Comparison of IS92 Emission Scenario Assumptions

	Least impact on GHG emissions		***Highest impact on GHG emissions***
Factors	**IS92c**	**IS92a**	**IS92e**
Carbon dioxide	Emissions fall below 1990 levels	Business as usual	High emissions
Population	Growth declines (6.4 billion)	Increases (11.3 billion)	Moderate growth (11.3 billion)
Economy	Low growth (1.2% / year)	Moderate growth (2.3% / year)	High growth (3.0% / year)
Energy	Increase use of renewable energy resources	Mix of conventional and renewable energy resources	High fossil fuel availability; nuclear energy is phased out
Average global temperature increase	1°C (by 2050s)	2°C (by 2050s)	3.5°C (by 2050s)

Source: IPCC, 1992

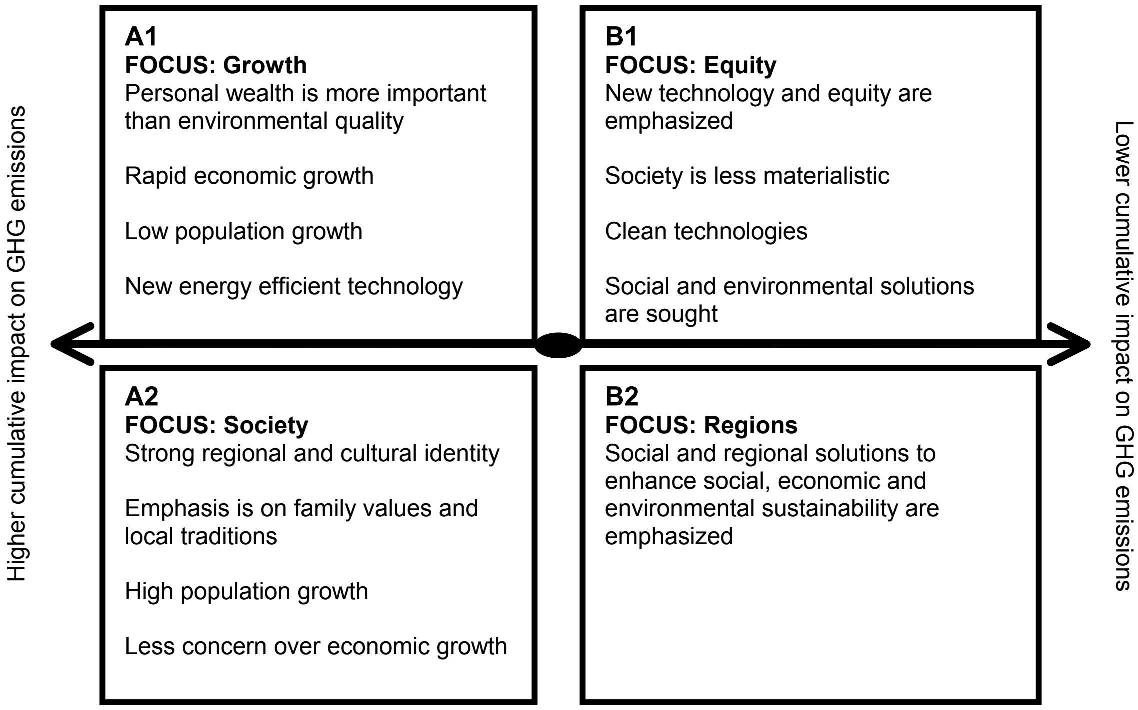
The IS92c and IS92e scenarios illustrate the extremes associated with projected minimum and maximum emissions of greenhouse gases. IS92c assumes that society takes action to curb greenhouse gas emissions by establishing control policies and switching to alternative fuels. IS92e assumes that new sources of fossil fuels are found that support their continued use. IS92a is considered middle-of-the-road or the 'business as usual' scenario. It assumes that society essentially maintains its current social, economic and technological directions. Scenarios IS92b and IS92f fall between those listed above - IS92b's assumptions place it between IS92c and IS92a, while IS92f is situated between IS92a and IS92e; IS92d is similar to IS92c.

SRES Emission Scenarios

For its Third Assessment Report (TAR), the IPCC commissioned a special report to develop a new set of emission scenarios. These scenarios, referred to as the SRES scenarios, were constructed to explore possible future changes in society, economics and technology with respect to their influence on greenhouse gas and aerosols out to 2100. Unlike the IS92 scenarios, SRES do not assume any additional greenhouse gas mitigation policies.

The SRES scenarios consist of four qualitative storylines (A1, B1, A2 and B2) - descriptions of the social, economic and technological characteristics of future world views. These storylines were then quantified by a number of socio-economic modelling groups in order to calculate the individual emissions scenarios. In all, a total of 40 SRES emissions scenarios were constructed, and consensus opinion has identified six marker, or illustrative, scenarios for use in impacts assessments. These include three scenarios from the A1 family, which focus on the development of different energy pathways (*i.e.,* A1FI – fossil-fuel intensive; A1B – a balanced scenario; and A1T – non-fossil fuel), and a single emissions scenario from each of the A2, B1 and B2 families. The assumptions behind the four scenario families are outlined in Figure 3. The global climate modelling community is still in the process of running climate change experiments with these six SRES marker scenarios. Unlike the IS92 scenarios, the aerosol effects have been incorporated directly into the SRES emissions scenarios and so there are no greenhouse gas only scenarios in this instance.

Figure 3 - Comparison of SRES Emission Scenario Family Assumptions



Source: Nakicenovic et al., 2000

Some global climate modelling centres have undertaken more than one experiment with the same emissions scenario – these are identical in all respects apart from the initial conditions. Averaging the results of these identical experiments to produce an ensemble-mean gives a better indication of the climate change signal in response to the imposed forcing since the averaging process damps the noise due to natural climate variability and concentrates the climate response. Whilst this ensemble-mean is useful for examining the climate change signal, the physical consistency of the scenario may have been reduced in the averaging process and so it should not be used in climate impacts models – the individual ensemble members, which contain the climate response as well as an element of natural climate variability are more reliable.

2.3 What GCM Scenarios are Available?

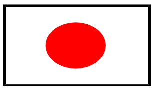
Government agencies and research organizations around the world have been actively involved in the development of GCMs over the last three decades. There are eight GCMs available at this time that have contributed to the IPCC. The names of each GCM are listed below, along with their country of origin and associated institution. Both Canada and the United Kingdom have several generations of GCMs.

CGCM: Coupled General Circulation Model
(Canadian Centre for Climate Modelling and Analysis – Environment Canada)
CGCMI: first generation; CGCM2: second generation

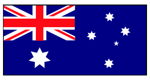
HadCM: Hadley Centre Coupled Ocean-Atmosphere Model

(United Kingdom Hadley Centre for Climate Prediction and Research)
HadCM2: second generation; HadCM3: third generation

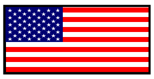
ECHAM: European Centre/Hamburg Model
(German Centre Research Group)



CCSR-98: Centre for Climate System Research
(University of Tokyo)



CSIRO-Mk2b: Commonwealth Scientific & Industrial Research Organization Model
(Commonwealth Scientific & Industrial Research Organization)



GFDL: Geophysical Fluid Dynamics Laboratory Model
(National Oceanic & Atmospheric Administration)

Table 2 summarizes the characteristics of each GCM, including the number of atmospheric and oceanic layers, and their spatial resolution (number and size of grid), and projected average global temperature increase by the 2050s.

Table 2 - GCM Comparisons

GCM	Atmospheric Resolution (lat° X long°)	Number of atmospheric layers	Ocean Resolution (lat° X long°)	Number of ocean layers	Average global increase by 2050s (°C)
CGCM1	3.75 x 3.75	10	13 x 35	29	2.7
CGCM2	3.75 x 3.75	10	13 x 35	29	N/a
HadCM2 and 3	2.5 x 3.75	19	20 x 35	20	1.7
ECHAM4	2.8 x 2.8	19	18 x 47	11	1.3
CCSR-98	5.6 x 5.6	20	9 x 24	17	2.4
CSIRO-Mk2b	3.2 x 5.6	9	3.2 x 5.6	21	2.0
GFDL	4.5 x 7.5	9	4.5 x 3.7	12	2.2

Each of these GCMs has undertaken a number of climate change experiments from which climate change scenarios have been constructed. Table 3 summarizes the range of climate change scenarios available for each GCM and for which data is provided on the companion CD-ROM. Each scenario provides projections of future climate conditions for the three 30-year time periods (2020s, 2050s and 2080s) with respect to the 1961-90 baseline. This means that there are over 114 scenarios available to researchers for use in climate change impact assessments.

Table 3 - Comparison of GCM Scenario Availability

CGCM1	CGCM2	HadCM2	ECHAM4	CCSR-98	CSIRO-Mk2b	GFDL
ga1	ga1	gg1	gg1	gg1	gg1	gg1
ga2	ga2	gg2	ga1	ga1	ga1	ga1
ga3	ga3	gg3			A11	
gax	gax	gg4			A21	
	A21	ggx			B11	
	A22	ga1			B21	
	A23	ga2				
	A2X	ga3				
	B21	ga4				
	B22	gax				
	B23					
	B2X					

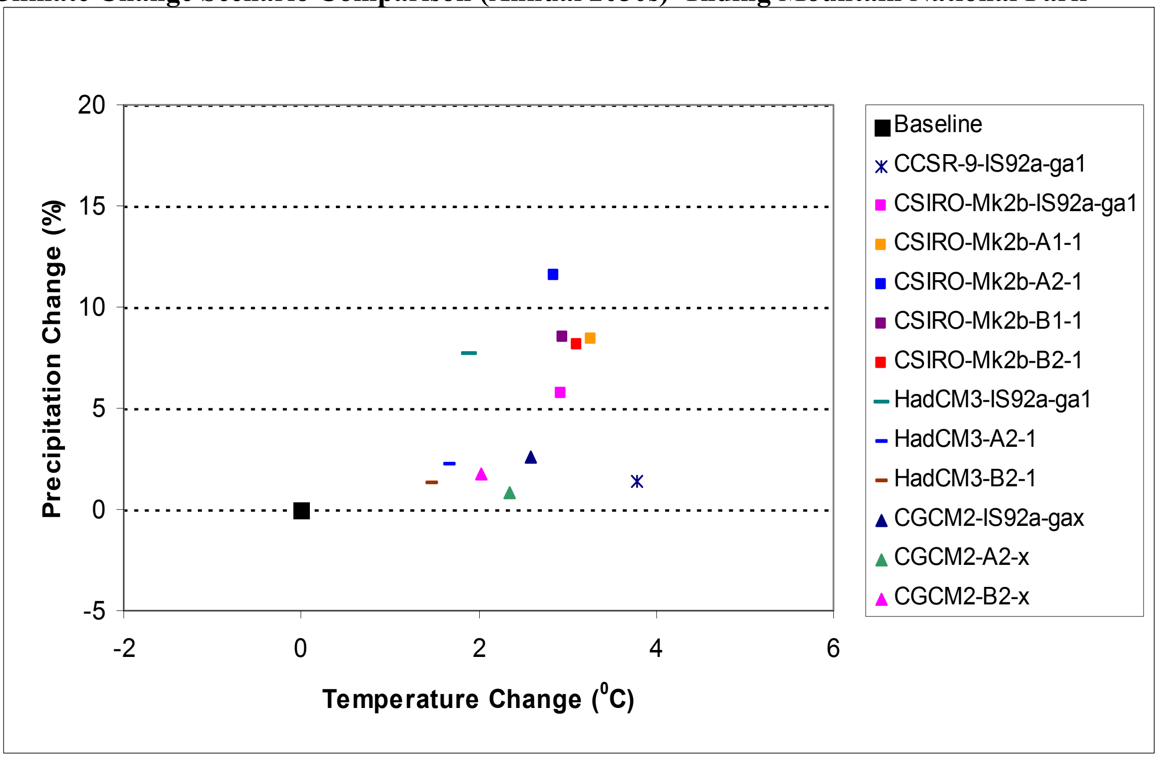
Note: X – the ensemble mean

2.4 How do I Choose Which GCM-based Scenario to Use?

A common question among climate change impact researchers is 'which scenarios should I use?" The thought of over 100 scenarios[1] is quite overwhelming. The IPCC recommends that researchers apply multiple scenarios in their impact assessments, choosing those that span a range of possible future conditions. In addition, the IPCC recommends that, at the very least scenarios produced from two different GCMs, (*e.g.*, CGCM and HadCM) be used. If it is impractical to use a wide range of scenarios, then it is wise to select those which illustrate the extreme range of projected changes in the region being examined.

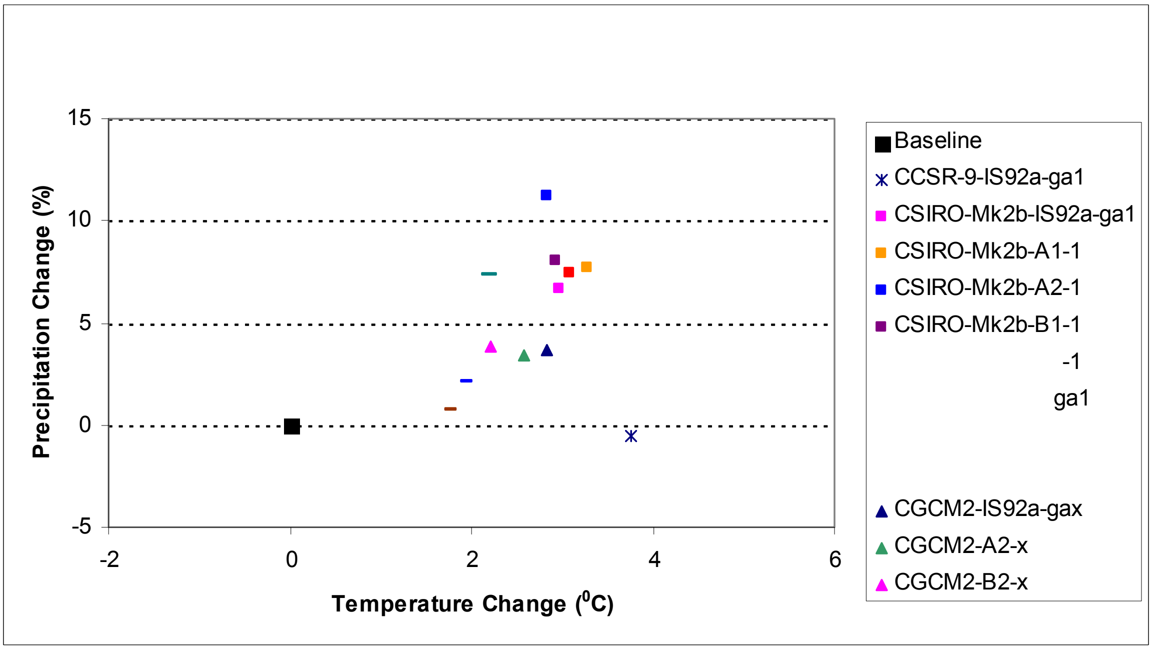
Scatter plots are the common method of determining which scenarios to use. Figures 5 and 6 are scatter plots of a range of GCM scenarios for Riding Mountain and Banff National Parks for the 2050s. The figures represent the annual mean temperature change (°C) and annual precipitation change (%) for the GCM grid boxes that are within 2.5° latitude and longitude of the geocentroid for each national park. The Canadian model (CGCM) is represented by triangles, the UK model (HadCM) by dashes, the Australian model (CSIRO-Mk2b) by squares and the Japanese model (CCSR-98) by a cross; no change (baseline) is represented by a large bolded box. In Figure 4, the UK (dashes) and Canadian models (triangles) generally depict one extreme – slightly cooler and drier; the Australian model (squares) depicts the other extreme – slightly warmer and wetter – relative to the baseline. The models representing a similar pattern of extremes for Banff National Park (Figure 5) are HadCM (cooler and drier) and CSIRO (warmer and wetter) .

Figure 4 -
Climate Change Scenario Comparison (Annual 2050s) -Riding Mountain National Park



[1] Scenarios are typically listed as GCM + Emission Scenario (i.e., CGCM2 – B2x)

Figure 5 - Climate Change Scenario Comparison (Annual 2050s)-Banff National Park



2.5 How Do I Access and Interpret the GCM–based Scenario Data?

GCM-based scenario data is provided on the companion CD-ROM entitled **Scenario & Impacts: Climate Change and Canada's National Park System**. Separate folders, each containing a Microsoft Excel workbook, are provided for each existing and proposed national park (Figure 6). A hands-on exercise is provided here. The step-by-step instructions provide guidance in accessing and selecting climate change scenarios for a hypothetical climate change impact assessment for Riding Mountain National Park.

Figure 6 - GCM Scenario Data: File Structure

1. Insert the CD-ROM into your computer and open it in Windows Explorer.
Go to GCM Scenario Data folder and open the sub-folder labelled GCM Exercises**.** Open the file entitled '*ridingmtn_example.'* This Microsoft Excel workbook contains three worksheets: 1) *ridingmtn_temp*, 2) *ridingmtn_precip*, and 3) *ridingmtn_figures.*

2. Make *ridingmtn_temp* active.
The Microsoft Excel worksheet will resemble Figure 7. This worksheet contains projected temperature data for the climate change scenarios listed earlier in Table 3.

To help familiarize yourself with the worksheet, a number of the features have been highlighted on the first model - CGCM1:

- model (*e.g.*, CGCM1) = yellow
- time periods = blue
- projected temperatures (^{o}C) = pink
- climate change scenarios (*e.g.,* gg1, A21) = light green
- months / seasons = gray

Scan through the rest of the temperature worksheet and locate the other climate change scenarios.

Figure 7 - Partial '*ridingmtn_temp*' worksheet

Grid boxes extracted for region are bounded by:
53.3622 102.5970 53.3622 97.5790 48.3622 102.5970 48.3622 97.5790

CGCM1

Region: number of boxes is 4

19	10
20	10
19	11
20	11

gg1	2020s	2050s	2080s
Jan	3.2	6.3	9.4
Feb	3.6	7.0	8.8
Mar	2.9	6.2	8.4
Apr	2.8	5.0	7.8
May	2.4	4.5	6.8
Jun	2.6	3.8	6.0
Jul	2.3	3.8	5.4
Aug	2.2	3.6	5.5
Sep	2.4	4.4	5.9
Oct	1.6	2.9	4.4
Nov	1.9	2.6	4.5
Dec	3.0	5.0	6.9
DJF	3.2	6.1	8.4
MAM	2.7	5.2	7.6
JJA	2.4	3.8	5.6
SON	2.0	3.3	4.9
ANN	2.6	4.6	6.6

ga1	2020s	2050s	2080s
Jan	3.7	5.5	10.4
Feb	4.5	6.1	8.9
Mar	2.8	4.6	6.6
Apr	2.4	4.1	6.9
May	1.4	2.3	4.8
Jun	1.9	3.5	5.5
Jul	1.7	3.0	4.2
Aug	1.5	3.3	4.3
Sep	1.9	3.4	4.6
Oct	1.1	2.2	3.6
Nov	0.8	1.4	2.8
Dec	3.7	5.6	7.5
DJF	4.0	5.7	8.9
MAM	2.2	3.7	6.1
JJA	1.7	3.2	4.7
SON	1.3	2.3	3.7
ANN	2.3	3.7	5.8

This indicates the model

This refers to the scenario

Monthly and seasonal summaries
DJF - Dec, Jan, Feb
MAM - Mar, Apr, May
JJA - Jun, Jul, Aug
SON - Sept, Oct, Nov
ANN - Annual

These are the three time periods

Projected temperatures for each time period

3. Make *ridingmtn_precip* active.
This worksheet contains the projected precipitation data, as a percent change, for the same climate change scenarios as before. A number of features have been highlighted on CGCM1 (Figure 8).
- models = yellow
- scenarios = light green
- months/seasons = gray
- time periods = blue
- projected precipitation change (%) = pink

Figure 8 - Partial *ridingmtn_precip* worksheet

Grid boxes extracted for this region bounded by:
53.3622 102.5970 53.3622 97.5790 48.3622 102.5970 48.3622 97.5790

CGCM1 — **This indicates the model**

Region: number of boxes is 4

19	10
20	10
19	11
20	11

gg1 — **This refers to the scenario**

These are the three time periods

(Precip is expressed a % change)
MOST COMMONLY USED

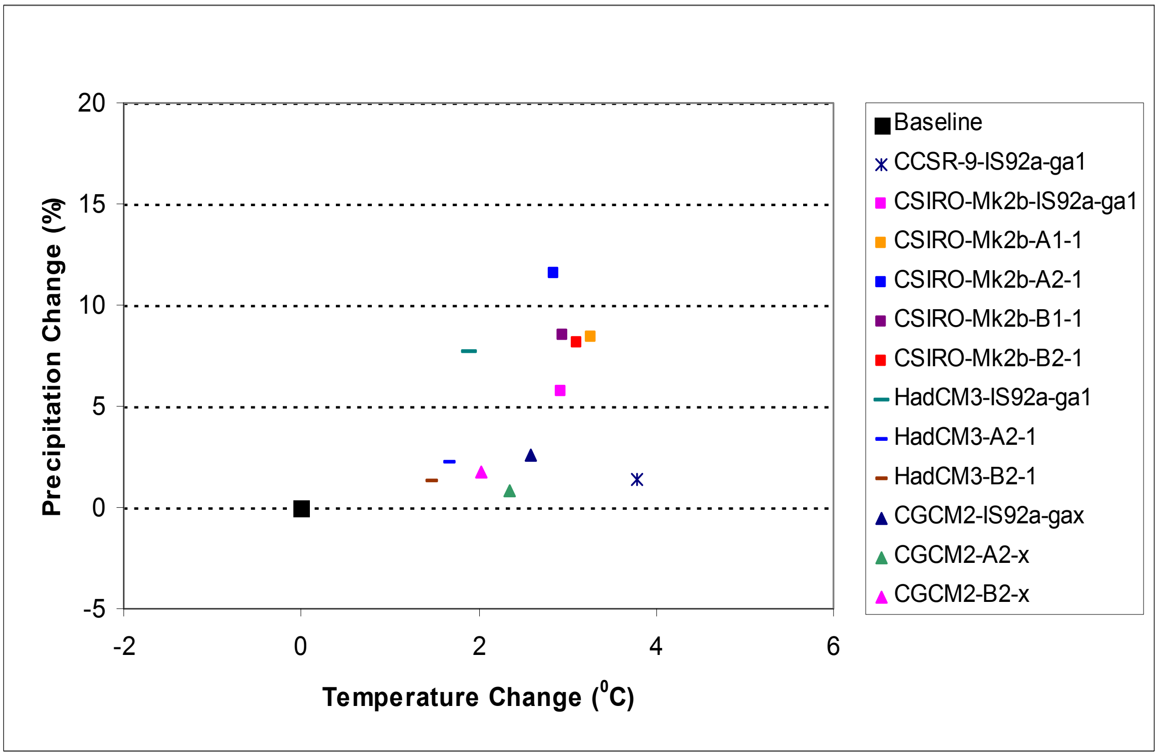
gg1	2020s	2050s	2080s
Jan	2.0	7.0	-0.8
Feb	6.4	-1.7	8.1
Mar	-0.5	2.6	9.4
Apr	11.5	36.2	35.7
May	3.3	6.9	22.8
Jun	-2.8	-8.8	-30.3
Jul	-4.2	-10.1	-12.5
Aug	-7.1	-0.6	-12.0
Sep	-0.2	-10.1	6.1
Oct	-4.2	4.8	11.6
Nov	4.1	6.6	12.9
Dec	-4.1	11.2	20.2
DJF	1.5	5.5	9.2
MAM	4.7	14.3	23.1
JJA	-4.3	-7.3	-20.4
SON	-0.1	0.1	10.1
ANN	0.2	2.6	3.5

4. Make *ridingmtn_figures* active.
This worksheet contains summary charts and graphs that can be used in presentations or park management plans. A set of similar figures is provided in the other park files.

The first chart is a summary of the *ridingmtn_temp* and *precip* worksheets. It illustrates the annual temperature and precipitation changes for a select number of climate change scenarios.

Scroll down.
Three scatter plots (2020s, 2050s, 2080s) are provided. The scatter plot for the 2050s is reproduced in Figure 9. These scatter plots graphically represent annual mean temperature change (^{o}C) and precipitation change (%) for a range of climate change scenarios. Some of the scenarios cluster together and represent extremes in conditions (*e.g.,* slightly wetter and cooler) relative to the baseline.

Figure 9 -
Climate Change Scenario Comparison (Annual 2050s) - Riding Mountain National Park



Based on these scatter plots, if you were interested in annual climatic changes in Riding Mountain National Park, UK models (HadCM) would provide one extreme – slightly cooler and wetter, while the Canadian (CGCM) or Australian (CSIRO-Mk2b) models would provide the other extreme – slightly warmer and drier.

5. *Scroll to the right.*
A number of line graphs are present. The graphs compare monthly changes in temperature and precipitation for certain GCM-based climate change scenarios. In doing so, they graphically illustrate a range of projected future temperature and precipitation conditions. These graphs can be extracted for use in presentations and park management plans.

3.0 Bioclimate Scenarios

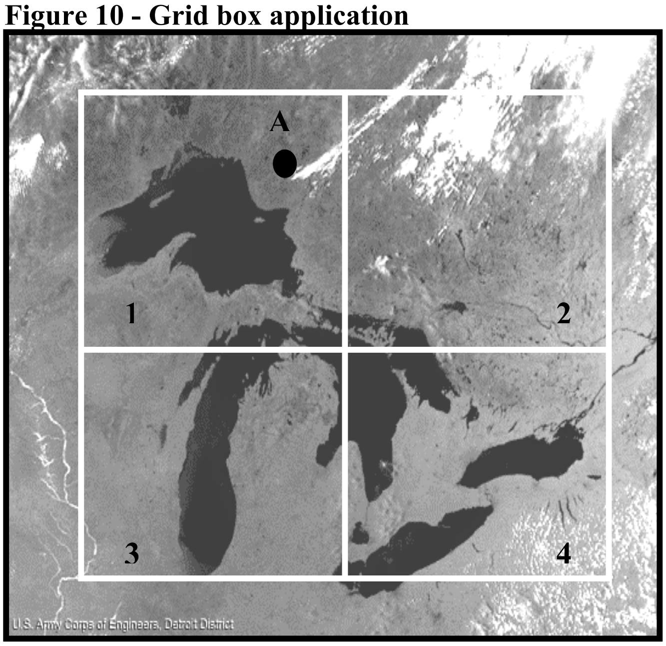
Bioclimate scenarios are the second type of climate change scenario discussed in this manual. Bioclimate scenarios, which provide projections related to different aspects of a region's bioclimate (*e.g.,* growing degree days, water deficits) are available for a number of sites across Canada. These scenarios provide site-specific future climate information, and have been obtained using the standard scenario practice of applying coarse-scale GCM-derived climate change scenarios to observed climate data. Bioclimate profiles for all scenarios are available soon on the CCIS Project website.

3.1 What are Bioclimate Profiles?
Bioclimate profiles are described as *'climates at a glance.'* They are comprised of individual climate variables (*e.g.,* minimum temperature) and related indices (*e.g.,* growing degree days) derived from site-specific daily climate observations from across Canada. When viewed holistically, bioclimate profiles provide a synopsis of the temperature and moisture conditions at specific climate stations, and act as a reference for generalizing about the climate in the area surrounding the station. The closest reference climate station for each national park, for which bioclimate analyses are available, is listed in Table 3.

3.2 How are Bioclimate Profiles Established?
A bioclimate profile is established by calculating a 30-year average for archived daily weather variables at each climate station. Daily maximum and minimum temperatures (^{o}C), total precipitation (mm), total rain (mm), total snow and snow depth (cm) from the Meteorological Service of Canada's National Data Archive are averaged over a 30-year period for each station. Three 30-year periods are used - 1951-80, 1961-90 and 1971-2000; each 30-year period corresponds to recent and currently defined 'normal', or baseline, periods.

3.3 How are Bioclimate Scenarios Generated?
To project future bioclimate conditions, a climate change scenario is applied to the bioclimate profiles. Changes in climate from the CGCM1 ga1 scenario are applied to the 1961-90 observed daily record of a particular climate variable (*e.g.,* maximum temperature) for any station located within the designated grid box. This method is illustrated in Figure 10.

Figure 10 - Grid box application



Grid box 1 represents a 1.5^{o}C increase in daily maximum temperature in June for the 2020s relative to the 1961-90 baseline. Station A's observed daily maximum temperature is 29^{o}C for the month of June. Since Station A is located within grid box 1, 1.5^{o}C is applied to the baseline temperature; the new projected daily maximum temperature in June is now 30.5^{o}C. Bioclimate scenarios are available for three 30-year periods: 2020s, 2050s and 2080s

Table 4 - Reference Climate Stations for each Canadian National Park

	Reference Station Information		
Regions and Parks	**Climate Station**	**Province**	**Closeness**[1]
Atlantic			
Cape Breton Highlands	Ingonish Beach	NB	
Forillon	Sept-Iles A	QC	
Fundy	Saint John A, Moncton A	NB	
Gros Morne	Daniel's Harbour, Stephenville	NF	
Kejimkujik	Yarmouth A	NS	
Kouchibouguac	Chatham A	NB	
Mealy Mountains*	Goose A, Cartright A	NF	
Mingan Archipelago	Sept-Iles A	QC	
Prince Edward Island	Charlottetown A	PE	
Terra Nova	Gander Int'l A	NF	
Torngat Mountains*	Iqaluit A, Goose A	NWT, NF	×
Great Lakes-St. Lawrence Basin			
Bruce Peninsula	Wiarton A	ON	
Georgian Bay Islands & Fathom Five	Wiarton A	ON	
La Maurice	Mont Joli A	QC	
Point Pelee	London A	ON	
Pukaskwa	Kapuskasing A, Sioux Lookout	ON	×
Saint Lawrence Islands	Ottawa	ON	
Saguenay Saint-Laurent	Natashquan A, Sept-Iles A	QC	
Prairie			
Elk Island	Elk Point A, Edmonton Municipal A	AB	
Grasslands	Moose Jaw A	SK	
Interlake*	Dauphin A	MB	
Prince Albert	Prince Albert A	SK	
Riding Mountain	Dauphin A	MB	
Wood Buffalo	Fort Smith A	NWT	
Western Cordillera			
Banff	Calgary Int'l A	AB	×
Glacier	Calgary Int'l A	AB	×
Mount Revelstoke	Calgary Int'l A	AB	×
Jasper	Beaver Lodge CDA	AB	×
Kootenay	Calgary Int'l A	AB	×
Nahanni	Watson Lake A	YT	×
Waterton Lakes	Lethbridge A	AB	
Yoho	Calgary Int'l A	AB	
Pacific			
Gulf Islands*	Vancouver Int'l A, Nanaimo A	BC	
Gwaii Haanas	Sandspit A	BC	
Kluane	Whitehorse A	YT	
Pacific Rim	Estevan Point	BC	
Arctic			
Aulavik	Cambridge Bay A	NU	×
Auyuittuq	Clyde A	NU	×
East Arm of Great Slave Lake*	Yellowknife A	NWT	
Ivvavik	Mayo A	YT	×
Northern Bathurst Island*	Eureka A	NWT	×
Quttinirpaaq	Alert	NU	
Simirlik	Clyde A	NWT	×
Tuktut Nogait	Norman Wells A	NWT	×
Ukkusiksalik*	Baker Lake A, Coral Harbour	NWT	×
Vuntut	Mayo A	YT	×
Wapusk	Churchill A	MB	
Wolf Lake*	Watson Lake A	YT	

Notes:
** Proposed parks*
1 - × indicates parks that are a significant distance (km) from its reference climate station

Bioclimate scenarios provide a finer spatial resolution for climate change impact assessments (only because coarse-scenarios have been applied to site data). However, the proximity (*i.e.,* km) of reference stations for each national park varies considerably!

Four types of bioclimate scenario data are available to Parks Canada. The types and associated variables are defined below, with respect to a 30-year average.

Temperature

Minimum temperature: lowest recorded temperature (^{o}C) in a 24-hour period
Maximum temperature: highest recorded temperature (^{o}C) in a 24-hour period
Mean temperature: average of the minimum and maximum temperature (^{o}C) in a 24-hour period

Degree days

Growing degree days: accumulated number of days above a threshold temperature (*e.g.,* 0^{o}, 5^{o},10^{o}C)
Growing degree units: accumulated departures of temperature above or below a particular threshold[2]

Precipitation

Total precipitation: total amount of rainfall (mm) plus the measured snowfall amount (cm)
Precipitation frequency: number of days with rain and snow per month

Water availability

Water deficit: amount by which moisture fails to meet the demand for water (*i.e.,* potential minus actual evapotranspiration)
Water surplus: amount of water remaining after evaporation needs of soil and storage capacity are met (*i.e.,* actual equals potential evapotranspiration)

3.4 How Do I Access and Interpret Bioclimate Scenario Data[3]?

In this section, a hands-on exercise is described to provide guidance in accessing and interpreting bioclimate scenario data. Using Dauphin station as a proxy for Riding Mountain National Park, step-by-step instructions explain projected changes in temperature, precipitation and degree days in the 2050s with respect to the 1961-90 baseline. Bioclimate scenario data are not provided on the CD-ROM, rather data are available directly from the CCIS Project website < www.cics.uvic.ca/scenarios>.

Temperature profile

Go to the CCIS Project website. Go to *Scenarios*; *Derived from Scenarios*; *Bioclimate profiles; Bioclimate Profile Viewing Page*. You will see a number of drop-down menus on the left hand side of the screen and a 'dotted' map of Canada on the right. The map identifies the location of Environment Canada's climate stations used in bioclimate analyses.

2. From the first drop-down menu, select the reference station for Riding Mountain National Park identified in Table 3 (*Dauphin A, MAN)*. Alternatively, you can run your cursor over the dots to locate it. From the second drop-down window, select *Temperature Profile.* From the third drop-down window, select the time periods *1961-90* and *2040-2069.*
Click *Show me.*

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[2] Example (threshold of 0^{o}C): an observed daily temperature of 8^{o}C represents eight growing degree units (8^{o}C – 0^{o}C); it also represents one growing degree day. Similarly, an observed daily temperature of –3^{o}C represents zero growing degree units and zero growing degree days

[3] Please remember that the bioclimate data are based on only **one** climate change scenario –CGCM ga1

The display window that opens contains a number of line graphs. The first two graphs resemble Figures 11 and 12. Figure 11 illustrates the 1961-90 baseline for maximum, mean and minimum temperatures on a monthly basis for Dauphin A station. The average temperature is also provided seasonally and as a yearly value to the right of each graph. Figure 12 illustrates the same information, but for the 2050s.

At first glance, the temperature profiles for the two time periods look very similar. Upon closer examination, a number of differences are noticeable. As would be expected, mean temperatures are projected to increase by the 2050s. Annually, the mean annual temperature at Riding Mountain National Park increases from 1.7°C to 6.2°C. Seasonally, the mean temperature for January to March is expected to experience the most noticeable change (+6.8°C).

The maximum and minimum daily temperatures are also projected to change. For example, the baseline maximum temperature for March and July is about –5°C and 24°C, respectively; in the 2050s, the maximum temperature for March and July increases to about 3°C and 29°C, respectively. With respect to minimum temperatures, values for March and July increase from –18°C and 8°C to about –9°C and 12°C in the 2050s, respectively.

Figure 11 - 1961-90 Baseline (temperature)

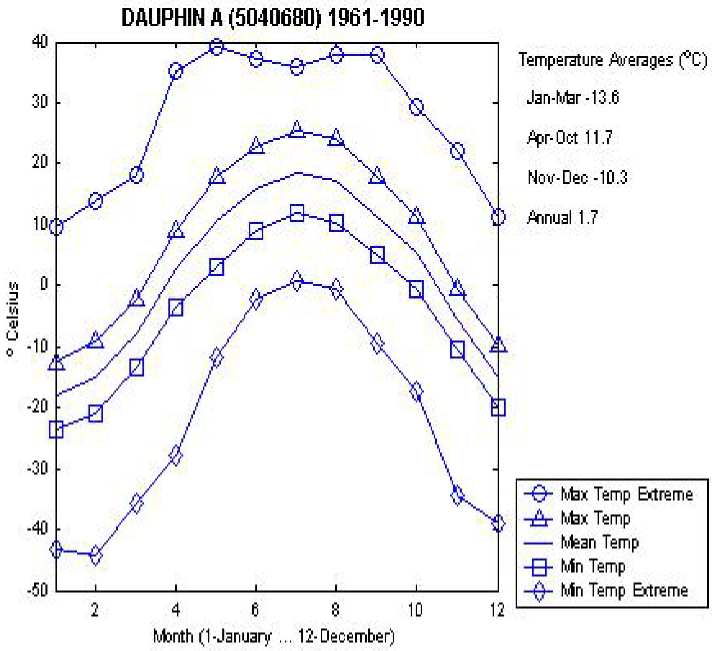
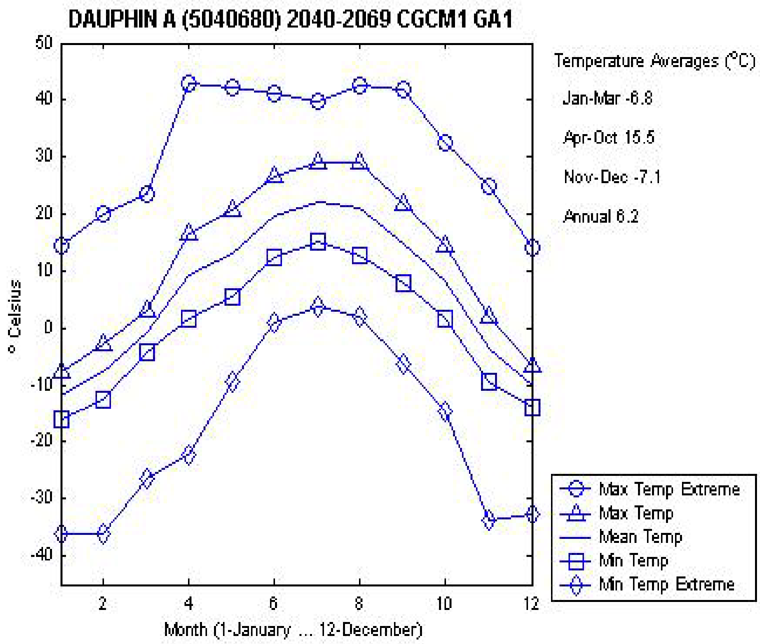


Figure 12 - 2050s Projections (temperature)



Precipitation profile
1. Scroll to the bottom of the current screen to the drop down menus. From the second drop-down menu, select *Precipitation and Evapotranspiration*. Click *Show me.*

The display window that opens contains two line graphs resembling Figures 13 and 14. Similar to the previous example, Figure 13 illustrates the 1961-90 baseline for potential and actual evapotranspiration, and the monthly, seasonal and yearly precipitation totals; Figure 14 illustrates similar information for the 2050s.

Figure 13 -1961-90 Baseline (Precipitation)

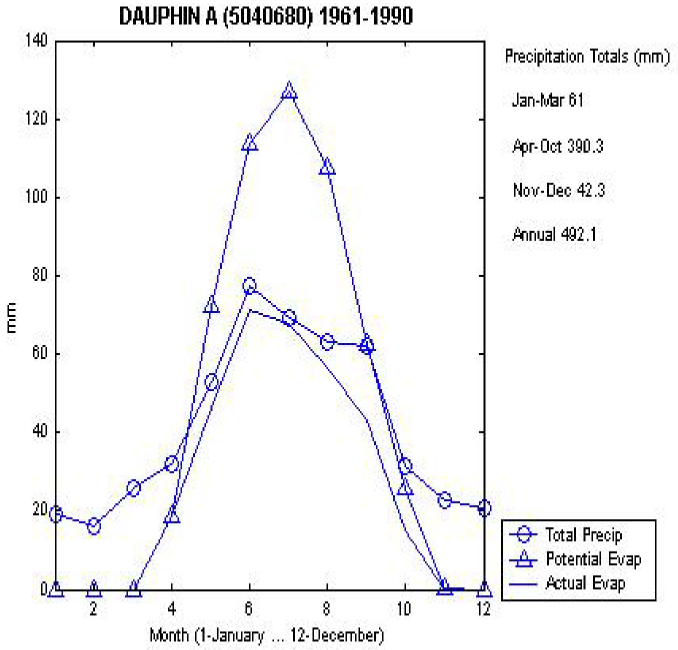
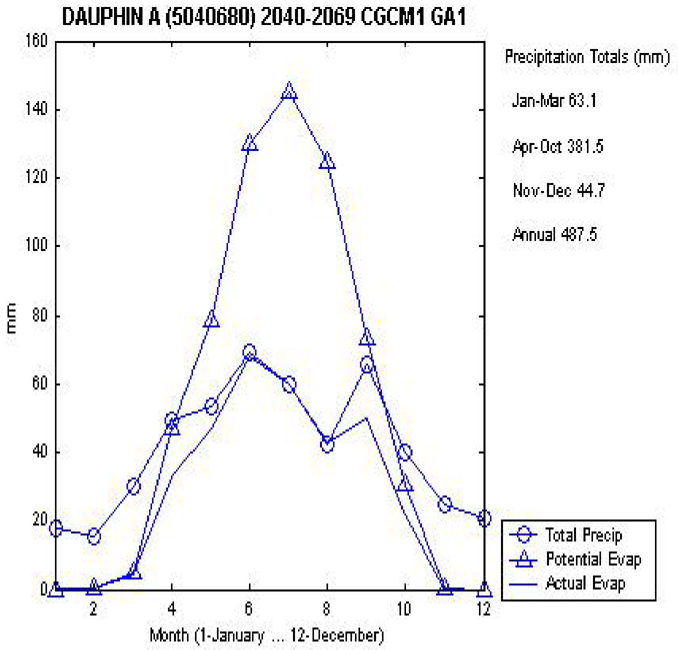


Figure 14 - 2050s Projections (Precipitation)



A quick glance at these figures reveals important information about moisture availability at Riding Mountain National Park. Most precipitation is received between May and August, when actual and potential evaporation are highest.

Closer examination reveals three important patterns about the projected availability of moisture in Riding Mountain National Park. First, total annual precipitation is expected to decline. The park typically receives 492.1 mm of precipitation annually; in the 2050s, it is projected that the park will only receive 487.5 mm.

Secondly, the total amount of precipitation received in any given month is projected to change. If March and July are again used, Figure 13 shows that Riding Mountain currently receives 25 mm of precipitation in March and 70 mm in July; in the 2050s, it is projected that precipitation will increase in March (to 30 mm) and decline in July (to 60 mm).

Finally, although Riding Mountain National Park is only projected to experience a slight decline in total annual precipitation, the moisture balance will likely become more tenuous. Currently, the amount of moisture that is received exceeds that which evaporates. By the 2050s, actual evaporation is projected to equal received moisture, perhaps contributing to drought-like conditions.

Growing degrees profile

1. Scroll to the bottom of the current screen to the drop down menus. From the second drop-down menu, select C*orn Heat Units and Growing Degree Units*. Click *Show me*.

The display window that opens contains two line graphs resembling Figures 15 and 16. Figure 15 illustrates the 1961-90 baseline of growing degree units based on temperature thresholds (e.g., 0°, 5° and 10° C) and growing season length (in Julian days) for Dauphin A; Figure 16 depicts similar information projected for the 2050s.

Similar to the other examples, the baseline and projected growing degree figures look similar at first glance. Upon closer examination, it is evident that Riding Mountain National Park's growing season will be extended in the future. The optimal period for vegetative growth is projected to be 195 days, an increase of five weeks over the 1961-90 baseline. Subsequently, the start and end dates also change. The growing season is expected to begin in late March (Julian day 87) and end in late September (Julian day 281).

In addition, the number of growing degree units above 0°C, 5°C and 10°C on a month-by-month basis is projected to increase by the 2050s. For example, the number of growing degree units above 0°C in March (early start to vegetative growth) is projected to increase from 110 (Figure 15) to 290 (Figure 16); the number of growing degree units in October above 0°C is projected to increase from 180 to 280 days by the 2050s, thus potentially influencinf blooming seasons, berry production and food availability for animals.

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Figure 15 - 1961-90 Baseline (degree units)

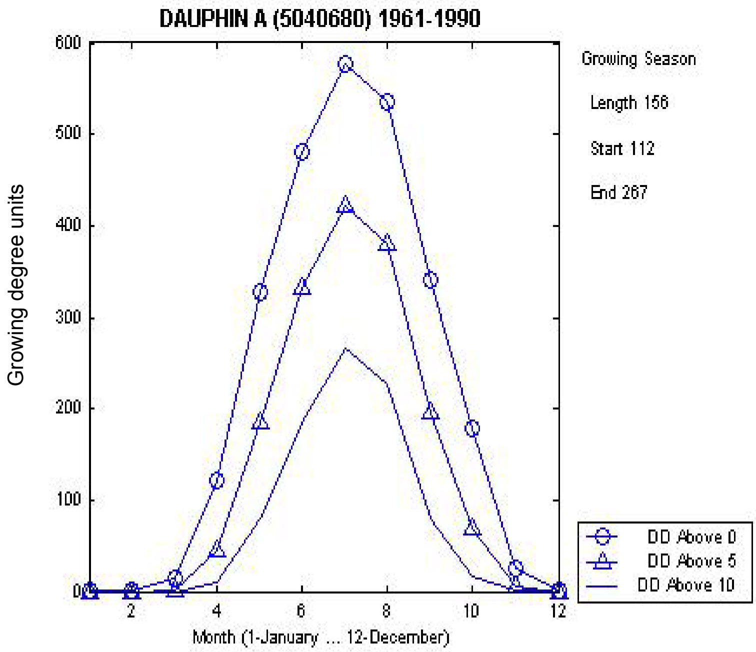
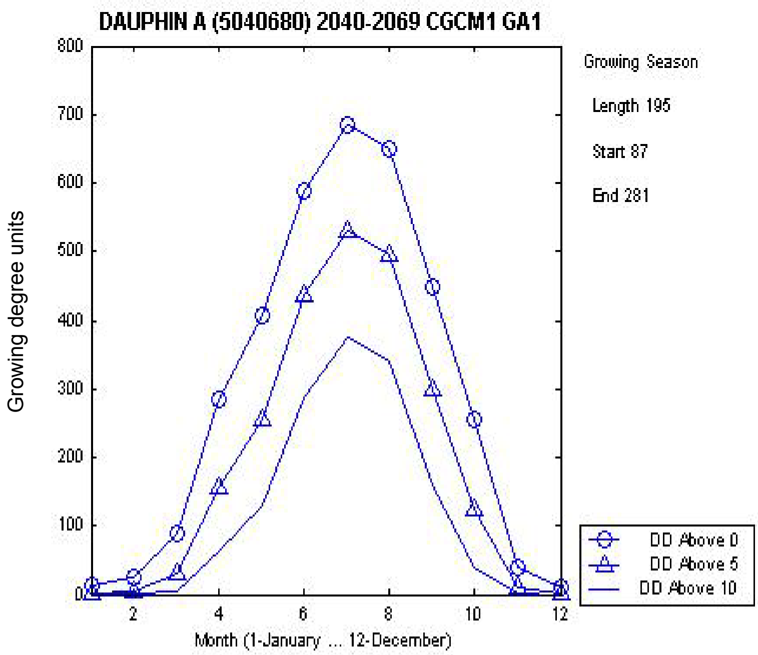


Figure 16 - 2050s Projections (degree units)



4.0 Daily Scenarios

Daily scenarios are the third type of climate change scenario discussed in this manual. Daily scenarios are temporally downscaled versions of the GCM-derived scenario output data. Daily scenario data is derived by applying climate change scenarios at the monthly time scale to a statistical representation of observed climate data in a stochastic weather generator.

4.1 What are Stochastic Weather Generators?
Stochastic weather generators are statistical tools that simulate daily weather data for a suite of climate variables at a given site. They are a means to generate 'synthetic' (simulated) weather that is statistically similar to observed climate data from climate stations and can also be used to derive daily scenario data from climate change scenarios at the monthly time scale. They are inexpensive computational tools that can provide site-specific multi-year climate change scenarios at a daily temporal level. The Long Ashton Research Station (LARS) weather generator has been used to develop daily climate scenarios for Parks Canada. Dr. Mikhail Semenov of the University of Bristol (UK) provided the use of the LARS weather generator software.

4.2 How is 'Synthetic' Weather Generated?
The process of generating synthetic weather with LARS involves a number of steps. Daily observed temperature (*i.e.,* minimum and maximum) and precipitation data from a particular station are first obtained for a 30-year period (1961-90) from the Meteorological Service of Canada's National Data Archive and reformatted to meet structural operating requirements (*e.g.,* column formats) of the LARS weather generator software. Every observation in the observed record is then used to parameterize LARS and derive site-specific climate statistics. Once the statistics are derived, a validation function (Q-Test) is run to compare the statistical distribution of temperature and precipitation variables produced by LARS with those of the observed data. For example, the quarterly probabilities for the distribution of days with maximum temperatures greater than 30^{o}C (length of hot series); other distributions include the length of wet, dry and frost series. The validation for local climate stations used for Parks Canada revealed no systematic significant differences between the observed and synthetic climate data. The next step is to incorporate climate change scenario output into the LARS weather generator. Monthly mean temperature and precipitation change values for the 2020s, 2050s and 2080s are selected from the four scenarios (CGCM2, HadCM3, CSIRO, CCSR). Each of the parameterized climate station files is run in the generator for the three time periods (2020s, 2050s, and 2080s) using the output data from the four scenarios. When completed, the daily temperature and precipitation data set for each climate station includes 1961-90 (observed) and 2080s (synthetically simulated) for all four climate change scenarios.

4.3 How Do I Interpret Daily Scenario Data?
Detailed here is a hands-on exercise to help first-time users interpret daily scenario climate data generated using the LARS weather generator. A sample dataset of temperature, precipitation and growing degree days are provided for Riding Mountain, Prince Edward Island and Simirlik National Parks. The data are contained in the Daily Scenario Data folder on the CD-ROM **Scenarios & Impacts: Climate Change and Canada's National Park System.**

1. Insert the CD-ROM into your computer and open it in Windows Explorer.
In the Daily Scenario Data folder, open the file entitled '*ridingmtn_LARS_example*.'

The Microsoft Excel worksheet that opens contains four worksheets. The four worksheets are CCSR-ga1, CGCM2-B2x, CSIRO-A21 and HadCM3-B21. In scrolling through them, you will notice a large amount of data and several graphs. The worksheets contain observed climate data (1961-90 baseline) for the Dauphin A station, projected daily climate data for the three time periods, and a number of summary tables.

2. Make *CCSR-ga1* active.
A Microsoft Excel worksheet similar to that in Figure 17 appears. Again, a number of features have been highlighted.

- Time periods = blue
- Temporal specifics = yellow
    - *Year: each individual year in the 30-year time period*
    - *Day: Julian days (e.g., 1 = January, 1; 365 = December, 31)*
- Climate variables = pink
    - *Tmax: maximum daytime temperature (^{o}C)*
    - *Tmin: minimum daytime temperature (^{o}C)*
    - *Precip: precipitation (mm)*

Column 1, labelled 1961-90, is the observed climate data for Dauphin A station for every day in the period January 1, 1961 to December 31, 1990. *Scroll down* to see the observed climate data for the other 29 years.

Return to the top of the worksheet and scroll to the right. Columns labelled 2020s, 2050s and 2080s are the projected daily climate data (using LARS) for Dauphin A station with respect to the three future time periods. The set up for these time periods is identical to the 1961-90 baseline. Data provided in the 2020 column, for example, represents projected values for January 1, 2010 to December 31, 2039.

Scroll down to see climate values for other 29 years.

Figure 17 - Partial *ridingmtn_LARS_example* worksheet (CCSR-ga1)

Original Data: 1961-90 Baseline

1961-1990				
Year	Day	Tmin	Tmax	Precip
1961	1	-34.4	-20.6	0.8
1961	2	-33.3	-22.2	0.3
1961	3	-37.8	-3.3	0
1961	4	-9.4	1.1	0
1961	5	-6.7	2.8	0
1961	6	-2.8	0	0
1961	7	-21.7	-15	0
1961	8	-28.9	-1.1	0
1961	9	-8.3	2.8	0
1961	10	-19.4	-10.6	0
1961	11	-15.6	-7.2	0
1961	12	-13.9	-8.3	0
1961	13	-17.2	-11.1	0
1961	14	-23.3	-3.9	0
1961	15	-10	5	0
1961	16	1.1	5	0
1961	17	-17.8	-10	0
1961	18	-18.3	-10	0.5
1961	19	-20	-10.6	0.5
1961	20	-26.7	-16.7	0
1961	21	-26.7	-20.6	0
1961	22	-28.9	-15	0
1961	23	-31.1	-21.1	0
1961	24	-36.7	-23.9	0.5
1961	25	-32.8	-24.4	0
1961	26	-32.8	-16.7	0
1961	27	-21.7	-11.7	2.3
1961	28	-19.4	-15	0
1961	29	-22.8	-17.8	0
1961	30	-23.3	-14.4	0.5
1961	31	-25.6	-15.6	0
1961	32	-30	-22.2	0
1961	33	-30	-8.9	0
1961	34	-14.4	-2.2	0
1961	35	-10	2.8	0
1961	36	-16.1	-2.8	0
1961	37	-16.1	6.1	0
1961	38	-3.9	5.6	0
1961	39	-2.2	5.6	0
1961	40	-10	-3.9	0

Projected Daily Data (using the LARS weather generator)

2020s				
Year	Day	Tmin	Tmax	Precip
1	1	-18.2	-7.4	0
1	2	-12.2	-1.3	0
1	3	-10	-3.3	0
1	4	-12.4	-7.4	0
1	5	-22.9	-10.9	0
1	6	-31.9	-9.5	0
1	7	-33.2	-11.7	0.7
1	8	-32.4	-7	0
1	9	-27.5	-4.1	0.2
1	10	-20.5	-3.3	0.9
1	11	-5.4	5.1	0
1	12	-8.2	-0.1	0
1	13	-19.2	-10.3	0
1	14	-19.4	-8.4	0
1	15	-26.4	-1.9	0
1	16	-37.6	-16.9	0
1	17	-28.8	-26.8	1.6
1	18	-36.4	-24.4	0
1	19	-24.9	-17.5	0
1	20	-14.3	-12.2	0
1	21	-4.5	3.4	0.1
1	22	-6.7	3	0.4
1	23	-5.4	7.3	0
1	24	-2.1	11.9	0
1	25	-6.1	11.7	0
1	26	-27.9	2.2	0
1	27	-39.4	-6.8	0
1	28	-36.9	1.4	0
1	29	-20.9	-4.4	0
1	30	-24.1	-7.8	0.5
1	31	-19.4	-6.2	1.4
1	32	-19.3	-1.3	3.9
1	33	-17	2.7	0.9
1	34	-25.5	-4.5	0.2
1	35	-22.8	-9.3	0.9
1	36	-18.2	-0.7	0
1	37	-22.6	1.3	3.1
1	38	-28.7	3.7	1.5
1	39	-30.5	-3.6	0
1	40	-32.7	-12.5	0

3. *Scroll down* to row 10,957.
In this summary table are the calculated growing degree units. This table lists the number of growing degree units per day above the temperature thresholds of 0°C and 5°C. For example, using the 0°C threshold, an observed daily mean temperature of 8°C would represent eight growing degree units; –3°C is below the threshold and thus would represent zero growing degree units.

Scroll to the right. A table similar to Figure 18 appears. The table summarizes the data you just saw, but provides the number of degree days, based on a threshold of 0°C, on an annual basis; the annual number of degree days provides an indication of the season length. As illustrated, the season length increases as early as the 2020s.

Figure 18 - Growing Degree Days (*ridingmtn_LARS_example*)

Summary: Number of Growing Degree Days Above 0oC					
1961-1990		2020s		2050s	
Year	# of gdd > 0	Year	# of gdd > 0	Year	# of gdd > 0
1961	158	2010	199	2040	213
1962	186	2011	213	2041	223
1963	186	2012	195	2042	200
1964	180	2013	199	2043	212
1965	172	2014	187	2044	199
1966	165	2015	188	2045	200
1967	157	2016	194	2046	205
1968	177	2017	209	2047	219
1969	171	2018	188	2048	202
1970	161	2019	200	2049	210
1971	178	2020	208	2050	220
1972	164	2021	211	2051	219
1973	174	2022	208	2052	218
1974	164	2023	198	2053	204
1975	174	2024	195	2054	209
1976	173	2025	206	2055	219
1977	202	2026	199	2056	205
1978	183	2027	193	2057	198
1979	157	2028	200	2058	212
1980	169	2029	189	2059	195
1981	184	2030	187	2060	201
1982	176	2031	203	2061	217
1983	165	2032	196	2062	203
1984	175	2033	180	2063	197
1985	171	2034	213	2064	220
1986	185	2035	203	2065	211
1987	192	2036	190	2066	203
1988	177	2037	200	2067	207
1989	176	2038	193	2068	200
1990	163	2039	201	2069	213

4. *Scroll* down below these summary tables[4] to row 11,030.
You will see the heading *summary:degrees.* This table and accompanying graph illustrate the observed and projected annual growing degree units. Similar data for a 5°C threshold is summarized below this table.

5. *Scroll* down to row 21, 916.

[4] Units are not calculated for years outside the 1961-90 baseline and projected time periods

You will see the heading *frost degree days.*
This table is again based on 30 years of daily climate data. Frost degree days are days that have minimum temperatures below 0°C. For example, an observed daily temperature of –3°C would represent one frost degree day; an observed daily temperature of 3°C would represent zero frost degree days. The table summarizes the number of degrees below 0°C that occurs each day in the thirty-year period.

Scroll to the right. You will see a table resembling Figure 19. The table summarizes the data you just saw, but provides the number of frost degree days per year. As illustrated, the number of days with frost declines in the future. Although it is not provided, you can also use the LARS data to determine the date of the projected first and last frost degree day.

Figure 19 -Frost Degree Days (*ridingmtn_LARS_example*)

Summary: Annual Frost Degree Days

1961-1990		2020		2050	
Year	# of fdd > 0	Year	# of fdd > 0	Year	# of fdd > 0
1961	155	2010	129	2040	114
1962	150	2011	122	2041	111
1963	138	2012	145	2042	133
1964	151	2013	123	2043	113
1965	154	2014	136	2044	128
1966	166	2015	133	2045	121
1967	167	2016	126	2046	112
1968	141	2017	123	2047	113
1969	151	2018	134	2048	126
1970	155	2019	130	2049	117
1971	155	2020	115	2050	101
1972	159	2021	130	2051	120
1973	144	2022	123	2052	111
1974	155	2023	139	2053	127
1975	152	2024	134	2054	120
1976	150	2025	124	2055	109
1977	138	2026	127	2056	103
1978	148	2027	141	2057	130
1979	161	2028	123	2058	110
1980	150	2029	135	2059	125
1981	127	2030	131	2060	120
1982	155	2031	118	2061	108
1983	161	2032	137	2062	128
1984	146	2033	136	2063	116
1985	145	2034	118	2064	103
1986	150	2035	133	2065	119
1987	138	2036	124	2066	106
1988	149	2037	130	2067	114
1989	151	2038	143	2068	133
1990	152	2039	129	2069	115

6. *Scroll down* below this table to row 21,991.
You will see the heading *summary:degrees.* This table and accompanying graph illustrate the observed and projected annual frost degree units. Like growing degree units, frost degree units are the accumulated departures from a given temperature threshold; in this case 0°C. For example, an observed daily temperature of -20°C represents twenty frost degree units (-20°C – 0°C); an observed daily temperature of 3°C represents zero frost degree units.

7. *Scroll* down to row 32,871.
You will see the heading *extreme temperatures.* There are two tables of extreme temperatures - annual highest and annual lowest. The tables summarize the highest and lowest temperatures in each year of the baseline and projected time periods.

6. *Scroll* through the other worksheets (CGCM2-B2x, CSIRO-A21, HadCM3-B21) to see similar daily climate data.

7. Open *pei_LARS_example* and *simirlik_LARS_example* to see daily climate data for the other two national parks.

This type of scenario data is useful in situations that rely on climatic thresholds at a very small temporal scale. Some examples might include:

Temperature-based
Insect infestations, forest fire season, ice forming/break-up periods, fowl migration triggers, berry producing season (bears), heating degree days, recreational season lengths, quality of recreational experience, and utility budgets for facilities.

Precipitation-based
Vegetation diseases, mosquito populations, avalanche activity, recreational season lengths, drought conditions, water and fire bans

4.4 What About Daily Scenario Data For Other National Parks?
Daily scenario data is only provided here for three national parks. If you are interested in obtaining daily scenario data for other national parks you can download the LARS weather generator software from the CCIS Project website and run the program on the GCM data that is provided with this manual on the companion CD-ROM.

Two documents are also available on the CCIS Project website (under *Resources*) to help you with daily scenarios. These include:
Statistical Downscaling Primer of GCM Output
Scenarios Using Stochastic Weather Generators

In addition, please feel free to join the CCIS Project's member newsletter list. This is an electronic discussion and announcements list about website updates, software and data availability and projects. Just send a blank email to the following address:
scenarios-subscribe@yahoogroups.com

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Scott, D., and Suffling, R. (2000). *Climate Change and Canada's National Park System*. Environment Canada, Downsview.

Appendix - Other Informational Resources

GCM scenarios
Carter, T., Parry, M., Harasawa, H., and Nishioka, S. (1994). *The IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations*. Intergovernmental Panel on Climate Change.

Canadian Climate Impacts and Scenarios Project
Available at: <http://www.cics.uvic.ca/scenarios/>

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