Climate Change and
BC’s Forest and Range Management

Climate Change, Impacts & Adaptation Scenarios

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Produced for the Future Forest Ecosystems Initiative

Preface

This report is one of two foundation papers for the BC Ministry of Forest and Range's (MoFR) Future Forest Ecosystems Initiative (FFEI). These papers will increase the awareness of the potential impact of a climate change on forest and range resources in British Columbia. They will also provide information to aid in assessing the vulnerability of British Columbia's forest and range resources and their management. This should lead to the development of adaptation strategies for a changing climate. The FFEI was initiated by the chief forester with a symposium and workshop in December 2005. At the same time the MoFR Climate Change Task Team was preparing a report on how the MoFR should strategically position itself with respect to the potential impacts of climate change on the province's forest and range resources. The present report draws on the Task Team report, recommendations from the FFEI workshop and numerous other documents including the most recent reports from the Intergovernmental Panel on Climate Change. It provides a summary of future possible climates for BC followed by a brief review of possible impacts on forest and range resources and options for and challenges to adapting to climate change. Finally, there are recommendations on how the MoFR might respond to climate change. The report contains four appendices that expand on material presented in the body of the report, including information on the past as well as on future climates of British Columbia.

Acknowledgments

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> "There is a theory which states that if ever anyone discovers exactly what the Universe is for and why it is here, it will instantly disappear and be replaced by something more bizarre and inexplicable. There is another theory that states this has already happened."
> *Douglas Adams, The Hitch Hiker's Guide to the Galaxy, 1979, Pan Books, London.*

Table of Contents

List of Figures

List of Tables

Executive Summary

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change states that warming of the climate system is unequivocal. It notes with a very high level of confidence that much of this warming is due to human activities through the release of greenhouse gases. The continued increase in greenhouse gas concentration over the next century could result in an increase in global mean annual temperatures by up to 4°C and changes in precipitation regimes. The rate of warming will be faster than has occurred in the past and there will be an increase in the frequency and intensity of extreme temperature and precipitation events.

British Columbia will have greater warming and changes in the precipitation regime than the global average. All models and emissions scenarios predict an increase in winter and summer temperature. Warming would be greater in northern British Columbia than southern British Columbia and larger in the winter than in the summer, particularly in the winter minimum temperature. Warming is least in coastal areas where it is moderated by the oceans.

If there is limited success internationally to control future emissions (the A2 emissions scenario), BC could see a warming of 3 to 5°C by the 2080s. Under the B1 emission scenarios with significant reduction in emissions, the warming is 2 to 3°C by the 2080s. These two scenarios have the winter minimums in northern BC increasing by 4 to 9°C by the 2080s and summer maximums increasing by 3 to 4°C. The frost free period, growing degree days and frequency of occurrence of extremely warm days will also increase.

Changes in precipitation will accompany changes in temperature. Southern and central British Columbia is expected to get drier in the summer while northern British Columbia will be wetter. Winters will be wetter across British Columbia. We can expect an increase in precipitation intensity and reduction in the return period of extreme events. The changes in mean precipitation are smaller than the inter-annual variability in precipitation resulting from inter-annual and inter-decadal variation in ocean conditions. Warming will result in less precipitation falling as snow, reduced snow packs, and earlier spring snow melt with the snow disappearing up to a month earlier under the highest warming scenarios. There will be an increase in evaporative demand of the atmosphere.

Ecosystems and species have responded to past changes in climate; however, future responses may not be compatible with our patterns of use or desires. Consequently, there could be significant biological, economic and social impacts with major implications for resource management. Species will be able to survive and grow in their current location under a changing climate. However, growth rates will be affected and there will be increased competition from other species or genotypes more suited to the climate. Warming and drying will increase forest fire frequency and severity. Disturbance due to insects and disease is expected to increase. The potential ranges of species will move northward and upward in elevation, and new assemblages of species will occur in space

and time. Species may be unable to move into areas of suitable climate due to barriers to movement, slow migration rates, unsuitable growing substrate or lack of habitat.

Although many of the impacts of climate change are decades away, resource managers need to start evaluating the vulnerability of forest and range resources to climate change. This will facilitate development of adaptation strategies to maintain the resilience of ecological systems and our uses of them. A guide to such activities and some challenges to implementing adaptation strategies are identified. A major challenge is the uncertainty in the magnitude and timing of future climate change. Another significant challenge is the size of the forest and range land base in British Columbia. It is likely that much of the vegetation will have to adjust without human intervention and society will have to adapt to this. In some areas, adaptation to reduce the vulnerability of resources such as water quality and quantity and biological conservation may become the highest priority.

The various emissions scenarios have similar warming trends over the next 20 years. During this period the global response to the risks of climate change should become evident, global climate models will have improved and we should have a clearer idea of the climate change to expect. This period should also see significant improvements in our understanding of the vulnerability of forest and range resources to climate change. In the meantime, it is recommended that:

- Vulnerability analyses use climate simulations for the B1 and A2 scenario, and simulations from at least two global climate models with different climatologies, e.g., the Canadian and Hadley Centre models.
- Analyses should also be done using annual as well as mean climate data to evaluate the effects of changes in the inter-annual variability and extremes.

It is recommended that the BC Ministry of Forests and Range respond to the potential impacts of climate change on forest and range management by cooperating with other agencies and groups in taking the lead to:

- Develop data bases and methods for assessing vulnerabilities to climate change and promote adaptation in forest and range management.
- Create a set of climate change scenarios for British Columbia at a high spatial resolution so that all users can work from a common data base.
- Provide a “one stop” facility that would be a source of climate change scenarios and other climate data for vulnerability analyses, and would facilitate access to the latest information.
- Determine user needs with respect to climate variables, time periods and tools for climate change vulnerability analyses.
- Develop adaptive capacity within the forest and range management community.
- Develop a set of key indicators of climate change that can help in monitoring the response of forest and range resources to climate change.
- Investigate management responses that can be applied in the near term that might alleviate some of the vulnerability without compromising the long term.

It is encouraging to note that many of these recommendations are being acted on.

Introduction

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPPC WG I 2007) reports that over the last 100 years there has been a 0.7°C warming of the global climate. The report states with a very high level of confidence that much of this warming is a result of human activities through the release of greenhouse gases to the atmosphere from the burning of fossil fuels, deforestation and agricultural activities. IPCC WG I (2007) presents a range of future greenhouse gas emission scenarios based on estimates of economic growth, technological development and international cooperation. Even the most optimistic scenarios require a few decades before emissions start to decline. According to the climate models a global warming of 1 to 4°C is possible by the end of the century along with an increase in the frequency and intensity of extreme temperature and precipitation events. Canadell *et al.* (2007) report that current emissions are now higher than those used in the IPCC WG I (2007) analyses.

Changes in British Columbia's climate over the last 100 years are consistent with global trends (Anon 2002, Vincent and Mekis 2006, Rodenhuis *et al.* 2007). Although ecosystems and species have responded to past changes in climate, future responses may not be compatible with our patterns of use or desires. Consequently, there will be significant economic and social as well as biological impacts (McCarthy *et al.* 2001, Spittlehouse and Stewart 2003, IPCC WG II 2007). Although large changes in climatic conditions may be many decades into the future, resource managers need to start developing responses now to adapt to the future climate and ecological conditions.

Before we can implement adaptive actions we need predictions of possible future climates and we need to assess vulnerabilities. In doing this it is important to recognise the scale of the issue and to manage expectations of our ability to respond. For example, the size of the forested land base in British Columbia means that much of the forest will have to adjust without human intervention. Adaptation will likely focus on the major commercial tree species and perhaps a few animal species, while the majority of forest plants and animals will have to adapt as best they can.

This paper describes some possible future climates for British Columbia and briefly reviews possible impacts. This is followed by a framework to help resource managers evaluate vulnerabilities to climate change and to determine adaptive actions (Spittlehouse and Stewart 2003, Spittlehouse 2005). Challenges to adapting to climate change are also reviewed. Additional reference material can be found in the Appendices.

British Columbia's Future Climates

Future global temperature and precipitation regimes: Forecasts of future climates are available from numerous global climate models (GCMs). These models simulate oceanic and atmospheric processes and their interaction with the land surface for a range of future greenhouse gas emission scenarios. These scenarios depend on future developments in technology, economic growth and international cooperation (IPCC WG 1 2007). The

GCMs are also a source of variability in the future climate simulations because of differences in how certain processes are modelled. At present, no one simulated future climate should be considered more likely than another.

A wide range of climate variables are available from the models. However, it is useful to focus on the average values of temperature and precipitation variables for certain periods. The models simulate well the rise in temperature over the last century showing the influence of past increases in greenhouse gas concentrations (Hengeveld *et al.* 2005). The change in mean annual temperature relative to current climate for the last century and four future emission scenarios predicted are shown in Figure 1. Changes in the global mean temperature of 1 to 4°C by 2100 are possible.

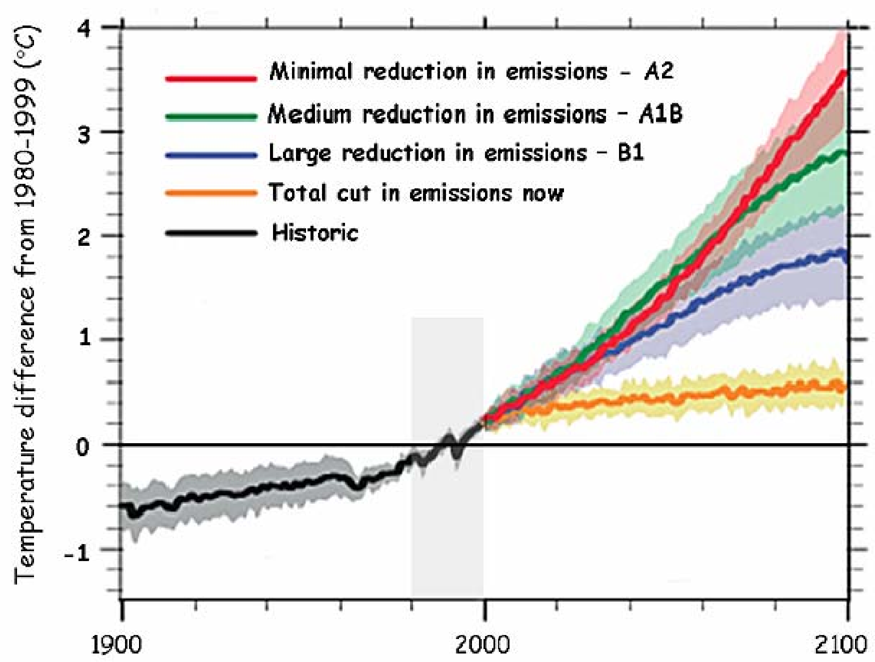


Figure 1. Simulated change in global mean temperature from 1900 to 2100 referenced to the 1980–1999 mean value. From 1900 to the present is based on past greenhouse gas emissions and natural factors (black line). From the present to 2100 is for selected emissions scenarios (red, green and blue lines – see Appendix II), and the effect of an immediate total cut in emissions (orange line). Shading indicates ±1 std. on range of annual means from 16 to 21 GCMs. (Adapted from IPCC WG I 2007).

The A2 scenario assumes emissions will continue to increase without significant efforts globally to reduce them. The B1 scenario assumes that the rate of emissions will slow down and begin to decrease by the middle of the century. A1B is intermediate between the A2 and B1 scenarios. The orange line shows that a cessation of all emissions now means we are committed to a further 0.5°C warming above current conditions. Changes in temperature will be accompanied by changes in precipitation. Summer precipitation is predicted to decrease in equatorial and temperate latitudes but to increase in northern latitudes (Appendix II, Figure A6). In the winter, the precipitation increase is greater than in summer and the increase tends to extend into the temperature latitudes.

All of the scenarios predict similar warming trends over the next 20 years. During this period the response of the global community to calls for reducing emissions should become evident. Also the GCMs will have improved such that we should have a much better idea of the climate change to expect for 2050 and beyond. It is accepted that emissions of greenhouse gases cannot cease immediately. Consequently, emissions targets have been proposed to limit warming to certain levels or to avoid certain climate impacts (Rive *et al.* 2007).

British Columbia's future temperature and precipitation regimes: The data in this section are based on climate change simulations produce for the IPCC's Third Assessment (Houghton *et al.* 2001) as well as the recently released Fourth Assessment (IPCC WGI 2007). The former uses a reference period of 1961–90 rather than the 1980–99 period of the latter, which is about 0.5°C warmer for BC than the former (Rodenhuis *et al.* 2007). The data presented here will be updated to the new simulations when they become readily available. However, allowing for the different reference period, the predicted climate changes for the various emission scenarios in the Third Assessment are similar those in the Fourth Assessment (Rodenhuis *et al.* 2007).

Table 1. Climate change scenarios for British Columbia for the 2020s, 2050s and 2080s from 7 models and for 8 emission scenarios. Data are the changes from 1961–90 climate as a change in mean temperature or a percentage change in total precipitation. The range of the data represents the differences in the emission scenarios and in the climate models. Values are based on data at www.ccsn.ca and www.pacificclimate.org/scenarios/

Southern BC

	2020		2050		2080	
	Temp. °C	PPT %	Temp. °C	PPT %	Temp. °C	PPT %
Winter	0 to 2	-5 to +15	1.5 to 3.5	0 to +20	2 to 7	0 to 25
Summer	0.5 to 2	-30 to +5	1.5 to 4	-35 to 0	2.5 to 7.5	-50 to 0

Central BC

	2020		2050		2080	
	Temp. °C	PPT %	Temp. °C	PPT %	Temp. °C	PPT %
Winter	0 to 2	-5 to +15	1.5 to 4	0 to +30	2.5 to 6	+5 to +40
Summer	0.5 to 1.5	-10 to +5	1.8 to 3.5	-20 to 0	2.5 to 6.5	-20 to +5

Northern BC

	2020		2050		2080	
	Temp. °C	PPT %	Temp. °C	PPT %	Temp. °C	PPT %
Winter	0 to 2.5	0 to 20	1.5 to 5.5	0 to +25	2.5 to 9	0 to +45
Summer	0.5 to 1.5	-10 to +10	1.5 to 3.5	-10 to +15	2 to 6	-15 to +25

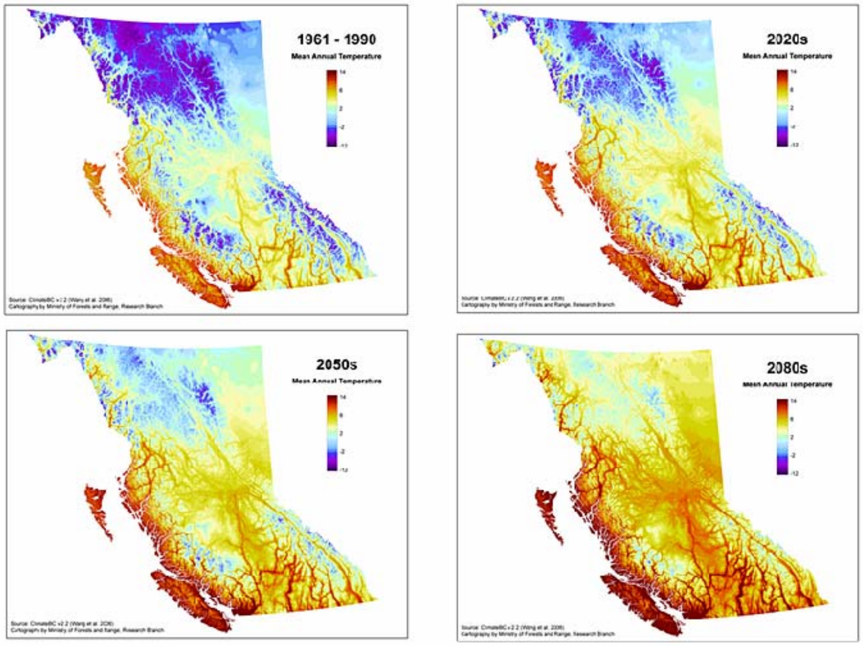
British Columbia (BC) will have greater warming and changes in precipitation than the global average (Table 1, Appendix II). All models and emissions scenarios predict a continued increase in temperature. There is a tendency for the warming to be greatest in northern BC and larger in the winter than in the summer. This warming is largest in the winter minimum temperature. Changes in precipitation vary in space as well as time. Southern and central BC is expected to get drier in the summer while northern BC is more likely to be wetter. Winters will be wetter across BC.

The global climate models provide climate change data at a coarse scale. These data were downscaled for use in forest and range management with the ClimateBC software that uses the delta method to produce values for individual locations and as high spatial resolution gridded data (Wang *et al.* 2006a, Spittlehouse 2006). The high resolution of the figures does not imply a high accuracy. Climates for the B1 and A2 emissions scenarios (Figure A4) are from the Canadian Global Climate Model CGCM2 (Flato *et al.* 2000). The climates are in the middle of the range of projections of the various GCMs and span the range of the most likely future climate. Mean annual changes in temperature and precipitation for the A2 scenario are presented in Figures 2 and 3. Seasonally-based climate maps and data for selected locations in BC for the B1 and A2 scenarios are presented in Appendix II.

The A2 scenario predicts a warming of 3 to 5 across BC over the next century (Figure 2). The lower emissions for the B1 scenario result in a warming 2 to 3°C by 2080, similar to those for the A2 in 2050 (Tables A2 and A3). Annually, most of BC is predicted to have an increase in precipitation which continues to increase over time. However, there is an area in the central and southern interior that is already relatively dry and is expected to get slightly drier. Seasonal data presented in Appendix II show that the southern half of the province could be drier in the summer. The increase in winter precipitation is large enough to result in an increase on an annual basis. The changes in mean precipitation are smaller than the inter-annual variability that results from inter-annual and inter-decadal changes in ocean conditions. As with temperature, the B1 precipitation climate of 2080 is similar to that of the A2 in 2050. In contrast to CGCM2 simulations, the Hadley Centre HadCM3 model tends to produce a warmer and drier summer for the A2 scenario.

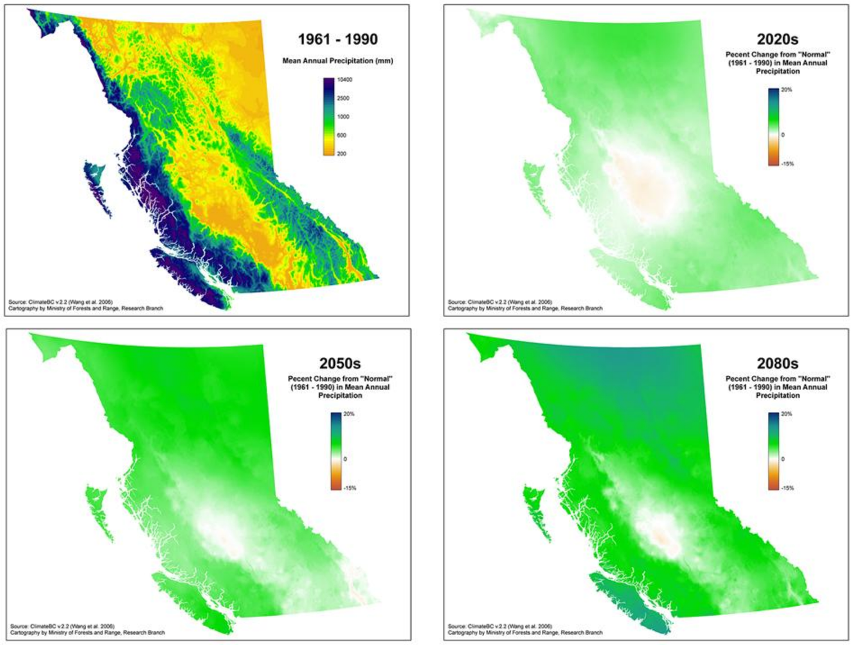
Changes in temperature and precipitation influence other climate variables of interest in resource management. Under the B1 and A2 scenarios frost free periods, growing degree days will increase (Tables A2 and A3). The depth of the snow pack and length of the snow season will decrease while the atmospheric evaporative demand and climatic moisture deficits will likely increase (Appendix II).

The data presented above are average conditions for specific time periods. Inter-annual variability in weather conditions and frequency of occurrence and magnitude of extreme conditions also has a significant effect on the production and use for forest and range resources. Analyses on a global basis from the Fourth Assessment (Tebaldi *et al.* 2006, Kharin *et al.* 2007) are applicable to BC.



Source: ClimateBC v.2.2 (Wang et al. 2006)
Cartography by Ministry of Forests and Range, Research Branch

Figure 2. Mean annual temperature for BC for current climate (1961–90 average) and that predicted for BC in 2020s, 2050s and 2080s for the A2 scenario from CGCM2. Downscaling was done with the ClimateBC software.



Source: ClimateBC v.2.2 (Wang et al. 2006)
Cartography by Ministry of Forests and Range, Research Branch

Figure 3. Mean annual precipitation for BC for current climate (1961–90 average) and the percentage change predicted for BC in 2020s, 2050s and 2080s for the A2 scenario from CGCM2. Downscaling was done with the ClimateBC software.

Changes in warm extremes follow changes in the mean summertime temperature. Extreme maximum temperatures would be higher than at present and cold extremes will warm faster, particularly in areas that see a retreat of snow with warming. There will also be an increase in intensity and maximum amount of precipitation. For both temperature and precipitation there will be a reduction in return periods of current extreme events (Tebaldi *et al.* 2006, Kharin *et al.* 2007). IPCC WG II (2007) states that it is very likely we will see an increase in the number of heat waves and heavy precipitation events.

Impacts of Climate Change on BC's Forest and Range Resources

There are numerous reports worldwide of the response of plants and animals to the increase temperature in over the last century (Walther *et al.* 2002, Breshears *et al.* 2005, Gulledge 2006, Parmesan 2006, IPCC WG II 2007). British Columbia is already experiencing biological and physical responses that at least may partially be a response to current climate changes (Anon 2002, Leith and Whitfield 1998, Geertsema *et al.* 2006, Gillet *et al.* 2004, Carroll *et al.* 2004, Woods *et al.* 2005). These responses will be exacerbated under the climate changes described in the previous section.

IPCC WG II (2007) states that climate impacts will be mostly negative and will fall hardest on those least able to adapt to changes such as the poor, developing countries and certain ecosystems. Extreme heat events could become more frequent and deadly for people, crops and animals. Warming will result in an increase in forest disturbance by drought, fire, insects and disease. Sea level rise will be a threat to coastal communities and result in a loss of estuarine ecosystem. Although some high latitude areas may see improvements in the growth of crops, global mean losses for a 4°C warming could be 1 to 5% of gross domestic product. Not every one will bear the costs equally. Although BC may be less vulnerable economically, socially and climatically than say Bangladesh, impacts will be significant and require responses.

Optimum growth conditions for local populations (genotypes) of trees can be relatively narrow (Rehfeldt *et al.* 1999, 2001, Parker *et al.* 2000, Wang *et al.* 2006b). Consequently, although species will be able to survive and grow in their current location under a changed climate, growth rates will be affected and there will be increased competition from other species or genotypes more suited to the climate. Concurrent with a changing climate there will be changes in the frequency and intensity of disturbance by fire, insects and disease (Dale et al. 2001, Volney and Hirsh 2005, Sieben *et al.* 1997). Insects and disease organisms may adapt to new environmental conditions more quickly than their long-lived hosts (Cammell and Knight 1992, Volney and Hirsh 2005).

Some generalizations can be made on species responses to climate change. The potential ranges of species will move northward and upward in elevation, and new assemblages of species will occur in space and time (Cummings and Burton 1996, Hebda 1997, 1998, Hansen *et al.* 2001, Hamann and Wang 2006, Wang *et al.* 2006b). However, species may be unable to move into areas where the climate is suitable because of barriers to movement, slow migration rates, unsuitable growing substrate or lack of habitat (Stewart *et al.* 1998, Gray 2005). Some specific implications of climate change for BC’s ecosystems are summarized in Appendix III and are developed in detail in the companion foundation paper.

The high spatial resolution climate data, e.g., Figures 2 and 3 and Appendix II, can be used in detailed assessments of climate change impacts on forest and range resources. The climate data were linked to a spatial distribution of BC’s ecosystem units to determine the realized climate space (characteristic values) of these units (Hamann and Wang 2006). Under the A2 scenario substantial shifts in climate zones could occur by the 2080s (Figure 4). The drier and warmer climate produced by the Hadley model produced a further northward movement of zone climates. The B1 emissions scenario would produce a zone climate map for the 2080s that looks like that for the A2 in the 2050s. This work is a preliminary assessment and the analysis needs to incorporate climate data from Alberta and the northwestern United States to determine if analogues of climates of these areas may develop.

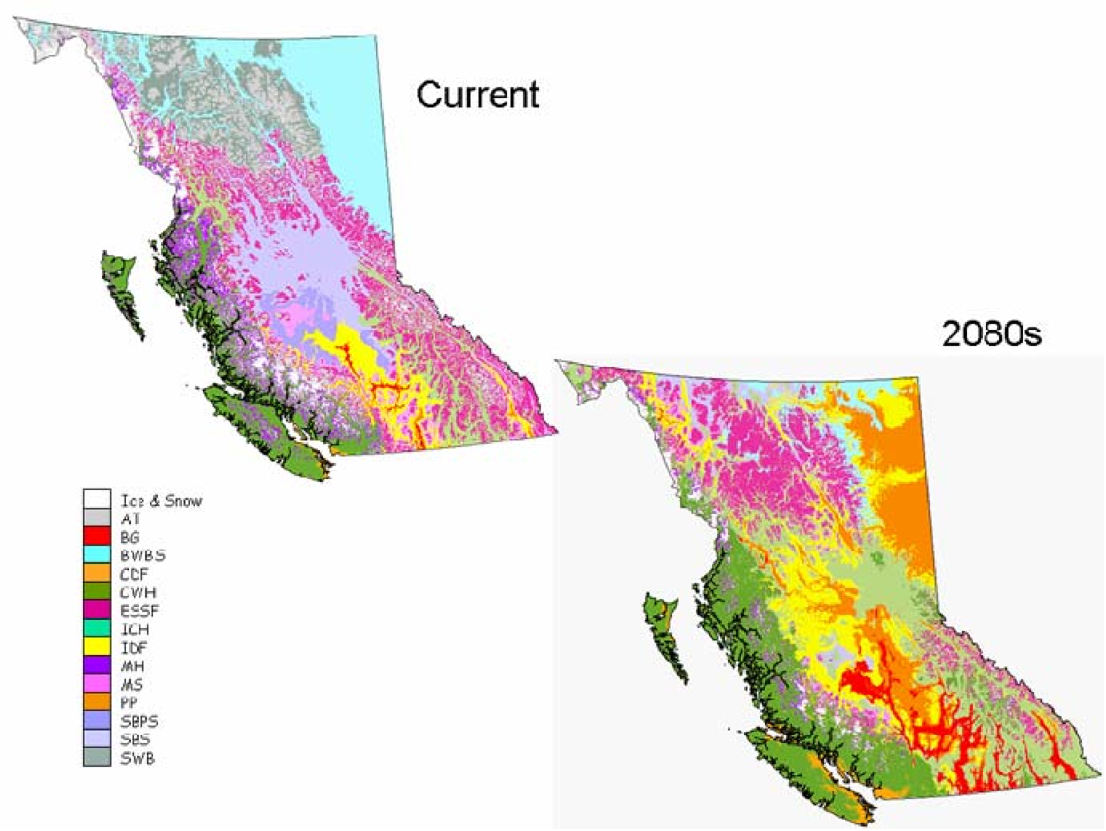


Figure 4. Biogeoclimatic zones in BC and where their climates might occur in the 2080s under the A2 climate change scenario. (Adapted from Hamann and Wang 2006.)

Hamann and Wang (2006) used their ecosystem-based climate envelop modelling to assess changes in the realized climate space for various tree species in BC. Tree species with their northern range limit in BC gained climatically suitable habitat at about 100 km per decade. Common hardwoods appeared to be less sensitive to climate change while some of the most important conifer species in BC lost a large portion of their climatically suitable habitat. A similar approach with similar results has been applied in the western United States by Rehfeldt *et al.* (2006).

A Guide to Developing Adaptation Strategies

Adapting to climate change reduces vulnerability. This is a way to reduce risks and capitalize on benefits by maintaining social and ecological resilience (Nelson *et al.* 2007). Vulnerability is the degree to which an entity (e.g., organism, ecosystem, company, community, or province) is susceptible to or unable to cope with climate change (Smit and Pilifosova 2002). Different entities are vulnerable to different aspects of change and what may be detrimental to one entity could be beneficial to another.

Determining adaptive actions requires a framework for analysis (Spittlehouse and Stewart 2003, Kellomäki and Leinonen 2005, Metzger and Schroter 2006, Johnson and Williamson 2007). The first step of the procedure involves defining the issue; second is evaluating vulnerability to the changing climate; third is determining how to reduce vulnerability, i.e., adaptation; and, fourth is implementing an adaptation strategy. For example:

- **Issue:** Define the subject, scale and time, i.e., the resource issue of concern, the location, and future time horizon.
- **Vulnerability Assessment:** Choose a range of climate change scenarios for the chosen time horizon. Determine the climate, economic, social and other factors that influence the vulnerability of the resource. A lack of information on the climate sensitivity of the resources in question should not stall the process of making a first cut vulnerability assessment. Educated guesses may be required at the beginning, but the analysis is an iterative process with continual updating of the vulnerability assessment as more information becomes available. Different issues, people, companies and organizations will have different timeframes to consider and different vulnerabilities.
- **Adaptation Strategy:** Determine what needs to be done to reduce vulnerability. Options can be developed and their cost effectiveness evaluated. Extension activities will be a critical component for the strategy. Immediate activities include those that facilitate future responses to reduce vulnerability. Adaptation strategies must include the ability to incorporate new knowledge about the future climate and forest vulnerabilities as they are developed. They should also recognize the impediments to implementation such as funding, policy, resistance to change and risk aversion. It is unlikely that any single issue or value can be considered in isolation. Thus, an important component of adaptation is balancing different time frames, needs and values. An adaptation strategy should include a

monitoring program to determine the state of the forest and to evaluate the success of the adaptation strategy.

- **Implementing the Adaptation Strategy:** This step should be self evident. As noted above, this is an iterative process and the vulnerability assessments and adaptation strategies will be revisited as more information such as improved simulations of future climate becomes available.

There are many smaller steps within the over-arching four steps outlined above. Details on processes for doing this work can be found in Ohlson *et al.* (2005), Ebi *et al.* (2004) and Evans *et al.* (2006). Doing vulnerability assessments and developing adaptation strategies is an iterative process with assessments and strategies being revisited as more knowledge becomes available. It is likely that a first run through the framework on an issue would be done to identify information needs and refine the issue. The vulnerability and adaptation steps would be cycled through a number of times before implementation of an adaptation strategy.

Numerous adaptive actions that have been proposed for forest management are summarized in Spittlehouse and Stewart (2003). They can be grouped into three categories: societal adaptation (e.g., develop forest policy to encourage adaptation, revise conservation objectives, and change expectations), adaptation of forest management techniques (e.g., change rotation age, use more salvage wood, and modify wood processing technology), and adaptation of the forest (e.g., species selection, tree breeding, stand management, and fire-smart landscapes).

Challenges to Adapting to Climate Change

Consideration of weather and climate conditions is part of forest and range management. For example, fire protection activities include calculating drought codes and developing fire smart communities. Climate is implicitly included in growth and yield modelling and ecosystem mapping. The challenge is to develop explicit descriptors of species and ecosystem responses to climate that can be used in vulnerability assessments and developing adaptation strategies, e.g., Wang *et al.* (2006b).

A major challenge in taking adaptive actions in the near term is the uncertainty in the magnitude and timing of future climate change. This uncertainty is compounded by the uncertainty in the future markets for our forest resources and that climate change may lead to relative increases in the timber and forest products supply from other nations (Sohngen and Sedjo 2005). The development of adaptation measures for some time in the future, under an uncertain climate, in an unknown socio-economic context is bound to be highly speculative (Burton *et al.* 2002). Some groups may view responding as a greater risk than doing nothing or that impacts can only be dealt with when they happen. Furthermore, there is a lack of awareness in the forestry community of the risks of climate change (Williamson *et al.* 2005) though this is changing.

The size of the forested land base in BC means that much of the forest will have to adjust without human intervention. Of the approximately 60 Mha of forest in BC there are about 35 Mha in the non-timber harvest land base (includes parks, wilderness areas and areas with operational constraints) where forest management consists mainly of fire protection and conservation. The remaining 25 Mha, the timber harvest land base, is harvested at about 0.2 Mha per year. Adaptation will likely focus on the major commercial tree species and perhaps a few animal species, while the majority of forest plants and animals will have to adapt as best they can. Any large-scale disturbances caused by climate change would be particularly difficult to address. Society will have to adapt to how the forest in the non-timber harvest land base adjusts. In some areas, adaptation to reduce the vulnerability of resources such as water quality and quantity and biological conservation will become the highest priority.

There are institutional and policy barriers to responding to climate change. For example, seed planning zones, reforestation standards and hydrologic and wildlife management guidelines are designed for the current climate regime. There are no requirements for adaptation strategies in forest management plans, nor are there guidelines and sufficient experienced personnel to aid such activities. Also, it is often difficult to get the long term funding required to address such a wide ranging issue as climate change brings.

Assessing vulnerabilities and developing adaptation strategies requires information about the possible future climates. At present, all of the future climate scenarios should be considered to have equal likelihood of occurrence. The next 20 years will see improvements in our knowledge of the future climate along with improved understanding of the vulnerability of forest and range resources to climate change. In the meantime, we may need to apply interim responses. In this case, these actions should be such that they do not have negative consequences if the future does not unfold as assumed. Near-term actions include forest policies to facilitate adaptation, training to develop adaptive capacity in forest managers and developing tools.

Conclusions and Recommendations

The next 20 years will clarify the global response to the risks of climate change, global climate models will have improved and we should have a clearer idea of the climate change to expect. This period should also see significant improvements in our understanding of the vulnerability of forest and range resources to climate change. In the meantime, it is recommended that:

- Vulnerability analyses use climate simulations for the B1 and A2 scenario, and simulations from at least two global climate models with different climatologies, e.g., the Canadian and Hadley Centre models.
- Analyses should also be done using annual as well as mean climate data to evaluate the effects of changes in the inter-annual variability and extremes.

Although many of the impacts of climate change may be decades away, assessing forest vulnerability to climate change, developing adaptation strategies and strengthening monitoring programs should start now. Most of British Columbia's forests and range are on crown land. The provincial government is responsible for developing management objectives, setting standards for species selection, seed transfer, stocking, and biodiversity, allocating land to parks and wilderness areas and maintaining health and growth monitoring plots.

It is recommended that the BC Ministry of Forests and Range respond to the potential impacts of climate change on forest and range management by cooperating with other agencies and groups in taking the lead to:

- Develop data bases and methods for assessing vulnerabilities to climate change and promote adaptation in forest and range management.
- Create a set of climate change scenarios for British Columbia at a high spatial resolution so that all users can work from a common data base.
- Provide a "one stop" facility that would be a source of climate change scenarios and other climate data for vulnerability analyses, and would facilitate access to the latest information.
- Determine user needs with respect to climate variables, time periods and tools for climate change vulnerability analyses.
- Develop adaptive capacity within the forest and range management community.
- Develop a set of key indicators of climate change that can help in monitoring the response of forest and range resources to climate change.
- Investigate management responses that can be applied in the near term that might alleviate some of the vulnerability without compromising the long term.

It is encouraging to note that many of these recommendations are being acted on. Recent announcements from the British Columbia provincial government on cooperation on emissions reduction with other jurisdictions and on setting emissions targets for BC are also welcomed.

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Appendix I: British Columbia's Past and Present Climates

British Columbia's climate has changed dramatically since the glaciers receded about 12000 years ago. A dry, cold late glacial climate was followed by a period of rapid warming, a warm and dry interval and then a warm relatively moist interval. Today's relatively cool climate in BC started about 4500 years ago (Rosenberg *et al.* 2004). Most of the vegetation regimes we are familiar with were established 4000 to 6000 years ago, though there have been adjustments in ranges and species composition with the fluctuations in climate and human activity during this period.

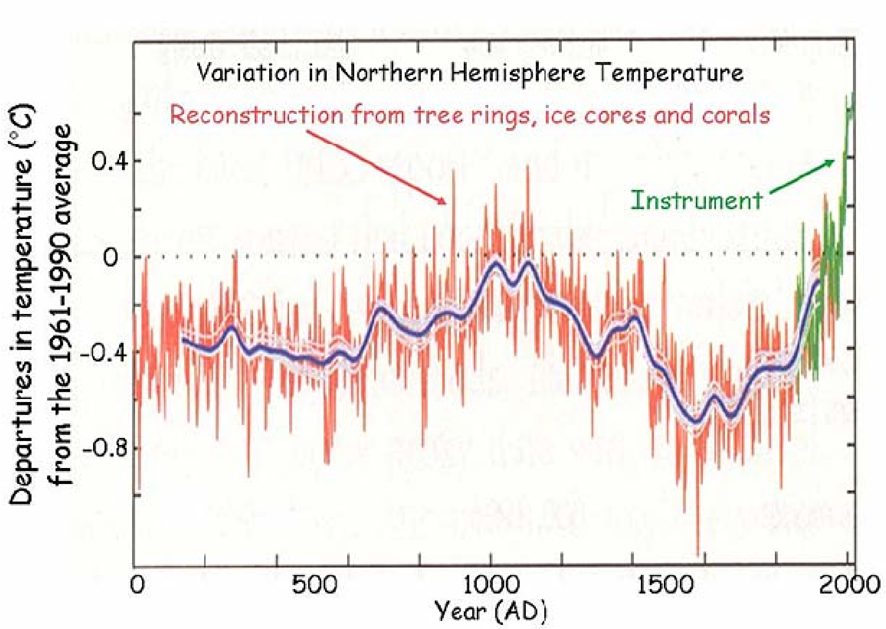
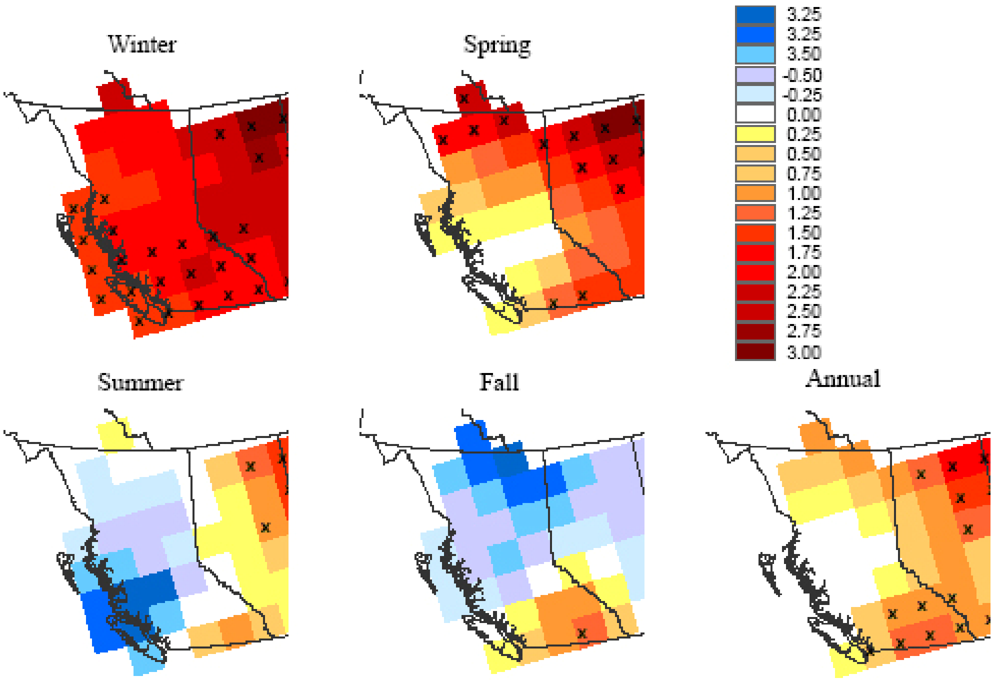


Figure A1. Variation in the annual Northern Hemisphere temperature over the last 2000 years expressed as the difference between the 1961–90 average and the annual values. The green line shows measured data and the red and blue lines are reconstructed from tree rings, ice cores and corals. The blue line is the long-term average. (Adapted from Moberg *et al.* 2005)

The last 1000 years in the Northern Hemisphere was a period of slow cooling of about 0.7°C followed by a warming that started about 200 years ago (Figure A1). The rate of warming over the last 100 years has been faster than any time in the past 2000 years. Temperatures are now warmer than any time in the past 2000 years and are about 1°C warmer than the early 1800s. The concentration of carbon dioxide has risen from 280 ppm before the start of the industrial revolution to about 381 ppm and is currently increasing at about 1.9 ppm per year (Canadell *et al.* 2007). Other greenhouses gases such as methane have shown similar rates of increase. Concentrations are greater than any seen in the last 650,000 years (Houghton *et al.* 2001, Hengeveld 2006, IPCC WG I 2007).

The temperature variation in BC in the last 2000 years has been similar to that of the Northern Hemisphere (Rosenberg *et al.* 2004, Hebda 2007).

A) Maximum temperature



B) Minimum temperature

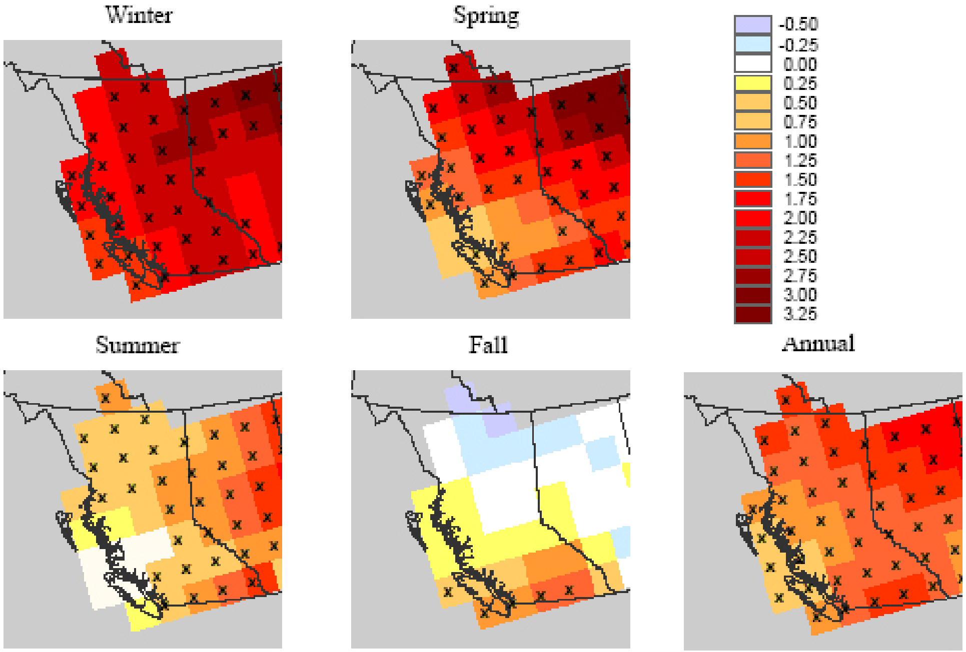


Figure A2. Seasonal trends in A) maximum and B) minimum temperatures for western Canada for 1900–2003 (Moore *et al.* 2007). Units are °C over 104 years. Grid cells with crosses indicate trends that are significant at a 5% significance level. Grey cells indicate areas with insufficient data to estimate gridded temperatures. Winter is December, January and February, Spring is March, April and May, Summer is June, July and August and Fall is September, October and November.

In the last 100 years there has been a tendency for a greater warming in the winter than in the summer air temperature. The warming has been greater in northern BC than in southern and coastal BC (Figure 2A) (Anon 2002, Zhang *et al.* 2000, Vincent and Mekis 2006, Rodenhuis *et al.* 2007). There have been fewer cold nights, cold days and frost days and more warm nights and warm days. Similar conditions have been found for most of southern Canada (Vincent and Mekis 2006). There is insufficient coverage in the first half of the 1900s to quantify changes occurring in northern Canada.

Trends in annual precipitation over the 20th century were positive but spatially variable. Increases have occurred in winter and summer but have been larger in the winter than in the summer in northern BC and larger in the summer in southern BC (Figure A3). Over the last 50 years there has been a reduction in winter precipitation and an increase in summer precipitation over most of BC (Zhang *et al.* 2000, Vincent and Mekis 2006). There has been an increase in the number of days with precipitation and decrease in the number of consecutive dry days since early in the 1900s. Woods *et al.* (2005) suggested that the recent increase in wet and warm days has resulted in an increase in the occurrence of a needle disease that kills lodgepole pine trees. Annual snowfall and snow pack depth have declined substantially in the last 50 years (Mote *et al.* 2005, Vincent and Mekis 2006). Similar conditions have been found for most of southern Canada (Vincent and Mekis 2006). Trends in precipitation are superimposed on large inter-annual and inter-decadal variations in precipitation that are affected by ocean conditions such as El Nino/La Nina events and the Pacific Decadal Oscillation (Rodenhuis *et al.* 2007).

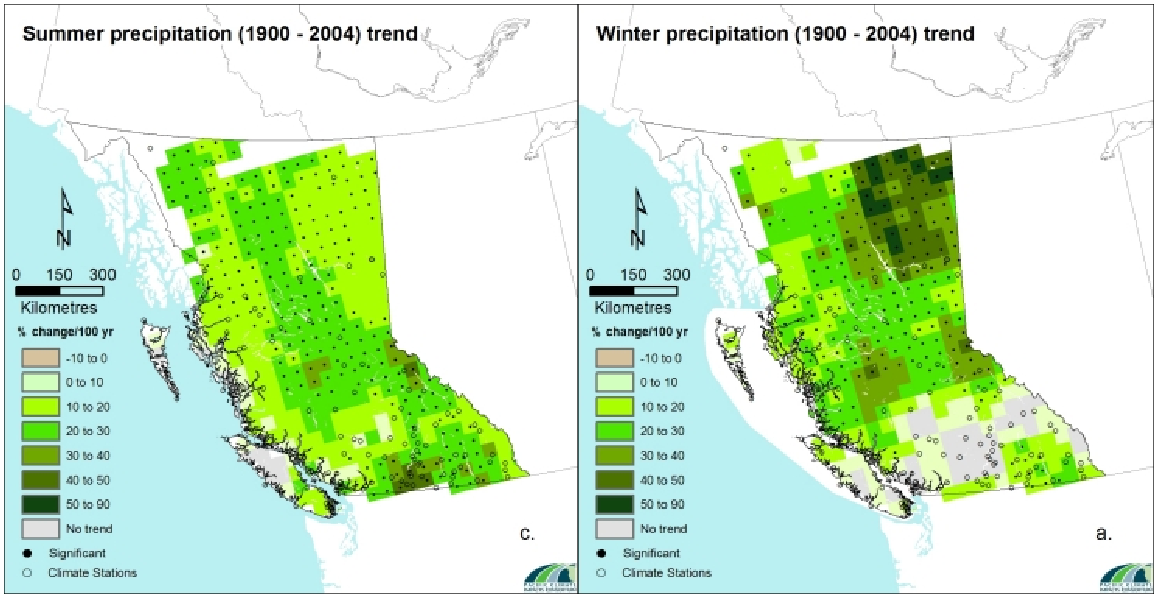


Figure A3: Trends in winter and summer precipitation (% change/100 years) in BC from 1900-2004 (Rodenhuis *et al.* 2007). Black solid circles indicate statistical significance at 95% confidence level. Summer is June, July and August and Winter is December, January and February.

Table A1. (i) 1961–90 climate normals for biogeoclimatic zones, and (ii) one standard deviation on these values (next page). Data were obtained by overlaying biogeoclimatic ecosystem variants (Meidinger and Pojar 1991) on a high spatial resolution (400 m grid) climate data base created with ClimateBC (Wang *et al.* 2006a, Spittlehouse, 2006). Climate variable and zone abbreviations are explained below the table. Data use to create this table are available at: ftp://ftp.for.gov.bc.ca/HRE/external/!publish/Climate/ .

i) 1961–90 climate normals

&Zone	$MAP mm	MSP mm	PAS mm	MAT ºC	MTCM ºC	MTWM ºC	xTmin ºC	FFP days	DD<0	DD>5	SHM
BAFA	1090	447	598	-2.6	-13.4	9.1	-44.6	15	2071	340	22
BG	342	161	100	6.1	-6.3	17.5	-35.8	118	575	1717	115
BWBS	514	308	178	-0.3	-16.0	14.3	-46.5	77	2090	1023	48
CDF	1091	201	61	9.6	3.0	16.9	-15.4	204	31	1965	88
CMA	3198	816	1795	-0.3	-9.7	9.6	-40.0	43	1364	440	15
CWH	2893	651	427	6.7	-0.4	14.5	-22.1	151	191	1339	28
ESSF	1096	404	566	0.3	-10.6	11.5	-41.8	51	1413	650	31
ICH	920	342	379	3.3	-8.4	14.7	-38.9	88	922	1152	46
IDF	493	210	178	4.0	-7.7	15.1	-38.6	84	813	1238	74
IMA	1539	473	959	-2.0	-11.3	8.4	-43.1	20	1791	301	20
MH	3119	730	1198	2.8	-5.7	12.0	-33.2	76	690	781	20
MS	648	261	292	1.9	-9.3	12.8	-40.8	62	1101	848	511
PP	382	165	112	6.3	-5.9	17.9	-35.2	120	517	1762	113
SBPS	473	228	191	1.7	-10.3	12.6	-43.2	35	1176	843	58
SBS	657	280	274	2.2	-10.3	13.6	-41.9	75	1169	988	20
SWB	691	352	322	-1.8	-13.9	10.9	-44.6	37	2038	525	13

$MAP=Mean annual precipitation, MSP=Mean summer precipitation (May to September), PAS=Precipitation as snow (water equivalent), MAT=Mean annual temperature, MTCW, Mean temperature of coldest month, Mean temperature of warmest month, xTmin=Extreme minimum temperature, FFP=Frost free period, NFFD=Number of frost free days, DD<0=Degree-days less than 0ºC, DD>5=Degree days greater than 5ºC, SHM=Summer heat/moisture index.

&BAFA=Boreal Alti Fescue Alpine, BG=Bunch Grass, BWBS=Boreal Black and White Spruce, CDF=Coastal Douglas-fir, CMA= Coastal Mountain-heather Alpine, CWH=Coastal Western Hemlock, ESSF=Engelmann Spruce-Subalpine Fir, ICH=Interior Cedar Hemlock, IDF=Interior Douglas-fir, IMA=Interior Mountain-heather Alpine, MH=Mountain Hemlock, MS=Montane Spruce, PP=Ponderosa Pine, SBPS=Sub-boreal Pine Spruce, SBS=Sub-boreal Spruce, SWB=Spruce Willow Birch. (http://www.for.gov.bc.ca/hre/becweb/)

ii) One standard deviation on mean values of 1961–90 climate normals

&Zone	$MAP mm	MSP mm	PAS mm	MAT ºC	MTCM ºC	MTWM ºC	xTmin ºC	FFP days	DD<0	DD>5	SHM
BAFA	524	150	345	1.2	1.6	1.2	1.5	19	330	114	7
BG	30	19	12	0.5	0.5	0.6	1.1	9	66	134	16
BWBS	61	37	24	0.7	2.1	0.7	1.4	8	259	107	7
CDF	166	47	13	0.3	0.5	0.4	1.3	19	14	87	18
CMA	1252	397	737	2.2	3.5	1.9	5.0	32	554	218	7
CWH	785	186	205	0.9	1.4	0.9	3.2	23	88	181	8
ESSF	251	76	156	0.8	0.9	0.8	1.2	15	176	116	6
ICH	197	59	111	1.0	1.0	1.0	1.7	14	162	175	9
IDF	82	27	39	0.7	0.7	0.9	1.3	13	101	160	11
IMA	351	113	251	1.2	1.2	1.4	1.6	20	278	133	6
MH	888	234	446	1.3	2.0	1.3	3.8	28	254	192	7
MS	128	46	74	0.6	0.7	0.7	1.0	11	103	110	10
PP	43	17	19	0.7	0.6	0.8	1.3	10	78	161	15
SBPS	55	32	31	0.6	0.7	0.7	1.0	18	90	104	11
SBS	107	38	58	0.6	0.8	0.6	1.0	11	108	104	3
SWB	134	77	89	0.7	1.5	0.8	1.2	18	191	97	3

Appendix II. Climate Change Scenarios for British Columbia

Climate model simulations use range of emissions scenarios that are based on possible future technological and economic developments and international cooperation (IPCC WG I 2007). An example for carbon dioxide is shown in Figure A4 and similar patterns occur for other greenhouse gases such as methane, nitrous oxide, and dust particles. Canadell *et al.* (2007) report that current rates of emissions are now higher than those used in the IPCC WG I (2007) analyses.

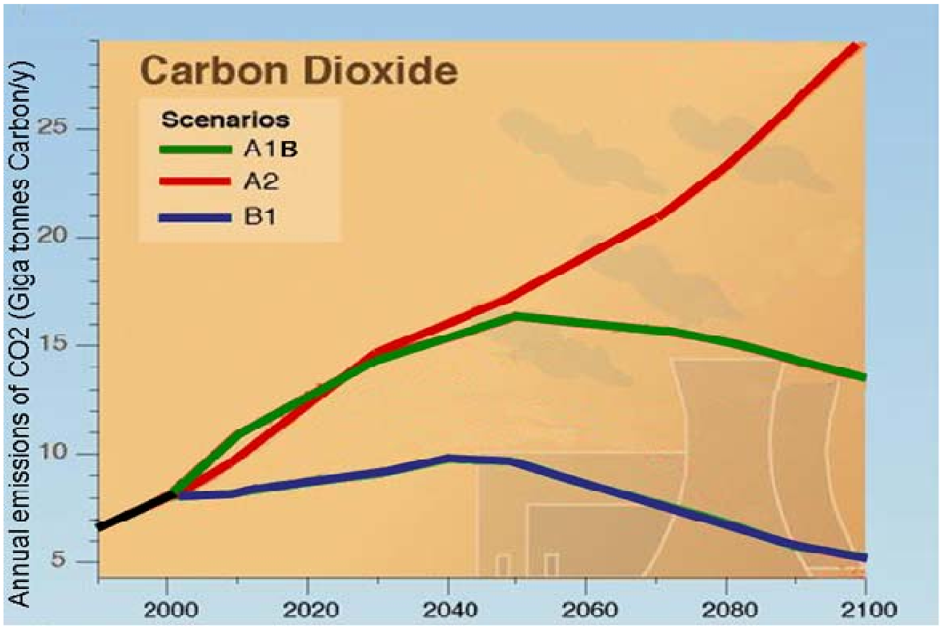


Figure A4. The B1, A1B, and A2 emissions scenarios for carbon dioxide used in global climate modeling (IPCC WG I 2007). Other greenhouse gases such as methane and nitrous oxide and particulates such as sulphur follow a similar trend. The simulated global mean air temperature for each scenario is shown in Figure 1. (Adapted from www.ipcc.ch.)

Future global temperature and precipitation regimes: The corresponding simulated global air temperatures for the emission scenarios in Figure A4 are shown in Figure 1 of the main body of this report. All scenarios have a temperature increase with time and the size of the change increases towards the poles (Figure A5).

Changes in precipitation have a more variable pattern and there is a greater range of variation between models and scenarios than with temperature. Summer precipitation is predicted to decease in equatorial and temperature latitudes but to increase in northern latitudes (Figure A6). In the winter, the precipitation increase is greater than in summer and the increase tends to extend into the northern temperature latitudes.

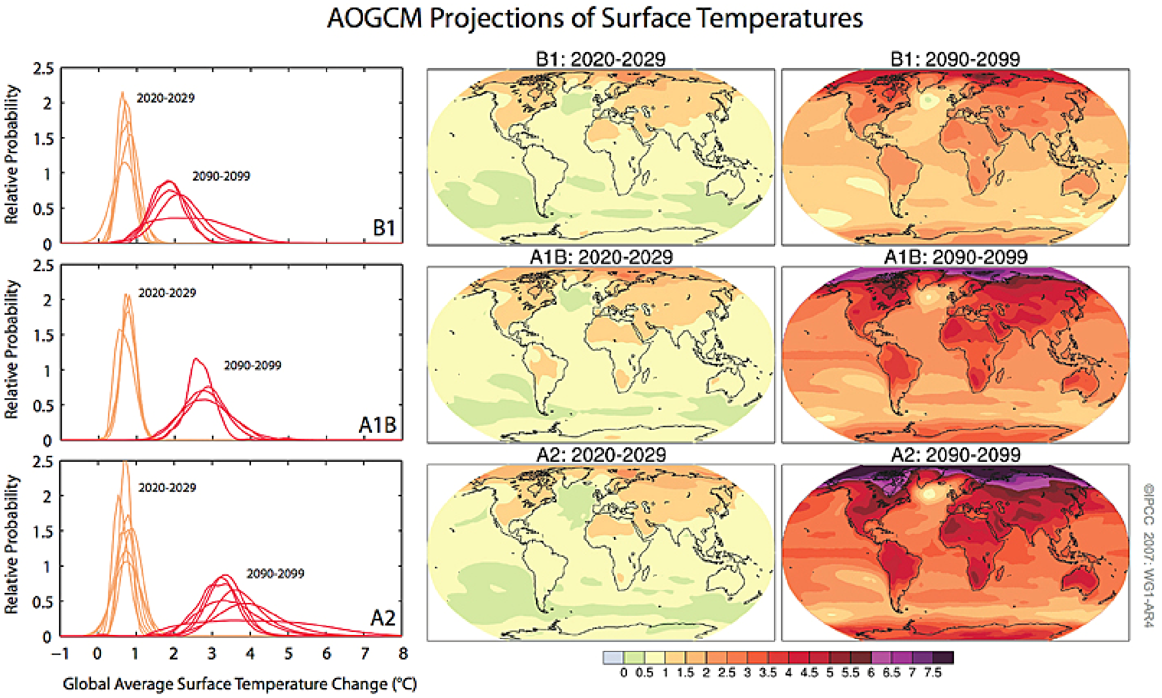


Figure A5. Projected global surface air temperature changes for 2020s and 2090s relative to the 1980–1999 period for the B1, A1B and A2 emissions scenarios shown in Figure A4. The data in the centre and right panels are averages for a number of model runs. The left panel shows relative probabilities of estimated global average warming from several different multi-model simulations. (From IPCC WG I 2007)

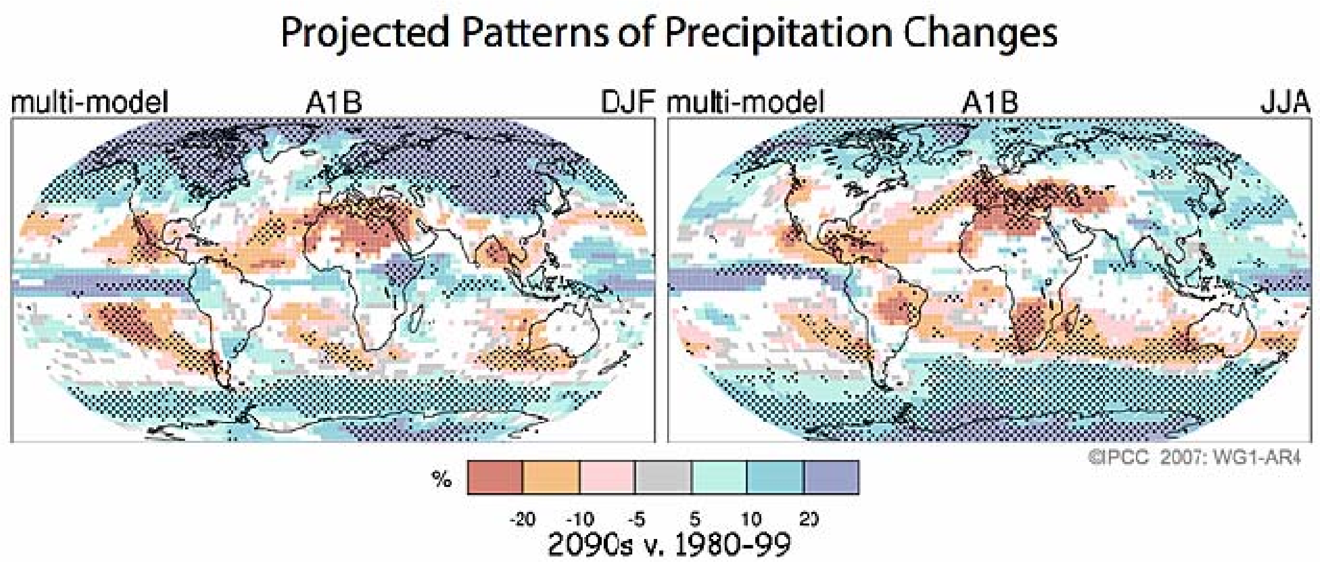


Figure A6. Percentage change in the global annual precipitation in 2090s relative to 1980–1999. Values are averages of various models for the A1B scenario for the December to February (DJF) and June to August (JJA) periods. White areas are where less than 66% of models agree in the sign of the change and stippled areas are where 90% or more of the models agree on the sign of the change. (From IPCC WG I 2007)

British Columbia's future temperature and precipitation regimes: The examples for BC are based on Canadian global climate model version 2 (CGCM2) for the A2 and B1 emission scenarios (Figure A4). Data were downscaled using the ClimateBC software (Wang *et al.* 2006a, Spittlehouse 2006).

Table A2. Climate in the 2020s, 2050s, and 2080s for five locations in BC for the A2 emission scenario. Based on ClimateBC interpolation of the CGCM2 simulation. Data adjusted to 1961–90 normals reported in AES (1993) for the airport weather stations. Scenario temperature data were rounded to 0.5°C and precipitation to 5 mm. MAT = mean annual temperature (°C), MWMT = mean warmest month temperate (July, °C), MCMT = mean coldest month temperature (January, °C), MAP = mean annual precipitation (mm), MSP = mean May to September precipitation (mm), FFP = frost free period (days), DD>5 is degree days above 5°C, SHM = Summer heat/moisture index.

Cranbrook

	MAT	MWMT	MCMT	MAP	MSP	FFP	DD>5	SHM
1961–90	5.6	18.2	-8.3	384	185	109	1671	98
2020s	7.0	19.5	-6.5	390	185	125	1960	105
2050s	8.0	20.5	-4.5	380	175	140	2220	117
2080s	10.0	22.0	-3.5	395	175	170	2680	126

Fort Nelson

	MAT	MWMT	MCMT	MAP	MSP	FFP	DD>5	SHM
1961–90	-1.1	16.7	-22.0	449	303	106	1289	55
2020s	0	18.0	-20.5	465	310	115	1480	58
2050s	1.5	19.5	-18.0	475	315	130	1670	62
2080s	3.5	21.0	-14.5	500	330	145	1950	64

Kelowna

	MAT	MWMT	MCMT	MAP	MSP	FFP	DD>5	SHM
1961–90	7.4	18.8	-4.5	366	171	125	1864	110
2020s	8.5	20.0	-3.5	375	170	140	2100	118
2050s	9.5	21.0	-2.0	370	160	150	2390	131
2080s	11.0	22.5	-1.0	375	160	175	2820	141

Prince George

	MAT	MWMT	MCMT	MAP	MSP	FFP	DD>5	SHM
1961–90	3.7	15.3	-9.9	615	287	93	1238	53
2020s	5.0	16.5	-8.0	615	280	110	1450	59
2050s	6.0	17.5	-6.5	630	285	125	1700	61
2080s	7.5	19.0	-5.0	635	275	150	2070	69

Port Hardy

	MAT	MWMT	MCMT	MAP	MSP	FFP	DD>5	SHM
1961–90	8.1	13.9	3	1871	410	183	1379	33
2020s	9.0	15.0	4.0	1885	395	205	1770	38
2050s	10.0	16.0	5.0	1935	385	260	2020	42
2080s	11.5	17.0	6.0	2035	375	325	2510	45

This method assumes that the relative geographical distribution of temperature and precipitation will remain the same under climate change as at present. The high resolution of the figures does not imply a high accuracy, that being limited by the GCM data and the interpolation methodology. Wang *et al.* (2006a) reported an accuracy of ±1°C temperature and ±15 mm for precipitation in a test against the 1961–90 normals. The grid-based data for monthly temperature and precipitation at 400 m spacing for current climate and the A2 scenario are available at: ftp://ftp.for.gov.bc.ca/HRE/external/!publish/Climate/ . ClimateBC software and a web-based version are at http://genetics.forestry.ubc.ca/cfgc/climate-models.html .

Mean annual temperature and precipitation data for current climate (1961–90 average) and for 2020s, 2050s and 2080s for the A2 scenario were presented in the main part of the report (Figures 2 and 3). This Appendix focuses on seasonal changes in temperature and precipitation for the A2 emissions scenario (Figures A7 and A8) and presents data for specific locations in BC (Tables A2 and A3) for the A2 and B1 emissions scenarios.

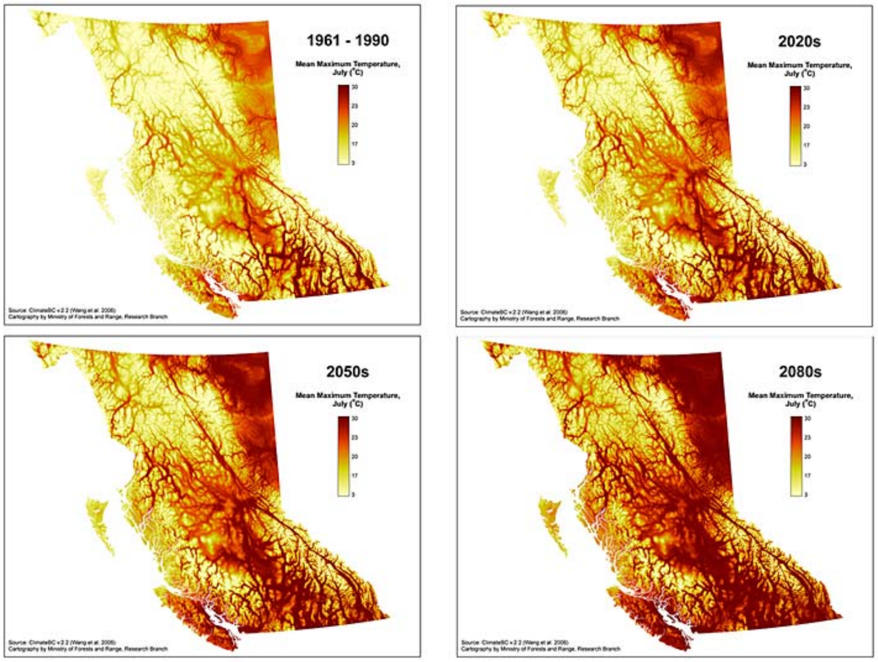
The reduced emissions under the B1 scenario result in less warming than that for the A2 scenario. Climate in 2080s for B1 is similar to that for A2 in the 2050s (Tables A2 and A3). In both scenarios, the temperature increases with time with a tendency for the warming to be greatest in northern BC and larger in the winter than in the summer. The warming is greater in the winter minimum temperatures than in the winter maximum temperature, with warming in winter greater than summer. For example, for Cranbook by 2080 under the A2 scenario winter minimums rise by 7°C, winter maximum by 3°C, summer minimum by 4°C, and summer maximum by 3.5°C. The respective values for Ft Nelson of 9, 6, 4.5, and 3.5°C, show the greater warming in northern BC. Warming is least in coastal areas where it is moderated by the ocean. Increasing temperature is accompanied by an increase in the frost free period and growing degree days.

Changes in precipitation are quite variable in time and space. Southern and central BC are predicted to get drier in the summer while northern BC is more likely to be wetter (Figure A8), though the volumes are not large. Winters in will be wetter across BC with a greater percentage increase in the north, though Coastal BC sees the greatest volume increase in winter precipitation (Tables A2 and A3). Warming means that less of the precipitation will fall as snow. For example, at Cranbrook there is a reduction from 120 mm to 70 mm (water equivalent) of the winter precipitation as snow by the 2080s under the A2 scenario. At Fort Nelson the change is from 130 mm to 115 mm.

Table A3. Climate in the 2080s for five locations in BC for the B1 emission scenario. For an explanation of symbols and 1961–90 normals see Table A2.

	MAT	MWMT	MCMT	MAP	MSP	FFP	DD>5	SHM
Cranbrook	8.0	20.6	-6.1	395	185	140	2060	111
Fort Nelson	1.5	19.0	-18.5	460	305	115	1690	62
Kelowna	9.5	21.0	-3.5	390	170	160	2400	124
Prince George	6.0	18.0	-6.5	600	275	130	1700	65
Port Hardy	10.0	16.5	4.5	1975	390	255	1940	42

A) Mean maximum July temperature



B) Mean minimum January temperature

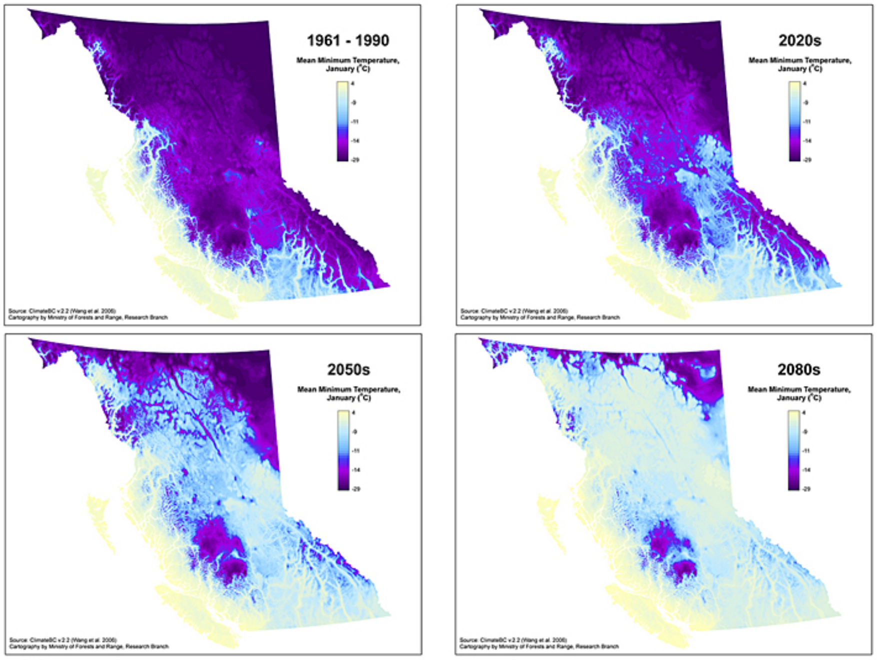
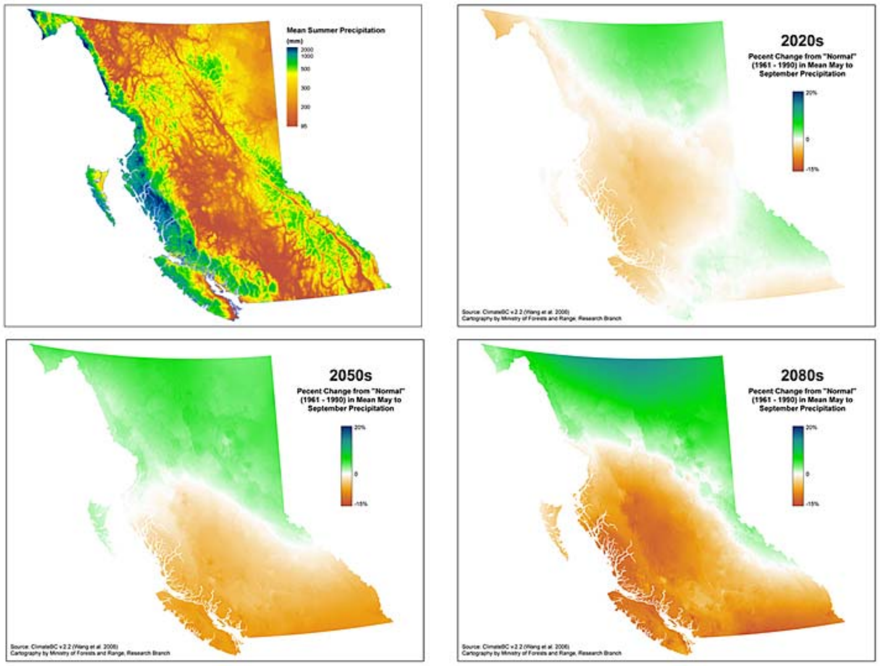


Figure A7. A) Mean maximum July temperature for BC for current climate (1961–90 average) and that predicted for BC in 2020s, 2050s and 2080s. B) Mean minimum January temperature for BC for current climate (1961–90 average) and that predicted for BC in 2020s, 2050s and 2080s. Data were produced by the ClimateBC software that downscaled change data for the A2 scenario from the Canadian global climate model version 2 (Wang et al. 2006a).

A) Mean May to September precipitation



B) Mean October to April precipitation

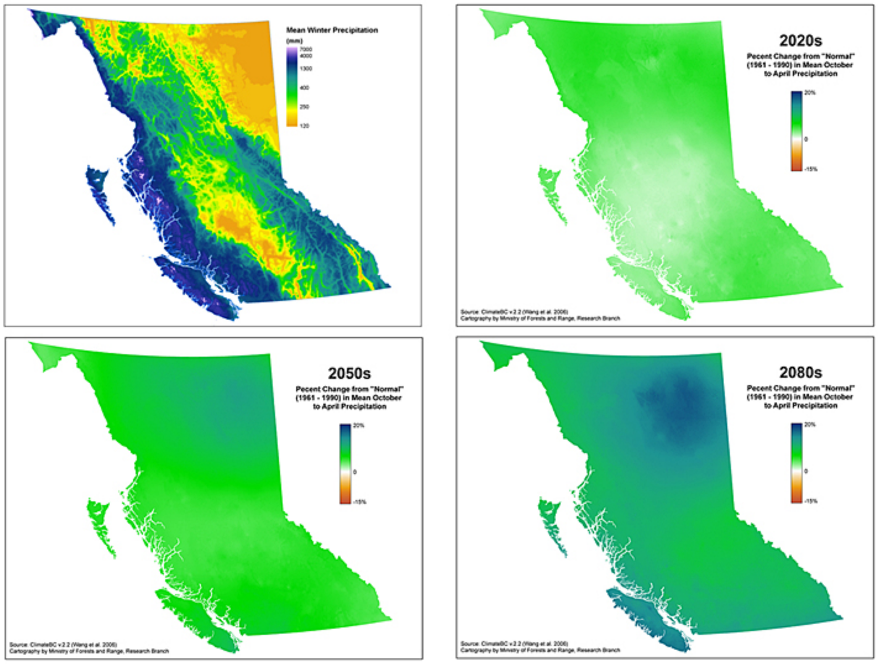


Figure A8. A) Mean May to September precipitation for BC for current climate (1961–90 average) and the percentage change predicted for BC in 2020s, 2050s and 2080s. B) Mean October to April precipitation for BC for current climate (1961–90 average) and the percentage change predicted for BC in 2020s, 2050s and 2080s. Data were produced by the ClimateBC software that downscaled change data for the A2 scenario from the Canadian global climate model version 2 (Wang et al. 2006a).

Influence of climate change on snow accumulation and melt

Mote *et al.* (2005) and Rodenhuis *et al.* (2007 report a general decline in snow packs over much of western North America from in the last 50 years. Increasing winter temperatures under climate change are expected to continue this trend. This is illustrated with data for Glacier Rogers Pass (Figure A9) for climate conditions equivalent to the A2 scenario in 2050s and 2080s or the B1 in the 2080s. A snow accumulation and melt model was used to determine the daily snow depth under current (winter of 2001/02) and changed conditions. The effect of changed climate was evaluated by assuming 2 and 4ºC increases in the daily temperature record for winter 2001/02. A third simulation involved a 4ºC increase plus a 10% increase in winter precipitation. Glacier had close to average October to April precipitation in 2001/02 and snow on the ground at the end of March and April.

As expected increasing the temperature reduced the amount of snow on the ground due to the later development of the pack and an earlier start to spring snowmelt. The larger the temperature increase, the shallower the pack and the shorter the snow season. Increasing precipitation offsets some the effect of a temperature increase. The 4ºC warming scenario reduced depth by about 30% and the snow disappeared about a month earlier than under current conditions

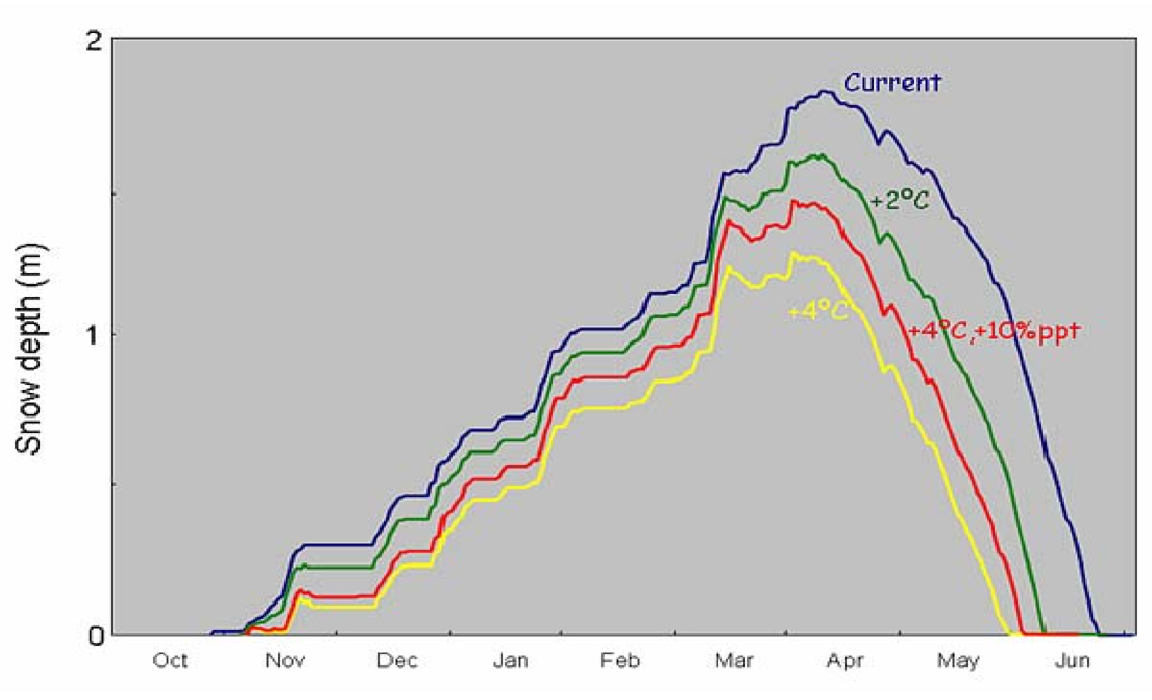


Figure A9. Simulated winter snow depth for Glacier Rogers Pass under current (winter 2001/02) temperature and precipitation (blue line) and three climate change scenarios. The scenarios are: 2ºC warming (increase to daily temperature record for winter 2001/02) with no precipitation change (green line), 4ºC warming with no change in precipitation (yellow line), and 4ºC warming and a 10% increase in precipitation (red line).

Influence of climate change on evaporative demand and climatic moisture deficit

Estimates of the evaporative demand for water and measurements of precipitation can be combined to give indicators of plant water stress and to predict water demand for agricultural irrigation and domestic use. A climatic moisture deficit occurs if the monthly precipitation is less than the demand for the month. If precipitation is greater than the evaporative demand there is a moisture surplus. Monthly evaporative demand was calculated following Allen *et al.* (1998) for months when the air temperature was above 0°C. Calculations were done for current conditions (1961–1990 normals) and for the 2080s' B1 and A2 climate change scenarios for the Campbell River, Cranbrook and Fort St. John areas. Temperature and precipitation data at 2080 were obtained from ClimateBC (Wang *et al.* 2006a, Spittlehouse 2006). The average monthly sunshine or solar radiation data and a mean wind speed for the 1961–1990 period were used for the 2080s calculations.

Evaporative demand increased at all locations due to an increase in the length of the time the air temperature was above zero and to an increase in the vapour pressure deficit. Under the B1 scenario by 2080s the demand increased by about 8% while under the A2 scenario, with greater warming, it increased by 15 to 20%. There was a greater difference between locations in the climatic moisture deficit reflecting the balance between changes in temperature and changes in precipitation (Figures A7 and A8). By the 2080s under the B1 scenario, the deficit at Campbell River increased by 20%, at Fort St John by 25% and at Cranbrook by 30%. For the A2 scenario, Campbell River and Fort St John increased by 30% while Cranbrook increased by 60%. The larger increase at Cranbook reflects the decrease in summer rainfall and an initially relatively low average deficit for 1961–1990. A moisture surplus did not occur during the summer at any of the locations. A detailed analysis should use estimates of changes in solar radiation and wind speed and assess inter-annual variability.

Appendix III: Potential Impacts of Climate Change on British Columbia's Forest and Range Resources

The response of forest and range species to climate change and the changing operating environment will challenge our ability to use forest and range resources. The wood supply for the next 50 to 100 years in most of BC is already "in the ground" or will be planted in the next few years with minimal consideration about climate change. Losses in productivity of natural and planted stands are expected to occur in the drier and warmer regions of BC, while modest increases are anticipated in near to mid term in the north (Rehfeldt *et al.* 1999, 2001, Johnson and Williamson 2005, Spittlehouse 2003). These changes will affect rotation age, wood quality, wood volume, and size of logs. An increase in disturbance by fire, insects and disease could lead to a greater amount of the harvest consisting of salvaged wood (Spittlehouse and Stewart 2003, Volney and Hirsch 2005). Technological change, trade disputes, changes in exchange and interest rates and in consumer tastes and preferences will take place along with climate change. Countries that are expected to be significant beneficiaries of climate change from a production standpoint, i.e., South America and Oceania, are already replacing Canadian products in the global market (Sohngen and Sedjo 2005).

Access to timber and harvest scheduling will change because warmer and/or wetter winters will limit site access for winter logging, and warmer and drier summers will reduce access due to increased fire risk. Expected higher rainfall intensities and a reduction in the return period of high intensity rains will affect road design and maintenance (Bruce 2003). More severe winter storm events in coastal British Columbia are likely to increase the probability of occurrence of landslides, including debris flow activity (Wieczorek and Glade 2005). This has implications for forest development planning and operations. Increase in warming in the north and an accompanying increase in permafrost melt will increase the risk of land slides (Geerstma *et al.* 2006).

Reforestation is based on the selection of species and genotypes that are genetically adapted to the site (climate and soil). A changing climate means that the appropriate plants for a site would change (Rehfeldt *et al.* 1999, 2001, Parker *et al.* 2000, Spittlehouse 1996, Spittlehouse and Stewart 2003, Wang *et al.* 2006b). Hamann and Wang (2006) indicate that tree species with their northern range limit in BC will gain climatically suitable habitat at a pace of about 100 km per decade. Common hardwoods appear to be less sensitive to climate change while some of the most important conifer species in BC could lose a large portion of their climatically suitable habitat. The climate will continue to change over the life of the stand and we must decide which climate regime the planting stock should be selected to meet. Increased competition from species more suited to this climate mean that there may be a need to increase stand management activities in established stands (Parker *et al.* 2000, Spittlehouse and Stewart 2003).

Changes in fire regime will have a direct impact on the safety of people and property (Volney and Hirsch 2005), as illustrated by the fires near Kelowna and Barriere in 2003. Smoke from forest fires can have health impacts many kilometres from the fire. Increased occurrence of wildfires would increase the likelihood of post-wildfire flood and landslide risks to human life, property and infrastructure. Forest harvesting and road building may have to increase efforts to mitigate the impacts of changes in the timing of peak flow and volume in streams on infrastructure, fish habitat, and potable water supplies (Mote *et al.* 2003). Warmer and drier summer conditions will increase the pressure to maintain cool stream temperatures by maintaining riparian cover in harvested areas (Moore *et al.* 2005). A priority may be placed on preserving habitat for conservation. However, the values and attributes that parks and wilderness areas were designed to protect may no longer exist within the protected areas (Scott and Lemieux 2005). Warmer winters will shorten the winter recreational season while the summer recreational season will increase, though increased fire risk may limit this increase. Increases in disturbance by fire may favour certain mushroom species and shrubs that are a source of berries (Spittlehouse 2005).

Some specific implications of climate change for BC's ecosystems are:

- In some areas of BC, the distribution of ages of the trees in BC is biased towards old trees. This means a build-up of fuels for fire and an increase in the susceptibility of trees to diseases and pests, a situation that may result in an increased sensitivity to disturbance.
- Increase in disturbance by fire will lead to an increase in the area of younger forests. Changes in disturbance, forest growth and species composition will affect habitat quality and availability for wildlife (Harding and McCullum 1997, Stenseth *et al.* 2002).
- Coastal forests: In the southern part of the area, warmer and drier late spring and summers could increase fire risk and decrease water availability. Increased water stress will affect species such as western red cedar on marginal sites on the east side of Vancouver Island. Present wet and cool mid and northern coasts will see an improvement in growing conditions. Increase in storm number and intensity will likely increase windthrow and breakage of trees. An increase in the severity storms could increase the probability of landslides, and debris flows.
- Lower elevations in southern interior: Drier sites may experience regeneration problems due to an increase in summer droughts. Grasslands are expected to expand (Hebda 2007) and the current encroachment of forests on grasslands may be reversed by climate change.
- Higher elevations in southern interior: A shorter snow season and increased length of growing season may initially be beneficial to regeneration and growth. In drier areas, reduction in summer precipitation and increase in temperature will increase the risk of fires and drought stress.
- Northern interior: Warming and only small changes in summer precipitation have the potential to result in increased tree growth in the near to mid term. A shorter winter season will reduce access to sensitive terrain.
- Alpine: The length of the snow pack season, soil conditions and slow regeneration rates will limit the rate of forest encroachment. Artificial warming studies in tundra ecosystems have shown changes in the occurrence of existing species.

Assessment of the implications of a changing climate change on ecosystems

Hamann and Wang (2006) assessed the change in spatial distribution of suitable climatic habitat for vegetation over time. Another approach is to evaluate impacts of a changing climate at a location. Ecosystem maps were overlain on grid-based climate data from ClimateBC to obtain descriptions of the climate of these units for current conditions and the A2 scenario in 2050 (Spittlehouse 2006). This type of analysis is expanded on in the accompanying foundation paper on resilience.

Table A4. The current (1961–1990 normals) and possible climate (CGCM2-A2x scenario for 2050s) of two biogeoclimatic variants. Means and one standard deviation (± SD) of each variable are presented (Spittlehouse 2006).

	Very Dry Maritime Coastal Western Hemlock (CWHxm2)			**Wet Cool Sub-Boreal Spruce (SBSwk1)**		
Area (ha)	580,250			785,950		
	1961–90	2050s	± SD	1961–90	2050s	± SD
Mean annual temperature (ºC)	8.3	10.3	0.7	2.5	4.9	0.5
Mean July monthly maximum temperature (ºC)	21.3	23.4	1	20.7	23.0	1
Mean January monthly minimum temperature (ºC)	–1.0	0.8	1	–14.8	–10.0	1
Frost-free period (days)	173	223	22	78	116	10
May to September precipitation (mm)	370	350	120	350	380	40
October to April precipitation (mm)	1870	2020	590	488	510	90
Water equivalent of the annual snowfall (mm)	190	100	90	340	280	70
Summer heat/moisture index	48	58	15	41	47	5

The very dry maritime Coastal Western Hemlock (CWHxm2) is on the eastern slope of the Vancouver Island Mountains. The wet cool Sub-Boreal Spruce (SBSwk1) is in the Central Interior of BC on the west side of the Quesnel Highlands and on the MacGregor Plateau. Climate varies within a unit but the climate change scenario shifts all values of a variable by about the same amount so the standard deviation on the means stays the same. Both units are warmer by about 2°C and wetter in the winter. The CWHmx2 has less rain in the summer while there is a slight increase in summer rainfall for the SBSwk1. The CWHxm2 climate changes towards that of the coastal plain on the east coast of the island. The implications for tree growth are that Douglas-fir should continue to grow well but western red cedar could disappear from currently marginal sites. The SBSwk1 climate is moving towards that of some units of the Interior Cedar–Hemlock zone. Warming of this unit may favour the growth of interior Douglas-fir and lodgepole pine over spruce.

Appendix IV: Examples of Using an Adaptation Framework

The use of the framework is illustrated with two forestry related issues that have already undergone a partial assessment of vulnerabilities and have started to develop adaptation strategies.

The Ministry of Forests and Range (MoFR) is developing an adaptation strategy in response to the threat of climate change for BC's forest and range resources. The first iteration of the Ministry's response can be placed in the framework as follows:

- **Issue:** Climate change will play a major role in shaping the future composition and use of forest and range resources in BC.
- **Vulnerability Assessment:** Climate change impacts are poorly known. There is a lack of awareness of the issue within the forest community. Some of the vulnerability may not be climate change related. Changing social and economic conditions are influencing forest and range resource utilization. There is a lack of research knowledge and policies to enable adequate response to these vulnerabilities.
- **Adaptation Strategy:** The MoFR established a Climate Change Task Team to review potential impacts of climate change on provincial forest and range resources, identify knowledge gaps, and develop recommendations on how the MoFR should proceed. The Future Forest Ecosystems initiative (FFEI) was launched to consult with a wide cross-section of society in BC on the future threats to BC's forest and possible responses. Although it will be a few years before operational adaptation actions are implemented, consultation, capacity building and vulnerability assessments are viewed as important the first steps in the adaptation process.
- **Implementing the Adaptation Strategy:** Recommendations from the Task Team were released in a report (Ministry of Forests and Range 2006). MoFR consulted widely on the reports of the Task Team and the FFEI. The recommendations from these reports and the consultations were amalgamated under the goal of adapting BC's forest and range management framework to changing climatic conditions. The FFEI is ongoing and has become part of the MoFR business plan.

The forest genetics research community is a leader in forestry in doing vulnerability assessments and developing adaptation strategies to respond to climate change. Examples of this can be found in Rehfeldt *et al.* (1999, 2001, 2006) and Wang *et al.* (2006b) and are used here to illustrate application of the framework at a provincial scale.

- **Issue**: Forest policies on the use of seed for reforestation are designed to minimize the risk of maladaptation. Thus there is a requirement to use "local" seed under the assumption that local seed is best adapted to the local climate. Under climate change this assumption may be invalid within the next 50 years. This is a province wide issue for all commercial species of trees.

- **Vulnerability Assessment**: The risk is that by 2080 the climate will have changed such that trees growing from the "local" seed may be in conditions well outside their envelopes for optimum survival and growth. Seed planning units are geographically based and only implicitly account for climatic conditions. Consequently, under a changing climate these management units may not be appropriate for managing seed selection (Wang *et al.* 2006b).
- **Adaptation Strategy**: Determine the climates of the sources of seed used for reforestation. Develop response functions of various seed sources to a wide range of climatic conditions using provenance trials. Determine the patterns in growth response to climate among populations. Predict impacts of climate changes on productivity with different seed deployment strategies. Develop climate based seed planning units.
- **Implementation of Adaptation Strategy:** Development of a high spatial resolution climate data base is facilitating determining the climate of seed sources and the trial sites (e.g. Hamann and Wang 2006, Wang *et al.* 2006a,b). Implement provenance trials for commercial tree species over a wide climatic range. Provenance trials were established for a number of species many years ago. However, although analyses can be done for a few species or provenances there is a need to establish more trials.

They rounded the foot of the Quentulus Quazgar Mountains, and there was the Message written in blazing letters along the crest of the Mountain … "We Apologise for the Inconvenience"…
Douglas Adams, So Long and Thanks for the Fish, 1984, Pan Books, London.