SUSTAINABLE FOREST MANAGEMENT NETWORK
RÉSEAU DE GESTION DURABLE DES FORÊTS

Global Climate Change

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> "The implications of climate change on our forest estate is an issue of immediate concern for Canada because: (a) climate change is going to be more pronounced at Canada's northern latitudes compared to other regions of the globe, (b) forests are sensitive to climate change and changes in forests may have significant socio-economic impacts (both positive or negative) on Canadian society, (c), early adaptation has the potential to reduce negative impacts and/or maximize benefits from climate change, and (d) forestry investments mature over long time frames and are generally irreversible. Therefore, it is important that foresters are aware of climate change and begin to identify and incorporate adaptation strategies and approaches in policy, management decisions, and long-term plans." (Williamson et al. 2007)

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1. Introduction

The atmospheric climate of planet Earth is a key controller of both biotic and abiotic processes occurring in the biosphere. The climate has always been dynamic, in the sense of changing significantly with time. However, changes during the past century, along with improved understanding of the mechanisms behind such changes, have led the world scientific community (IPCC 2007) to sound alarm bells about our climate's future and the attendant effects during the 21st century.

In this paper, climate change relates to changes in the atmosphere driven by anthropogenic emissions of CO_2 and other radiatively active gases (so-called greenhouse gases, or GHGs). Emphasis is placed herein on ways in which climate (past, present, future) influences forests. Thus, means, distributions and extremes associated with air temperature, precipitation and wind command our attention. As a further indication of the scope of the paper, it will focus on adaptation (i.e., how society adapts forest management and the forest sector to the effects of climate change) (Parry et al. 2007) rather than mitigation (i.e., how society manages forests to take up and store more carbon from the atmosphere, thus attempting to slow the rate of climate change) (Metz et al. 2007).
The purpose of the paper is to draw attention to the potential impacts and implications of future climate change on Canada's forests and forest sector. It begins with a brief look at how climate links with various driving forces and with forest ecosystems. Following a summary of climatic changes in Canada in the 20th century, it then explores the kinds of climatic changes we might

expect in the 21st century. It concludes with a plea to consider climate change seriously in all forest and forest-sector decision-making.

2. Time and Space Dimensions of Climate Change

While the global climate has always been in flux, the changes documented by scientists during the past century - linked strongly to rising anthropogenic GHG emissions - are of interest here. But much more importantly, changes expected during the 21st century are paramount for Canadian forests and the forest sector. Gradual changes are discernable decade by decade and altered patterns of extreme events such as storms and droughts are evident year by year. Climate change is a worldwide phenomenon, and all parts of Canada will be affected. That notwithstanding, some areas will experience far larger changes in temperature, precipitation and winds than will others.

Canadians have important roles to play in climate change mitigation and adaptation. Whether we honour Kyoto commitments or not, we will still have to find ways to curb GHG emissions and store as much carbon as possible in ecosystems such as forests. However, real progress in mitigation depends strongly on concerted efforts worldwide, partly because Canada's overall contribution to global GHG emissions is relatively small. On the other hand, how well we can adapt our socio-economic systems and help forest ecosystems adapt to the changing climate is entirely a domestic matter. Indeed, adaptive responses to forest-related effects of climate change can be taken at all levels of Canadian society - individuals, communities, corporations, governments.

3. Climate Change and Other Driving Forces

The condition of the atmosphere profoundly influences the condition of Earth's ecosystems and their use and management by people. Moreover, the global climate has strong influences on most drivers of change associated with forests and the forest sector. Climate change will affect forest productivity (growth, succession, disturbances) worldwide. Some forests will prosper, and many others will become disrupted and experience reductions in wood accretion. Disturbances may lead to salvage harvests which can generate turbulence in the wood markets (Shugart et al. 2003). Climate change will have large direct undesirable effects on Canadian ecosystems (Williamson et al., 2007), and these effects may behave cumulatively (synergistically) with other threats to ecosystem health such as air, water and soil pollution.

Renewable energy supplies (e.g., hydro, solar, wind, biomass) may be affected by climate change, in some cases adversely but in others positively. Climate-change mitigation policies will have strong implications for non-renewable energies, particularly fossil fuels. Climate change may lead to a rise in demand for wood biomass for energy given its renewability.

Climate change will disrupt many types of land use and thus lead to increased land-use conflicts. For example, there may be competing demands for land to grow food crops rather than trees. In addition, climate change is expected to disrupt freshwater systems, which may put water users at conflict with each other. Climate change may lead to large movements of Canadians seeking to live elsewhere in the country, as people living in strongly affected areas may be inclined to move (e.g., rural dwellers moving even more numerously to cities, northerners moving south due to collapse of Arctic ecosystems, southerners moving north to escape excessive heat). Climate change may strongly affect the human habitability of other countries (e.g., excessive heat, water shortages, reduced food production), so environmental refugeeism may become important.

Other driving forces can be expected to have their own influences on climate change. Some such forces - e.g., declining ecosystem health, unfavourable geopolitical circumstances and events, increased global fossil-fuel consumption - may well exacerbate climate change. Others - e.g., shifts in social values and consumer behaviours, technology - may actually help slow the rate of climate change.

4. Influences of Climate Change on Forest Ecosystems

As well as influencing most other driving forces, climate change has strong and complex linkages with forest ecosystems (Table 1). For this discussion, we shall concentrate on temperature, precipitation and wind as the main climate variables of interest. Temperatures are expected generally to rise, to a greater extent the further north and the further inland one goes. Also, temperature extremes - both hot and cold spells - are expected to be more frequent. As for precipitation, change projections are much more uncertain, with some areas of Canada expecting more precipitation, some less, and some about the same. However, even when total annual precipitation will not change much, the amount falling and remaining as snow is expected to decrease, and the relative amount falling in large doses, as opposed to frequent light rains and snow, is expected to increase. As for wind, with more energy in the atmosphere due to warming, storminess is expected to increase, with attendant increases in strong winds.

If the global climate is such a strong determinant of the patterns of life on Earth, and if impending changes in it are unprecedented in human history, then it behoves us to take serious account of climate change in deciding how to use and manage Canada's forests.

Table 1. Selected influences of climate change on forest ecosystems.

Forest Ecosystem Response Variable	**Climate Variable**		
	Temperature	**Precipitation**	**Wind**
Growth (Productivity)	**Increases where temperature is growth-limiting.**	**Only increased where precip increases in areas where water shortage is growth-limiting.**	**??**
Phenology	**Longer growing seasons; chances of more frequent frost events.**	**??**	**??**
Evapo-transpiration	**Increased rates.**	**Increased if precip changes from snow to rain.**	**Increased rates.**
Decomposition	**Increased rates.**	**Increased if precip increases.**	**??**
Community Relationships	**Altered competitive dynamics among tree species; altered herbivory patterns and predator-prey dynamics.**	**Altered competitive dynamics among tree species; altered herbivory patterns and predator-prey dynamics.**	**??**
Regeneration	**Higher seedling mortality.**	**If reduced precip, higher seedling mortality.**	**??**
Insects and Diseases	**Potential for range extensions and widespread outbreaks.**	**Potential for range extensions and widespread outbreaks.**	**??**
Fires	**Increased number and size.**	**If reduced precip, increased number and size.**	**Larger and more intense due to higher winds and blowdowns.**
Tree Mortality	**Increased mortality for cold-adapted species.**	**If reduced, increased mortality for wet-adapted species.**	**Increased due to blowdown (windthrow).**
Soil Stability	**??**	**With larger precip events, higher rates of erosion.**	**??**
Soil Nutrients	**Increased rates of mineralization.**	**With larger precip events, higher rates of leaching.**	**??**
Water Bodies and Soil Water	**Lower water tables, stream flows and lake levels.**	**If reduced, lower water tables, stream flows and lake levels. If changed from snow to rain, smaller spring freshet. If larger events, more storm freshets with higher silt loads.**	**??**

5. A Look Back: Climate Change in the 20th Century

Scientists expect the next 100 years of climate change to dwarf the changes of the past 100 years (IPCC 2007). However, it is still instructive to examine briefly what is known about 20th-century climatic changes and what effects such changes may already have had on Canada's forests and forest sector. According to the IPCC (2007), human-induced warming over the last century is unequivocal and amounts to about 0.75 C increase in global mean temperature.

According to Williamson et al. (2007),

> "Climate change is already affecting Canada's forests. Evidence of climate change impacts in the Canadian forest sector over the last 30 years is mainly in the form of changes in frequency and/or severity and/or geographic location of disturbances. However, changes in growing season, phenology, productivity, and shifts in tree line boundaries are being observed".

Below are two examples of recent/current influences of climate change on Canada's forests. They are offered to show what types and magnitudes of forest changes might be in the offing as a result of continued climate change. The following text has been abridged from Williamson et al. (2007).

5.1 Mountain Pine Beetle in BC and AB

The mountain pine beetle (MPB) is native to North America and feeds primarily on mature lodgepole pine (Carroll et al. 2004). MPB feeds on live phloem tissue under the bark, eventually killing the tree through girdling. It also carry the blue stain fungus which spreads through a tree's sapwood and eventually stops water from moving from the roots to the crown.

Occasionally, MPB outbreaks result in widespread pine mortality. Four major outbreaks have occurred in BC over the last 120 years (Carroll 2006). The current infestation is by far the most widespread. As of 2007, over some 13 million ha of pine forest in BC have been affected (BC Ministry of Forests and Range 2007). This is an area almost twenty ten times larger than any of the previous infestations (Carroll 2006). Moreover, the areas currently affected have never been exposed to MPB attacks. To date, MPB has killed about 40% of the province's inventory of mature lodgepole pine (BC Ministry of Forests and Range 2007; Walton et al. 2007). At current rates of increase, the killed inventory of mature lodgepole pine could amount to almost 80% by 2015, a number representing almost a quarter of the total wood inventory on BC's harvestable forest land base (BC Ministry of Forests and Range 2007). MPB has recently spread into areas of northwestern Alberta that have never before been infested.

Two factors have contributed to the current outbreak: the presence of large areas of mature lodgepole pine, and an unprecedented number of consecutive abnormally warm winters (Carroll et al. 2004). MPB range is limited by climate. Recent changes in BC's climate have resulted in a greater than 75% increase in climatically optimal beetle habitat (Carroll et al. 2004).

5.2 Forest Fires

Occurrences of abnormal fire seasons and/or severe burning conditions at times of year when this typically does not occur are becoming commonplace. For example, the 2003 fire season in BC was worse than any previous fire season in the province's history. The total area burned was over 255,000 ha, and hundreds of homes and businesses were destroyed. Similar abnormal fire activity has occurred in other parts of Canada as well. The summer of 2004 was the warmest on record in the Yukon. The Yukon also experienced below-normal precipitation and a record number of lightning strikes. These conditions combined to produce a record fire season in the Yukon where about 1.8 million ha burned. The previous record (in 1958) was less than half this area. Abnormal fire weather conditions have also been observed in central Canada. For example, extreme fire-weather conditions existed in northwestern Ontario as late as September 2006. Fire suppression operations are also beginning to gear up much earlier in the season compared to previous start-up times.

Researchers have established that forest fires have increased significantly over the last 40 years (Flannigan and Van Wagner 1991, Stocks et al. 2002, Gillet et al. 2004). Kasischke and Turetsky (2006) reported that despite concurrent increases in suppression capacity, the frequency of large fire years and area burned in the North American boreal region (i.e., Alaska and Canada) doubled between the 1960s/1970s and the 1980s/1990s. Although many factors influence fire activity, temperature provides one of the strongest predictors of area burned (Gillet et al. 2004, McCoy and Burn 2005).

6. A Look Ahead: Future Scenarios for Climate Change and Its Effects

6.1 General Considerations

Climate scientists use process-based simulation models to project future possible climates given specific assumptions about emissions of GHGs (IPCC 2007). Given that there are many possible assumptions about such emissions, and several climate models from reputable labs around the world, the literature contains a range of scenarios of future climates. Model resolution is still coarse in both space and time, but we can extract useful information from even quite coarse-scaled climate projections for Canada.

Without endorsement as the most plausible climate-change scenario for Canada to 2050, presented here is one picture from recent/current literature (Hengeveld 2002) (Figure 1). In this scenario, average mean annual temperature across Canada's forested area by 2050 rises by anywhere from one to a few degrees C. Summer temperature rises may well be smaller, and winter rises are expected to be substantially larger. For the sake of discussions here, let us imagine that, for current forested areas of Canada, summer temperatures could rise in the range of 1-5 C, and winter temperatures in the range of 5-10 C. Accompanied with this would be stable or slightly increased precipitation across most of Canada, with substantially more of the annual precipitation arriving in large events. Let us also imagine a future with substantially increased storminess across Canada, from which we can draw the inference of stronger and more-frequent wind events.

Such scenarios for future climate change as painted above would lead to substantially increased numbers, sizes and severities of forest fires in many parts of Canada. Implications of such changes include: "increase in risk of property loss in communities and increased risk of evacuation, negative health impacts from increased smoke, increased fire management costs, disrupted harvest operations, timber supply impacts in terms of both expected values and risk, more salvage wood, a younger forest and less old growth" (Williamson et al. 2007).

Regarding forest insects and diseases, the following potentials, while subject to huge uncertainties as to specifics, are real: increases in the size, duration and intensity of infestations; potential improvements in forest health in some locations and declines in other, with an overall the net undesirable effect; increased occurrences of insect and disease infestations outside the normal range of variability; and increased uncertainty about the timing and magnitude of major insect and disease occurrences (Williamson et al. 2007).

Extreme weather events are likely under a changing future climate, and include: (a) increased precipitation intensity; (b) increased frequency, duration and intensity of drought; (c) increased frequency and intensity of summer heat waves; (d) abnormally warm winters; and (e) increased frequency and intensity of severe thunderstorms, windstorms, ice storms, and hurricanes reaching eastern Canada (Williamson et al. 2007). All these types of events can stress trees and many other forest biota. They can also invalidate forest-management plans based on continuation of recent past trends in weather and climate. Implications of this are an increase in unplanned interventions like salvage timber harvests and ecological restoration projects. Increases in events associated with climatic extremes may also make it difficult to secure the kinds of ecological and social services society has now come to expect from Canadian forests.

The jury is still out as to whether climate change to 2050 will bring about increases in forest productivity and wood growth (Shugart et al. 2003; Field et al. 2007). In some areas, modest temperature increases may improve growing conditions, particularly where soil moisture is not limiting. However, large temperature increases may bring the opposite reaction, and areas currently moisture-limited are unlikely to display growth improvements.

Many studies address the topic of shifts in forest biomes and tree-species ranges (e.g., McKenney et al. 2007). For Canada, this generally means shifts in tree-growing conditions from south to north across the country, and from lower elevations to higher elevations where these are pronounced. It is one thing to predict the locations of the species-specific suitable climate under alternative scenarios of climate change (such studies ought also to examine intra-specific variation among provenances to get a clearer picture of potential species responses). It is another altogether to ponder how species-specific propagules might get to the new areas of suitable climate, and whether other growth-controlling factors (e.g., soils) will be hospitable (Duinker et al. 1992). McKenney et al. (2007) presented two extreme scenarios for species migration up to the end of the 21st century: one of full dispersal, where the species keep up with the pace of climate change, and one of no dispersal, where species' current distributions demarcate the furthest possible limits of their potential future distributions. If we assume pessimistically that many tree species will have difficulty keeping up, migrationally speaking, with the climate changes, and other growth-controlling factors present obstacles to tree establishment, then any climate-change scenario means a serious redrawing of the map of forest biomes in Canada. Without significant human intervention to assist species establishment, the forest ecosystems of Canada could become quite disrupted, throwing into serious question most of our knowledge of forest succession and community dynamics.

6.2 Specific Scenarios

This is not the place for detailed projections of climate change to 2050 for all parts of forested Canada. Two plausible extremes that bracket the general scenario (Figure 1) are presented below (Table 2).

Benign Climate Change. In this scenario, temperatures do indeed increase, precipitation events become off-normal, and more storms produce higher winds (Table 2A). However, these changes, while outside the range of our recent experience, are not beyond the bounds of the combined adaptive capacity of the forests and the forest sector. This applies, of course, to forests where the full suite of silvicultural tools can be used, as in timber-producing forests. Where timber harvests are not allowed, forest adaptive capacity may be exceeded. Not only have forests been managed better during the first half of the 21st century to increase their resilience to the vagaries of climate change, but the relatively small negative impacts can be accommodated within the evolving system. At the same time, forest managers have found ways to capitalize on forest productivity gains where these have occurred due to relaxed constraints of low temperatures and precipitation levels. The wood-products industry can just keep up with the required structural changes to match the changes in wood supplies.

Wicked Climate Change. In this scenario, our worst fears have come true (Table 2B). Mean temperatures have risen substantially, with serious extremes on the high side. Variation in annual precipitation has increased substantially, with decade-long droughts and subsequent flood years. Most precipitation falls during storms that are characterized also by high winds. In the east, hurricanes are, on average, a decadal occurrence. Despite all the early efforts to increase forest resilience, forests nationwide fall victim to massive forest fires, pest outbreaks and general declines. Biomass energy becomes a key forest product as both wood quantity and quality become unpredictable year to year.

Table 2. Two hypothetical climate scenarios for Canada's forests in 2050. Changes are defined as means for the period 2040-2050 minus means for the period 1990-2000.

A. Modest climate-change scenario

Climate Variable	Region of Canada						
	BC Coast	**BC Interior**	**Prairie Provs**	**North ON & QC**	**South ON & QC**	**Maritimes**	**NL**
Mean Jan Temp	2 C incr	3 C incr	3 C incr	3 C incr	3 C incr	2 C incr	2 C incr
Mean Jul Temp	1 C incr	2 C incr	2 C incr	2 C incr	2 C incr	1 C incr	1 C incr
Days over 35C Max T	50% incr	50% incr	50% incr	50% incr	50% incr	50% incr	50% incr
Total Precipitation	10% incr	no change	10% decr	no change	no change	10% incr	10% incr
Prop. Precip as Snow	10% decr	20% decr	20% decr	40% decr	50% decr	40% decr	40% decr
Large Precip Events	50% incr	50% incr	50% incr	50% incr	50% incr	50% incr	50% incr
Wind-storm Events	20% incr	20% incr	20% incr	20% incr	20% incr	40% incr	40% incr

B. Strong climate-change scenario

Climate Variable	Region of Canada						
	BC Coast	**BC Interior**	**Prairie Provs**	**North ON & QC**	**South ON & QC**	**Maritimes**	**NL**
Mean Jan Temp	4 C incr	6 C incr	8 C incr	10 C incr	8 C incr	6 C incr	4 C incr
Mean Jul Temp	2 C incr	4 C incr	6 C incr	6 C incr	4 C incr	3 C incr	2 C incr
Days over 35C Max T	100% incr	100% incr	100% incr	200% incr	200% incr	100% incr	100% incr
Total Precipitation	10% incr	no change	20% decr	no change	no change	10% incr	10% incr
Prop. Precip as Snow	50% decr	70% decr	70% decr	80% decr	80% decr	80% decr	80% decr
Large Precip Events	100% incr	100% incr	100% incr	100% incr	100% incr	200% incr	100% incr
Wind-storm Events	100% incr	40% incr	40% incr	40% incr	40% incr	100% incr	100% incr

7. **Conclusions**

Climate change may well be the grand wildcard among drivers of global change that will dominate humanity's agenda in the 21st century. This applies not only to forests and the forest sector but also in all other facets of life that depend on ecosystems - examples include food production; several types of energy production such as hydro, solar, wind and biofuels; land use; transportation; and human health.

What about forest and forest-sector adaptability? As noted above, the total package of climate changes coming in the next half-century in Canada could be modest and of gentle pace. If they are, then the impacts on forests could be corresponding small. Given an assumption of considerable adaptive capacity in both the forest ecosystems and in society's use and management of them, perhaps the combination would result in unspectacular change where we can cope well with all that climate change presents to us.

On the other hand, it is not inconceivable that the total package of climate changes could be substantial and eventful (Table 2B). Under such circumstances, impacts on forests could be correspondingly large. This may overwhelm even a well-developed adaptive capacity, but imagine if that adaptive capacity were indeed of modest proportion. Not only would forest ecosystems be disrupted, given that the climates they had become adapted to over the past few thousand years changed rather abruptly and became unsynchronized with vegetation and soil patterns. Forest users and managers would become confused, and probably rapidly frustrated that Canada's forests could no longer be managed with any confidence to support the myriad values society associates with them (Duinker 1990; 2007).

Details of the overall picture of what climate change in Canada through the 21st century might mean for the forests and forest sector are far from clear. What IS clear, though, is that the picture is exceedingly complex, and predictability is but a dream. Incisive scenario analysis is needed to shed even dim light on the opportunities for adaptive responses in the face of the grand global environmental experiment.

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Appendix: Interactions of Climate Change with Other Forest Drivers

Table A1. Climate-change influences on other forest drivers.

Driver	**How Climate Change Affects the Driver**
Global Wood Supply	Climate change will affect forest productivity (growth, succession, disturbances) worldwide. Some forests will prosper, and many others will become disrupted and experience reductions in wood accretion. Increases in growth increase long-term supply; decreases in growth decrease long-term supply. Disturbances may lead to salvage harvests which can generate turbulence in the wood markets (Shugart et al. 2003).
Forest Products Demand	Climate change may lead to a rise in demand for wood biomass for energy given its renewability. If wood products have lower embodied energy than concrete and metals and this matters in mitigation policy, demand for structural wood products may increase.
Geopolitics	Climate change may strongly affect the human habitability of many world regions (excessive heat, water shortages, reduced food production), so environmental refugeeism may become important. International strife may ensue (even wars might be fought) over changing access to water.
Global Energy	Renewable energy supplies (e.g., hydro, solar, wind, biomass) may be affected by climate change, both adversely and positively. Mitigation policies will have strong implications for non-renewable energies, particularly fossil fuels.
Technology	Climate change will likely spur technological developments in many fields.
Governance	Increased pressure to mitigate climate change is likely to result in some centralization of regulation at the national and international level, which may spill over into other areas related to the governance of Canadian forests. Climate change adaptation can be addressed at the local and regional level, but depending on the magnitude of the problem, may require redistribution of resources that might promote centralization. The need to adapt to environmental change is likely to increase the demand for cross-sectoral integration.
Aboriginal Empowerment	If climate change leads to disruptions of forest ecosystems, with reduced growth and debilitating disturbances, Aboriginal peoples may feel disenfranchised from the land and unempowered.
Ecosystem Health	Climate change will have large direct undesirable effects on Canadian ecosystems (Williamson et al., 2007), and these effects may behave cumulatively (synergistically) with other threats to ecosystem health such as air, water and soil pollution.
Competition for Resources	Climate change will disrupt many types of land use and thus lead to increased land-use conflicts. For example, there may be competing demands for land to grow food crops vs. trees. In addition, climate change is expected to disrupt freshwater systems, which may put water users at conflict with each other.
Societal Values	Climate change may dominate people's thinking about the earth and its component ecosystems to such a degree that they change the way they want to value, use and manage forests.

Demographics	Climate change is unlikely to change rates of births and deaths in Canada. It may, however, encourage immigration. People living in strongly affected areas may be inclined to move (e.g., rural dwellers moving even more numerously to cities, northerners moving south, environmental refugees to Canada).

Table A2. Influences of other forest drivers on climate change.

Driver	**How the Driver Might Affect Climate Change**
Global Wood Supply	If wood volumes for economic use are large and allocated to biomass energy, then the rate of climate change might be, to some small degree, mitigated.
Geopolitics and Global Energy	If the geopolitical situation leads most countries in the world to use fossil fuels at ever more rapid rates, climate change may well be accelerated.
Technology	Optimistic developments in technology, particularly energy technology, could get the human population off fossil fuels earlier than expected, thus potentially slowing climate change.
Ecosystem Health	Declining ecosystem health may exacerbate climate change (e.g., changes in albedo).
Competition for Resources	If lands move out of forest cover into agricultural production or urban/industrial infrastructure, climate change might be exacerbated.
Societal Values	Globally, if we really value today's climate, we will reduce GHG emissions dramatically, and soon. The values of Canadians have minimal effects on the global climate.
Demographics	Globally, the more people there are, the greater the demand for fossil fuels and the greater the GHG emissions. The demographics of Canadian society, immigrants included, are likely to have little influence on global climate change.

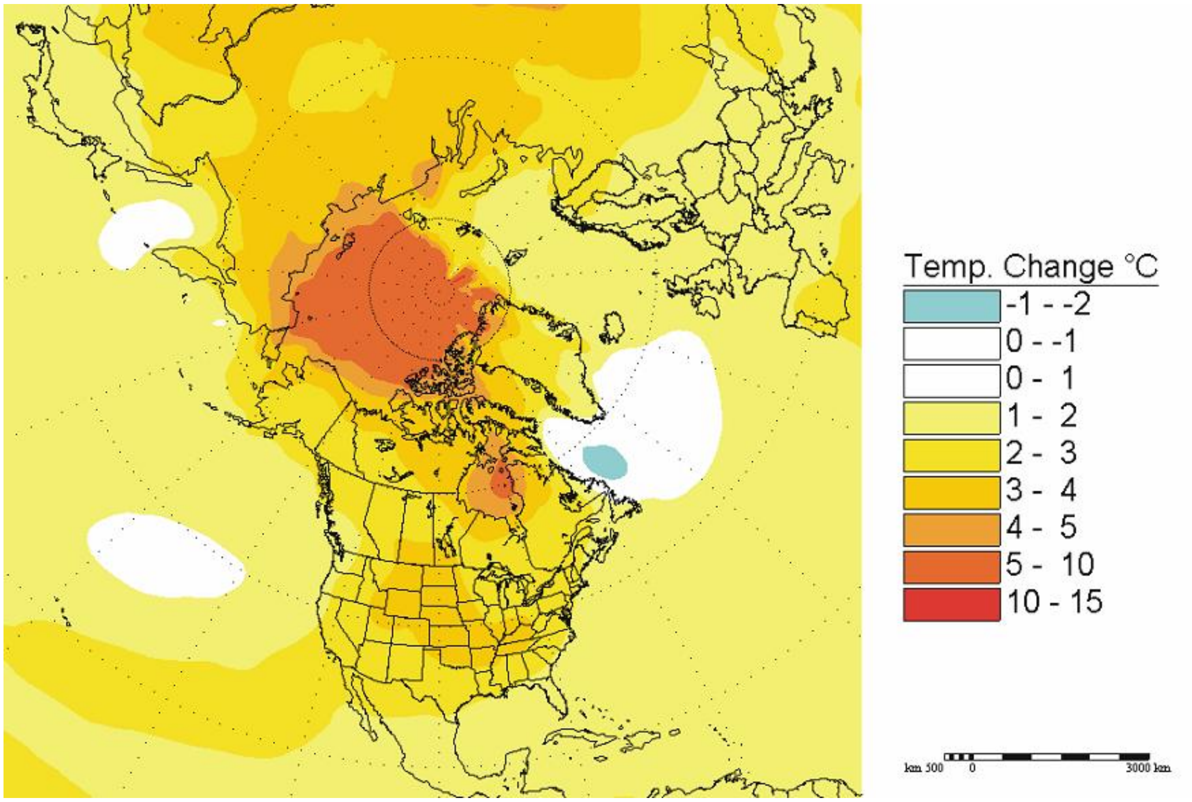

Figure 1. Change in annual mean temperature by the year 2050. (Source: Hengeveld 2002).