A POSSIBLE WAY TO INCORPORATE GLOBAL WARMING / CLIMATE CHANGE CONSIDERATIONS OVERTLY IN GEORGIA BASIN QUEST OUTPUT

by
VICTORIA ELIZABETH LONG
B.A., University of British Columbia, 1966
B.E.S., University of Waterloo, 1996

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
In
THE FACULTY OF GRADUATE STUDIES
(DEPARTMENT OF GEOGRAPHY)
We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA
JANUARY, 2005

ABSTRACT

Georgia Basin QUEST is a computer-based scenario generation and evaluation system designed to encourage thinking about sustainability in a regional context. Global warming/ climate change is an important public policy issue for every world citizen especially for those who contribute much more to the causes, like the residents of the Canadian side of the Georgia Basin in British Columbia. Through QUEST users explore different possible scenarios of the region's future by selecting a Worldview to characterize the global future as well as particulars in many categories that are pivotal in forging sustainable lifestyles locally. Strategic choices in these categories, which include land use, transportation, energy, waste, agriculture, forestry and fisheries, also affect the average regional citizen's greenhouse gas emissions both directly and indirectly. Could there be a way to interweave informative material about global warming/ climate change in with the piecewise linear graph QUEST produces showing greenhouse gas emissions decade by decade in a user's scenario? Since there is a time lag between emissions and impacts in climate change processes that is longer than the 40-year time frame QUEST offers users to build their future scenario, it is impossible to offer the opportunity to express preferences about global warming/ climate change considerations and link output directly with those choices as is done in the other QUEST categories. However, this thesis proposes to use the remaining 'real estate,' three-quarters of a single output computer screen for global warming-related material by accompanying the graph showing greenhouse gas emissions resulting from the user's choices with graphs or text dealing with climate change impacts, adaptation or mitigation. Categories the user has emphasized in scenario construction would be highlighted and the slant could be keyed to the chosen Worldview. It argues that the issue is too important to sustainability efforts to overlook.

Table of Contents

Abstract i

Table of Contents ii

List of Figures iii

Adknowledgements vi

Foreword: Background 1

Chapter 1: Introduction **9**
- Why include global warming/climate change considerations in GB-QUEST 12
- Difficulties inherent in subsuming Climate Change considerations in GSG scenarios 16
- The structure of the rest of the thesis 18

Chapter 2: Humankind vs. human-caused global warming in the 21st century **21**
- The underlying problem: physical processes are largely outside human control 24
- The threat of abrupt changes means future dangers caused by present-day actions 34
- Feedbacks mean human actions are dwarfed by processes we set into motion 39

Chapter 3: Regional results of the global problem in the Georgia Basin **56**
- Past climate regime and long-term climate norms 57
- Changes observed in the last century 61
- Changes that are fairly sure for the QUEST study period and impacts expected 65
  - Forests 71
  - Fisheries 74
  - Impacts on other social and economic activities 76
- Longer term changes expected 78

Chapter 4: Conclusion: How climate change considerations might be included **80**

Bibliography.......... 96

List of Figures

Figure 1: Sectoral Breakdown of Canada's GHG Emissions, 2000 2

Figure 2: IPCC 2001 Presentations and Graphics Figure 2.17.......... 5

Figure 3: Indicators of the human influence on the atmosphere during the Industrial era 14

Figure 4: Atmospheric CO2 Concentrations Last 400,000 Years from Antarctica ice and air data 25

Figure 5: Atmospheric CO2 Concentrations 26

Figure 6: The Atmospheric "window" (footnoted explanation) 27

Figure 7: Pie-chart of estimated carbon reservoirs (footnoted explanation) 29

Figure 8: A simplified representation of the CLAW Hypothesis, an example of a negative climate feedback loop 54

Figure 9: Temperature trends (1920 – 2000) from CSES 2004.......... 62

Figure 10: Temperature Difference (CSES 2004) 63

Figure 11: Precipitation trends (1920 – 2000) from CSES 2004.......... 64

Figure 12: Four 1/4 screen layout format 85

Figure 13: One centered 1/4 flanked by 6 - 1/8 text boxes format 85

Figure 14: Percentage of years with degree reach hours (DRH) above the baseline critical value 87

Figure 15: Fraser River flows at Hope, B.C. Canada 88

Figure 16: World Wind Energy Generating Capacity 1980 – 2002.......... 89

Figure 17: World Fossil Fuel Consumption by Source, 1950 – 2002.......... 89

Figure 18: Number and Cost of Weather-Related Disasters.......... 90

Figure 19: CO2 Contraction for 450 ppmv & Convergence by 2050 to globally equal per capita emissions rights (GCI 2004).......... 92

Figure 20: Electricity price over the years 2000 – 2040 for both Worldview choices................ 93

Figure 21: Change in Temperature for Scenario A2.. 95

Figure 22: Change in Temperature for Scenario B2.. 95

Sincere ACKNOWLEGEMENTS of gratitude are due to:

My supervisor John Robinson who I believe discovered reservoirs of patience and adaptability during the process of bringing this work to fruition

and my co-supervisor Stewart Cohen who taught me that a worthy journey can begin with baby steps

and to the third member of my committee, Brian Klinkenberg for being there when I really needed him and offering sound advice at one critical juncture and encouragement always.

My employer Steven Badger for g giving me time off to work on this project and to my colleagues at Adventure Touring for covering for me so I could make the deadline on this thesis.

And, most especially to my family who have supported my efforts even when success seemed unlikely and to my son, Terran, for growing up admirably well with less help from me than I hoped to give him.

Foreword: Background Information

The Georgia Basin Futures Project (GBFP) is a Major Collaborative Research Initiative, funded principally by the Social Sciences and Humanities Research Council of Canada (SSHRCC), that gave me a Research Assistantship to work on the Climate Change topic in its Model Development Component. The model to be developed was an extension to a larger geographical area of an earlier QUEST that was described in the funding application to SSHRC as a computer-based system "designed to encourage thinking about sustainability in a regional context" (SDRI 1998 A9.8). In addition, the application stated that, "the user-selected policy choices in QUEST represent the most significant issues for the region" (SDRI 1998 A9.8) so allowing users in the expanded QUEST to engage directly with aspects of the global warming/ climate change issue seemed a valuable addition.

The original Lower Fraser Basin QUEST had dealt with climate change/ global warming by simply reporting the amount of carbon dioxide, methane, nitrous oxide and chlorofluorocarbons (CFCs) the user's scenario produced under the heading of "Greenhouse Gas Emissions" (GHG[1]). My personal goal was to find a way to expand the QUEST user's experience beyond that important output summary and somehow tie in other aspects of the complex public policy issue here in one of the world's historically highest per capita GHG emitting countries. Canada's national GHG Inventory reported that, "In 2000, Canadians contributed about 726 megatonnes of CO2 equivalent (Mt CO2 eq)3 of GHGs to the atmosphere4, which represents about 2% of total global GHG emissions. On a per capita basis, Canada ranks ninth in the world (second in the G8)

---

[1] "Greenhouse gases" means those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and re-emit infrared radiation. (UNFCCC Article 2) The UN greenhouse gas inventory lists six main gases: CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and shows figures as well as for CO, NO_x, NMVOCs, and SO_2 (UNFCCC 2004)

for CO2 emissions due to a variety of factors, in particular its energy-intensive economy. Approximately 73% of total GHG emissions in 2000 resulted from the combustion of fossil fuels. Another 7.4% resulted from fugitive emissions, for a total of almost 81% from the Energy sector. A sectoral breakdown of Canada's total emissions for 2005 is shown in Figure 1. It shows that over 92% of Canadian emissions were directly tied to the categories in which QUEST offered users choices.

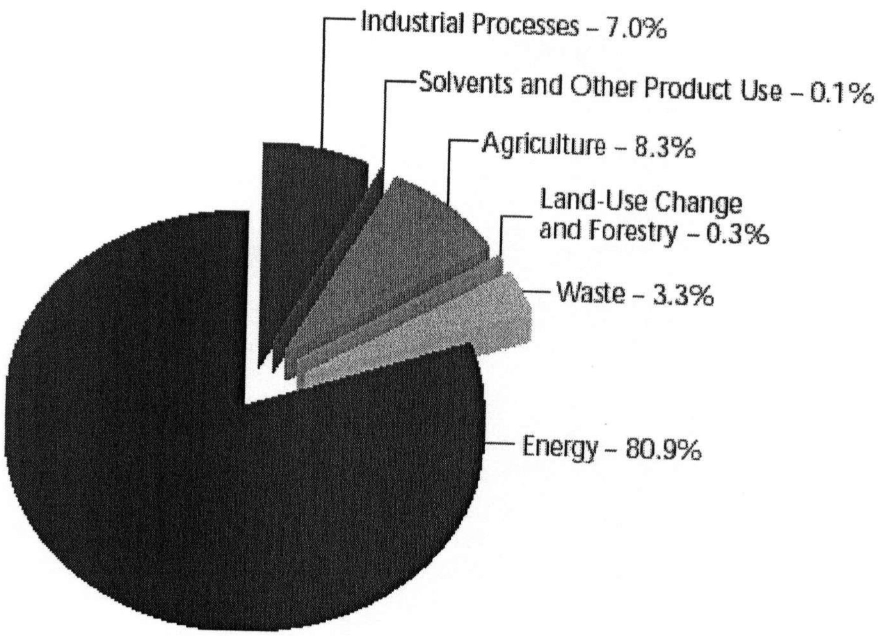


Figure 1: Sectoral Breakdown of Canada's GHG Emissions, 2000
(Environment Canada Green Lane 2004)

I came to UBC from Ontario where my studies had focused on the science of global warming and I looked forward to tapping into the Impacts and Adaptation aspects in British Columbia. My studies had given me a clear understanding that many experts in climate science were recommending that emissions drop dramatically and soon to have any chance of aiming at even the most modest restraint of the warming processes at work in the climate system worldwide. In

1987, facing the potential threat of a global-scale warming, the nations of the world adopted the Framework Convention on Climate Change. A year later, the Intergovernmental Panel on Climate Change (IPCC) was founded by the World Meteorological Organization (WMO) and the United Nations Environment Programme. Through it, climate scientists and researchers from many disciplines have instituted a worldwide cooperative process to share and disseminate information. Over the intervening years, the IPCC process has involved many thousands of researchers and analysts with fields of expertise suited to involvement in one of the three working groups: physical science (WG1), impacts, adaptation and vulnerability (WG2) or mitigation (WG3). As a student interested in many aspects of climate change, I was curious about the implications of the time lags in the pathways of information flowing from the science reports to those working in the other groups and ultimately to government decision makers. And as I came to read some portions of the mitigation reports, I developed concerns about the approach taken and hoped that the climate change-related materials in QUEST would be an opportunity for citizens to encounter some of the complexity of the issue that was not being explained fully since mitigation is, by definition, a human undertaking and other agents are not central to the discussions.

After 1992, the panel group studying and reporting formally on abatement issues stopped mentioning any long-term goals for atmospheric concentrations below 450 ppmv although the pre-industrial level had been well below that figure: in the 280 ppmv range. And this pre-industrial level was of such long standing that when concentrations rose to a level outside the band of multi-millennial variation, it was a clue that the climate system might have lost its stability (e.g. (Goddard SFC 2003). By 2001 that achievable minimum standard level had been raised to 550 ppmv. The jump appeared to signify the science experts considered the challenge significantly greater than estimated just a few years earlier. But the fundamental concept of projecting a variety of stabilization concentrations puzzled me and I worried that non-science people might not question it. A concept underpinning the assessment of the costs and benefits of various GHG emissions reduction scenarios that governments were using to inform policy making must have a sure footing in physical science. The problem I was concerned with was two-fold:

1] the assumption that the emission reduction scenarios actually led to a stable atmospheric concentration of GHGs, in the usual meaning of the word, 'stable,' in physics and that

2] the representation of most quantities in graphs, such as atmospheric GHG concentrations, as continuous curves conveyed a false impression of humanity's ability to control the warming processes underway.

Regarding the first concern, I found it hard to imagine a 'stable' climate system at concentrations above the very long-term average. It wasn't just that high impact/ low probability issues were overlooked but also cumulative effects that triggered new processes as thresholds were reached. Many of the graphs depicted conditions hundreds of years into the future and troubled me because I had read the 'fine print' and knew that most of the projections were based on computer models that did not claim to represent all processes. My reading and climate science studies have taught me the only other proven long-term semi-stable state was an 'ice age' condition that had ended abruptly (over decades) just before the recent era of humankind's spread to inter-connected global societies starting about 25,000 years ago. Some of the processes that are underway now could lead to a climate 'flip' into that other state where the penetration of warm tropical water into the North Atlantic is curtailed with dramatic differences in the 'normal' patterns of Northern Hemisphere climate during the last 12,000 or so years. That scenario might be viewed as a remote possibility but there was also the fact that Earth's climate had been radically different millions of years ago when global air and sea temperatures were 10oC higher than at present. And some climate model forecasts showed half that temperature rise was possible over just the next century (e.g. IPCC WG1 1995). That such an extreme rate of change should even be considered by the experts marked global warming/ climate change in my mind as the predominant environmental issue of our time and a backdrop of every policy decision regardless of its foreground focus.

The second obstacle I perceived is the notion conveyed by graphs such as those in Figure 2 below that show smooth, continuous curves resulting eventually in temperature stabilization and CO_2 stabilization (as an indicator for greenhouse gas overloading) if humanity cuts back on emissions:

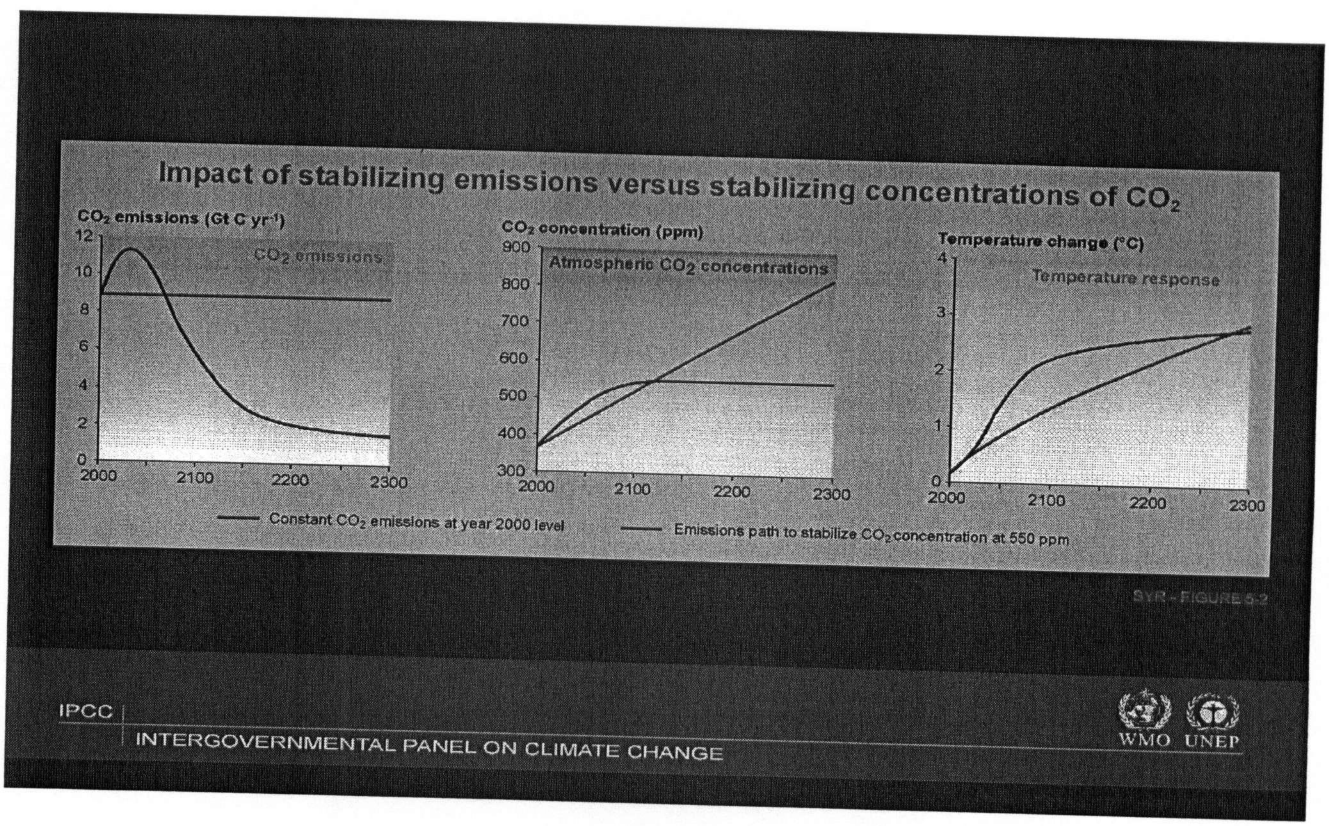


Figure 2: from IPCC 2001 (2.17)

The type of graph in Figure 2 shows the shapes of the mathematical curves resulting from alterations in human emissions and does not appear to take into account the non-anthropogenic emissions and other spurs to the warming that arise internally once a warming is underway. And these smooth, unbroken curves are typical of all the graphics in the IPCC abbreviated reports which are read by intelligent people whose areas of expertise are in fields other than the science of climate change. I wondered how many took the time to read the sidebars and explanations of uncertainties in order to find out what is omitted. And I saw an opportunity for QUEST users to delve into the hard questions that climate change science raises as to the consequences of the choices they made for the collected citizenry of the Georgia Basin over the next forty years.

Besides the above-mentioned concerns with the IPCC reports for informing the public through teachers, journalists and commentators, the material on what reduction targets or trajectories to aim for seemed to be dominated by economic analyses of various emission reduction scenarios. The problem I had with these was they usually seemed to start from the status quo and emphasize costs rather than benefits. It seemed to me that finding ways and means to enable Canadians to think about what we could do to move down on the list of GHG emitters and helping the public discussions move towards adopting a "War on Warming" mentality (or its equivalent in terms of peaceful resolve) that would embrace innovations and put our country on a par with some of the European leaders made sense, and that QUEST could be ideal for helping that process along. The difference between QUEST and looking at Canadian government websites is the nature of the experience. I knew students would often do QUEST scenarios as part of a group of their peers, collectively envisioning a future for their home community. Even the best informational websites only offer individual insights into ways to reduce emissions at the household level. They lack a mechanism for broadening the experience to a societal group or for showing cumulative results through time.

Currently, the IPCC's most ambitious scenario only aims for 550ppmv (e.g. Figure SPM-6 in the Third Assessment Summary for Policymakers shows the former lower target as a WRE scenario but the lowest IPCC mentioned aims for 550) [2]. Since the main purpose of projections is to figure out how to apportion the cutbacks and limits to growth for nation states during this century, if one does not make a mental note to remember these are just the human contribution, one might take this whole discussion as involving all the gases and all the sources as well as all the processes at work in the real world. Moreover, a person seeing graphics like Figure 2 could get the impression that stability is possible above 280ppmv with a global climate regime somewhat closely resembling that of the 19th or 20th century when in fact, as mentioned above, the only other stable (lasting for millennia) climate states known in Earth's history are radically different. There is potential for reliable artificial sink creation but biotic sink capacity will be affected by the warming so must not be assumed to remain at present or historic levels even with assistance from deliberate human efforts. The non-human feedbacks that will increase the atmospheric overload of heat-trapping gases and decrease the natural sink capacity will be outlined in Chapter 2. Even if the IPCC is trying to simplify the interactions in the climate system at this point in history, I would argue we do a disservice to the next generation if we downplay the complexity of climate change-related material in an educational outreach project like the GBFP which will attract a younger audience than the readers of IPCC reports.

I wish the present work were reporting how a climate change submodel was developed and implemented in GB QUEST but that has not yet happened. Synchronizing and harmonizing the spatial and temporal scales of the more strictly local topics that could be quantitatively modeled without controversy and the global scale of the climate change issue was a challenge that has not yet been met. About a month after the project meetings started, a 'new kid' appeared on 'my block' in the form of the Stockholm Environment Institute

[2] http://www.ipcc.ch/pub/un/syreng/spm.pdf

Global Scenario Group (GSG) scenarios as the World View choices in which GB-QUEST users would situate their regional scenarios. One would offer the user a pro-sustainability "Great Transitions" Worldview choice and the other a breakdown of international cooperation "Fortress World" Worldview (Carmichael 2001). Recent information shows that QUEST eventually adopted 2 choices from each category (Carmichael et al. 2004). Showing information suited to a user's initial choice of Low, Medium or High Climate Change impacts, as proposed by the co-researchers focused on the climate change topic to enable delivery of the range of impacts and adaptation possibilities to the QUEST user, would have been ideal in my opinion for stimulating discussions on this important issue. But, with the decision that the GSG scenarios would adequately cover the climate change topic, there was no place left to do this. This did not and does not make sense to me because it doesn't actively promote discussion on what is surely one of the "most significant issues" for the geographical region that QUEST covers. So the goals of this thesis are to explain why I think explicit content pertaining to global warming/ climate change complements the other topics GB-QUEST deals with and has the potential to be an asset to the users of the full version. I believe the multi-decade lag between emissions and impacts opens the door for a user-chosen global future in which to stage their local scenario to be compatible with choices on the severity of impacts from global warming/ climate change separately from the commercial, political and other environmental impacts implicit in the GSG scenarios. As well, I believe allowing QUEST users to make overt choices of impact levels they want their custom scenario to report on, showing the range impacts researchers project both in the Georgia Basin and other locales, could be guided by the True to Life criterion and meaningfully contribute to even the (relatively short) 4-decade lifespan of a QUEST scenario.

Chapter 1: Introduction

> February 26, 2004 (Reuters): Global warming poses a greater long-term threat to humanity than terrorism because it could force hundreds of millions from their homes and trigger an economic catastrophe, Canadian Environment Minister David Anderson said.
> Current preoccupation is with terrorism, but in the long term climate change will outweigh terrorism as an issue for the international community," he said. "Terrorism will come and go; it has in the past ... and it's very important. But climate change is going to make some very fundamental changes to human existence on the planet."
> Anderson said Canada would need to cut its emissions of greenhouse gases by 60 percent of 1990 levels by 2050. Canada has ratified the Kyoto protocol on climate change, which calls for a 6 percent cut from 1990 levels by 2012.
> "The British have decided ... that a 60 percent reduction (in greenhouse gas emissions) by 2050 is necessary and we will probably have to be in a similar range," he said.
> In 2001, those emissions were 18.5 percent above 1990 levels and energy producers say the costs of fulfilling Kyoto will be prohibitive. ~Lyunggren 2004

Responding to scientists' forecasts of climatic change and other impacts of a global-scale warming is an unprecedented challenge to the human family. Over the coming centuries, researchers tell us it is expected to cause major risks to many physical and social structures of civilization and ecosystems over much of the planet. While the specific vulnerability of any particular place at any given time is unknowable, the destructive weather extremes and the epidemics, heat waves and rapidly shifting ecozones are acknowledged statistically as a definite threat in most regions.

Climate change as a public policy issue has dimensions for citizens of industrialized nations like Canada that transcend their aspirations for the character of their local community since global warming can affect both their own lives and the prospect for their descendants being able to live out their lives in their birthplace. Some impacts expected in the Georgia Basin on daily life for those sensitive to poor air quality or high temperatures, on economic factors and urban/rural planning issues on which QUEST users make choices, or on revenue from natural resources are noted in Chapter 3. But the Climate Change issue raises questions of ethics and morality in addition to complicated questions of what are the local risks and the costs of building protection or adapting practices to reduce impact severity. It appears to be caused by the 'rich,' developed countries, but is likely to be most hazardous to poorer countries that do not have the financial resources to build protective infrastructure (e.g. Houghton 1997). And its potential for painful outcomes is elusive in the sense that no one is able to pinpoint specific perils the developed countries will have to share with the developing countries or with those societies who choose to keep to traditional ways.

The multinational response is extending the human family's proven capacity to cooperate and it is drawing partnerships together that might have seemed unlikely even a decade ago. Can barriers of religion, political and economic ideologies, and cultural animosities fanned by long histories of inequity, be melted as humanity sets its common goals in harmony with our common aspirations for life's abundance as we face a common threat? The first formal statement of the pledge to concerted action, the Objective of the United Nations Framework Convention on Climate Change, stated that the ultimate objective of the cooperative efforts of the signatories was, "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." And that, "such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.' (UNFCCC Article 2 1988). The participants were setting a lofty and perhaps unattainable goal but the Convention has now been ratified by 188 governmental bodies and so represents the stated objective of governmental representatives of most of the planet's human population.

Ironically, although the process was started by excesses of the 'rich,' the 'poor' on their road to riches will soon outstrip the developed world's GHG emission levels. Seeking the greater prosperity they see in developed countries, developing nations like China with immense coal reserves carry a 'big stick' in international negotiations. The industrializing world has huge reserves of fossil carbon and a citizenry who believe their material well being will approach equality with those of their more industrialized neighbours if they burn that coal and oil. A recent forecast from the U.S. Energy Information Administration to the year 2025 projects the strongest growth in energy use from developing countries, especially China and India. Energy use in developing countries is forecast to soar by 91 percent over the next two decades, while only 33 percent in industrialized nations with slow-growing populations and mature economies, shifting from energy-intensive manufacturing to service industries. (Doggett 2004)

Our response to date to this perceived threat is a testament to our species' ability to adapt by cooperating to protect our enlightened self interest. But the crunch is still ahead of us, the time when we have to make substantive changes in our personal and collective business-as-usual practices. What emotional reaction we have to the changes will come partly from our perceptions of the fairness of any 'sacrifices' we see our selves or social group making and partly from our understanding of why we and those we care about will benefit from any changes we collectively make. Until recently, there has been a deliberate disinformation campaign by economic interests that financed partisan research to focus public discourse on the lack of certainty that the proximate cause of any global warming trend was the human species[3]. (*e.g.* Avery 2004). Since the free press journalists' credo demands balanced coverage on controversial issues, this small, but well funded so possibly credible, fringe group was given a sentence or two to stress the lack of proof in most of the press coverage on global warming. In the Summary for Policymakers of Working Group I (Science) in the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 1995, the first definitive statement

[3] "There appears to be a concerted and systematic effort by some individuals to undermine and discredit the scientific process that has led many scientists working on understanding climate to conclude that there is a very real possibility that humans are modifying Earth's climate on a global scale. Rather than carrying out a legitimate scientific debate through the peer-reviewed literature, they are waging in the public media a vocal campaign against scientific results with which they disagree." (Avery et al. 1996)

that human activities were most probably implicated[4] signaled the beginning of the end of that era. And nowadays, that point of view, often referred to as 'the skeptics' viewpoint,' is much less often given space. However the campaign's effect lingers because, with the multiplicity of demands on citizens' time, an urgent public policy issue needs to be perceived as clear cut in order to get public support from a broad base of citizens holding views that span the spectrum of political philosophies. In October, 2004, Russia's ratification finally put the Kyoto Protocol into effect and set the course for the next decade to reduce the industrialized nations' emissions below 1990 levels. The slow progress, over seven years needed to reach sufficient acceptance for the protocol to enter into force, suggests there has been widespread public doubt concerning the need for any action.

Why include global warming / climate change in QUEST?

Action on the scale climate scientists calculate is necessary to actually reduce atmospheric GHG concentrations means much greater cuts than those needed to comply with the Kyoto Protocol (*e.g.* Figure 2). This situation means global warming could be considered a 'required element' for any major public education-oriented project done by a pro-sustainability organization which deals with the practices that result in enhancing the natural greenhouse effect. And QUEST deals explicitly with exactly those topics shown in Figure 1 as the major contributors to Canada's GHG emissions. Land use, urban planning strategy, transportation, energy production, waste, agricultural and silvicultural methodology, are the economic sectors in all industrialized nations that affect sources and sinks of greenhouse gases[5]. This means GB-

[4] "The balance of evidence suggests a discernible human influence on global climate" (IPCC WG1 1995 4)

[5] "In many policy discussions, climate-change mitigation policy is assumed to involve actions for which the primary target is a reduction in GHG concentrations. These include efforts directly aimed at reducing carbon emissions, at expanding carbon sinks, at reducing emissions of other GHGs (like methane and

QUEST offers an excellent opportunity to convey some solid information on the current state of knowledge as to the global warming/climate change implications of the user's scenario-generating choices.[6] Discussing the approach QUEST employs to engage users in social learning, Robinson mentions a recent study report which argues that 'social learning should be seen as a process of moral and cultural development as well as cognitive change" (2003 852).

The GBFP proposal includes a rationale for giving a fuller treatment of global warming/climate change considerations in GB-QUEST that goes beyond reporting emissions of greenhouse gases generated during the 40-years of activity in the user's scenario. It posed the question, 'How can we reconcile ecological limits with increasing human welfare?' as a core dilemma in achieving sustainability. GBFP proposed it would test a new conceptual framework that allows the harmonizing of ecological, economic and social goals through dematerialization (uncoupling economic growth from environmental impact) and resocialization (uncoupling economic growth from human well-being). And part of the project's stated goal was 'improving public and individual understanding of complex policy issues' (SDRI 1998 9.0).

---

nitrous oxide from agriculture), and at promoting the development of new technologies and production processes that rely less on carbon-based fuels. If this is the domain of mitigation policy, then other (anticipated) actions that do not fall in this category need to be regarded, by default, as part of the baseline. However, other activities have important consequences for climate change. For example, policies oriented towards local air pollution–such as controls on hydrocarbon emissions from automobiles–affect levels of emissions of CO_2 as well as the formation of tropospheric ozone, and thus have consequences for climate. Moreover ,,, some policies, such as poverty alleviation, may ultimately have significant implications for the emissions of GHGs and are therefore extremely important to climate change." IPCC WG3 SPM 1.2.6 (2001)

[6] "*Social learning and innovation, and changes in institutional structure could contribute to climate change mitigation.* Changes in collective rules and individual behaviours may have significant effects on greenhouse gas emissions, but take place within a complex institutional, regulatory and legal setting. Several studies suggest that current incentive systems can encourage resource intensive production and consumption patterns that increase greenhouse gas emissions in all sectors, *e.g.* transport and housing. In the shorter term, there are opportunities to influence through social innovations individual and organizational behaviours. In the longer term such innovations, in combination with technological change, may further enhance socio-economic potential, particularly if preferences and cultural norms shift towards lower emitting and sustainable behaviours. These innovations frequently meet with resistance, which may be addressed by encouraging greater public participation in the decision-making processes. This can help contribute to new approaches to sustainability and equity" IPCC WG3 SPM Introduction point 10 (2001)

From the perspective of the present writer who has examined the issue from a variety of vantage points as part of her recent university studies, climatic change considerations are as fundamental as considerations of gravity to the future of natural ecosystems as well as to many essential features of the built environment. Anthropogenic climate change on a global scale is unprecedented but the Third Assessment released by IPCC scientists in 2001 claimed that, "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities" (IPCC WG1 2001 panel 77)[7]. QUEST could help widen the understanding of the issue by offering often overlooked sustainable development perspectives. This approach is based on the best possible scientific information and analysis of risk; counters uncertainty with precaution; considers the possibility of irreversible changes as a call to attention; and allocate costs to the polluter (Houghton 1997). Sustainability efforts are doomed on a warming planet unless initiatives driven by any social, environmental or economic

---

7

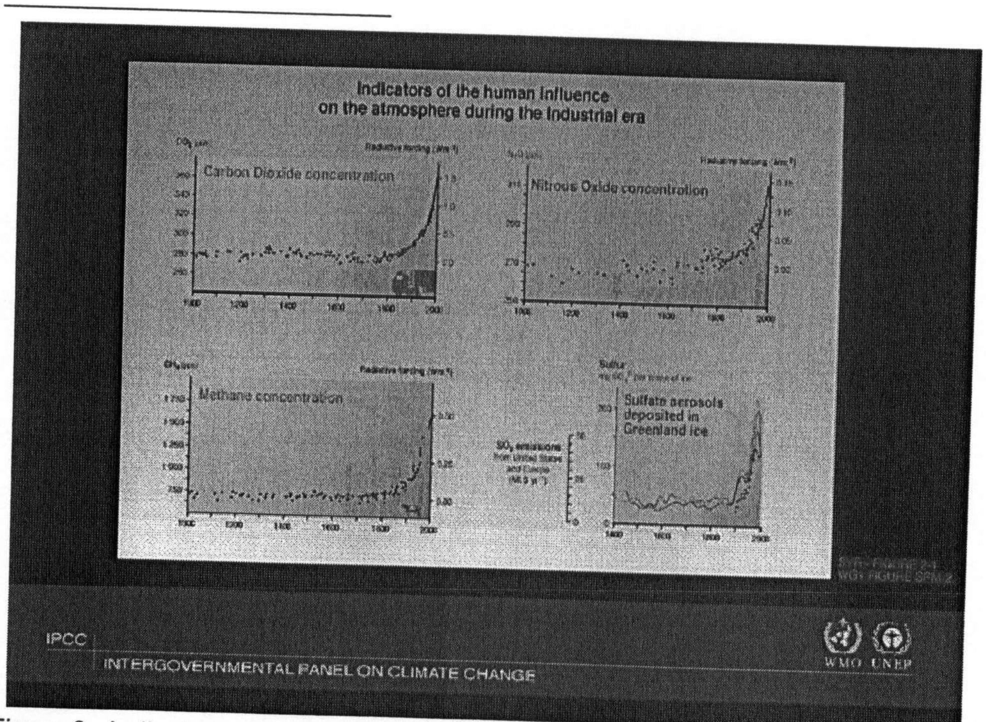


Figure 3: Indicators of the human influence on the atmosphere during the Industrial era (IPCC WG1 spm 2001 Figure 2-1)

motivation also work to make a difference in the thermodynamics of the planetary life-support systems. "Climate change is one of the most important symptoms of 'unsustainability'" (Cohen 1998 342). So human-caused changes in climate fall into any discussion of complex policy issues for the 40 years of the 21st century that GB-QUEST covers and the challenge is finding a way to do it that blends in with the methodology applied to the other topics. As will be shown in Chapter 4, the layout for climate change related displays can conform to the QUEST standard. And, whether or not the user is offered explicit climate change-related choices, it will note that there is material keyed to user choices that could provoke stimulating educational conversations.

The major metropolitan regions of the Canadian side of the Georgia Basin are Vancouver and the British Columbia provincial capital, Victoria, on Vancouver Island across the Georgia Strait from Vancouver. Climate severity in this region is rated the lowest of any in the country (CICS 2004) so how can QUEST hope to raise any consciousness here about the impacts of global warming and climate change? One clue comes from examining the sources of wealth and essential provisions for the region's residents. Economically, the region far from self-sufficient. This means the impacts on the local land/air/seascape of a user's QUEST choices cannot give the full picture of the consequences of those choices. Like any 'heartland' region where commodities concatenate before dispersion to final markets, the ports of the region depend on the movement of goods from the very much larger 'hinterland' region of the province of B.C., as well as the rest of Canada, across the Pacific Ocean. The area imports most of the 'necessities' of modern life including food, electricity, fuels, home furnishings, business machines, construction materials or transport vehicles. The changes that will eventually come based on climate change considerations will affect residents of the Georgia Basin profoundly despite the fact that precipitation and temperature are expected to undergo relatively less change than in most other regions in the country (CICS 2004). Only telling the QUEST user the size of the region's eco-footprint and the volume of GHG emissions makes it difficult for the user to catch the implications of those output categories without a clear impact statement. So the goal with paralleling the treatment of the climate change issue would be to mimic those other output formats with solid, relevant and thought-provoking graphs or text that are chosen based on the user's worldview choice as well as all the choices that give rise to the GHG emissions output.

Difficulties inherent in subsuming Climate Change considerations in GSG scenarios

Although QUEST was originally intended to be freely available via the internet for all interested players, this has not yet happened. This thesis project was based on that large audience being available but the arguments for including global warming/climate change in a clear and informative way apply also to the restricted audience that is able to access the current supervised-use version of or to a CD-based version for private use, like Lower Fraser Basin had, should that become available. QUEST is a learning tool whether or not it is eventually made available to all comers or whether it stays in the control of the project handlers who have taken it to schoolrooms or focus groups, and who run an abbreviated version at Vancouver's Science World. The only difference might be that supervised use means a restriction on the time available so perhaps some would argue climate change considerations should be glossed over as part of the World View choice because having a specific focus on the consequences of local choices on global warming would take too long for short encounters with the tool. But, one could easily counter that argument by having the presenter mention that an abbreviated session must overlook that aspect and suggest that interested parties get some time with the fuller version to explore the connection QUEST offers between their apparently 'local' choices and the consequences if others worldwide expect the freedom to make the same choices for their own region.

The QUEST user wears the hat of policymaker while building their custom future scenarios and so Principal Investigator Robinson's point quoted at the beginning of Chapter 4, that the process of construction is important to policymakers could naturally be extended to QUEST users as well. The natural assumption for these participants is that whatever is said about any particular topic is what the constructors considered important. Global environmental risk levels in recognizable future pathways that evolved over much of the planet (GSG scenarios in the QUEST case) and user-created local scenarios, outcomes from a series of local lifestyle and development choices, that have implications for future global conditions, can mesh logically because of the temporal offset. This delayed response is essential to engaging with the physical aspects of global warming /climate change phenomena and since the GBFP had wanted to deal with this topic, this pattern of lagged response is a core concept to be dealt with directly.

On a strictly logical basis, the climate change issue should be dealt with separately from the other attributes of the GSG scenarios which are totally under human control. As Chapter 2 will detail, once started, the warming can initiate many (positive) feedback loops that will compound it and only a few (negative) loops that work to restrain it and restore stability. In order to avoid masking the complexity and follow the sustainable development principles outlined above, it should be approached as holistically as possible. For example, the delays between GHG emissions and climatic or other impacts is a key component of the 'mystery' of climate change that could be addressed in such a way as to stimulate discussion or inspire a class lesson plan. To subsume the complexities of global warming in a short description of a fork in civilization's road leading towards either cooperation in a Great Transitions (Carmichael 2001) Scenario or isolation by choosing to construct a Fortress World scenario (Carmichael 2001) risks giving a message to QUEST users that climate change considerations are unimportant in the process of achieving the GBFP's goal of formulating some "varied scenarios for a sustainable Georgia Basin in 2040." (SDRI 1998 A9.11)

The structure of the rest of the thesis

The format of this work is a synthesis from the literature supporting the claim that QUEST would be improved by offering users overt climate change-related choices and could blend the output in on a strictly local level if designers objected to any mention of extra-regional material at the output phase.

To expand on the rationale for the importance of including information regarding global warming / climate change, the next chapter will focus on the mechanisms in the planetary life support system that will move the warming beyond humanity's ability to restrain it at some unknown point in time. Chapter 2 is a list of (predominantly positive) feedbacks that scientists expect to start up as threshold conditions are exceeded and wrest control of the warming processes out of human control. Since the timing of the start up of most of these processes that accelerate the warming is unknown, the chapter is intended to promote the idea that rapid response timing is critical and thus any groundwork for public acceptance of the need for speed is inherently good. Abrupt changes and feedback loops can start to produce impacts or accelerate the warming quickly. Examining the types of processes that will come into play as thresholds are crossed is intended to support the argument that earlier GHG reductions are more cost-effective and will mean less human suffering and ecosystem displacement or loss than later ones. QUEST could help rally present and future public support for low emission lifestyles by educational emphasis on global warming.

In Chapter 3 there is a look at climatic change impacts in the Georgia Basin over the last century as well as that expected during the QUEST 40-year time slice and mentions beyond-the-end-point trends that could have relevance now because of the possibility of irreversible changes or long lead times inherently necessary for protective action plans. On an international scale, one use of this material is to take a global perspective when choosing QUEST output segments contrasting local impacts expected in the Georgia Basin and the magnitude and scope of impacts on more vulnerable populations in other parts of the world. Such a use of the material would allow school classes and public focus groups discussions to contemplate the ethics of the global warming/ climate change issue. On a national scale, it could be used to make the point that although the Georgia Basin region is expecting relatively little direct impact, its sensitivity stems from its reliance on the rest of the province for natural resource income and on the rest of the country for trans-shipment of raw materials, agricultural produce and manufactured products. At the provincial level, climate change-related crises are currently looming in the main natural biotic resources: forestry plagued by a pest epidemic induced by a series of winters where insufficient cold allowed proliferation and salmon fisheries by shrinking of habitat for the most prized species due to its rigid thermal intolerance. Canada's crises may take longer to manifest than British Columbia's but the federal government has been investing in benchmark setting studies, consultation with industry groups regarding adaptive measures, and educational initiatives to promote understanding of the severity of the potential consequences from extreme weather, prolonged droughts, floods, heat waves, spread of diseases and pests, etc. These expenses are considerable and growing as the severity of the threat has become increasingly acknowledged.

The intent in Chapter 4 is to conclude this thesis with a brief suggestion of layout and content for an output screen focusing on global warming/climate change in order to show that there exists at least one possibility that is compatible with the rest of GB-QUEST. The object is to express meaningful global warming / climate change material keyed to the user choices in the other topics where choices are currently permitted. Adding choices specifically related to climate change could be seen as a natural extension of reporting on the local scenario's contribution to the global problem at some point. Although screen 'real estate' on QUEST can accommodate only a pithy comment or small picture, global trends or 'success stories' showing legislative resolve or cooperative efforts to achieve relevant goals could be seen as suitable topics to display in graph format as well as material mentioned in the other chapters. Burgeoning costs paid by taxpayers to offset some of the cost of severe weather impacts as well as the current and projected costs of funding research and education might be of interest also. Helping slow the acceleration of global warming is one of those motivators that could be chosen by QUEST users regardless of the GSG future choice they chose to describe the external conditions which relate strictly to choices made by the most powerful groups of human beings because, as the next chapter outlines, the warming can become self-sustaining.

Chapter 2: **Humankind vs. human-caused global warming in the 21st century**

> It (climate change) is global, long-term (up to several centuries), and involves complex interactions between climatic, environmental, economic, political, institutional, social and technological processes. This may have significant international and intergenerational implications in the context of broader societal goals such as equity and sustainable development. Developing a response to climate change is characterized by decision-making under uncertainty and risk, including the possibility of non-linear and/or irreversible changes.
>
> ~ (IPCC WG3 2001spm 3)

The ever-expanding IPCC is now working on its fourth set of comprehensive reports, a wealth of research, analysis and commentary that continues to guide the world's governments to informed opinions and responses relating to this complex policy issue. However, both the nature of the cooperative process and the prevalence of Western science educational training[8] of the participants can produce gaps in their audience's understanding of the risks we collectively face.

The import of key variables, such as emissions, may be clear to the initiated but others, including experts in other fields, may miss the significance of the statements of uncertainty presented. The estimates of how certain each outcome is that appear are attempts to clarify various situations but they are not always effective enough to prevent misunderstanding, simply because the topic is so complex and the phenomenon so newly recognized. The import of the omissions may be clear to the initiated but others, including experts in other fields, may not have enough information to integrate the significance of the statements of uncertainty in one area with those from others. The estimates of how certain each outcome is are attempts to clarify various situations but they are not always effective enough to prevent misunderstanding. It might happen because the topic is so complicated or because the phenomenon so newly recognized that readers may not yet have acquired a sense of the basic framework of the core science, politics

[8] "Science represents a radically different and powerful way of looking at the world. By focusing on a part of nature, controlling everything impinging on it, and measuring and describing a particular fragment, we acquire profound insights ~~~into that fragment. In the process, scientists lose sight of the context within which that part exists, no longer seeing the rhythms, cycles, and patterns that made the fragment interesting in the first place." (Suzuki and Grady 2004 7)

and economic factors.

Other perils to complete coverage of the global warming issue include the inability to communicate effectively on some topics because certain academic disciplines use common English terms for specialized meanings that members of other disciplines may take to have the common English language meaning, or with some variant from their own discipline, instead of the writer's intended usage. For example the term 'stability' in a science sense is referred to above on page 2 but the common usage in the IPCC and other mitigation literature refers to atmospheric stabilization at particular concentrations of CO2. This can be confusing because achieving and maintaining a concentration level outside the long-term (over half a million years) range, is not proven possible and stabilizing a key component in a system which is 'out of balance' (e.g. Hansen above) on just that variable is quite likely to cause a non-expert reader confusion.

Even labeling the global warming issue, 'Climate Change,' a natural appellation for the WMO to devise, has produced a limited mental image in the public mind. The term, 'global warming' correctly describes the increase of heat energy held in the surface elements, oceans and atmosphere. But 'climate change' refers to only one outcome of global warming. There are dangers of muddying the waters for an entire generation if Art delivers the message, as in the 2004 'blockbuster action thriller, The Day After Tomorrow, rather than Science.

Other than the IPCC reports, major influences on the approach to thinking about this public policy issue have been the Steve and Elizabeth Malone series Human Choice and Climate Change and Sir John Houghton's book, Global Warming: The Complete Briefing. The latter touches on the main points of all facets of the issue from physical science and physical science research directions, to technological possibilities, economics, policy opportunities and ethical considerations. If one were to read only one book on the global warming issue, Houghton would suffice even though a book published seven years ago might logically seem dated in such a burgeoning field of study. Rayner and Malone reviewed and analyzed the underpinnings of policy choices to be made by governments and institutions in a comprehensive manner. Besides the wealth of information presented in their books, they have also produced a Ten Suggestions booklet recommending an inclusive philosophy of responding to the climate change issue. This slim booklet is a most effective 'summary for policymakers' because instead of disputable facts, it suggests approaches that minimize risk of ignorance leading to avoidable missteps. Like any distillation to a short list, their suggestions are necessarily general but their focus is on keeping a broad vision so the likelihood of surprises is minimized has been an inspiration to the point of view taken in the present writing. The crucial point taken from them is an awareness of how dramatically a society's main technological facets and lifestyle priorities can change as inventions or legislative restrictions force change within a generation. Also, Climate Change and Sustainable Development: Towards Dialogue (Cohen et al. 1998) influenced the development of some of the thought trains in this paper. It examines the history of the main-stream climate change abatement literature alongside that of the parallel discourse in the sustainable development (SD) field. The authors note that a unified approach makes sense since the impacts of all the activities and processes that sustainable development deals with have interactions with those that consideration of climate change impacts and global warming processes involves. One of its particularly compelling points is the overt acknowledgement of the anthropocentrism in SD, often due to the urgency of survival-threatening conditions that climate change impacts are expected to intensify (IPCC WG2 2001). Although the climate change literature, including country studies, does acknowledge impacts on unexploited ecosystems of events or processes stemming from global warming or human response to the perceived threat, there is a distinct focus on those ecosystems viewed as having commercial value. Finally, and far from least, this work is inspired and influenced by the voices of the AOSIS9 nations whose pleas to the industrialized world have been eloquent and by the writings and accomplishments from those northern European nations, particularly the Dutch and the Danish, whose overt acknowledgement of both their local and our common global vulnerability to enhancement of Earth's greenhouse effect, and their leadership in social and technological innovations, have been consciously exemplary.

In the rest of this chapter, the Earth Systems literature on global warming is drawn on to support the claim made in Chapter 1 that the climate change issue involves an urgency to try to slow the physical processes apparently already underway that merits separate treatment in QUEST from the GSG scenario components which are strictly results of human choices.

The underlying problem: physical processes are largely outside human control

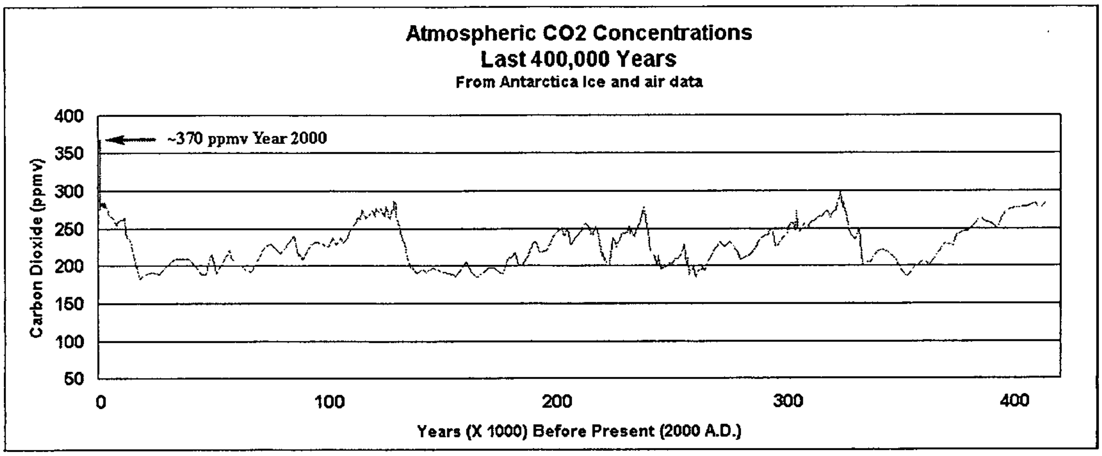
> People generally like simple answers. This happened, so this happened.
> Cause and effect. Simple. But nature doesn't work that way. Just when we think we've got something figured out, another idea comes along that turns our preconceived notions upside down. In spite of all our scientific advances, we are only just beginning to understand how ecosystems work. ~ David Suzuki (2004)

The underlying problem is that the integrated Earth ocean-land-atmosphere system physical processes are largely outside human control even though it appears that industrialized human activity has recently destabilized the planet's heat balance (e.g. Goddard SFC 2003). Completion of drilling at Vostok station in East Antarctica produced an ice record of atmospheric composition and climate for the past four glacial–interglacial cycles. Figures 4 and 5 below show the pre-human CO2 range was about 180 – 280 ppmv and the IPCC (2001) data for the 20th century and projections for the 21st do not show levels below double the highest pre-

[9] Alliance of Small Island States (**AOSIS**)

industrial human value.

> The succession of changes through each climate cycle and termination was similar, and atmospheric and climate properties oscillated between stable bounds. Interglacial periods differed in temporal evolution and duration. Atmospheric concentrations of carbon dioxide and methane correlate well with Antarctic air-temperature throughout the record. Present-day atmospheric burdens of these two important greenhouse gases seem to have been unprecedented during the past 420,000 years. (Petit et al. 1999 429)



2001-1958: South Pole Air Flask Data
1958-1220 B.P.: Law Dome, Antarctica
1220 B.P.- 2302 B.P.: Taylor Dome, Antarctica
2302 B.P.- 414k B.P.: Vostok Ice Core Data (Petit et al. 1999)
Figure 4: Atmospheric CO2 Concentrations Last 400,000 Years from Antarctica ice and air data

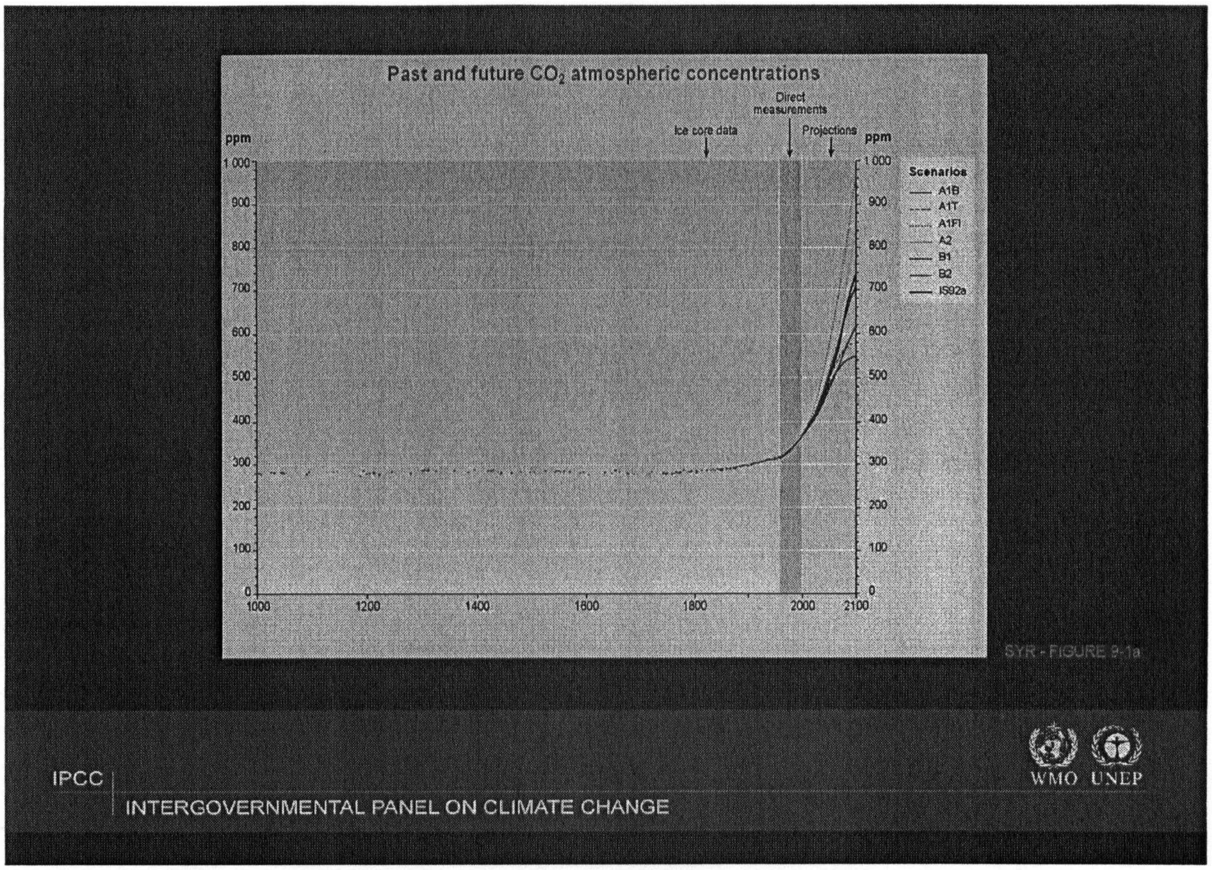


Figure 5: Atmospheric CO2 Concentrations (IPCC Figure 9-1a 2001 2.21)

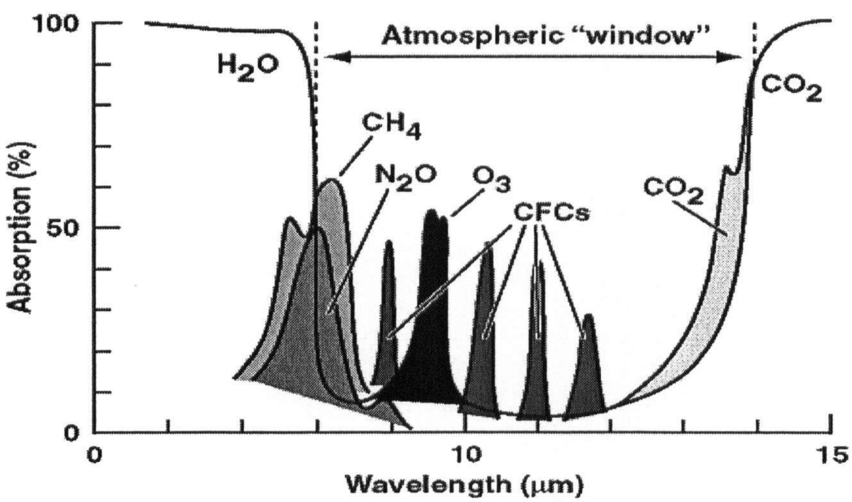
The graph above only shows carbon dioxide but there are dozens of other trace gases that have a sizeable Global Warming Potential (GWP[10]) value based on their heat-trapping ability and atmospheric lifetime. The buildup of radiatively active gases reaches a maximum functional

[10] GWPs are an index for estimating relative global warming contribution due to atmospheric emission of a kg of a particular greenhouse gas compared to emission of a kg of carbon dioxide. GWPs calculated for different time horizons show the effects of atmospheric lifetimes of the different gases." (IPCC WG1 2001ts)

amount at the point the infrared 'atmospheric window[11]' of the planetary 'greenhouse' spectrum becomes saturated at various frequencies. The infrared 'windows' in our metaphorical 'greenhouse' are the spectral regions of wavelengths 3.5 - 4 and 8 - 12 μm in which very little thermal radiation emitted from the Earth's surface into the atmosphere is normally absorbed. Water vapour and the trace gas carbon dioxide are capable of closing this atmospheric window because their absorption band is within those wavelengths (Maunder 1992). This is 'radiative forcing', where heat energy that normally passes freely through to dissipate in space, is captured by these atmospheric components and increases the total held captive in the combined atmosphere/land/ocean system.

As shown in the figure above, the IPCC projects that for the SRES illustrative scenarios[12], relative to the year 2000, the global mean radiative forcing due to greenhouse gases continues to increase through the 21st century. The portion due to carbon dioxide is expected to increase while that from other atmospheric constituents, both those with positive and negative

---



11

Figure 6: The Atmospheric "window" (Lee, 1999)

12 The term SRES scenarios refers to the IPCC set of global futures. Since they are a more extensive set of possibilities than the GSG scenario set, it is safe to assume that whatever subset of the GSG scenarios QUEST uses, comments from the IPCC applied to the entire range of SRES scenarios will apply.

forcing effects, will be increasingly less significant. Since pre-industrial times, carbon dioxide concentrations have gone up about 30% while methane has increased about 150%. (IPCC WG1 2001) For the next century, the carbon cycle model projections are between 90% and 250% above pre-industrial levels for CO2. Methane, removed quickly from the atmosphere relative to carbon dioxide, concentration projections vary between -190 to +1.970 ppb by 2100. (IPCC WG1 2001) However, that assessment does not mention that there are sources of methane (GWP 20+ times as high as CO2) from hydrates probably because the majority of their release is not expected in that time frame. This gaseous residue of decomposed ancient vegetation trapped inside water molecule lattices can release both slowly, as in the diffused melting permafrost of northern North America and Russia, and quickly, as in coastal deposits of methane hydrate released by an underwater slump. Some of these are already being released and others may not start until this century is over but are very significant sources[13] compared with anything currently

---

13 "There could be as much as 10,000 Giga (US billion) tons of carbon stored naturally as gas hydrates; more than ten times the amount of carbon currently in the atmosphere." (Maslin 2004 1)They can be found in most submarine continental shelf and continental slope settings as well as in many permafrost areas. (Maslin 2004). When trapped between rock layers in discrete reservoirs and tapped for use as a fuel, gas mixtures formed as ancient vegetation decomposed are called 'natural gas' (NaturalGas.org 2003) but much of the gas hydrates are in widely dispersed deposits and are not recoverable for piping without unacceptable risk.

contributing to enhancing the natural greenhouse effect.

Once, started, the warming appears to lie largely outside human control because of the potential for feedbacks. Feedbacks are responses within a linked system where change in some characteristic of the system sparks processes that work to intensify (positive) or damp down (negative) the processes of interest. There are two seminal syntheses on feedbacks in the global warming literature. The first was a paper by Daniel Lashof who was a researcher with the US Environment Protection Agency when he published The Dynamic Greenhouse: Feedback Processes that Can Influence Global Warming in 1989. In this paper, Lashof drew together the accumulated quantification on a variety of potential feedbacks to estimate the total Earth system

---

Figure 3. Pie chart of estimated carbon reservoirs. Note that gas hydrates could represent over half all the world's carbon reserves (adapted from Kvenvolden, 1998).

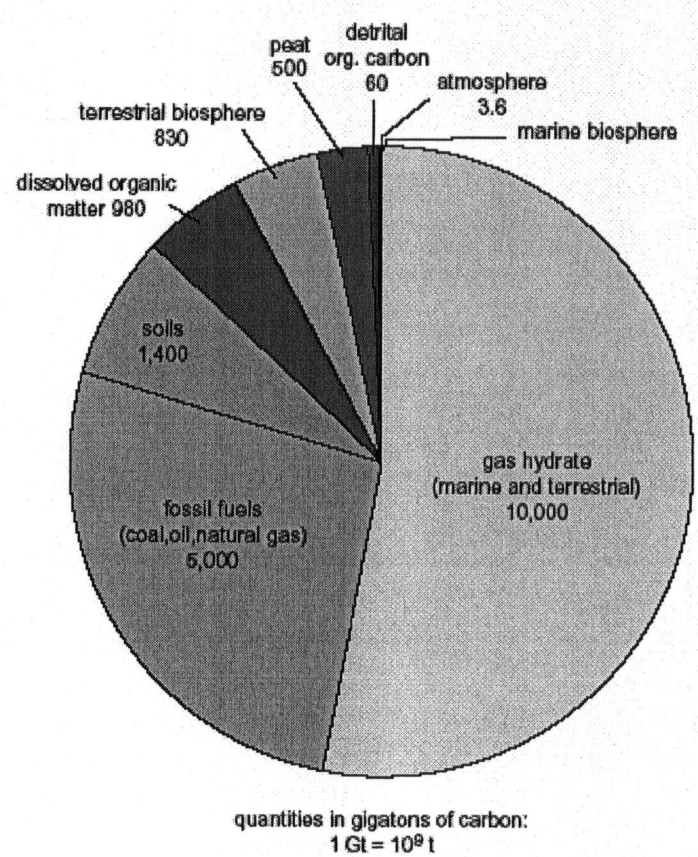


Figure 7: Pie-chart of estimated carbon reservoirs (Maslin 2004)

gain from feedbacks at doubled pre-industrial CO2 levels. He concluded that the largest feedbacks to be seen in this century would most likely be the geophysical type (water vapour, clouds, ice/snow albedo) and the likely amplification that would be produced by these feedbacks was about 80%. The second groundbreaking work in the feedback synthesis literature is the 1995 book on feedbacks in ecosystems edited by George Woodwell, founder and Director of the Woods Hole Research Center and University of Hawaii Oceanography professor Fred Mackenzie, Biotic Feedbacks in the Global Climate System: Will the Warming Feed the Warming? As both atmospheric trace gas concentrations and climate change, the complex interactions in living communities is a harder question to tackle than the effects of the warming on purely chemical or physical structures.

> Continuous warming is chronic disturbance, the classical cause of a shift from later-successional species to earlier-successional species, from larger, long-lived species to small-bodied, short-lived species, from forest to woodland to grassland - progressive biotic impoverishment (Woodwell, 1995, 13).

This book came from a collaborative attempt to isolate biotic feedbacks in global warming processes from other natural weather effects and from other environmental changes that took place at a 1992 workshop attended by approximately 100 scientists from around the world. Dr. John Houghton, Chairman of IPCC Working Group I at the time, stated, "the discussions were lively, and it was interesting to note the considerable disagreement that exists regarding the likely scale, magnitude, and, in some cases, even the sign of the potential feedbacks" (1995, v). This book does not attempt to quantify the additional feedback potential due to alterations global warming processes may make in the habitats of living communities. In keeping with the wise approach advocated by Rayner and Malone, some of the points made in Woodwell and Mackenzie will be mentioned in the list below.

Lashof emphasized that even the geophysical feedbacks cannot be listed as discrete cycles, processes whose gains are selectively summed to estimate system gain, over any but the shortest time periods (1998). This means there is no simple answer to any questions regarding feedbacks, and analysis of climate or carbon cycle model projections needs to be tempered with consideration of the nature as well as the magnitude of any feedbacks with potentially significant effects. Feedbacks may be interactive or may produce oscillations simply by operating simultaneously. Climate models simulate more and more of these internal responses as the models become more and more complex but modelers do not always specify which feedbacks their model includes so their projections are hard for the non-specialist to evaluate accurately. The IPCC says that

> By 2100, carbon cycle models project atmospheric CO2 concentrations of 540 to 970 ppm for the illustrative SRES scenarios (90 to 250% above the concentration of 280 ppm in the year 1750). These projections include the land and ocean climate feedbacks. Uncertainties, especially about the magnitude of the climate feedback from the terrestrial biosphere, cause a variation of about -10 to +30% around each scenario. The total range is 490 to 1260 ppm (75 to 350% above the 1750 concentration). (IPCC WG1 2001spm)

But, when one reads the list with many potential feedbacks below, it is unclear from the statement above which of the items on that list have been considered in the models cited. And, as the field is a major research focus, more and more feedback processes are being incorporated into climate models every year (IPCC 2001ts). The IPCC focus as regards feedbacks in the 2001 Report concerns updating public awareness of the progress in including more and more loops in the major global climate models. QUEST policymakers have the opportunity only to get explicit output for the next 35-40 years but, one of the points the Climate Change display screen could make is that the effects of activities in that time frame commits the planetary system to much longer effects.

Based on analysis using as accurate data as are possible to obtain with the equipment available[14], it appears that changes in temperature and greenhouse gas concentrations have almost coincided in the past. Data from the Vostok (Antarctica) ice core show that CO2, temperature and methane (CH4) concentrations appear to have shifted in unison during the cycles of warming and cooling over the last hundreds of thousands of years. Although a causal relationship cannot be deduced because of the low temporal resolution on the record, the overall pattern of climatic change during the period was dominated by a positive feedback on the warming (cooling) through the CO2 and CH4 concentration increases (decreases). Confirmation for the feedback relationship comes from data from ice cores for the period 1300-1900 AD which shows a decline in atmospheric CO2 trapped in ice coincident with declines in temperature (Enting 1995).

In current data, however, gas concentration increases following temperature rises, with a lag measured in weeks to months (Woodwell 1995). This recently observed sequence suggests increasing temperatures may trigger some process that results in greater atmospheric greenhouse gas concentrations, i.e. a positive feedback mechanism on greenhouse gas sources appears to be operating already. The Mauna Loa observatory in Hawaii where carbon dioxide levels are monitored reported that 2003-2004 shows a much higher year-to-year increase than the average over the last decade. The interannual change rate was three times the average rate in the 1950s when observations began there. "Leading climatologist, Ralph Keeling, whose father, Charles D. Keeling, developed methods for measuring carbon dioxide, noted that the rate "does fluctuate up and down a bit," and said it was too early to reach conclusions. But he added: "People are worried about 'feedbacks.' We are moving into a warmer world. ... He explained that warming

---

[14]" Up to 2003, the longest core drilled was at Vostok_station. It reached back 420,000 years and revealed 4 past glacial cycles. Drilling stopped just above lake vostok. The Vostok core was not drilled at a summit; hence ice from deeper down has flowed from upslope; this slightly complicates dating and interpretation. ... The EPICA core in Antarctica has now gone back 720,000 years and revealed 8 previous glacial cycles. (Fablis Encyclopedia 2004)

itself releases carbon dioxide from the ocean and soil. By raising the gas's level in the atmosphere, that in turn could increase warming, in a "positive feedback." (Associated Press 2004)

But atmospheric accumulation of heat-trapping gases is not the only possible mechanism for initiating a positive feedback looping sequence for the world future generations will inherit, which could be active over the timescale of potential interest to QUEST policy makers. Modifications to planetary albedo, resulting directly or indirectly from temperature rises, can alter the energy absorbed at the affected surfaces and thus the probability of chemical interactions as well as the magnitude and/or speed of some biotic processes. Or modifications to ecozones can result in large-scale changes in carbon sink function. Further, latitude-dependent differential warming can instigate loops involving heat/energy transfer and long-term storage. And finally, the impacts of the warming on human communities, or the widely-held perception that deleterious outcomes are probable, can induce changes in behaviour to reduce harmful activities or to act in concert with natural processes in mitigating damage already done. One can reason that policy decisions made in order to mitigate climate change are "forced" by global warming in the same way as a physical forcing. Although Rayner and Malone (1998) note that there are other significant sources of uncertainty in these times of accelerating socioeconomic and technological change, they counsel policymakers to incorporate climate change concerns into decision-making processes focused on other more immediate issues. The recognized hazards arising from many changes global warming brings mean humans are being goaded into action as knowledge of the perils increase and we see this in initiatives on addressing many areas of concern, local to global, immediate to long-term. "Population and economic growth, technological advance, fossil fuel supplies, nuclear and renewable energy availability are among the factors which could exert a major influence on future levels of CO2 emissions" (Leggett et al. 1992 74). Allowing the QUEST policymaker-for-an-hour to respond to projections of future outcomes of her or his choices, simulates real world situations in a way that meets the QUEST design criterion of being 'True to Life' (SDRI 1998).

The threat of abrupt changes means future dangers caused by present-day actions

> Reducing uncertainty in climate projections also requires a better understanding of these non-linear processes which give rise to thresholds that are present in the climate system. Observations, palaeoclimatic data, and models suggest that such thresholds exist and that transitions have occurred in the past. The occurrence of such transitions can clearly not be excluded in a climate that is changing. On the contrary, model simulations indicate that such transitions lie within the range of changes that are projected for the next few centuries if greenhouse gas concentrations continue to increase. A particular concern is the fact that some of these changes may even be irreversible due to the existence of multiple equilibrium states in the climate system.
>
> ~ (IPCC WG1 2001 7.7)

A good example of this type of change would affect the climate of Northern Europe. Using model results as well as expert opinion, the IPCC warned that models project weakening of the thermohaline heat transport into high latitudes in the North Atlantic possibly as early as next century so that "the thermohaline circulation could completely, and possibly irreversibly, shut-down in either hemisphere if the change in radiative forcing is large enough and applied long enough" (IPCC WG1 2001) European agriculture supports more than twice the population of the United States and Canada. To sustain this level of productivity, the cold, dry winds that blow eastward across the North Atlantic after crossing the interior of North America must somehow be warmed. This is done by warm water flowing north from the tropics, as the eastbound Gulf Stream merges into the North Atlantic Current. This warm water then flows up the Norwegian coast, with a westward branch warming Greenland's tip, at 60°N. It keeps northern Europe about 9 to 18 degrees warmer in the winter than comparable latitudes elsewhere. Except when it fails.

And recent history has shown produced a glimpse of what can happen. Studies of the

Great North Atlantic Salinity Anomaly of 1968 to 1982 show that the downward transport can be subject to rapid change. The 1 to 2oC colder, and as much as 1.4% less salty, than normal body of water circled from north of Iceland near the east coast of Greenland around the Labrador Sea, crossed the Atlantic and headed north into the Norwegian Sea before returning to its starting point 14 years later. Its effects slowed North Atlantic downwelling so that one-third less warm Gulf Stream flow was recorded and, for a decade, the whole Northern Hemisphere cooled sharply. (Kerr 1992 1509)

The models used to project future surface temperature trends are the GCMs, the General Circulation Models, which have grown in complexity and coverage as computers have gotten bigger and faster but which are still limited in two important ways. First, they are based solely on what modelers can represent mathematically about how the oceans store heat and distribute it as forced by temperature and density gradients. And there seems to be much room for improvement in the models even though they are being made ever more sophisticated. For example, Hoffert (1997) concludes that poleward heat transport is "not being properly represented in GCMs" based on an analysis of the driving forces arising from equator-to-pole temperature gradients reconstructed for two historical periods – the last Glacial Maximum 18,000 years ago and the mid-Cretaceous climate 100 million years ago. He concludes that the net transport appears to be governed by small-scale turbulence that the large-scale models do not yet have the ability to represent. Second, the transient models, the ones that move step-wise through time, are subject to 'drift' which means that if a small error occurs, it will compound as the simulation continues so adjustments are necessary to correct for these deviations (Hoffert 1997).

Abrupt changes as part of the process of planetary warming can come from the other polar region also. The West Antarctic Sheet (WAIS) is the only marine ice sheet that remains from the last glacial maximum Although its disintegration is unlikely over the next century, it is not impossible. (Studinger 1999). Over the next fifty years, the mass balance of the Antarctic ice sheet will probably be more influenced by increased precipitation adding to its volume than by increased oceanic temperatures melting the underside of ice shelves unless there is a substantial sea level rise in the area (Morris 1991). "Any ice sheet that fills a marine basin is inherently unstable when global sea level is on the rise, which most scientists agree has been the case for the past 20,000 years. This instability arises because the edges of a marine ice sheet can be easily stressed or even lifted off the underlying sediment by the natural buoyant effects of water." (Bindschadler and Bentley 2002) However, concerns about the stability of the WAIS persisted due to 'dozens of scientific studies conducted over the last 30 years' (Bindschadler and Bentley 2002). Most of the sheet rests on a rock base below sea level and is held in place by ice shelves and sea ice. If the protective ice barriers are weakened by ocean or atmospheric warming, over two million cubic kilometers of ice could surge into the ocean. Calving processes could well follow which would promote disintegration of the main ice sheet. Since the smaller ice shelves of the Pine Island and Thwaites glaciers may already be collapsing, the timetable of global warming's impact on the West Antarctic Ice Sheet is uncertain. Were it to add step-wise to the sea level rise in massive amounts, the resultant rise in sea level would affect many feedback loops already functioning at the time. The sediment and water in the seabed are in control of the discharge rate over days and years, but global climate, principally through air temperature and sea level, dominates over millennia. "Increasing temperatures related to global warming could begin creeping toward the South Pole from the Antarctic Peninsula, where the summertime atmosphere has already warmed by more than two degrees C since the 1950s. Even seemingly subtle changes in air temperature could trigger disintegration of ice shelves that are relatively stable at present. Evidence reported this year also suggests that warmer ocean waters mixing from lower latitudes may be melting the ice sheet's grounded edges faster than previously assumed, along with reducing the amount of ice in the Amundsen Sea." (Bindschadler and Bentley 2002)

Another abrupt change type comes from a prolonged increase in wildfire frequency and/or extent. A recent modeling project suggest that rapid and prolonged burning of accumulated Paleocene terrestrial organic carbon (peat and surficial matter) could have significantly contributed to the short-lived negative carbon isotope 'spike' at the global temperature maximum 55 million years ago. This burst of carbon from global wildfires entering the atmosphere may have been in addition to massive releases of underwater gas hydrates from the continental slopes but perhaps was solely responsible for the soaring temperatures worldwide. (Kurtz et al. 2003) A present day example of this type of phenomenon occurred during the 1997-8 El Nino in Indonesia. A prolonged period of dry weather resulted in drought, and favoured the ensuing forest and peat fires that were among the largest of the past century. Massive amounts of carbon were released into the atmosphere, which led to the biggest annual increase in atmospheric CO2 of the past 50 years. (Weissert and Bernasconi 200) El Nino events, whose impacts can be viewed as analogues for the effects of global warming, seem to have lengthened, on average in recent times. During the period from 1870 to 1940, only three of the seventeen El Ninos were two-year events but four out of the ten most recent events have lasted at least two years. During El Ninos, drought is common in Africa and Asia, and productivity in the North American prairies, from whence supplies could be directed to famine relief overseas, is usually lowered as a result of near-global teleconnected atmospheric pressure equalization tendencies (Nkemdirim 1996). Besides depleting global food reserves, greater duration of drought and other climatic stresses may well weaken trees, bushes and perennial plants, if they survive at all. Dry soil is susceptible to aeolian displacement and desertification processes are intensified.

In Canada, the fire season severity rating (SSR) is expected to increase almost 50% under doubled CO2 climate. Under warming conditions, the length of the fire season is expected to increase in both earlier spring starts and autumn finishes. The quantity of fuel available as a result of changed climate may vary thus affecting fire intensity and propensity to spread. In addition, if climate change has affected forest species composition and age distribution, average burn area will change (Flannigan and Wagner 1991). When areal extent of forest fire increases, the CO2 emissions from the rapid oxidation of timber release a large portion of the carbon stored above ground; normal decomposition would take decades and would also be staggered as trees of varying age passed maturity and were downed by wind, insect damage or senescence. If the Canadian forests are typical of the global figures for increased fire spread, not only will the localized pulses of carbon dioxide from burned forests increase atmospheric greenhouse gas concentrations but feedbacks involving climate zone displacement phenomena may also be affected. There is a pronounced asymmetry of risk in forest ecosystems in the sense that a forest area, where favorable conditions had maintained carbon sink function for centuries, can be devastated by one extreme year of environmental conditions while recovery takes decades. Kurz et al. point out that the warmer and drier forest limit is more vulnerable to catastrophic change since regeneration failure is more likely there than in areas well inside the biome boundary. One regeneration failure here may well reduce the forest extent permanently. However, expansion not only requires more time than contraction, it also demands more elements be in place. Viable seed sources, good soil tilth and fertility plus many years of favorable growing conditions are necessary for a new forest ecosystem to become established (Kurz et al. 1995). The aftereffects of human activities, principally logging, compound the challenge in many areas by reducing seed stocks and genetic diversity. As well, clearcutting often targets advance disjunct colonies that are vulnerable since access is easier (Davis 1989). One characteristic of a pro-sustainability Worldview choice might be legislation protecting vulnerable stands.

A carbon pulse from underwater slumping of methane is possible where melting of glaciers has reduced the weight of the water column that restrains them. In most areas, global warming processes will increase the restraint by deepening the deposits but shrinking of both the Greenland and Antarctic ice sheets in response to global warming may also destabilize gas hydrates. As ice sheets shrink, the weight removed from coastal regions allows them to recover and rise. This can also raise the adjacent continental slope, which reduces relative sea level. The resulting reduction in hydrostatic pressure could destabilize gas hydrates leading to massive slope failure. (Maslin 2004)

Feedbacks mean human actions are dwarfed by processes we set into motion

A major feedback, accounted for in all model projections of the progress of global warming, is usually referred to as the Sea Ice Albedo feedback. Researchers at the University of Bergen, Norway, have studied changes in global sea ice cover using two satellite systems' passive microwave sensors. They find the extent of Arctic sea ice has decreased 5.5% over the 16 year period from 1978-1994 although no trend was detected in the Antarctic (Bjoergo 1995). Such asymmetry is not new. Glomar Challenger's Deep Sea Drilling Program found the Antarctic troposphere was 18-20oC (today only 11oC) colder for about 10 million years preceding the Pleistocene era. During that period, the meteorological equator was shifted 9 -10oN whereas today on average it is 6oN (Bach 1984). In a global warming scenario, annual sea-ice formation is delayed, giving a pronounced warming in polar regions through temperature-albedo feedback. Less area of highly reflective sea-ice means greater surface heating, especially in summer (Mitchell et al. 1990). In a warmed ocean surface, dilute carbonic acid chemically breaks down into carbonate ion, water and carbon dioxide gas; elevated pCO_2 causes gas evasion which could amplify a future CO_2 increase by about 5% (Mackenzie 1995), increasing atmospheric CO_2 by about 1%/OC (Lashof 1989).

Another kind of feedback with the ability to move the warming beyond humanity's ability to restrain it involves the addition of radiatively active substances to the atmosphere from reservoirs where they have been previously sequestered. Some of the major feedbacks anticipated of this sort come from warmer environments meaning faster decomposition of organic matter which means release of potent greenhouse gases (Schlesinger 1995). There is about 25 times as much carbon biomass stored in terrestrial ecosystems as there is in the oceanic reservoir of living, particulate and dissolved organic carbon. Gaseous products of decomposition, such as CO_2 and NH_3, are released to the atmosphere where they add to greenhouse gas overloading (Mackenzie 1995). Once in the atmosphere, some of these breakdown molecules interact with hydroxyl (OH) radicals to produce nitrogen oxides (NO_x). NO_x are also directly produced by bacterial decomposition of organic matter in soils, a flux which warmer conditions are likely to intensify (Mackenzie 1995). In the presence of reactive nitrogen oxides, the greenhouse gas, ozone (O_3), is produced by the photo-oxidation of CO, CH_4 and non-methane hydrocarbons (NMHCs) (Watson et al. 1990). When NO_x concentrations are low (5-30 pptv), increases in concentrations of methane, carbon dioxide and NMHCs generally lead to a decrease in the concentration of tropospheric ozone. However, at the higher NO_x levels anticipated to be more frequent in a warming world, increases of the above trace gases will lead to more ozone production, a positive feedback onto radiative forcing (Mackenzie 1995).

Under present day conditions, most aggrading temperate forest ecosystems export less nitrogen than they receive from the atmosphere but increased decomposition rates under warming conditions could change this. In a warmer world, nitrogen availability will be the limiting factor for carbon storage in soils and vegetation unless drought, soil acidification, ozone pollution or some other stress increases to the point of surpassing it. The integrated ecosystem response to changed climate cannot be forecast at this time (Davidson 1995). Plants affected by CO2 fertilization, a negative feedback because of enhanced sink function, have increased biomass, particularly underground. However, the result is a high C:N ratio which generally reduces the speed of microbial decomposition and thus the gain of the positive feedbacks on temperature or moisture breakdown speed (Mooney and Koch 1994).

About 10% of the atmospheric carbon is absorbed by net primary production (NPP) of terrestrial plants each year. This is almost balanced by decay of organic matter, about 0.5-1% of which is anaerobically decomposed thus producing the more radiatively active CH4 rather than CO2. Because CH4 has a much larger global warming potential (raised to approximately 23 at the century mark after release in the third set of IPCC Reports (WG1 2001ts)) small shifts to anoxic conditions can have a substantial impact on the overall greenhouse forcing (Lashof 1989). Up to 20 years, the GWP of methane is rated at 62 so the short term heat-trapping effect is substantial for fueling feedback cycles. Both natural methane emissions and its removal from the atmosphere can be 'influenced substantially by climate change' (IPCC WG1 2001ts 42).

In a warmer climate, both the radiative cooling of the atmosphere and the radiative heating of the surface are greater so the increased temperature difference between top and bottom of the atmosphere amplifies the force driving convective transport. Since evaporation potential increases faster than temperature, the increase in vertical heat transport is more likely to be accomplished through latent heat thereby producing a marked increase in convective rainfall. A major result expected from these changes is an increased frequency of intense local rain storms which result in significant runoff volumes (Mitchell et al. 1990). Models project more extreme precipitation events are likely over many North Hemisphere mid- and high-latitude areas. "Mean and peak precipitation intensities from tropical cyclones are likely to increase appreciably." (IPCC WG1 2001ts 73) Where existing drainage systems cannot increase flow rates rapidly enough, greater area will be covered by standing water bodies such as bogs, marshes and ponds. (Lashof 1989)

Two factors come into play in increasing anaerobic respiration in a global warming scenario. The first is the direct temperature response of microbes whose metabolic processes speed up under warmer conditions and the second is an increase in the length of the emission season which amplifies total annual output (Lashof 1989). High latitude wetlands are more prone to becoming significant sources of CH4 under global warming conditions than low latitude wetlands because the ambient temperatures are low enough to make evaporation to the point of dry surface conditions unlikely. The Canadian North, with its vast area of flat topography underlain in many places by bedrock or permafrost will be particularly susceptible to wetland expansion. Methane output over the vast tundra areas could be a major positive feedback onto greenhouse warming (Watson et al. 1990).

Huge quantities of methane from pre-Tertiary decomposed vegetation underlie permafrost in the former Western Interior Basin which extended from the Gulf of Mexico, through Alberta, the Northwest Territories, the Arctic shelf of North America to Western Siberia. Gas hydrates are rigid cages of water molecules surrounding methane gas molecules which formed during major glacial events as gas from decaying organic material was trapped within and under the developing permafrost. Arctic gas hydrate is an extremely large potential source of atmospheric methane since there is at least 500 times as much as is in the modern troposphere. (Nisbet and Ingham 1995) "In permafrost regions the major influence is temperature, with regional temperatures experiencing increases and falls between cold glacial periods and the warmer interglacials. A current concern lies in the fact that temperature rises due to global warming are likely to be greater at higher latitudes, perhaps leading to the catastrophic release of gas hydrate methane from permafrost regions." (Maslin 2004 10) This can be a strong positive feedback once the release becomes widespread because of the huge quantities of methane stored under the permafrost.

Another major type of feedback expected involves changes to carbon sinks or sink process function. An intense search has been under way to identify the `missing sink' in the world carbon budget of perhaps 2 Pg year-1 (petagrams, or billion tonnes) of carbon, but its location and mechanism have proved elusive. Using new forest inventory data sets to estimate the carbon sink and the carbon pool of woody biomass in 55 countries that accounts for nearly all temperate or boreal forests and approximately half the world's total forest area, a 2003 study identified over half of the missing sink. In each country there was a net accumulation of biomass; together, the carbon sink of woody biomass was 0.88 Pg per year during the 1990s with estimated uncertainty from 0.71 to 1.1 Pg per year. This estimate would probably be even larger if carbon accumulation in soil and detritus were also accounted for, but they were unable to quantify that reservoir. The sink is twice that estimated for the woody biomass of these forests a decade ago due to the new study's higher estimates for tree growth throughout the region and decreased timber harvests in Russia. In contrast, the new data indicate a carbon pool that is smaller than earlier estimates because of improved data for Russia and Australia. (Liski et al. 2003) As the CO2 concentration of the atmosphere increases, ocean and land will take up a decreasing fraction of anthropogenic CO2 emissions. The net effect of land and ocean climate feedbacks as indicated by models is to further increase projected atmospheric CO2 concentrations, by reducing both the ocean and land uptake of CO2. (IPCC WG1 2001spm)

Current models consistently indicate that when the effects of climate change are considered, CO_2 uptake by oceans and land becomes smaller. (IPCC WG1 2001ts 51)

Atmospheric CO_2 is taken up by terrestrial ecosystems through several possible mechanisms, for example, land management, CO_2 fertilization (the enhancement of plant growth as a result of increased atmospheric CO_2 concentration) and increasing anthropogenic inputs of nitrogen compounds as fertilizer. This uptake is limited by the relatively small fraction of plant carbon that can enter long-term storage (wood and humus). The fraction of emitted CO_2 that can be taken up by the oceans and land is expected to decline with increasing CO_2 concentrations. Process-based models of the ocean and land carbon cycles (including representations of physical, chemical and biological processes) have been developed and evaluated against measurements pertinent to the natural carbon cycle. Such models have also been set up to mimic the human alterations to the carbon cycle and have been able to generate time-series of ocean and land carbon uptake that are broadly consistent with observed global trends.

Most land plants' metabolic rates are limited by CO_2 availability and enhanced atmospheric levels may assist that sink process. The exceptions are those which evidently evolved in the Cretaceous Period in response to the reduction in atmospheric CO_2 and thus have their photosynthetic rates saturated at current concentrations. The grasses of tropical savannas and crop species selectively bred from grasses, such as corn and sorghum, are in this group. Studies confirm that the C4 plants are not able to compete effectively with C3 species under enhanced CO_2 concentrations (Mooney and Koch 1994). Since C3 plants, comprising 95% of known species, show the greatest potential for responding to elevated CO_2 levels, on average globally, photosynthesis is likely to respond positively to increased CO_2 concentrations (Allen and Amthor 1995). This change would be a negative feedback onto CO_2 concentration increases, and thus, radiatively-forced warming, since more carbon would be sequestered in growing plant structures. The effect is not detected in older plants, whose shape and size have already been defined (Woodwell 1989). Forest gaps are predicted to infill faster under doubled

CO_2 but climax stands are limited by leaf area and moisture availability. The net result expected is an increase in average stand biomass but no change in its maximum (Lashof 1989). Furthermore, it may be that the CO_2 fertilization effect is only operative over the short term. Researchers have detected a pattern of acclimation stabilizing photosynthetic rates over long-term exposures (Allen and Amthor 1995). Since forests conduct about two-thirds of global photosynthesis, it is crucial to determine whether the CO_2 -fertilization effect will persist beyond a few growing seasons. If the additional carbon will be stored long-term in living plants, CO_2 fertilization can be a significant negative feedback on atmospheric CO_2 (Sannueza 1993). This effect is accounted for in most models. (Wullschleger et al. 1995)

The biosphere's response to global change will impact the atmospheric composition of the 21st century. The anticipated changes in climate (e.g., temperature, precipitation) and in chemistry will alter ecosystems and thus the "natural", background emissions of trace gases. There is accumulating evidence that increased N deposition (the result of NO_x and ammonia (NH_3) emissions) and elevated surface ozone (O_3) abundances have opposite influences on plant CO_2 uptake: O_3 (>40 ppb) inhibits CO_2 uptake; while N deposition enhances it up to a threshold, above which the effects are detrimental. In addition, the increased N availability from atmospheric deposition and direct fertilization accelerates the emission of nitrogen-containing trace gases (NO, N_2O and NH_3) and CH_4, as well as altering species diversity and biospheric functioning. These complex interactions represent a chemistry-biosphere feedback that may alter greenhouse forcing. IPCC WG1 (2001) A recent study has found the species alteration effect due to CO_2 enrichment is already present. The largest expanse of tropical forest on Earth, the Amazon covers about five percent of the Earth's land surface. The forest acts as a huge reservoir of stored carbon but a 20-year study has noted a change in species composition which they postulate is a result of CO_2 fertilization due to the increase in atmospheric concentration, particularly since the 1960s. Faster growth means big, fast growing species of trees probably have an advantage over smaller or slower growing trees. The problem could extend beyond loss of biodiversity to a future lack of slower growing trees, which produce denser wood and foliage. This species composition shift could eventually lead to a drop in the amount of carbon dioxide that the rainforest removes from the atmosphere. (ENS 2004b) This trend would mean the models would need revision of the factors input to simulate CO2 fertilization.

Data show an increase in the amplitude of the annual oscillation in the CO2 content of the atmosphere, reflecting the seasonal pattern of vegetative metabolism. This means the residual of the phase difference between gross production and total respiration of terrestrial ecosystems is growing larger. A global warming has the potential to raise the rate of respiration more than that of photosynthesis which means the trend will be to lesser amplitudes as greenhouse warming progresses (Woodwell 1989). If the annual peak continues to rise following the projected approximately exponential curve, a positive feedback from increased vegetative respiration being in operation already is suggested by the accelerated increase in the annual mean.

Soil carbon stocks are located in undecomposed litter on the soil surface and humic materials dispersed through the soil profile. On a global basis, the carbon pool in soils is estimated to have a mean residence time of 32 years. The large portion of this pool in the organic soils of tundra and boreal forest ecosystems, is predicted to experience dramatic changes from global warming over the next century. Since a significant portion of soil carbon is relatively labile, temperature increases may result in reduced soil carbon residence times, a positive feedback on atmospheric carbon overloading (Schlesinger 1995).

A huge category of potential feedbacks come from terrestrial climatic zone shifts caused by global warming. The total area capable of supporting forest ecosystems is expected to increase under greenhouse climates. Amelioration of climates in present-day tundra regions will probably represent the largest areal gain. If climate change occurs at a slow rate, forests are likely to persevere even though conditions become unfavorable for reproduction (Woodwell 1989). However, if the rate of environmental change is so high that plant distributions are altered radically, large areas of forest may be unable to adapt quickly enough (Watson et al. 1990). The net effect of northern forest migration polewards will in all probability be a positive feedback onto global warming and is included in estimates based on GCM results. The factors taken into account in this opinion are stand reduction at the warmer and drier margins of current forests, increased insect, disease and fire damage, and increased rates of soil and plant respiration (Woodwell 1995). Under conditions which have occurred in the past, centuries, sometimes even millennia, were required for the successful migrations of plants over the distances predicted to be necessary to accommodate the changes forecast for only decades by the mid-21st century. The upper range predicted for coming climate change may require adjustment at ten times the speed of the post-glacial migration. (Woodwell 1989)

Forest ecosystems are subject to disturbance in nature. All disturbances, whether fire, insect, windstorm or logging, transfer biomass carbon to soil and detritus carbon pools as well as to the atmosphere. The annual disturbance rate has a large effect on the forest's composition so that an increase in disturbance frequency means a larger proportion of young stands which have less biomass, therefore, less stored carbon. Sensitivity analyses show that if the probability of fire and the length of regeneration delay are increased, regional biomass storage decreases more than the effects of better growing conditions or CO_2 fertilization can offset. Moreover, the analyses do not take into account the contribution to regional carbon storage from soil or detritus pools (Kurz et al. 1995).

Changes anticipated as climate warms are progressive reductions of the northern boreal and temperate forests, positive feedbacks onto warming processes. Insect predators are predicted to migrate northwards also, as temperatures rise and forest distribution changes, thus expanding their habitat. In addition, the warm and dry conditions which lead to increased fire activity can also increase net host susceptibility to insects, both native species and those whose range is expanding due to more favorable climatic conditions. The infestations occurring in young forest stands are often different from those affecting older ones so it is difficult to predict the risk from insects if greater fire damage extent has resulted in a larger proportion of young stands. And global warming is expected to increase incrementally both average annual forest fire frequency and extent (Kurz et al. 1995).

In the far North, the warming has a dual effect as biome boundaries shift in response to changing climate. A warming of 2°C, very likely under most model outcomes, would shift most of the peatland regions of Canada, notably the vast Hudson Bay Lowland, from the zone of discontinuous, to the zone of sporadic, permafrost. This change would have impacts on the biogeochemistry and ecology in the regions affected. Over the long term, permafrost melting will have two opposing effects on the trace gas chemistry of peatlands. In areas where runoff leads to thermokarst erosion and gully formation, geochemical CO_2 production will increase while biogenic CH_4 emissions will decrease. In regions where thaw lakes form, decomposition releasing methane will be the dominant process only initially until plant succession establishes fens and bogs whose vegetation will sequester CO_2 from the atmosphere as peat and emit lesser amounts of CH_4 (Gorham 1995). Note that this long-term sink enhancement process is independent of the releases of ancient methane hydrate deposits mentioned earlier.

There is about 25 times as much carbon biomass stored in terrestrial ecosystems as in the oceanic (Mackenzie 1995) but they only fix about 80% as much CO_2 annually into organic matter (Smith 1995). Thus, primary marine productivity is a much shorter term carbon sink than terrestrial. Marine climatic zones are bounded by currents, coastlines, coral reefs, upwelling zones and ice cover; this combination of solid and moveable barriers makes for a different spatial organization under water where most of the inhabitants move freely over their 3-dimensional range. It is not an easy task for surface dwellers to study marine environments so data banks on marine ecosystems are less complete than on their terrestrial counterparts. The removal of the CO_2 burden added by human activities from the atmosphere takes far longer in natural oceanic sinks. This is because of processes that limit the rate at which ocean and terrestrial carbon stocks can increase. Anthropogenic CO_2 is taken up by the ocean because of its high solubility (caused by the nature of carbonate chemistry), but the rate of uptake is limited by the speed of vertical mixing. (IPCC WG1 2001ts)

> Watson Gregg, a NASA GSFC researcher and lead author of the study, finds that the oceans' net primary productivity (NPP) has declined more than 6 percent globally over the last two decades, possibly as a result of climatic changes. NPP is the rate at which plant cells take in CO2 during photosynthesis from sunlight, using the carbon for growth. ~ Goddard News 2003

Circulation pattern changes can affect the biological pump, the rain of small debris that sinks to the ocean deeps removing POC from potential contact with the atmosphere for millennia. Because of the biological pump's action, the deep ocean is oversaturated with dissolved CO2 relative to the thin surface layer which is in equilibrium with the atmosphere (Rowe and Baldauf 1995). The stability of the water column may increase as the result of the initial warming. This would lessen the export of organic carbon from the euphotic zone via the biological pump and be a positive feedback which could amplify future CO_2 by about 5%. But warming may also lead to changes in wind patterns and intensity along western coastal margins where nutrient upwelling would be enhanced. Since upwelling water transports carbon according to the Redfield C:N:P ratio of organic production of 106:16:1, all the carbon needed for production will be supplied by the upwelled waters and less atmospheric CO_2 will be drawn down, a regional positive feedback of indeterminate strength (Mackenzie 1995).

There is uncertainty about trends in annual mean cloudiness during this century and cloudiness changes are a continuing source of uncertainty in global warming scenarios. While European and North American land-based data show substantial increases, a major change made in the observing practice: from using decimal to using okta units in 1949, except in the U.S.A., Canada and the U.S.S.R., is possibly the cause of some unknown fraction of the recorded increase. A further complication is that, from 1940 onwards, the obscuring effect of dust, smoke, haze and fog were included in cloud cover reports.

Clouds are the primary modulators of absorption of solar energy by the Earth's surface and atmosphere. A four-year global record of solar flux, from surface, airborne and space vantage points, shows the radiation budgets of both surface and atmosphere may differ from those computed in GCMs by up to a factor of two (Li et al. 1995). The IPCC 2001 report states that the greatest uncertainty in projecting future climate remains the changing location and type or thickness of clouds as well as their interactions with radiation. Clouds absorb and reflect solar radiation cooling the surface as well as absorbing and re-emitting outgoing heat waves. The height of the clouds, their thickness and opacity as well as their radiative properties determine which effect predominates. Studies show the calculated ratio of the measured short-wavelength cloud radiative forcing at the Earth's surface over that at the TOA, is significantly larger than 1.0 in the tropics. This means that tropical clouds enhance atmospheric absorption over clear sky levels. Representing cloud formation and dissipation and assigning location and characteristics to them has been the focus of much modeling work and great progress has been made but the IPCC 2001 acknowledges it is still not possible to accurately simulate the effect of global warming on clouds and, therefore, the net feedback effect.

> The physical basis of cloud parameterizations is greatly improved in models through inclusion of bulk representation of cloud microphysical properties in a cloud water budget equation, although considerable uncertainty remains. Clouds represent a significant source of potential error in

> climate simulations. The possibility that models underestimate systematically solar absorption in clouds remains a controversial matter. The sign of the net cloud feedback is still a matter of uncertainty, and the various models exhibit a large spread. Further uncertainties arise from precipitation processes and the difficulty in correctly simulating the diurnal cycle and precipitation amounts and frequencies. (IPCC 2001ts)

As the atmosphere warms, it can hold more water vapour, so its total latent heat energy is increased. The saturation vapour pressure (SVP) of water increases (non-linearly) with temperature so that at higher temperatures, proportionately more of the gain in radiative heating of the surface increases evaporation rather than temperature (Mitchell et al. 1990). The evaporation rate is affected both by the difference between the SVP at the water surface and that of the air, and the availability of energy to the surface, which are both, on average, increased in a global warming scenario. Thirdly, and to a lesser extent, the evaporation rate depends on wind velocity since the imported air is likely to be less saturated (Barry and Chorley 1992). Although changes in instrumentation and natural variability may be factors, it appears ocean wind speeds have increased in recent decades, especially in the tropics (Wigley and Barnett 1990). If the evaporation rate accelerates as warming progresses, it is possible that the latent energy of the atmosphere will be increased by the feedback. Most models forecast increased precipitation year-round for the tropics under global warming conditions. As warmer air draws more moisture from surface sources, the tropical upper troposphere will warm more than the global mean due to the presence of more water vapour releasing its latent heat when adiabatic cooling turns it to liquid water (Mitchell et al. 1990). Water vapour feedback in climate models approximately doubles the warming expected with fixed water vapour (IPCC WG1 2001ts) so estimates of this effect are included in projections of future warming.

The dominant influence of the cryosphere comes from the high albedo of snow covered surfaces and sea ice (Cubasch and Cess 1990). Most model simulations suggest that north of 50ON, in the winter half of the year, warming will be enhanced due to feedbacks associated with sea-ice and snow cover as mentioned at the beginning of this discussion. Sea ice in the Arctic and around Antarctica responds directly to climate change and may, if properly monitored, become increasingly important for detecting accelerations of global warming.

> Although sea ice covers only about 5% of the Earth's surface, its extent and thickness have important influences in the coupled atmosphere-ocean system. Increasing the understanding of these processes and representing them more realistically in climate models is important for making more reliable climate change projections. (IPCC WG1 2001)

This is another important statement from the experts that computer climate change simulation modeling is not yet able to represent all factors that will strongly influence the progress of the warming.

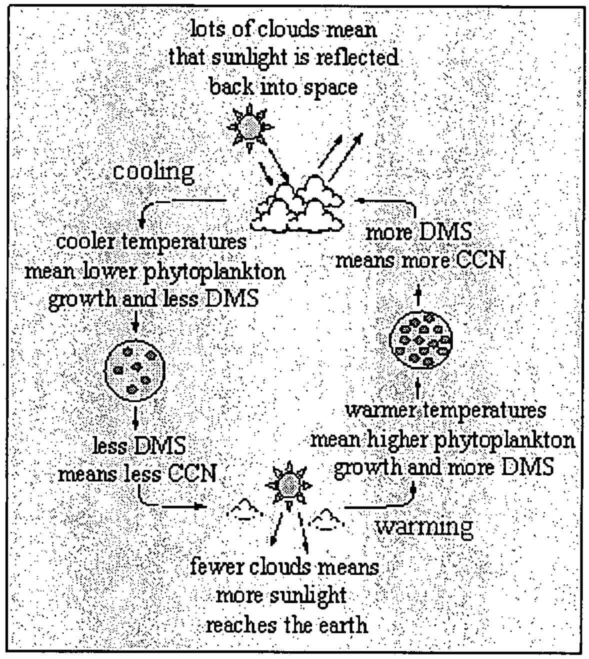
"The feedback mechanisms between soil moisture conditions and precipitation are particularly relevant to climate change studies since they may interact with, and determine the response to, larger-scale changes in atmospheric circulation, precipitation and soil moisture anomalies." (IPCC WG1 2001 7.4.3) Enhancement of surface warming is expected to result from the soil moisture temperature feedback in areas such as the northern mid-latitude continents where limits to evaporative processes are anticipated routinely. In this loop, warming leads to more evaporation until the surface becomes sufficiently dehydrated to restrict it. Then, since less heat is being absorbed in phase changes, more remains in the surficial elements further raising the temperature (Mitchell et al 1990). Since model projections show nearly all land areas warming more rapidly than the global mean surface rate (IPCC WG1 2001ts), this surface feedback will be continually intensified as the warming progresses.

The self-correcting forces in the planetary thermodynamic system, the negative feedbacks, are not as many or as strong as the positive ones. The major damping down processes discussed are the CO2 fertilization effect and the di-methyl sulfide plankton response called the CLAW hypothesis.

Most land plants' metabolic rates are limited by CO_2 availability. The exceptions are those which evidently evolved in the Cretaceous Period in response to the reduction in atmospheric CO_2 and thus have their photosynthetic rates saturated at current concentrations. The grasses of tropical savannas and crop species selectively bred from grasses, such as corn and sorghum, are in this group. Studies confirm that the C4 plants are not able to compete effectively with C3s under enhanced CO_2 concentrations (Mooney and Koch 1994). Since C3 plants, comprising 95% of known species, show the greatest potential for responding to elevated CO_2 levels, on average globally, photosynthesis is likely to respond positively to increased CO_2 concentrations (Allen and Amthor 1995). This change would be a negative feedback onto CO_2 concentration increases, and thus, radiatively-forced warming, since more carbon would be sequestered in growing plant structures. The effect is not detected in older plants, whose shape and size have already been defined (Woodwell 1989). Looking at CO_2 fertilization from the point of view as an aid to enhancing food security, Matthews et al. (1997) report that two process-based crop simulation models project that the positive effects of enhanced photosynthesis resulting from doubling of CO_2 are more than offset by increases in temperature greater than 2°C (IPCC WG2 2001)

Biogenic sulphur compounds arise from two separate processes. The first is anoxic and abiotic reduction of sulfates in places limited by slow oxygen diffusion, such as sediments, or in places where a density gradient prevents turbulent mixing from transporting oxygen in rapidly, as in stratified ponds. This prepares the reduced sulphur for assimilation by plants and marine algae which produce a variety of sulphur compounds. The main volatile compound produced by marine species is dimethylsulfide (DMS); in terrestrial environments, volatile reduction products from plants and soils include DMS, carbon disulfide and carbonyl sulfide. When DMS enters the atmosphere where oxygen is readily available, sulfate aerosol is produced by oxidization

(Andreae 1991). This sulfate is the predominant source of CCN in the remote marine atmosphere. The CLAW hypothesis (named after the authors Charlson, Lovelock, Andreae and Warren) postulates DMS abundance influences cloud albedo, which in turn influences the radiation budget, feeds back into climate and affects the organisms which produce DMS. (Charlson 1995) If operational on a sufficient scale, the loop would be a negative feedback tending to slow the warming.



(DMS stands for dimethyl sulphide and CCN for cloud condensation nuclei)

Figure 8: A simplified representation of the CLAW Hypothesis, an example of a negative climate feedback loop (Spokes 2003)

The feedbacks, generally speaking outside human control, in the global climate system are being incorporated into climate models as this becomes scientifically and technologically possible. There is a timetable whereby these advances can trickle down to regional-scale models and forecasts, the topic of Chapter 3. Moving from the global scale of Chapter 2 to the Georgia Basin regional scale, involves a move in time as well as space because the regional model results cited by the major studies for that geographical area incorporate projections from GCMs done earlier. This means recent advances in portraying feedbacks will be not have been available for the regional impact assessment teams.

The timing for individual feedback loops to become operational is dependent on the nature of the elements or processes in the particular loop so some may already appear to be in operation while others may be a fairly sure but temporally distant threat. If one were devising appropriate output displays for at least the two QUEST worldview choices, probably feedbacks would be well down on the list of choices because they become critical so far in the future. But they might be helpful in the cases where the user had made consistently extreme choices in constructing his/her scenario. Those choices might signal a preference for information of a more pronounced sort and a feedback relating to forest impacts as climate change progresses might suit one scenario whereas the broad principles involved in the sea/ice/albedo might be more appropriate for a scenario with middle-of-the-road choices. However, the regional impacts that appear in Chapter 3 are much more likely to be the best choices since only a small amount of information can be shown on a single computer screen display. The ideal output would probably allow the user to click on an icon and get more detailed information of interest to him or her.

Chapter 3: Regional results of the global problem in the Georgia Basin

The Canada Country Study released in 1997 covered the Canadian portion of the Georgia Basin as part of the British Columbia & Yukon regional assessment. In 1999, the Climate Impacts Group (CIG) at the University of Washington released a similar report called Impacts of Climate Variability and Change: Pacific Northwest as part of the U.S. Global Change Research Program which covered the American side of the basin along with areas South and East of it. Both reports focused on bridging the natural science aspects of global climate change resulting initially from human activities amplifying the atmospheric 'greenhouse effect' and the need to make policy choices individually and collectively to reduce emissions while adapting to inevitable impacts.

There is no peer review process of the usual kind found in academic or professional journals for these first regional assessments but they have drawn on the best government and university personnel as the initiative to respond to the challenges began. As more studies are done and more benchmarks extrapolated creatively from natural records such as tree rings, lake sediments, etc., greater confidence will emerge in the pictures being painted of regional expectations for global warming/climate change and its consequences. However, the dominant theme is that the region, climactically, is in the grip of hemispherical scale rhythms governed by the laws of physics. Once the planetary system lost its thermal balance, the transfer of the excess heat from air to and from ocean and land reservoirs set up a continual change framework. Precise prediction of unprecedented events is impossible. We work with the best available information and, at the regional scale, there has been some allocation of research funds at least in the USA so there will be more and more studies to rely on as time goes by.

Climate is operationally defined in Canada by 30-year time series of average and extreme, daily and annual, temperature, precipitation, wind and cloud cover available for many locations from the Environment Canada archives (e.g. PFC 2002). However, recent analyses of apparently cyclical processes appear to suggest a dominant cycle of about that length, now referred to as the PDO or Pacific Decadal Oscillation (Mantua 2000) so perhaps a longer time series would be more meaningful in pinpointing climatic changes. Researchers are reconstructing the longer term norms as well as unusual extremes from proxy records, and meteorological observations, made for more than a century, are now being used for longer analyses since it is impossible to identify a change unless one knows what the status quo is or was. With climate, it may depend on the definition of the word (usually based on length of time to define 'normal' climate for the area) and the precise identification of the type of change may be irrelevant to all but researchers. What most people care about is changes in valued resources – notably, productive soils, abundant fresh water, healthy forests, sustainable ocean/ freshwater ecosystems that support fisheries and, of course, some other assets not overtly addressed in QUEST categories.

Past climate regime and long-term climate norms

The 1999 CIG report identifies recurring patterns that describe much of the climate history of the Pacific Northwest, a region which contains the Georgia Basin geographically and climatologically although the QUEST mapped area is truncated at the international border on the South and about 100 miles inland. The climate in the Georgia Basin strongly resembles the area west of the Cascades south of the international border which the CIG describes as having a maritime climate with abundant winter rains, dry summers and mild temperatures year round so that snow seldom stays on the ground for more than a few days at sea level. Mainland climate in the low-lying valleys west of the mountains is characterized by mild year-round temperatures, abundant winter rains, and dry summers. Average annual precipitation in most places west of the Cascades is more than 30 inches (75 cm). Precipitation in the mountains is much higher. (Mote et al. 1999)

Pacific Northwest (PNW) climate and ecology are largely shaped by the interactions that occur between seasonally varying atmospheric circulation (i.e., weather) patterns and the region's mountain ranges. These seasonal variations are related to changes in large-scale atmospheric circulation occurring over the Pacific Ocean, including the Gulf of Alaska. The strongest climatic pattern CIG notes for the PNW is the tendency for winters to be either relatively cool and wet, or relatively warm and dry. Approximately two-thirds of the region's precipitation occurs in just half the year (October-March) when the PNW is on the receiving end of the Pacific storm track. Much of this precipitation is captured in the region's mountains, influencing both natural and human systems throughout the region. From late spring to early fall, high pressure to the west generally keeps the Northwest fairly dry. (MOTE ET AL.. 1999)

Two oscillatory patterns have been proposed to explain the observed variability in the climatic pattern. On the year-to-year timescale, ENSO (El Nino / Southern Oscillation) is the predominant influence but there also seems to be another oscillation in operation on longer, decadal, timescales overlaying the shorter cycle. Mantua et al. (1997) demonstrated a strong connection between salmon abundance and a North Pacific climate variation that they named the Pacific Decadal Oscillation (PDO). During its warm phase, the PDO shows as a cooling in the North Pacific accompanied by a warming in the equatorial Pacific similar to that found in El Nino, the warm phase of ENSO. El Niño winters tend to be warmer and drier than average with below normal snowpack and streamflow. Under La Niña conditions, the reverse to El Nino in the equatorial ENSO indicators, winters in the Pacific Northwest tend to be cooler and wetter than average with above normal snowpack and streamflow. These two oscillations may reinforce each other giving rise to extremes ("in phase" with each other) or cancel each other so effects are diminished. (Mote et al. 1999)

Together they determine the latitudinal patterns of atmospheric circulation that bring Pacific moisture into the Georgia Basin region. During winters when an El Nino event occurs in the tropics or the PDO is in its warm phase, the low-pressure area off Alaska known as the Aleutian Low tends to deepen, i.e. to have lower barometric pressure than at other times. When the Aleutian Low is deeper than usual, the mid-latitude storm track, the typical path of storms moving eastward across the continent, bifurcates around the Northwest. One branch brings storms to Alaska and the other to California leaving the PNW with a slightly warmer and drier winter than otherwise. (Mote et al. 1999) During the 20th century, the ENSO pattern appeared to be shift towards having more warm events, El Ninos. (Watson et al. 2001)

However, it must be kept in mind that both the ENSO and PDO are theoretical constructs postulated to explain observed inter-annual variations. Since the period of the PDO cycle is longer and reliable records are not available for the North Pacific before about 1900, only about two complete cycles have been postulated. The cool phase years were approximately 1900 to 1925 and 1945 to 1977 and the warm phase years were 1925 to 1945 and after 1977. It is as yet impossible to determine if a phase change occurred in the mid-1990s. (Mote et al. 1999) The PDO signature has been sought in proxy climate records such as tree rings dating back into the 1600s but it does not show such a clear regular set of phase changes in earlier centuries as it seems to have done in the 20th (Gedalof et al. 2002). And even the oscillatory nature of the postulated patterns is not certain. Kessler (2002) suggested convincingly that El Ninos are event-like disturbances to a stable base state rather than self-perpetuating cycles since the effects of the extremes of the cycle have dissipated by the time the changes they have been presumed to cause actually start to be observed.

We are dealing with an imperfect understanding of our environment in a time when it seems the human influence on the atmosphere may be causing changes in the long-term normals. We need an assessment of the situation in order to formulate reasonable responses and prudent policies to mitigate any damage we may have engendered. Since there are so many fewer of the longer PDO cycles and what research has been done has not found the 20th century pattern persisting through the 19th, natural variability in the region may have a wider range than previously thought. Our current knowledge of the past climate variations in the Georgia Basin shows they have been wide enough that it is possible that none of the next forty years will show a significant departure from climatic 'normal' conditions of the late 20th century, primarily due to the moderating influence of the ocean in a maritime climate. In the PNW region as a whole, cool-wet winters are generally associated with increased risk of flooding, abundant summer water supply, more abundant salmon, reduced risk of forest fires and faster tree growth. Warm-dry winters may be followed by summer water shortages, less abundant salmon and greater risk of forest fires (Mote et al.., 1999). Since the Georgia Basin region is only similar to the coastal regions of the American PNW, water shortages and forest fire risk may be less variable in the Pacific Maritime rain forest ecozone (CCEA 2004). However, it is important to be aware that summary climate descriptions or statistics can be identical in years when there are immense differences in benefits or damages to features society prizes or life- or livelihood-threatening weather events.

Changes observed in the last century

> Region-wide warming of about 1.5°F (0.8°C) in 100 years. The warming has been fairly uniform and widespread, with little difference between warming rates at urban and rural weather monitoring stations. Only a handful of locations recorded cooling. Although the warmest year was 1934, the warmest decade was the 1990s. Largest increases occurred during winter.
>
> (Mote 2003)

As noted in Chapter 2, average global temperatures are rising and the 20th century was the warmest the world has seen in 1,000 years. In British Columbia, according to Environment Canada records, average annual temperatures warmed during the 20th century by 0.6°C on the coast including the Georgia Basin, 1.1°C in the interior, and 1.7°C in the north. Average spring and nighttime temperatures in particular are now warmer than they were 100 years ago. Precipitation increased by 2 to 4 percent per decade in southern British Columbia. Climate models project that the greenhouse gases already in the atmosphere will continue to change climate continuously for centuries to come. By the end of the 21st century, average temperatures in British Columbia will likely be 1°C to 4°C warmer than now. (NRC 2004b)

The graphics from CSES (2004 below) are quite clear on the areal distribution of recorded changes between 1920 and 2000: large lighter grey dots (red colored in the original), indicating increases of 1.5°C, cluster around the southern end of the Georgia Strait in both Canada and the USA.

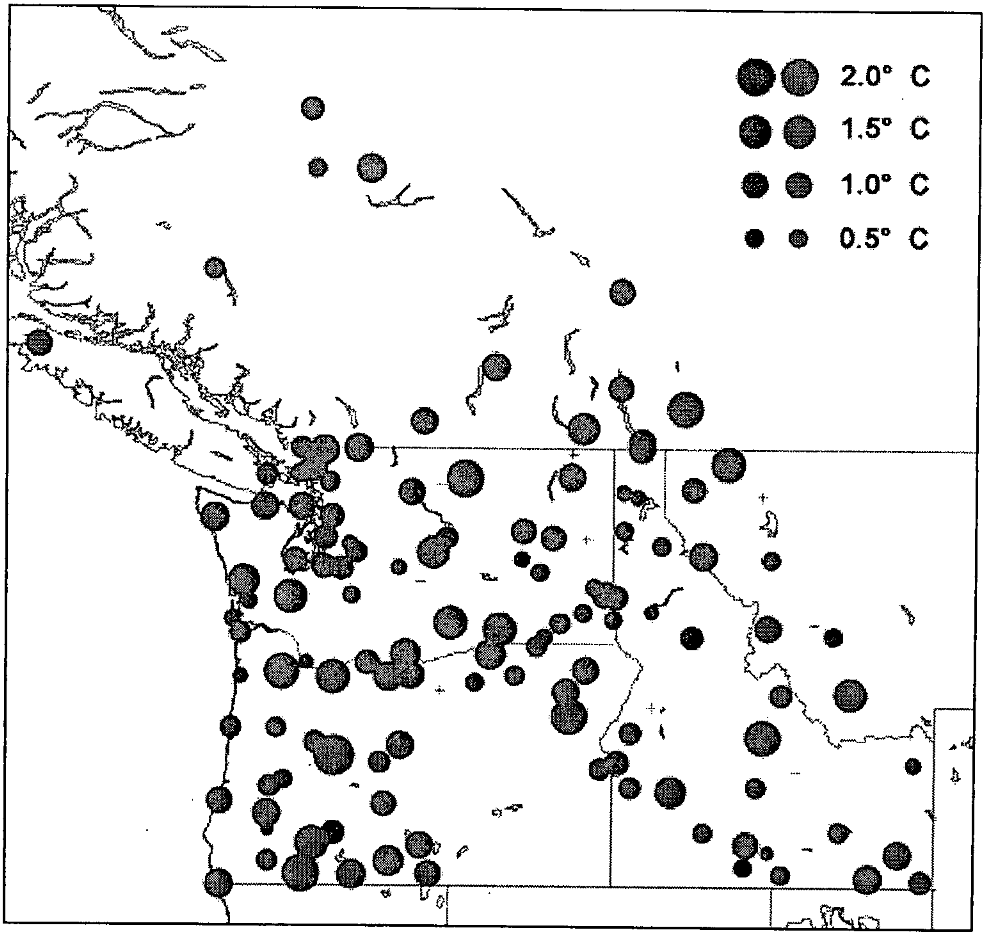


Figure 9: Temperature trends (1920 – 2000) from CSES 2004

Over the 20th century, the temperature trend of +0.82°C is statistically significant at the 99% level for the agglomerated PNW region of Washington, Idaho and Oregon.. However, some of the trend is explained by the PDO since the century began in the cool/wet phase and most of the last 20 years were in the warm/dry phase.

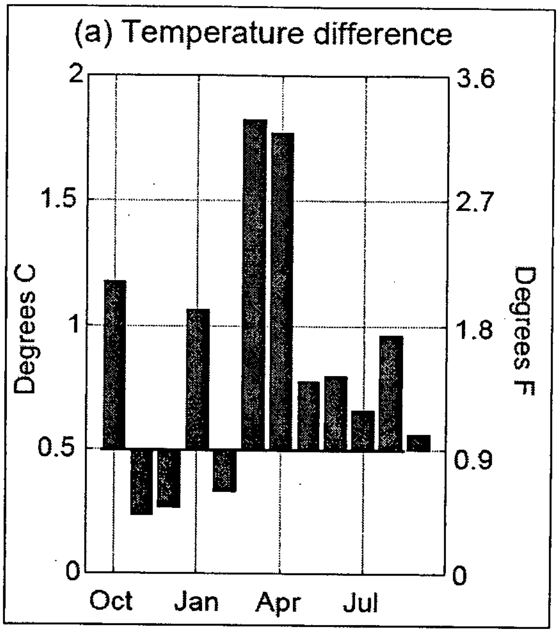
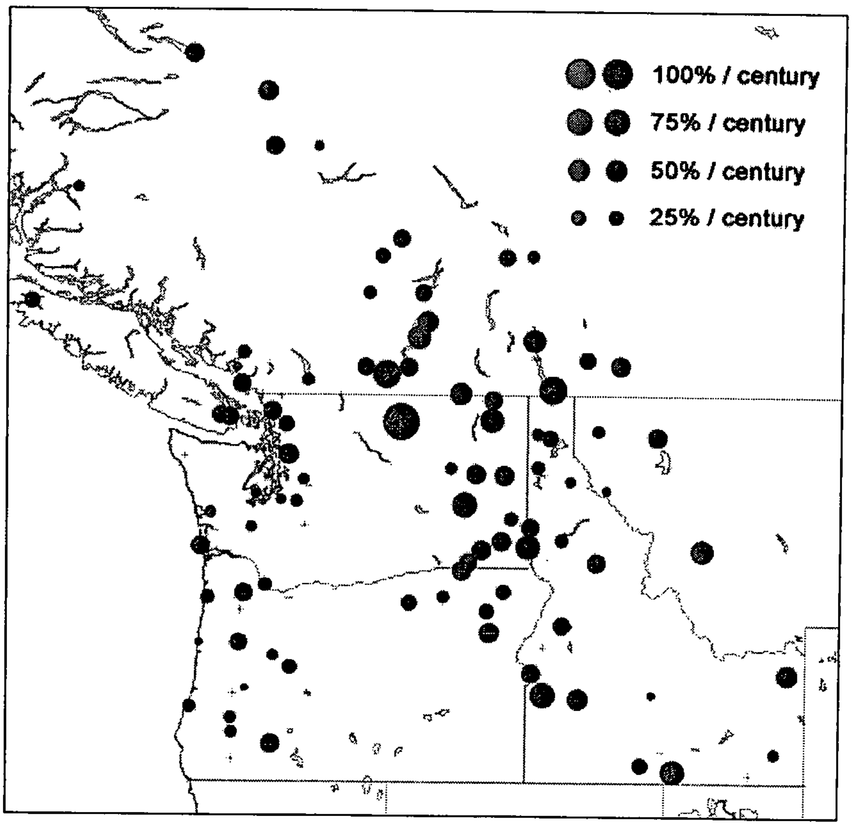


Figure 10: Temperature Difference (CSES 2004)

The graph above, a composite of monthly temperatures from 1931 to 1999, shows that the largest increases were in March and April during the warm PDO phases compared with the cool phases. August, October and January also showed substantial (about 1°C) differences. This then sets out a range for natural variability for a 60-year period. With that sense of scale in mind, the estimates of temperature 'change' are put in perspective. Using statistical regression to remove the PDO influence from the temperature data at each station, the resulting trend is +0.64°C which is slightly greater than the global average trend of 0.5°C for the 20th century. This is consistent with GCM projections that usually show greater changes as one moves polewards. Summer and winter trends in the PNW were nearly equal. (Mote et al. 1999)

The Canada Country Study shows a warming of 0.4°C along coastal BC during the 20th century but cautions it does not appear to be statistically significant. Along the coast of British Columbia there has been a gradual increase of annual average temperatures of 0.4°C over the last century (Taylor 1997 15)

The literature shows agreement on an increase during the past century in precipitation. In the Canada Country Study, Hengeveld (1997) says coastal BC regions appear to show slightly increasing precipitation over the past 50 years. And Mote et al. (1999) say the linear trend in precipitation was +7.11cm/century (an increase of 14%) although the pattern of PDO phases would have led to a negative trend by itself. The University of Washington Center for Science in the Earth System Climate Impact Group website map shows most areas around Georgia Strait with a trend over the 1920 to 2000 period to more (blue dots in the original – darker dots when printed in black and white) annual precipitation levels and even more increases in upslope precipitation in the interior mountain ranges where the major rivers which empty into the Georgia Basin start.



[15] In chapter 19-2, he attributes this value to Gullett et al. 1992

Figure 11: Precipitation Trends (1920 -2000) CSES 2004

Heavy or 'extreme' precipitation events are defined as those in the upper or lower ten percentiles of the precipitation distribution for a region. New analyses show that in regions where total precipitation has increased, there has usually been even more pronounced increases in heavy and extreme precipitation events. In some regions, however, heavy and extreme events have increased despite the fact that total precipitation has decreased or remained constant. This is attributed to a decrease in the frequency of precipitation events. Overall, it is likely that for many mid- and high latitude areas, primarily in the Northern Hemisphere, statistically significant increases have occurred in the proportion of total annual precipitation derived from heavy and extreme precipitation events; it is likely that, on average there has been a 2 to 4% increase in the frequency of heavy precipitation events over the latter half of the 20th century. (Watson et al. 2001)

Changes that are fairly sure for the QUEST study period and impacts expected

> Increasing temperatures will lead to changes in many aspects of weather, such as wind patterns, the amount and type of precipitation, and the types and frequency of severe weather events that may be expected to occur. Such climate change could have far-reaching and/or unpredictable environmental, social and economic consequences. (Environment Canada 2004)

To communicate the range of impacts anticipated for Canada, the country study drew together 26 component reports covering six regions of Canada including the BC/Yukon region which contains the Canadian portion of the Georgia Basin. It covered 20 sectoral and related issues of socio-economic significance to describe the effects that global warming and climate change might have. The report concluded that there could be significant impacts on British Columbia and Yukon, including increased flood dangers in some areas, drought in others, and widespread disruption to forests, fisheries, and wildlife. The Georgia Basin with its moderate maritime climate is less directly affected by changes than many other regions but the economic base for the region extends throughout the province into areas that are directly affected. They also noted the indirect effects, of projected changes in the occurrence and severity of extreme events, which would have "serious implications for the security and integrity of Canada's natural resources, social systems, and infrastructure with subsequent implications for the insurance industry and supporting public sectors" (NRC 2004a).

Canadian climate change projections suggest that over the next century, further warming of 1° to 3.5° C will occur. Based on this scenario, the Canada Country Study found that the implications of climate change for water resources are a key to defining overall impacts for all sectors and regions of the country. (NRC 2004b) Putting that rate of change in perspective, 9000 years ago, average temperatures in southern British Columbia were 1° to 2°C warmer than today (NRC 2004b). But the impacts potential of 2°C change in average temperature over thousands of years is quite different than over one hundred years even if the change is mostly that lowest cold-seasons temperatures become more moderate. As we have seen in recent years, even that kind of change can be devastating for valued resources as mountain pine beetle populations have burgeoned and extended their range well beyond historic limits with profound impacts for timber harvest dependent communities. (COFI 2003)

In general terms, climate models agree that there will be substantial increases in PNW temperature in the forty-year period the GBFP covers but the decadal average of precipitation is forecast to be in the range of the last century (Mote et al. 1999). Global climate models scaled to the PNW project an increase in average PNW temperature on the order of 0.3°- 1°F (0.166 – 0.55°C) per decade throughout the 21st century. Changes in annual precipitation are less certain. Increases in winter (October-March) precipitation range from 0-20% by mid-century. Changes in April-September precipitation are uncertain; a decrease in June-August precipitation is considered possible. (Mote et al. 1999)

The ENSO and PDO states have important impacts on PNW climate and natural resources on seasonal to inter-annual scales. Researchers say it is not clear how climate change will affect ENSO and PDO given the difficulty of simulating these patterns in complex global circulation models. The Intergovernmental Panel on Climate Change (IPCC) concluded in the Third Assessment Report that "little change or a small increase in the amplitude for El Niño events" is projected by climate models over the next century as a result of climate change (Watson 2001 16) while at the same time noting a steady shift towards more El Ninos as ENSO maxima. In fact, climate models offer disparate views of future changes, with some indicating that El Niño will be more frequent in the future, others that it will be less frequent, and still others that it won't change. (Mote et al. 1999) "Even with little or no change in El Niño amplitude, global warming is likely to lead to greater extremes of drying and heavy rainfall and increase the risk of droughts and floods that occur with El Niño events in many different regions." (Watson et al. 2001 16).

The severity of impacts of climate variability and change often depend on seasonal values so annual averages may not be useful statistics for those considerations. The coldest year (1916) in the 1900-97 period had an average temperature 3.4°C below the warmest (1934). Precipitation in the region was even more variable. The wettest year (1996) was almost twice as wet as the driest (1929). For example, a year with normal average precipitation may be a year with an exceptionally dry summer if winter precipitation was well above the long-term mean. (Mote et al. 1999) CIG looked at two generations of GCM output and produced regional climate scenarios with a regional climate model, PNNL-RCM. The newer (1998) generation models included more elaborate models of ocean, sea ice and land surface processes than the older (1995) generation. In addition, the emission scenarios in the newer generation also included changes in sulphate aerosols. These computer models forecasting climate change over the next 40 years generally agree that the PNW will become gradually warmer and wetter and that the greatest precipitation increase will come in the winter season. This prediction mostly agrees with changes observed over the last century.

Less snowpack at moderate elevations in response to warmer winter temperatures would have enormous, and mostly negative, impacts on PNW water resources, forests and salmon. A diminished ability to store water in reservoirs for summer use, more drought-stressed trees and a consequent reduction in forested areas, and spawning and rearing difficulties for salmon are specific outcomes anticipated. A slight increase in precipitation during warm-dry summers is also anticipated but this would be more than offset by losses due to increased evaporation (Mote et al. 1999). Again, certain of these impacts may not be seen in the Georgia Basin since the PNW includes the areas east of the Cascade Range in the United States, an area with a dissimilar climate.

The most remarkable commonality of the GCM model output CIG studied was the lack of seasonality in modeled PNW regional temperature changes. Usually, for midlatitudes, GCMs show winter temperatures rise more than summer. The average temperature increase over the group of models used was 1.74°C for the 2020s and 2.92°C for the 2050s. Similarly, average annual precipitation, expected to increase about 5% by the decade of the 2020s and remain at that level until the 2050s. Average precipitation decreases for the warm half of the year averaged 0.69cm for the 2020s and 1.14cm for the 2050s. Average increases for the cool half were 3.99cm for the 2020s and 3.43 for the 2050s. The models were generally in agreement that future winters will be warmer and wetter but were divided on the question of whether summers would be wetter or drier. (Mote et al. 1999)

In the two new generation models the CIG studied, a deepening and southward shift of the Aleutian Low was noted which led to a "dramatic" change in the atmospheric circulation over the Pacific towards the end of the century. This resulted in displacement of the winter storm track southward and a tendency to stronger winds as was observed during strong El Nino events like those of 1982-83 and 1997-98. Warm, wet winter storms were likely to occur much more commonly by 2100. (Mote et al. 1999 20)

One area CIG identified as remaining uncertain despite advances in GCMs was the future behaviour of the PDO. Although progress has been made towards representing ENSO, the longer-period variations of the observed character and magnitude remain elusive. "Even if climate models demonstrated an ability to faithfully generate natural climate variability (like that observed in the 20th century), their ability to predict how ENSO and PDO might change in a warming world would still be in question." (Mote et al. 1999 24) There is the possibility of abrupt changes in the cycling of these oscillatory patterns. In one model, the magnitude of the ENSO increases abruptly at a future point. In another, the PDO increases dramatically in amplitude. In a third, the PDO amplitude stays about the same but the mean state drifted towards a permanent warm phase. The CIG notes the suddenness with which climate changes can occur, citing the mostly natural global warming of the 1930s. (Mote et al. 1999)

Results from the first General circulation model (GCM) simulation for the region of Western Canada, comprising BC, Alberta, Saskatchewan and Manitoba, were released in 1998. The study used the Canadian Regional Climate Model (CRCM), nested within the Canadian Global Climate Model, GCMII, simulated data as lateral boundary conditions, to run two five-year integrations for conditions corresponding to current and double current CO2 scenarios (Laprise et al. 1998). Regional climate models of this type which "regionalize or downscale GCM simulations" are affordable simulations at a finer spatial resolution which are intended to address the needs of climate impact researchers and planners in agriculture, forestry, ecology and other climate-sensitive fields. The more detailed topographical representation in regional climate models results in a more accurate treatment of moist processes in general, and precipitation in particular. (Laprise et al. 1998) However, the scale is still not fine enough to capture local details in the Georgia Basin region such as the Vancouver Island ridge (Laprise et al. 1998).

The inaugural report on the regional model compares its resultant climate with that generated by GCMII. One major difference shown in the regional model is a 1oC lower value for the minimum warming expected to occur off Vancouver Island (Laprise et al. 1998). Another difference is the increase in winter precipitation anticipated over the western slopes of steep topographical areas in south-western BC. Although the GCM predicted marked increases of 3+mm/day, the regional model showed increases exceeding 6 mm/day in this type of terrain so common in the Georgia Basin.

The CIG also used a regional model for the PNW. They used boundary conditions taken from a transient GCM that had CO2 concentrations increasing at 1% per year from 1990 values to twice that (by about 2060). The control run output was closer to observed climate data for the PNW than the global models but it was still about 20% too wet and 1.5°C too cold in winter. In summer, it was about 50% too dry and 1.1°C too warm. Laprise et al. caution that, "the validation of the regional climate simulated by the CRCM is hampered by the lack of available climatologies at comparable spatial scales. Global climatologies used to validate GCMs are typically of too coarse resolution to be useful to validate RCM simulations. Station climatologies exist, but there is always a question regarding the representativeness of such point observations. Finally some field campaigns provide high-resolution data fields for some regions, but only for periods too short to derive climatologies." (1998 130)

The CIG climate change scenario, at about double present day CO2 concentrations, showed increased precipitation in the cool half of the year and slight decreases in the warm. They note that only the spring precipitation signal (about 30% increase) was statistically significant. This time of year showed both a change in the large-scale circulation and an increase in water vapour which together enhanced the moisture convergence towards the north Pacific coast. The simulation produced annually averaged surface temperature increases of about 2.2°C where the warming was 1.15 – 1.2°C greater during the cool season than during the warm. The combined effects of temperature and precipitation changes caused a significant reduction in the regional snow pack, about 50% over the Cascades range. (Mote et al. 1999)

Forests

The climate in the coastal regions are projected to become warmer and wetter resulting in the upward elevation movement of forest species ranges and reduction of the alpine and montane ecosystems (Hebda 1997). Risks due to pests, both local and exotic, and fire hazard are expected to increase. Forests at the southern or lower elevation limits of their range are at most risk as the climate changes. These forests are likely to be come more stressed due to changes in temperature and precipitation patterns and, therefore, less able to fend off attack from pests that currently exist in their ecosystem. A longer fire season is also possible. (Spittlehouse, 1997)

The CIG in Washington State reports that they have examined the effects of the PDO on forest growth and on forest fire activity. They concluded that climate variations associated with the PDO affect Pacific Northwest forests both directly and indirectly but they found no discernible effect of the short-lived ENSO maxima. Forests closer to their physiological limits and, therefore, more prone to stress were examined for inter-annual variation. These border stands, at upper (cold) or lower (dry and/or hot) timberlines, were considered most likely to show strong direct effects of climatic variation on tree growth. At upper timberline, tree ring analyses showed that mountain hemlock growth correlates well with climatic variations associated with the PDO. This correlation occurs because the cool phase of the PDO tends to result in greater snowpack, a limiting factor for growth at upper timberline. At lower treeline, forests are in severe competition for water with grasses and shrubs. The extended periods of drought associated with the warm phase of the PDO intensify this competition, limiting growth rates for ponderosa pine near the lower timberline. (Mote et al. 1999)

Another change in forest composition may come from direct CO2 fertilization effects. Many studies have been done in various locations world wide, by isolating small plots in forests and artificially enriching their atmosphere to see what differences the test trees have from the nearby 'controls.' However, it was a study documenting the effects of clearing the rainforest that released a report recently on a large-scale change. A 'control' group of trees in a 120-square mile area far from human activities that had been under observation for 20 years, showed changes in forest dynamics and species composition with no other apparent cause than increased atmospheric CO2. The lead author of the study, said, "It is a little scary to realize that seemingly pristine forests can change so quickly and dramatically." The most likely reason for these changes was that rising CO2 levels are fertilizing the forests, leading to faster growth and more competition among trees for light, water, and soil nutrients. Under these conditions, big, fast growing species of trees probably have an advantage over smaller trees and slower growing trees. (ENS 2004d)

Indirect impacts of climate change include effects on the abundance of other members of forest ecosystems besides trees. In the Interior of British Columbia, since 1994, the population of the indigenous mountain pine beetle has spread to 'epidemic' (COFI 2003) proportions. From 322,500ha known to be infected over endemic levels in 1995, the area affected grew to over 10 million hectares in 2003 because, since 1994, mild winters have decreased the winter mortality rate of beetle larvae from the usual 80 per cent to less than 10 percent. Complicating the effect of reduced winter mortality were two successive hot dry summers in the late 90s in the early stages of the outbreak, and the hot summer of 2003. These seasons put pine stands under drought stress, making them less resistant to beetle attack, thus accelerating the spread. Late in 2001, when the volume of harvestable timber killed by beetles was about equal to the amount harvested province-wide annually, the provincial government declared a state of emergency and a task force set up to focus on dealing with the crisis. By 2003, the volume was about 3½ times the interior's annual harvest level. (COFI 2003) and last winter's temperatures were not sufficiently cold at the times when the spread could have been set back.

The affected area is outside the Georgia Basin and the species targeted by this particular insect is not a common lumber resource in the coastal region but this does not diminish the scale of impact for the economy of the coastal region where the exported timber and timber products are transshipped. In tandem, affected logging-based communities must adapt as uses and markets are hastily found for the blue-stained timber from beetle ravaged trees, and also step up logging to isolate infected areas in an attempt to slow the spread. Once that initial concentrated response phase is over, they are left with a forest landscape where debris must be cleared to avoid accelerating forest fires and the natural cycle of succesional species must start anew. If nothing intervenes, after 50 to 80 years logging can resume. (COFI 2003) The deaths from beetle attacks mean the economic base of many Interior forest communities has been dramatically changed for at least two generations so displaced families may migrate to the urban centres in the Georgia Basin.

Fisheries

> There are seven species of salmon in the PNW region ... with a total of 36 substantially isolated breeding populations, or evolutionarily significant units (ESUs). Each of these ESUs has developed a distinct migratory rhythm, giving it a somewhat different sensitivity to climate variations at different stages of life. Today, wild populations of PNW salmon are at historically low numbers, with many ESU's now listed as either Threatened or Endangered under the U.S. Federal Endangered Species Act. (Mote et al. 1999)

Climate variability plays a large role in driving fluctuations in salmon abundance by influencing their physical environment, the availability of food, the competitors for that food, and the predators that prey on small salmon. Researchers say it is challenging to identify the links between salmon and climate because of the complexity of influences on salmon, both climatic and otherwise, and because of the scarcity of observations of factors important to salmon in estuaries and the ocean. However, Pacific salmon living in cool ocean waters. Southern British Columbia are near the southern limit of their range. Warming of the North Pacific could force salmon northward, reducing their numbers in rivers in southern British Columbia. Warm-water fish, such as tuna and mackerel, may take their place. Mackerel, a warm-water fish species, has been found in recent years in the waters off Vancouver Island. There is concern that mackerel may eat young salmon, further depleting stocks. A warmer climate also poses problems for salmon as they swim upriver to spawn. Salmon stop eating and rely on stored fat when they enter fresh water for the swim upstream. Salmon are cold-blooded so their metabolic rate is tied to the temperature of the surrounding water. If the water is too warm, salmon use up their energy stores and are unable to reach their spawning grounds. Warmer waters also increase the risk of bacterial and fungal infections in salmon. (NRC 2004c)

The average summer temperature of the Fraser River increased by 1.1°C over the past 50 years. Salmon are extremely sensitive to temperatures warmer than 7oC which can deplete their energy reserves, and make them more vulnerable to stress, infection, and disease. If summer river temperatures continue to rise, fewer fish may make it to their spawning grounds, and some salmon populations may be at risk. (NRC 2004b)

Warm phase PDO is associated with reduced abundance of coho and chinook salmon in the Pacific Northwest (PNW), while cool phase PDO is linked to above average abundance of these fish. A diverse set of climatic factors helps determine salmon abundance. Warm phase PDO means conditions, which are predominantly unfavorable for chinook and coho salmon. Warm ocean marine habitat and warm stream and estuary conditions that could cause thermal barriers to adult salmon upstream migration and stress for resident juveniles are typical warm phase negative impacts. However, reduced spring and summer river flow, which could make river-flow barriers less likely, promotes salmon abundance. Although ENSO extremes have climatic effects that are similar to PDO states, ENSO varies during the salmon life cycle and its effects are consequently more spread out than those of the more persistent PDO. (Mote et al. 1999)

The potential for changes in many of the key marine environmental factors related to human caused climate change are considered highly uncertain. For the factors researchers simulate with some confidence, the prospects for many PNW salmon stocks look "bleak". The general picture of increased winter flooding and decreased summer and fall streamflows, along with elevated warm season stream and estuary temperatures would be especially challenging for in-stream and estuarine salmon habitat in the PNW. These changes will likely cause more severe problems for salmon runs that are already stressed from degraded freshwater and estuarine habitat than for more robust salmon runs that utilize healthy streams and estuaries. (Mote et al. 1999)

Impacts on other social and economic activities

Summer droughts along the south coast and southern interior will mean decreased stream flow in those areas, putting fish survival at risk, and reducing water supplies in the dry summer season when irrigation and domestic water use is greatest.' (NRC 2004a) Dry winter weather and warm spring temperatures, more common during warm phase ENSO events or a warm phase PDO, lead to lower springtime snowpack and streamflow during spring and summer in snowmelt-driven rivers. As a result, flooding is less likely and drought more likely, during warm phase ENSO (El Niño) and PDO. The opposite is true for cool phase ENSO (La Niña) and PDO. PNW winters tend to be cooler and wetter during cool phase ENSO and PDO, resulting in higher than average winter snowpack and spring and summer streamflow in snowmelt-driven rivers. (Mote et al. 1999) Spring flood damage could be more severe both on the coast and throughout the interior of British Columbia and Yukon, and existing flood protection works may no longer be adequate so major investments will be necessary to protect developed or productive agricultural areas. (NRC 2004a)

Some important climate-related factors on impacts to the coastal zone are sea level, air and sea surface temperatures, winter precipitation, and storminess. These factors influence coastal erosion, landslides, flooding and inundation, estuarine water quality, and invasion of exotic species. El Nino years show higher sea levels so the increased chance of coastal erosion associated with them may presage the impact of elevated sea levels from global warming.

Projections of 21st century global sea level rise by the Intergovernmental Panel on Climate Change (IPCC) are 0.8 to 2.3 mm/year, compared to 1.0-2.5 mm/year observed during the last century. On average, global mean sea level is expected to be 0.09 to 0.88m higher by 2100. (Watson et al. 2001) The sea level rise that will be experienced along the coasts of the PNW will also depend on circulation changes in the Northeast Pacific (in much the same way that El Niño elevates our sea levels) and on local vertical land movements. Sea levels rose along most of the BC coast during the 20th century. Higher sea levels may also create drainage problems and overwhelm municipal sewage systems. Low-lying agricultural lands may become too saline for cultivation. (NRC 2004b)

Some climate models project changes in sea-level pressure patterns that suggest a more southwesterly direction of future winter winds, much like the strong El Niño events of 1982-83 and 1997-98. Combined with higher sea levels, these changes suggest an acceleration of coastal erosion on the Pacific Ocean coast since erosion is sensitive to these two factors. (Mote et al. 1999)

The heavier winter rainfall that is projected by nearly all of the climate models suggests an increase in saturated soils and therefore landslides. (Mote et al. 1999)

Climate models predict that over the coming century we can expect heat waves during summer months to be more extreme, occur more frequently, last longer and have higher levels of humidity. (NRC 2004b) Health impacts during heat waves in parts of he Canadian Georgia Basin region sufficiently far from the ocean for the temperatures to be moderated could be severe and even fatal. Coincidently, photochemical smog levels can reach dangerous levels in those very same locations due to the local topography.

Longer term changes expected

In the two new generation models the CIG studied, a deepening and southward shift of the Aleutian Low was noted which led to a "dramatic" change in the atmospheric circulation over the Pacific towards the end of the century. This resulted in displacement of the winter storm track southward and a tendency to stronger winds as was observed during strong El Nino events like those of 1982-83 and 1997-98. Warm, wet winter storms were apparently much more common by 2100. (Mote et al.. 1999 20)

Biophysical inference and the results of vegetation change modeling suggest that a number of different vegetation change scenarios are possible for the PNW. These scenarios differ dramatically, ranging from projections of forest expansion to forest dieback, as a result of uncertainty regarding how projected temperature and precipitation changes will interact to affect drought stress in trees or otherwise modify total annual productivity. Other major uncertainties are whether increased levels of carbon dioxide (CO2) in the atmosphere would increase primary productivity or help trees withstand reduced soil moisture. The likeliest scenario seems to be that increased forest growth could occur during the next few decades, but that at some point temperature increases would overwhelm the ability of trees to make use of higher winter precipitation and higher CO2. In any case, the changes in climate are likely to cause plant communities to undergo shifts in their species composition and/or experience changes in densities. Species range shifts are expected to be individualistic rather than primarily as collections of currently associated species. Extinction of local populations and, potentially, species are expected with climate change. Species with poor dispersal ability may have particular difficulty in shifting their spatial distributions in response to climatic changes. Loss of biological diversity is likely if environmental shifts outpace species migration rates and interact with population dynamics to cause increased rates of local population extinction. (Mote et al. 1999)

Some of the provincial impacts from changing climate may already be familiar even to urban British Columbians because of newspaper stories about the pine beetle epidemic spread over the last few years or the massive outlay to fight forest fires. A recent debris slide closed a highway near Creston for a few days but the magnitude of impacts experienced to date is much less than entire villages in Central or South America being buried by massive mudslides after torrential rains or hundreds of thousands being left homeless and with no dry ground to flee to in Bangladesh during the recent heavy monsoon. As climate changes and extreme weather events become more frequent it may seem like climate change output for the Georgia Basin is remarkable primarily for its lack of severity. QUEST users might benefit from considering the contrast between being a member of a society that continues to make lifestyle choices that result in worsening the global climate imbalance and yet getting off relatively lightly on the consequences of their actions. By the time their generation is ready to retire, the situation may be reversed as huge coal reservoirs were tapped in the intervening years to power rapid industrialization in Asia and the sub-continent. Including a contrasting pair of impact graphs might be a helpful springboard to classroom explorations of morally and practically wise proposals based on equal rights to emit greenhouse gases.

Chapter 4: Conclusion: How climate change considerations might be included

> In the actor system view of the world, natural systems and human interactions with those systems, are represented in the form of formal data bases and other information about the world. Whatever their real nature out in the world, natural and human systems must be represented in the form of information to be able to be used in human decision-making. The information can be in the form of quantitative computerized data bases, or the intuitive knowledge in the head of an experienced individual. The point is simply that decisions can only be made on the basis of whatever information is made available to the decision-maker. This in turn suggests the importance of the process whereby scientific and other information is 'constructed' by data collectors and organizers … and by data users and manipulators. (Robinson 1991 632-3)

Authors of a landmark analysis of climate change policy response options, Rayner and Malone, point out the benefits of policymakers viewing the climate change issue holistically, not just as the problem of emissions reductions, and employing the full range of analytic perspectives from the natural and social sciences as well as the humanities (1998). QUEST could do this even if the only output available was the quantity of GHG emissions generated by the user's scenario if the latitude to accompany that single output variable report with graphed quantities and text keyed to the user's choices that constructed the scenario were to be permitted. Even if no overt choices on impact level or means of stimulating social behaviour changes were permitted, there is ample quantifiable material and success stories from mitigation or adaptation perspectives, impact examples or trends, and technological or legislative innovations that could be considered worth displaying as part of the user's custom output. Design philosophy could 'accentuate the positive' to complement the GSG scenario choice of the pro-sustainability paradigms and give a 'reality check' to those who chose the Breakdown Worldviews. Global trends such as the committed warming from the emission projections shown in Figure 2 or it could present national information such as the sources of Canada's GHG emissions as shown in Figure 1. But there are also many 'success stories' of initiatives already taken to reduce, offset or avoid emissions as well as many ingenious adaptive strategies that could be of interest to

QUEST users – particularly those who opted for the hopeful road to sustainability. Those whose chose a breakdown worldview might prefer information on what happens under a 'business as usual' or slow transition to emissions reduction scenario. This could feature little investment in protective infrastructure such as dykes, or cases of inability to afford technological innovations such as fuel cell vehicles or the implications of refusal to make lifestyle changes for the 'common good.' Whatever information were chosen to depict the Climate Change issue considerations could be shown as graphs with text so that the style of presentation would be somewhat consistent throughout the QUEST report phase.

This chapter will sketch one way the global warming / climate change topic could blend in with the other QUEST topics presented at the output stage. The intention is twofold: to show such a display could be done without violating the QUEST design criteria and to suggest subjects for inclusion that relate to choices users made during the custom scenario creation phase. Strictly speaking, most of the technological innovations making novel regional planning options possible are not developed locally. Natural resource extraction, processing and transport machines are designed and manufactured elsewhere. Transportation vehicle styles originate outside the Georgia Basin. Even legislation that applies to air quality or food cultivation and preparation is likely to be inspired by advances in other jurisdictions. With the speed of money movement and the creation of trading blocks already, the spurs to adopt new practices everywhere often originate far from the Georgia Basin. Viewed in that light, QUEST cannot be purely local in character and the items mentioned above can be largely independent of the GSG scenario chosen over only 40 years. However, business as usual in transport, mining, forestry, fishing, neighbourhood planning, air and water quality regulation, etc. could be most particularly affected by a concerted vigorous attempt to lower GHG emissions. Already, emissions trading, carbon sequestration, low GHG emitting cars, GHG-neutral public transport, etc. are underway.

An explosion of innovations and implementation of schemes already proposed could show quite a range of effects quickly. Enriching the GHG outcomes from the relevant topics in QUEST might be seen as too speculative but mentioning some of the known possibilities in a Climate Change output report screen might be a valuable addition. Over the QUEST time span, portraying global warming and climate change scenario outcomes is not feasible because the person playing the policymaker role cannot significantly affect the outcome over the period for which s/he is making choices. But that apparent stumbling block meets the QUEST "True to Life" design criterion since that is also the conundrum with dealing with this slippery public policy issue in the real world. There may be a 'middle way' to deal with the issue holistically and key its display to user choices in GB-QUEST while acknowledging that the character of this topic is fundamentally different from that of the others.

From the material available on the internet regarding Georgia Basin QUEST use during the initial phase of the GBFP, it appears that one principal audience is high school students. This means these future citizens are practicing on a time period which pre-dates their adult involvement in Canadian society's focus on a realistic engagement with the global warming issue. Media coverage of the debate on ratifying the Kyoto Protocol and announcements in the media of new institutions formed to assess Canada's performance and enable emission trading have turned the thoughts of those Canadians who follow the news to the possibility that we may soon be forced to take climate change into account in some fashion. But until the emissions reduction goals are in line with what European leaders are currently suggesting, many times larger than Kyoto targets, how can Canadian citizens be expected to grapple with the real scale of change called for to minimize the impact of feedbacks listed in Chapter 2 that will speed the warming? And, as Chapter 2 has detailed, it is uncertain whether restraint of the warming is still within humankind's power to effect. So, the opportunity to stimulate young minds with some of the ramifications of trends to more or less greenhouse gas emissions in lifestyle choices in richer countries as well as subsistence-oriented practices in poorer ones could be seen as an exciting learning opportunity. Their generation will have more impacts impelling them to engage with the complexities of this public policy and international negotiation issue. And, as shown in Chapter 3, the present generation is busy playing 'catch up' because reliable long-term records are not available for many regions' climate descriptors. As well, correlations of agricultural, fisheries and forestry variations have not been correlated with meteorological data in an organized way until recently. We were caught off guard. The urgency provoked by the possibility of a human influence on global climate has meant major investments in reconstructing climatic records and gathering oral and local written material to piece together a picture of the longer term 'normals' with which to compare the apparently changing climate patterns. Baseline data are essential in order to distinguish between variability within usual bounds and unidirectional change but until recently, recording these data has not been seen as an important investment.

Accompanying a QUEST user-generated scenario output with meaningful and appropriate information from the perspective of ameliorating climate change processes and stimulating discussion on aspects of the public policy issue is neither straightforward nor easy. The QUEST reporting screens are the 10 categories: Land Use / Sea Level Rise, Transportation, Agriculture, Food security, Health/air quality, Water supply/quality issues, Energy, Forestry, Fisheries, and Government costs. For most of them, there is an aspect of the global warming / climate change issue that could be of interest to scenario builders. One approach that might have been taken would have been to place an icon signifying Climate Change on each output page so the user could choose to access more detail on the ramifications of global warming /climate change on that particular category. But this approach would have been obviously making climate change different from the other categories and would have meant diluting the regional focus of QUEST so was rejected. The current proposal blends the climate change considerations in quite smoothly so might be a workable alternative.

The proposed approach means adding another panel to the output phase – a Global Warming/ Climate Change screen. There would be nothing extraordinary since it would be used to report the GHG emission tally from the user's scenario and it could show the breakdown of the sectoral contributions to the total. However, that leaves a fair bit of screen 'real estate' to fill with whatever complimentary information the designers would permit. It would be important to have a variety of information to show so that multi-scenario generators see that the Climate Change output responds to their Worldview choices and to the categories they chose most explicitly to explore in building each scenario. Where a scenario has a balanced response pattern, QUEST could have a random pattern for which category in which to give output displays. However, if choices were clustered, it is proposed that the top one or two areas of expressed interest would be featured in the Climate Change output. As with the other QUEST topics (Carmichael 2003), the range of impacts or whatever topic was slated for display would be apportioned by the user's choice of levels of Social Adaptability, Technological Innovation and Ecological Resilience.

Using one of the following allocations of screen real estate, the program might be set to show multiple panels from the least sustainable of the user's choices or it could offer a mix of topics when many reporting categories fared poorly. The physical arrangement could be either of the following depending on the user's scenario choices:

GRAPHS TAKE ONE-QUARTER SCREEN EACH IN QUEST REPORT PHASE	Vertical Bar Graph with no text
	Horizontal Graph ---------------------------------- text relating to graph above

Figure 12: Four 1/4 screen layout format

<table>
<tr><td>Food Security

1/8 screen = text segment only</td><td colspan="2">Greenhouse Gas Emissions

QUEST Graph from scenario</td><td>Transportation

Or two-bar vertical graph comparing Canadian data with user's</td></tr>
<tr><td>Forestry
or
Agriculture
or
Fisheries</td><td>Health Issues</td><td>Air Quality</td><td>Water Issues</td></tr>
</table>

Figure 13: One centered 1/4 flanked by 6 - 1/8 text boxes format – lower half 4 horizontal (graphs) or 4 vertical (text)

The main categories of climate change information may be available for global, continental/ climate region, governmental unit (country, province, state, municipality) or topographical unit (e.g. the Georgia Basin) scales. Some topics are less meaningful when specific to a small area like the QUEST study region so are best summarized at those scales which seem to have maximum relevance. But one consideration in choosing the scale of information to present would be who will be the scenario builders and what regions would they be most interested in. Do urban Vancouver students understand much of what the major pine beetle epidemic that is currently out of control in the Northern Interior region means to the Georgia Basin? If not, mention of this pronounced effect of a string of warm winters could be a springboard to teachers focusing on this topic which might otherwise not have come up. Since the forestry activity and government costs both impact Vancouver residents, these topics are surely pertinent. But, even if GB-QUEST was available on CD or on the internet, it might be that scenario builders from other locations would understand the import of the warming allowing population explosions since this type of phenomenon is becoming increasingly common as the warming changes habitats both on ocean and on land.

On the only QUEST version available to the present work, the one accessible on the internet through the SDRI website links, graphs appear to be the format of choice for all categories. And graphs are effective ways many climate change-related data can be compactly portrayed. Local graphs are not readily available but the Georgia Basin region is covered specifically in the maps for the BC Climate Change Indicators Report (MWLAP 2002). Most of the categories are dominated by changes in other parts of the province but a few could provide text segments for the Georgia Basin. Perhaps the best example would relate to Energy Use for heating or cooling. Over the period of record, about a century, "In southern BC, the amount of energy required for cooling increased." (MELP 2002 50) A sentence stating the percentage increase could be added without using more than a 1/8 screen box and, if projections were available for the period to 2040, a graph could be made and shown in a 1/4-page box or and 1/8 page half-high with accompanying text. Impacts discussed in Chapter 3 can also be shown in a meaningful fashion in graphs that relate to impacts on natural resources spread over a larger area than just the Georgia Basin. For example, some Fraser River salmon runs not threatened by rising ocean temperatures may be in jeopardy at some places in the river itself as shown in Figure 14.

Percentage of years with degree reach hours (DRH) above the baseline critical value.

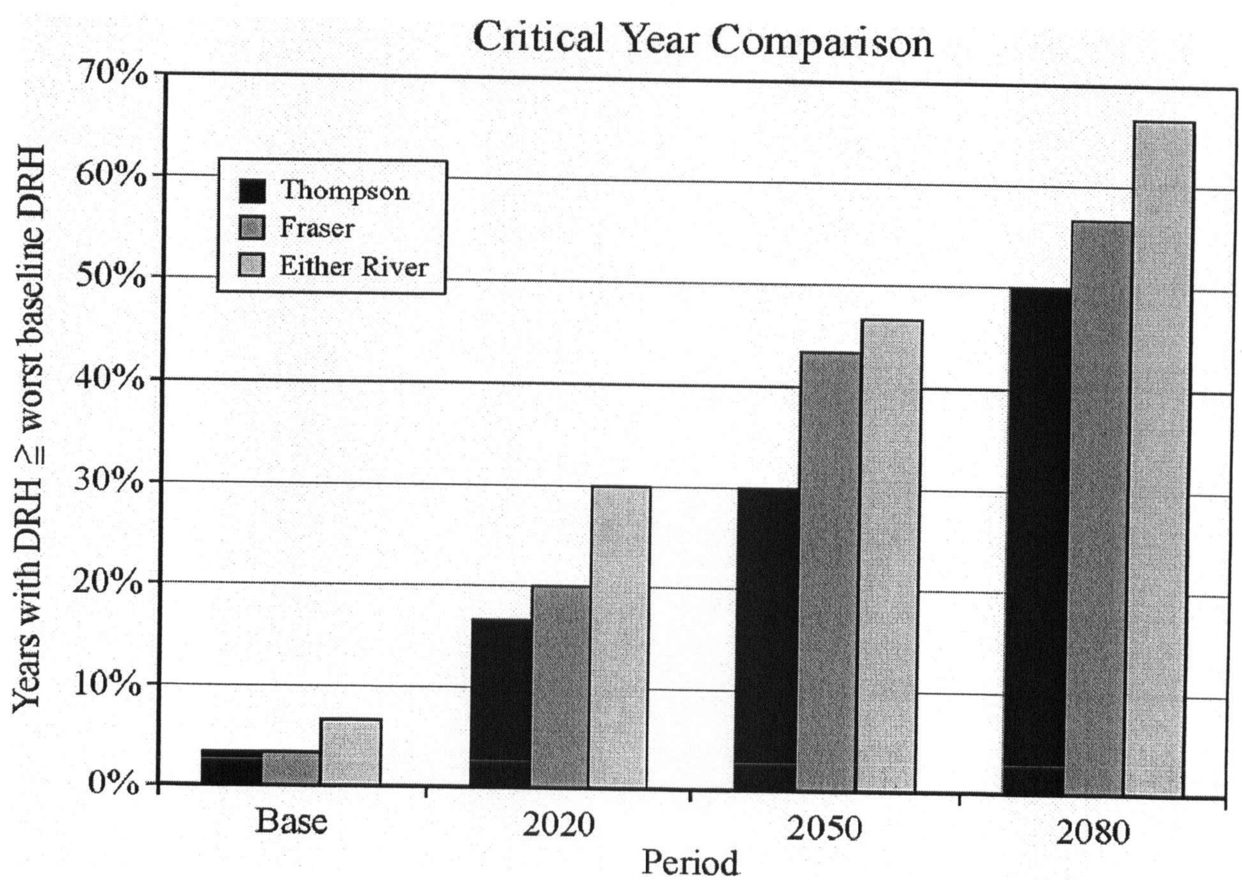


Figure 14: from Morrison et al. (2002 Figure 14).

"The unit displayed here is years exceeding critical Degree Reach Hours (DRH), referring to the number of hours where water temperature exceeds 20 C. This is an indicator of threat to salmon spawning success. The graphic shows that with climate change, the number of years with high DRH increases." (Cohen 2005)

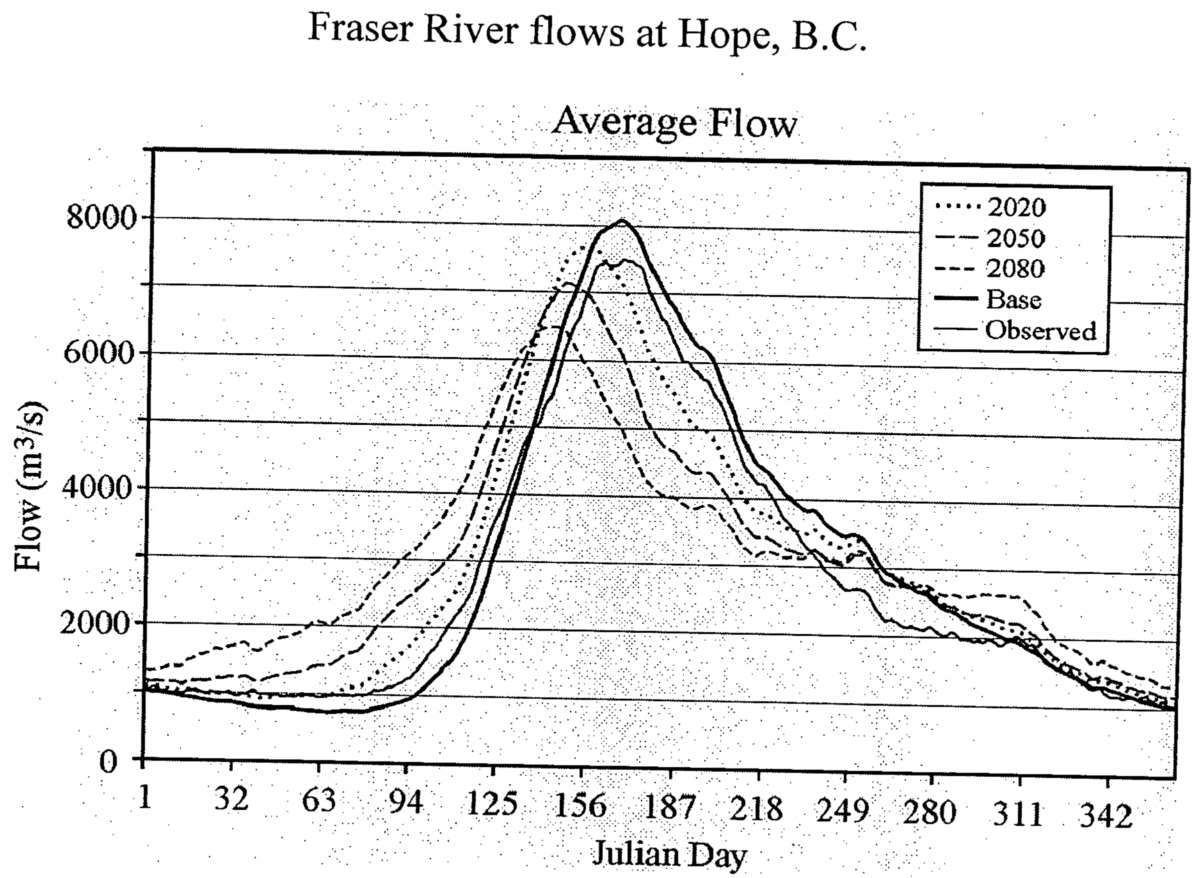
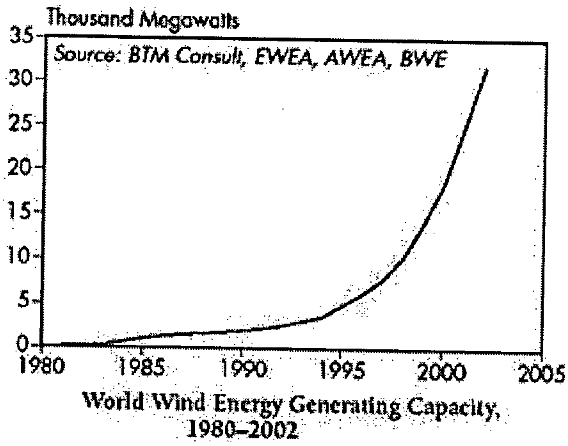


Figure 15: from Morrison et al. (2002 Figure 6).

Figure 15 relates to two QUEST categories, Fisheries and Agriculture. "The earlier peak flow means that summer flows are reduced, with implications for water users, including irrigators and in-stream needs of fish." (Cohen 2005)

A few examples from the World Watch Institute website show the effectiveness of simple graphs to show that global impacts are much more severe than what Georgia Basin residents see in their own backyard. Opportunities to show the pattern of the greater impacts in 'poorer' countries are abundant. If there were room for accompanying text, Figure 14 is the amount World Watch chose to show and might be a reasonable amount for 1/4 screen-size box but the content could easily be trimmed to a 1/8 box accompanying the graph.



"Global wind-generating capacity grew by 27 percent in 2002 and is projected to expand 15-fold over the next 20 years. Europe houses nearly 73 percent of global wind capacity, with more than half of this capacity in Germany. In 2002, Denmark, a nation of 5 million people, installed more wind capacity than all of the United States, a nation of more than 290 million." (WWI 2003a)

Figure 16: World Wind Energy Generating Capacity 1980 – 2002 from WWI 2003a

QUEST could show a similar graph to this one from World Watch under the Energy category on the Climate Change display for the pro-sustainability Worldview choice and perhaps something similar to the fossil fuel usage graph below for the GSG Breakdown scenario:

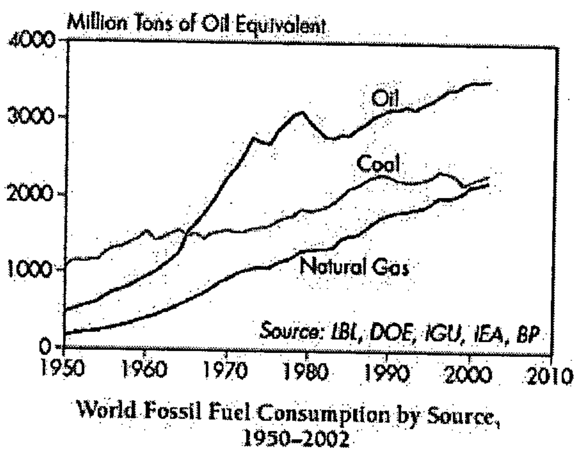
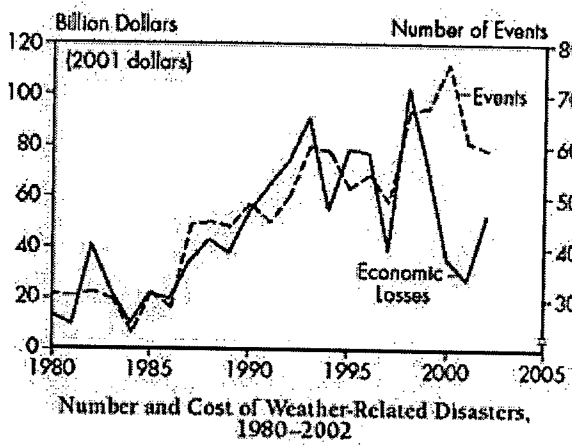


Figure 17: World Fossil Fuel Consumption by Source, 1950 – 2002 from WWI 2003b

For graph-savvy audiences, both the rapid rise of the wind generating capacity line or the steady upward march of the fossil fuel consumption lines convey a clear message. Of course, projections to the end of the GB-QUEST scenario period in 2040 would be used.

Presented under the headline, "Stormy Weather Spells Disaster for many Millions," World Watch shows this graph and story:



"In 2002, the world experienced about 700 natural disasters—nearly 600 of which were weather-related events. Economic losses from weather disasters worldwide approached $53 billion, a 93 percent increase over 2001. The year also set numerous local and regional records for windstorms, rain intensities, floods, droughts, and temperatures." (WWI 2003c)

Figure 18: Number and Cost of Weather-Related Disasters from WWI 2003c

Some graphs, like this one accompanying the text below (and more text not shown here) are a prime example of how QUEST display could be a springboard to teaching or discussion as to why the Number of Events peak could coincide with a trough in the Economic Losses attributed to Weather-Related Disasters. The presenter could have a handbook for each of the possible displays with a public and a private section. The public section would be presented by the graph as a dry fact, but the private section could have a further elaboration like this one from WWI:

> Poorer nations are the most vulnerable to climate change. While the average number of deaths per weather event has declined, the total number of people affected is on the rise. Over the past two decades, floods and other weather-related disasters were among factors prompting some 10 million people to migrate from Bangladesh to India. In 2002, rains in Kenya displaced more than 150,000 people, while more than 800,000 Chinese were affected by the most severe drought in over a century. Erratic weather patterns are the primary cause of famine for about 18 million Africans. (WWI 2003c)

Equity issues are no longer only moral questions for the 'rich' nations in the global greenhouse but practical ones also. QUEST could show the increase of area prone to climate-sensitive diseases, the rapid rise of Third World emissions although the per capita rate is little changed, the loss of habitat in temperature-sensitive ecosystems, etc. as well as direct climate change impacts. Showing some of the less often publicized initiatives and proposals might stimulate wide-reaching conversations. For example, the Contraction and Converge graph might spark interest in multi-cultural Georgia Basin audiences with its fundamental premise that each individual have an equal right to emit greenhouse gases regardless of geographical location. It also shows clearly the projected rise in China's emissions that becomes important longer term. This graph has too much detail to show except full screen but would be a prime candidate for a second-tier display if that capability to allow the user to click an icon for more information ever becomes available. But the graph could be simplified into groups of nations and even be shown piecewise linear in different time series to shift the emphasis in keeping with the user's worldview choice. Of course, that tack could be taken with much of the IPCC material also.

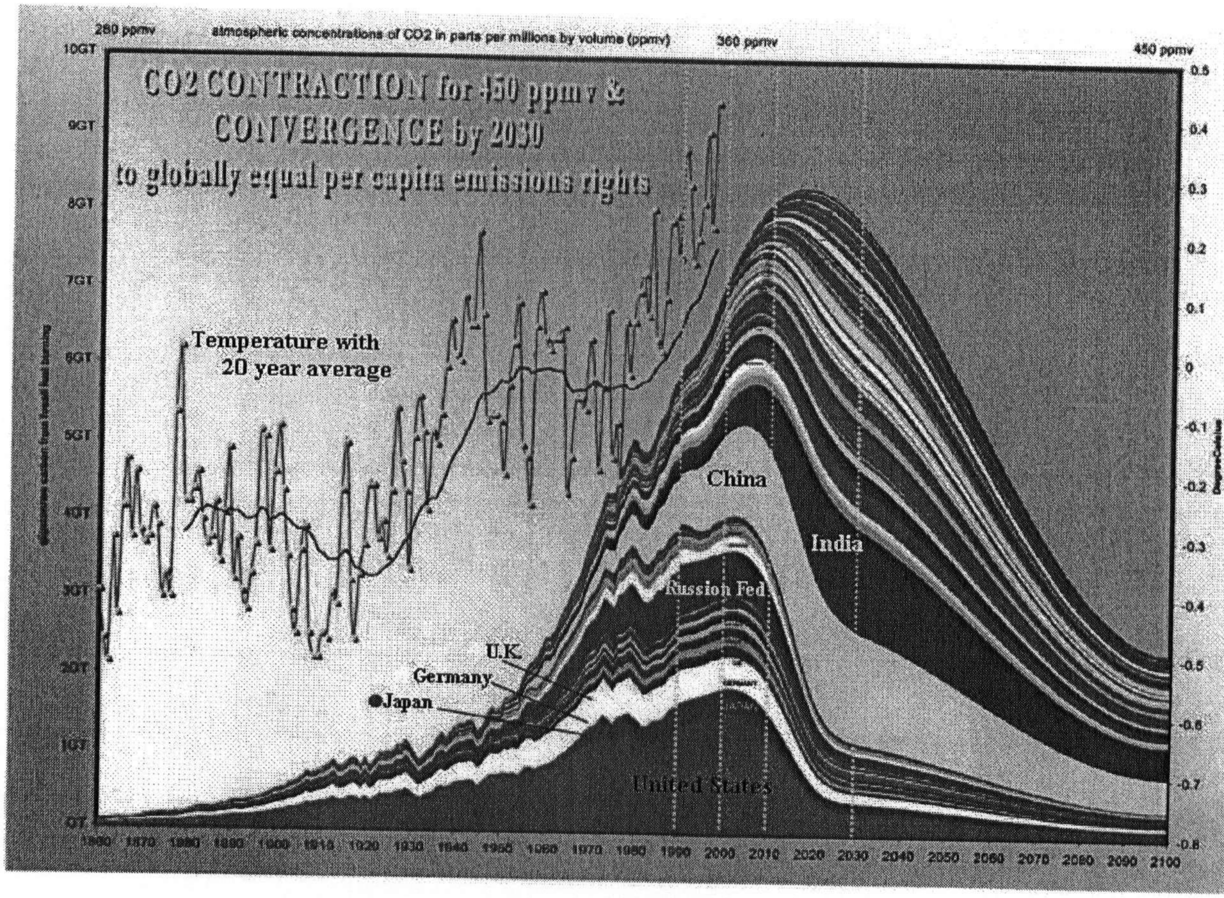


Figure 19: CO2 Contraction for 450 ppmv & Convergence by 2050 to globally equal per capita emissions rights (GCI 2004)

However, perhaps maps like these two from the IPCC projecting temperature changes in the year 2050 for the IPCC equivalents to Fortress World scenario and Great Transitions scenario respectively could be shown without modification because on some aspects of this issue, the global scale is the most meaningful. These maps cannot show to full advantage in black and white since the colour coding is crucial to conveying their message but in QUEST on a computer screen, they could be quite informative. Scenario A2 would correlate fairly closely with a QUEST user's Great Transitions Worldview choice and B2 with the Fortress World Worldview choice. "Note that local greenhouse gas emissions (and reductions of those emissions) have no impact on climate change, and do not affect any climate change-related calculations within Quest. However, reporting of local greenhouse gas emissions is important as part of the learning experience, particularly given the "Commons" nature of greenhouse gas warming." (Carmichael 2001)

In 2001, there were still hopes that it would be possible to allow the QUEST user to make some choices of an adaptive nature regarding climate change impacts but the misalignment of the timescales prevented that approach being workable. The graphs from the 2001 Meeting Summary pictured below show the type of modification envisioned as desirable at the time. They also show a characteristic difference between the two Worldview choices that would guide selection of contrasting material to accompany each of them when such pairs were available. At that time, plans were mentioned for only the two GSG scenarios but later two others were added (Carmichael et al. 2004)

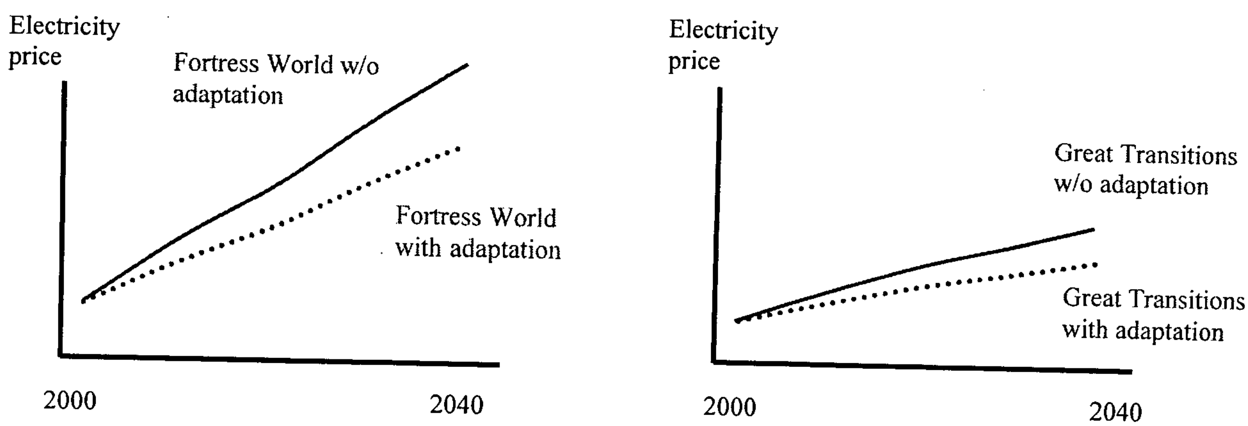


Figure 20: Electricity price over the years 2000 – 2040 for both Worldview choices from Carmichael (2001)

The date on the IPCC maps, Figures 19 and 20 below, showing when the projected temperature changes are expected would need to be specified as further into the future than the user's regional scenario. The discrepancy in dates could lead to discussions of important global warming / climate change considerations such as the length of time greenhouse gas overloading persists and the commitment to climatic or sea level changes brought about by storage of additional heat in oceans or by that excess energy causing changes in state by melting glaciers or sea ice. Or it could lead to lessons or seminars on a multiplicity of considerations that derive from the lack of a clear cause and effect link based on the complexity of this puzzling phenomenon we are only beginning to recognize as a major change already upon us.

One further value of the QUEST output on the 'climate change' issue might be to rename the issue global warming / climate change because that puts the focus more overtly on reducing emissions – the only quantified custom output in the user's scenario. It also keeps the awareness level high that this is a global problem and the paucity of regional impacts does not imply a similarly easy ride for other regions. In addition, it emphasizes the fundamental unfairness in the history of the development of the planet-wide imbalance caused by the abuses of the relatively wealthy citizenry of industrialized nations like Canada. That point could be made by displaying matched short text items that speak to the impacts or graphs compiled from data on the scale suited to the topic, showing the disparity of causes and effects between the Georgia Basin and a geographically similar but economically different region like the Mekong Basin in Vietnam, for example.

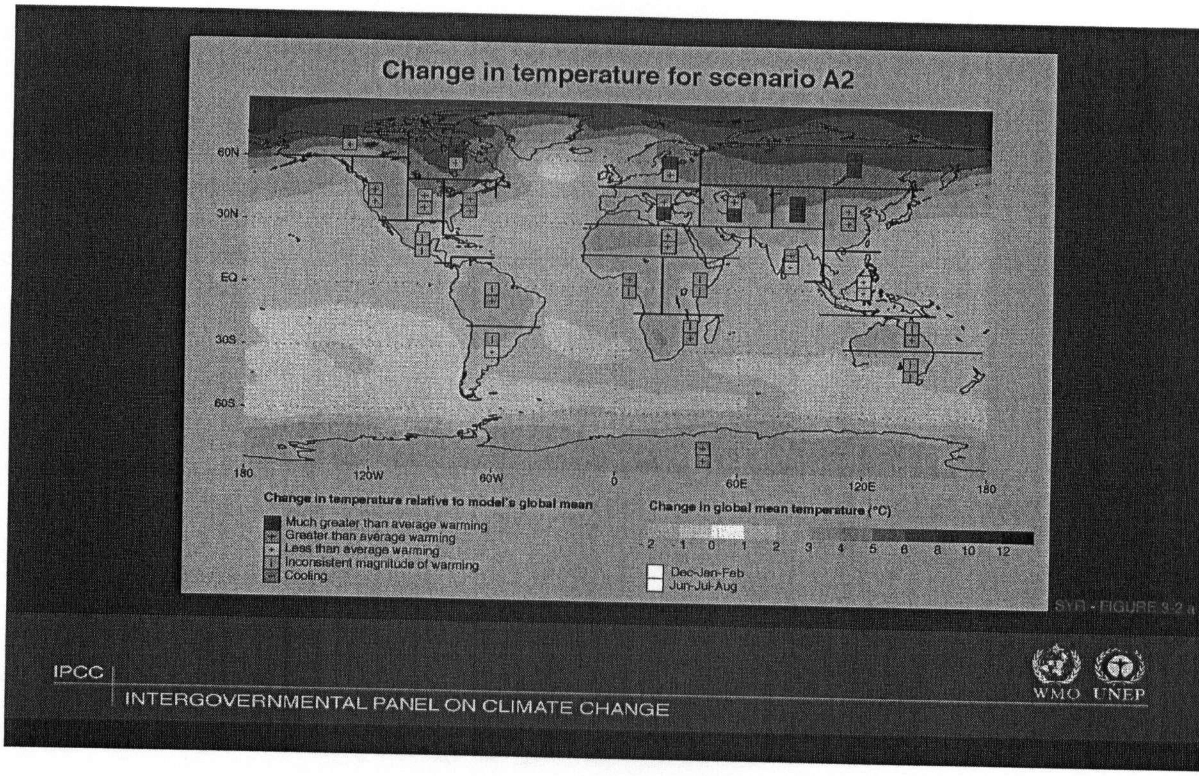


Figure 21: Change in Temperature for Scenario A2 (IPCC 2001 figure 3-2a)

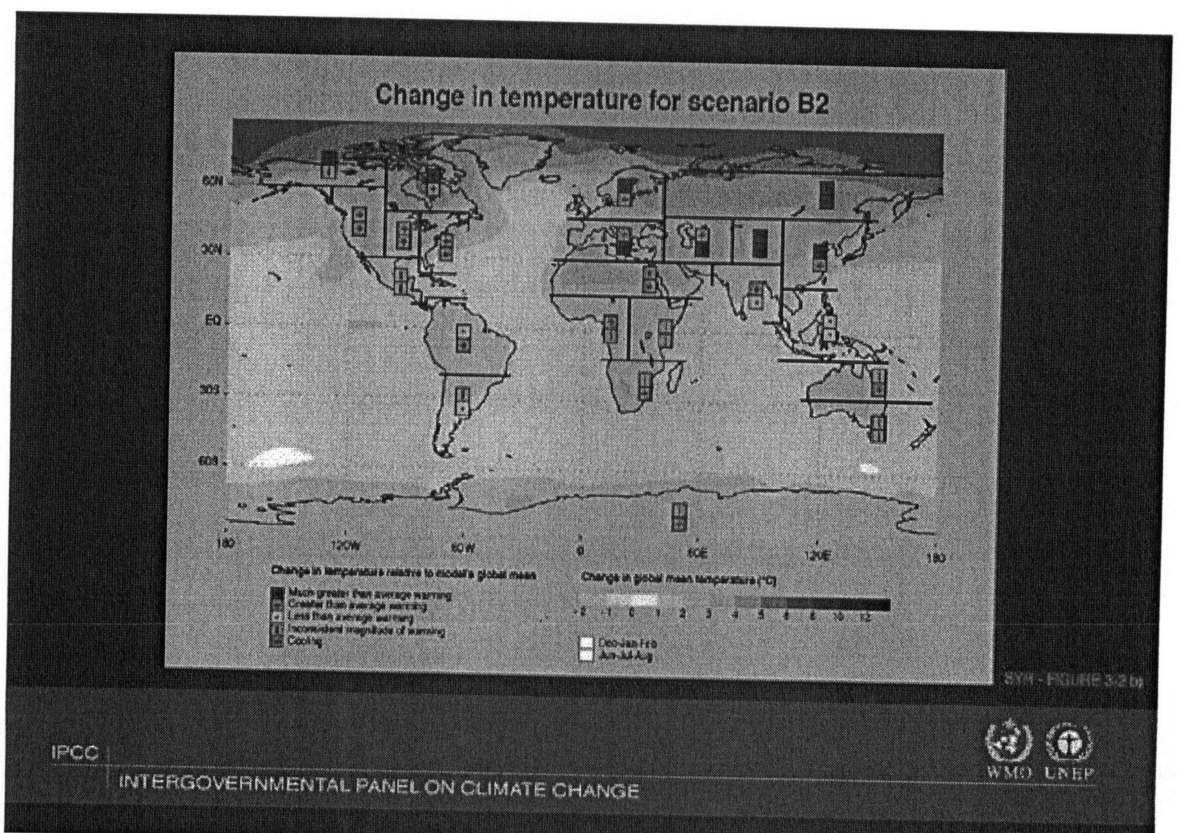


Figure 22: Change in Temperature for Scenario B2 (IPCC 2001 Figure 3-2b)

Bibliography

Allen, L.H. Jr. and J.S. Amthor 1995 Plant Physiological Responses to Elevated CO_2, Temperature, Air Pollution and UV-B Radiation *Biotic Feedbacks In The Global Climate System: Will The Warming Feed The Warming?* G.M. Woodwell and F.T. Mackenzie Eds. Oxford University Press: New York, Oxford pp. 51-76

AGU (American Geophysical Union) 2004 *Climate change could release old carbon locked in Arctic soils, researchers say* March 2 http://www.eurekalert.org/pub_releases/2004-03/agu-ccc022704.php

Andreae, M.G. 1991 Geophysiological Interactions in the Global Sulfur Cycle *Scientists on Gaia* S.H. Schneider and P.J. Boston Eds. Pub. MIT Press: Cambridge, Mass. pp.131-139

Associated Press 2004 *Report: Carbon dioxide buildup accelerating* Associated Press March 20

Avery, Susan K ,(UCAR Board of Trustees) Paul D. Try (President American Meteorological Society), Richard A Anthes (President University Corporation for Atmospheric Research) and Richard E. Hallgren (Executive Director American Meteorological Society) 1996 *an open letter to Ben Santer* http://info-pollution.com/warming.htm

Avery, Susan K. 2004 Global warming / climate change http://info-pollution.com/warming.htm

Bach, W. 1984 *Our Threatened Climate: Ways of Averting the CO_2 Problem Through Rational Energy Use* D. Reidel Pub.: Dordrecht, Boston, Lancaster 368 pp.

Barry, R.G. and R.J. Chorley 1992 *Atmosphere, Weather and Climate Sixth Ed.* Routledge, Chapman and Hall Pub.

Bartlemus, P. 1994 *Environment, Growth and Development: the concepts and strategies of sustainability* Pub. Routledge: New York, London

Bindschadler, Robert A. and Charles R. Bentley 2002 On Thin Ice? *Scientific American* Vol. 287, Issue 6 page 98

Bjoergo, E. 1995 The Sea Ice in the Arctic is Melting, Is This A Sign of Global Warming? *Press Release from the Nansen Environmental and Remote Sensing Center, University of Bergen, Norway*

CCEA Canadian Council on Environmental Areas 2004 Ecozones of Canada http://www.ccea.org/ecozones/index.html

CICS Canadian Institute for Climate Studies, U. Vic *Climate Severity Index* http://www.cics.uvic.ca/severity/maps/select.cgi

Carmichael, Jeff 2001 GBFP Climate Change meeting summary February 5

Carmichael, Jeff; James Tansey and John Robinson 2004 An integrated assessment modeling tool *Global Environmental Change* 14:171-183

Charlson, R.J. 1995 The Vanishing Role of Dimethyl Sulfide *Biotic Feedbacks In The Global Climate System: Will The Warming Feed The Warming?* G.M. Woodwell and F.T. Mackenzie Eds. Oxford University Press: New York, Oxford 416 pages pp.251-261

Cohen, Stewart, David Demeritt, John Robinson and Dale Rothman (1998) Climate Change and Sustainable Development: Towards Dialogue *Global Environmental Change* 8(4): 341-371.

Cohen, Stewart 2005 Personal Communication by email January 4

COFI Council of Forest Industries 2003 *Epidemic Expansion Facts* Mountain Pine Beetle Task Force http://www.mountainpinebeetle.com/epidemic_facts.html

CSES 2004 Center for Science in the Earth System Climate Impact Group at the University of Washington website http://cses.washington.edu/cig/pnwc/pnwc.shtml

Cubasch, U. and R.D. Cess 1990 Processes and Modelling *Climate Change: The IPCC Scientific Assessment* Cambridge University Press Houghton, J.T., G.J. Jenkins and J.J. Ephraums Eds. pp.69-92

Davidson, E. A. 1995 Linkages Between Carbon and Nitrogen Cycling and Their Implications for Storage of Carbon in Terrestrial Ecosystems *Biotic Feedbacks In The Global Climate System: Will The Warming Feed The Warming?* G.M. Woodwell and F.T. Mackenzie Eds. Oxford University Press: New York, Oxford pp. 219-230

Davis, M.B. 1989 Lags in Vegetation Response to Greenhouse Warming *Climatic Change* 15:75-82

Diaz, H.F. 1989 Understanding El Nino and Other Long-Term Climate Variability Over the Oceans *Coping With Climate Change: Proceedings of the 2nd North American Conference on Preparing For Climate Change: A Cooperative Approach* Climate Institute, Washington D.C. Pub. pp.125-130

Doggett, Tom 2004 Global energy demand to rise 54 percent by 2025, says U.S. EIA Thursday, April 15 Reuters http://www.enn.com/news/2004-04-15/s_22838.asp

Doyle, Alistair 2004 *Thaw of icy gas may worsen global warming, says report* Reuters News Service ENN Environmental News Network May 20 http://www.enn.com/news/2004-05-20/s_24062.asp

Enting, Ian G. 1995 . CO_2-climate feedbacks: aspects of detection *Biotic Feedbacks In The Global Climate System: Will The Warming Feed The Warming?* G. M. Woodwell, and F. T. Mackenzie editors . New York: Oxford University Press. p. 313-329.

ENS 2001a Mountain Pine Beetle Epidemic Panics British Columbia *Environment News Service ENS* June 27 http://forests.org/archive/canada/mtpinebe.htm

ENS 2004a Rich Nations Gobbling Resources at an Unsustainable Rate *Environment News Service ENS* March 30 http://www.ens-newswire.com/ens/mar2004/2004-03-30-10.asp

ENS 2004b Carbon Dioxide Escalation Alters Amazon Rainforest Panama, *Environment News Service ENS* March 12 http://www.ens-newswire.com/ens/mar2004/2004-03-12-02.asp

ENS 2004c Bush Administration Reports Warming Climate, Rising Seas *Environment News Service ENS* August 27 http://www.ens-newswire.com/ens/aug2004/2004-08-27-02.asp

Environment Canada 2004 Climate Change website Last updated 2004-03-03 http://www.climatechange.gc.ca/english/climate_change/

Environment Canada Green Lane 2004 Canada's Greenhouse Gas Inventory 1990-2000 *Greenhouse Gas Division Environment Canada* June 2002 http://www.ec.gc.ca/pdb/ghg/1990_00_report/exec_e.cfm updated 2004-05-02

Fablis Encyclopedia 2004 http://encyclopedia.fablis.com/index.php/Ice_core

Flannigan, M.D. and C.E. Van Wagner 1991 Climate Change and Wildfire in Canada *Canadian Journal of Forest Research 21: 66-72*

Gedalof, Z., N.J. Mantua and D.L. Peterson 2002 A multi-century perspective of variability in the Pacific Decadal Oscillation: new insights from tree rings and coral *Geophysical Research Letters 29:24 pp. 57-61*

Goddard News 2003 *Ocean Plant Life Slows Down and Absorbs Less Carbon* September 19 http://www.gsfc.nasa.gov/goddardnews/20030919/carbon.html

Goddard SFC (Goddard Space Flight Center) 2003 *Ocean Sponging Up Some Warmth Over Next 50 Years* Top Story September 3 http://www.gsfc.nasa.gov/topstory/2003/0901oceansponge.html

Gorham, E. 1995 The Biogeochemistry of Northern Peatlands and Its Possible Responses to Global Warming *Biotic Feedbacks In The Global Climate System: Will The Warming Feed The Warming?* G.M. Woodwell and F.T. MacKenzie Eds. Oxford University Press: New

Gullett, D. W. 1992 *The State of Canada's Climate: Temperature Change in Canada, 1895-1991* Atmospheric Environment Service, Ottawa pp.169-187

Hanley, Charles J. 2004 CO_2 Hits Record Levels, Researchers Find Associated Press on National Oceanic and Atmospheric Administration: http://www.noaa.gov

Hebda, Richard J. 1997 *Impact of Climatic Change on Biogeoclimatic Zones of British Columbia and Yukon* Chapter 13 in Responding to Global Climate Change in British Columbia and Yukon Volume I of the Canada Country Study: Climate impacts and Adaptation Eric Taylor and Bill Taylor, Editors. Environment Canada

Hengeveld, H. 1997 *The Science of Climate Change* Chapter 2 of Responding to Global Climate Change in British Columbia and Yukon, Volume 1 of the Canada Country Study: Climate Impacts and Adaptation E. Taylor and B. Taylor editors published by Environment Canada and B.C. Ministry of Environment, Lands and Parks

Hieb, Monte 1996 Comparison of Atmospheric Temperature with CO2 Over The Last 400,000 Years *Plant Fossils of West Virginia* http://www.clearlight.com/~mhieb/WVFossils/last_400k_yrs.html Last update September 18, 1998

Hoffert, Martin I. 1997 *Turbulence in the Atmosphere and Oceans* Transcription from Aspen Global Change Institute *Elements of Change* Conference Presentation http://www.agci.org/publications/EOC97/eoc97session1/Hoffert.html

Houghton, J.R. 1995 Foreword *Biotic Feedbacks In The Global Climate System: Will The Warming Feed The Warming?* G.M. Woodwell and F.T. Mackenzie Eds. Oxford University Press: New York, Oxford pp.v-vi

Houghton, Sir John R. 1997 *Global Warming: The Complete Briefing* Cambridge University Press 2nd edition

IPCC 2001 Presentations and Graphics from Third Assessment Reports http://www.ipcc.ch/present/graphics.htm

IPCC 2001 Climate Change 2001: Synthesis Report *Summary for Policymakers* http://www.ipcc.ch/pub/un/syreng/spm.pdf

IPCC Working Group 1 WG1 1995 *Climate Change 1995: The Science of Climate Change* University of Cambridge

IPCC Working Group 1 WG1 2001spm SPM Climate Change 2001: The Scientific Basis *Summary for Policymakers* http://www.grida.no/climate/ipcc_tar/vol4/english/078.htm

IPCC Working Group 1 WG1 2001 Climate Change 2001: The Scientific Basis http://www.grida.no/climate/ipcc_tar/wg1/index.htm and subsequent panels

IPCC Working Group 1 WG1 2001ts Climate Change 2001: The Scientific Basis Technical Summary http://www.ipcc.ch/pub/wg1TARtechsum.pdf

IPCC Working Group 2 WG2 2001 Climate Change 2001: Impacts, Adaptation and Vulnerability *Summary for Policymakers* http://www.grida.no/climate/ipcc_tar/wg2/pdf/wg2TARspm.pdf

IPCC Working Group 3 WG3 2001spm Climate Change 2001: Mitigation Summary for Policymakers http://www.grida.no/climate/ipcc_tar/wg3/001.htm and subsequent panels

Kerr, R.A. 1992 Unmasking A Shifty Climate System: Did the Great Salinity Anomaly Cool the Atlantic? *Science 255:1508-1510*

Kessler, William G. 2002 Is ENSO a cycle or a series of events? *Geophysical Research Letters* Vol. 29 No. 23: 2125

Kurtz, A.C.; L.R. Kump; M.A. Arthur; J.C. Zachos and A. Paytan 2003 Early Cenozoic decoupling of the global carbon and sulfur cycles *Paleoceanograhpy*, VOL. 18, NO. 4, 1090 http://www.agu.org/journals/pa/pa0304/2003PA000908/

Kurz, W.A., M.J. Apps, B.J. Stocks and W.J.A. Volney 1995 Global Climate Change: Disturbance Regimes and Biospheric Feedbacks of Temperate and Boreal Forests *Biotic Feedbacks In The Global Climate System: Will The Warming Feed The Warming?* G.M. Woodwell and F.T. Mackenzie Eds. Oxford University Press: New York, Oxford pp.119-133

Laprise, R., D. Caya, M. Giguere, G. Bergeron, H. Cote, J. Blanchet, G.J. Boer and N. A. McFarlane 1998 *Climate and Climate Change in Western Canada as Simulated by the Canadian Regional Climate Model* Atmosphere-Ocean Vol. 36 No. 2 pp. 119-167

Lashof, D.A. 1989 The Dynamic Greenhouse: Feedback Processes That Can Influence Global Warming *Coping With Climate Change: Proceedings of the 2nd North American Conference on Preparing For Climate Change: A Cooperative Approach* Climate Institute, Washington D.C. Pub. pp.102-110

Lee, Timothy J. 1999 Calculation of Global Warming Potentials http://ameslib.arc.nasa.gov/randt/1999/earth/chemistry1.html

Leggett, J., W.J. Pepper and R.J. Swart 1992 Emissions Scenarios for the IPCC: An Update *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment* J.T. Houghton, BA.Callander and S.K. Varney Eds. Pub. Cambridge University Press, Cambridge, U.K. pp.69-96

Li, Z., H.W. Barker and L. Moreau 1995 The Variable Effect of Clouds on Atmospheric Absorption of Solar Radiation *Nature* 376:486-490

Liang, L. and G.P. Kershaw 1995 Climate Change in the Mackenzie Mountains, N.W.T., Canada *Climate Research* Vol. 5:1-13

Liski, J., A.V. Korotkov, C.F.L. Prins, T. Karjalainen, D.G. Victor, P.E. Kauppi 2003 Increased Carbon Sink in Temperate and Boreal Forests *Climatic Change* 61 1-2 : 89-99

Lyunggren, David Reuters 2004 Global warming bigger threat than terrorism, says Canada *Environmental News Network* http://www.enn.com/news/2004-02-06/s_12843.asp February 26

Mackenzie, Fred T. 1995 Global Climatic Change: Climatically Important Biogenic Gases and Feedbacks *Biotic Feedbacks In The Global Climate System: Will The Warming Feed The Warming?* G.M. Woodwell and F.T. Mackenzie Eds. Oxford University Press: New York, Oxford pp.22-46

Mantua, Nate 2000 PDO Pacific Decadal Oscillation site at the University of Washington http://tao.atmos.washington.edu/pdo/ http://jisao.washington.edu/pd

Maslin, Mark 2004 Gas hydrates: A hazard for the 21st Century *Issues in Risk Science series issue #3* Benfield Greig Hazard Research Centre Department of Earth Sciences, University College London http://www.benfieldhrc.org/SiteRoot/activities/issues/issues3.pdf

Matthews, R.B., M.J. Kropff, and D. Bachelet, 1997 Simulating the impact of climate change on rice production in Asia and evaluating options for adaptation *Agricultural Systems* 54:399-425.

Maunder, W. John 1992 *Dictionary of Global Climate Change* London: UCL Press Limited

Mitchell, J.F.B., S. Manabe, T. Tokioka and V. Meleshko 1990 Equilibrium Climate Change *Climate Change: The IPCC Scientific Assessment* Cambridge University Press Houghton, J.T., G.J. Jenkins and J.J. Ephraums Eds. pp. 131-172

Molinari, R.L 1989 The Atlantic Ocean: Unsung Partner in Global Climate Change *Coping With Climate Change: Proceedings of the 2nd North American Conference on Preparing For Climate Change: A Cooperative Approach* Climate Institute, Washington D.C. Pub. pp. 131-134

Mooney, H.A. and G.W. Koch 1994 The Impact of Rising CO_2 Concentrations on the Terrestrial Biosphere *Ambio* Vol. 23 No. 1

Morris, E.M. 1991 Antarctic Ice Studies in Global Climatic Change *Antarctica and Global Climatic Change* C.M. Harris and B. Stonehouse Eds. Lewis Pub.:Boca Raton, Fl. 198 pp. pp. 51-62

Morrison, J., Quick, M.C. and Foreman, M.G.G. 2002 Climate change in the Fraser River watershed: flow and temperature projections *Journal of Hydrology 263: 230-244*

Mote, P. W., D. J. Canning, D. L. Fluharty, R. C. Francis, J. F. Franklin, A. F. Hamlet, M. Hershman, M. Holmberg, K. N. Ideker, W. S. Keeton, D. P. Lettenmaier, L. R. Leung, N. J. Mantua, E. L. Miles, B. Noble, H. Parandvash, D. W. Peterson, A. K. Snover, and S. R. Willard 1999 *Impacts of Climate Variability and Change, Pacific Northwest* National Atmospheric and Oceanic Administration, Office of Global Programs, and JISAO/SMA Climate Impacts Group, Seattle, WA. 110 pp.

Mote, Philip W.; Edward A. Parson; Alan F. Hamlet; William S. Keeton; Dennis Lettenmaier; Nathan Mantua; Edward L. Miles; David W. Peterson; David L. Peterson; Richard Slaughter; Amy K. Snover 2003 Preparing for Climatic Change: The Water, Salmon, and Forests of the Pacific Northwest *Climatic Change* 61 1 : 45-88

Mote, P. W. 2003 Trends in snow water equivalent in the Pacific Northwest and their climatic causes. *Geophysical Research Letters* 30 12 1601

MWLAP (Ministry of Water, Land and Air Protection) 2002 Indicators of Climate Change for British Columbia 2002 http://wlapwww.gov.bc.ca/air/climate/indicat/pdf/indcc.pdf

Myers, N. 1993 Environmental Refugees in a Globally Warmed World *BioScience* 43:11 pp. 752-761

Nisbet, E.G. and B. Ingham 1995 Methane Output from Natural and Quasinatural Sources: A Review of the Potential for Change and for Biotic and Abiotic Feedbacks *Biotic Feedbacks In The Global Climate System: Will The Warming Feed The Warming?* G.M. Woodwell and F.T. Mackenzie Eds. Oxford University Press: New York, Oxford pp.188-217

Nkemdirim, L.C. 1996 The El Nino - Southern Oscillation Has a Truly Global Impact: A Preliminary Report on the ENSO Project of the Commission on Climatology *IGU Bulletin* Vol. 46

NRCan National Resources Canada 2004a *Regional Impacts: Climate Change in British Columbia* http://www.climatechange.gc.ca/english/issues/how_will/fed_bc.shtml replaced by NRC 2004d below on March 3

NRCan National Resources Canada 2004b *Climate Change and Your Health* http://www.climatechange.gc.ca/english/issues/how_will/health.shtml

NRCan National Resources Canada 2004c *Temperature Rising: Climate Change in Southwestern British Columbia* http://www.adaptation.nrcan.gc.ca/posters/reg_en.asp?Region=bc various articles bc_1 through bc_12

NRCan National Resources Canada 2004d *Provincial and Territorial Impacts: Regional Impacts – British Columbia* http://www.climatechange.gc.ca/english/affect/prov_territory/bc.asp updated March 3

PFC Pacific Forestry Centre 2002 Environment Canada Climate Monthly and 1961-1990 Normals Data http://www.pfc.forestry.ca/climate/change/Userdoc/ccma_e.html

Petit, J.R., J. Jouzel, D. Raynaud, N. I. Barkov, J.M. Barnola, I. Basile, M. Bender, J. Chappellaz, M. Davis, G. Delaygue, M. Delmotte, V. M. Kotlyakov, M. Legrand, V. Y. Lipenkov, C. Lorius, l. Pépin, C. Ritz, E. Saltzman & M. Stievenard 1999 Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica *Nature399:429-436*

Rayner, Steve and Elizabeth L. Malone 1988 *Human Choice and Climate Change: Ten Suggestions for Policymakers* Battelle Press, Columbus OH

Rind, D. 1989 Future Changes in Climate Variability Coping With Climate Change: Proceedings of the 2nd North American Conference on Preparing For Climate Change: A Cooperative Approach Climate Institute, Washington D.C. Pub. pp.111-114

Rising Tide 2004 Climate Action News Sheet 36

Rising Tide 2004 Climate Action Video List http://www.risingtide.org.uk/pages/resources/materials.htm

Rasmusson, E.M. 1989 Potential Shifts of Monsoon Patterns Associated with Climate Warming *Coping With Climate Change: Proceedings of the 2nd North American Conference on Preparing For Climate Change: A Cooperative Approach* Climate Institute, Washington D.C. Pub. pp.120-124

Rasmusson, E.M. 1990 Intraseasonal and Interannual Climate Variability *Climatic Change* 16:153-171

Rayner, Steve and Elizabeth L.Malone 1998 *Human Choice and Climate Change: Ten Suggestions for Policymakers* Batelle Press Columbus OH

Rind, D. 1989 Future Changes in Climate Variability *Coping With Climate Change: Proceedings of the 2nd North American Conference on Preparing For Climate Change: A Cooperative Approach* Climate Institute, Washington D.C. Pub. pp.111-114

Robinson, John B 1991 Modelling the interactions between human and natural systems *The International Social Science Journal* 43 4 , 629–647

Rowe, G.T. and J.G. Baldauf 1995 Biofeedback In the Ocean in Response to Climate Change *Biotic Feedbacks In The Global Climate System: Will The Warming Feed The Warming?* G.M. Woodwell and F.T. Mackenzie Eds. Oxford University Press: New York, Oxford pp.233-245

Sannueza, E. 1993 Terrestrial Biogeochemical Feedbacks *Earth Systems Response to Global Change: Contrasts between North and South America* H.A. Mooney, E.R. Fuentes and B.I. Kronberg Eds. Academic Press: San Diego California pp.131-142

Schlesinger, W.H. 1995 Soil Respiration and Changes in Soil Carbon Stocks *Biotic Feedbacks In The Global Climate System: Will The Warming Feed The Warming?* G.M. Woodwell and F.T. Mackenzie Eds. Oxford University Press: New York, Oxford pp.159-168

Smith, S.V. 1995 Net Carbon Metabolism of Oceanic Margins and Estuaries *Biotic Feedbacks In The Global Climate System: Will The Warming Feed The Warming?* G.M. Woodwell and F.T. Mackenzie Eds. Oxford University Press: New York, Oxford pp.246-250

Spittlehouse, David L. 1997 *Forest Management and Climate Change* in Responding to Global Climate Change in British Columbia and Yukon. Volume I Chapter 24 of the Canada Country Study: Climate impacts and Adaptation. Eric Taylor and Bill Taylor, Editors. Environment Canada

Spokes, Lucinda 2003 *The Oceans: the CLAW Hypothesis* Espere http://www.atmosphere.mpg.de/enid/p1.html

Studinger, Michael of the Lamont-Doherty Earth Observatory of Columbia University 1999 http://www.ldeo.columbia.edu/~mstuding/wais.html

SDRI Sustainable Development Research Institute 1998 Reconciling Ecological Carrying Capacity and Human Well-Being: Exploring Alternative Futures for the Georgia Basin *Proposal submitted to the Social Sciences and Humanities Research Council of Canada Major Collaborative Research Initiatives Grant Program*

Suzuki, David 2004 *Nothing Simple About Nature* an Editorial Environmental News Network http://www.enn.com/news/2004-02-25/s_13448.asp February 25

Suzuki, David and Wayne Grady 2004 *Tree: A Life Story* Greystone Books Vancouver BC

Taylor, Eric 1997 *Impacts of Future Climate Change on the Lower Fraser Valley of British Columbia* Chapter 19 of Responding to Global Climate Change in British Columbia and Yukon, Volume 1 of the Canada Country Study: Climate Impacts and Adaptation E. Taylor and B. Taylor editors published by Environment Canada and B.C. Ministry of Environment, Lands and Parks

Thomson, B. 1997 *Impacts of Climate Change on Air Quality in British Columbia and Yukon* Chapter 14 of Responding to Global Climate Change in British Columbia and Yukon, Volume 1 of the Canada Country Study: Climate Impacts and Adaptation E. Taylor and B. Taylor editors published by Environment Canada and B.C. Ministry of Environment, Lands and Parks

Thompson, S.L. and D. Pollard, 1995 A global climate model (GENESIS) with a land-surface-transfer scheme (LSX): part II: CO_2 sensitivity. *Journal of Climate* 8: 1104-1121

Tol, Richard 2001 *Personal Communication* from a Principal Lead Author in the IPCC WG2 Second Assessment Report for the chapter Integrated Assessment of Climate Change: an Overview and Comparison of Approaches and Results email message received March 11

United Nations Development Programme UNDP 2004 UNDP and the Montreal Protocol http://www.undp.org/seed/eap/montreal/

UNFCCC United Nations Foundation on Climate Change 1988 reprinted on http://www.unfccc.de/index.html 1992

Watson, R.T., H. Rodhe, H.Oeschger, U. Siegenthaler 1990 Greenhouse Gases and Aerosols *Climate Change: The IPCC Scientific Assessment* Cambridge University Press Houghton, J.T., G.J. Jenkins and J.J. Ephraums Eds. pp.5-40

Watson, Robert; John Houghton, Ding Yihui 2001 *Summary for Policy Makers: A Report of IPCC Working Group I* Third Assessment Report http://www.grida.no/climate/ipcc_tar/wg1/pdf/WG1_TAR-FRONT.PDF and http://www.ipcc.ch/pub/spm22-01.pdf

Watson Robert T., Daniel L. Albritton, Terry Barker, Igor A. Bashmakov, Osvaldo Canziani, Renate Christ, Ulrich Cubasch, Ogunlade Davidson, Habiba Gitay, David Griggs, Kirsten Halsnaes, John Houghton, Joanna House, Zbigniew Kundzewicz, Murari Lal, Neil Leary, Christopher Magadza, James J. McCarthy, John F.B. Mitchell, Jose Roberto Moreira, Mohan Munasinghe, Ian Noble, Rajendra Pachauri, Barrie Pittock, Michael Prather, Richard G. Richels, John B. Robinson, Jayant Sathaye, Stephen Schneider, Robert Scholes, Thomas Stocker, Narasimhan Sundararaman, Rob Swart, Tomihiro Taniguchi, D. Zhou, and many IPCC authors and reviewers 2001b
Climate Change 2001 Synthesis Report: Summary for Policymakers
http://www.ipcc.ch/pub/un/syreng/spm.pdf

Weissert, Helmut and Stefano M. Bernasconi 2004 Global change: An Earth on fire *Nature* Vol 428 No 6979 p.130 http://www.nature.com/cgi-taf/DynaPage.taf?file=/nature/journal/v428/n6979/full/428130a_fs.html

Wigley, T.M.L. and T.P. Barnett 1990 Detection of the Greenhouse Effect in the Observations *Climate Change: The IPCC Scientific Assessment* Cambridge University Press Houghton, J.T., G.J. Jenkins and J.J. Ephraums Eds. pp.239-257

Wullschleger, S.D., W.M. Post and A.W. King 1995 On the Potential for a CO_2 Fertilization Effect in Forests: Estimates of the Biotic Growth Factor, Based on 58 Controlled-Exposure Studies *Biotic Feedbacks In The Global Climate System: Will The Warming Feed The Warming?* G.M. Woodwell and F.T. MacKenzie Eds. Oxford University Press: New York, Oxford pp. 85-107

Woodwell, G.M. 1989 The Warming of the Industrialized Middle Latitudes 1985-2050: Causes and Consequences *Climatic Change* 15: 31-50

Woodwell, G.M. 1995 Biotic Feedbacks From the Warming of the Earth *Biotic Feedbacks In The Global Climate System: Will The Warming Feed The Warming?* G.M. Woodwell and F.T. Mackenzie Eds. Oxford University Press: New York, Oxford 416 pp.3-21

Woodwell, G.M. and F.T. Mackenzie 1995 Preface *Biotic Feedbacks In The Global Climate System: Will The Warming Feed The Warming?* G.M. Woodwell and F.T. Mackenzie Eds. Oxford University Press: New York, Oxford 416 pages pp.vii-ix

WWI (Worldwatch Institute) 2003a *Vital Signs Fact of the Week* #13: Wind Power Blows a Clean Breeze http://www.worldwatch.org/features/vsow/2003/08/13/

WWI (Worldwatch Institute) 2003b Vital Signs Facts: Fossil Fuels Continue to Cloud Up the Skies http://www.worldwatch.org/features/vsow/2003/10/29/

WWI (Worldwatch Institute) 2003c *Vital Signs Fact of the Week* #18: Stormy Weather Spells Disaster For Millions http://www.worldwatch.org/features/vsow/2003/10/01/