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A Periodical Newsletter Devoted to the Review of Climate Change Research

RECENT UNUSUAL WEATHER AND RELATED IMPACTS AND DISASTERS: NATURAL VARIABILITY OR CLIMATE CHANGE?

Fall 2002 Issue

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INTRODUCTION

Economic experts suggest that between 20 and 60% of economies in countries such as Canada are sensitive to the effects of day-to-day and year-to-year changes in weather. As a result, conservative estimates indicate that Canadians currently spend in excess of $12 billion per year in coping with and adapting to weather and climate, including losses of about $1.1 billion per year due to weather related traffic accidents (Andrey *et al*. 2001; Cohen *et al*. 2001, Marteau, 2001; Rothman *et al*. 1998).

One of the most costly aspects of coping with weather and climate is that of unusual weather conditions that have high impacts or result in disasters. That is because these events, in the most obvious sense, lie outside a locale's normal range of expected weather. By definition, they have a low probability of occurrence and hence are generally unexpected. Since our economy, our social behaviour and even our ecological communities are conditioned to 'normal' weather behaviour and, in general, ill-prepared to deal with unusual weather events, such events can become problematic and, at times, disastrous. As we have witnessed on a number of occasions in recent years, a single weather disaster can cause many millions and occasionally billions of dollars in lost property or infrastructure, can result in severe trauma to individuals involved and can create damages to ecosystems that take decades and even centuries to recover.

Not surprisingly, these events generate tremendous public interest when they occur, and frequently raise a number of related questions: How unusual are they? Are these events becoming more (or less) frequent? Is climate change a factor? What are the probabilities of such events occurring in the future?

Some aspects of these questions have been addressed in the Climate Change Digest report on Extreme Weather and Climate Change, published by Environment Canada in 1998. The following provides an update on that analysis through a case-by-case discussion of various types of unusual weather events that have occurred in Canada and elsewhere over the past five years or so. For each case, best estimates of real economic and social costs or benefits are provided (where available), and possible linkages to our changing climate are discussed.

RECENT UNUSUAL WEATHER BEHAVIOUR, RELATED IMPACTS AND CLIMATE CHANGE LINKAGES

i) Temperature Related Events

a) Unusual Annual and Seasonal Temperatures

- ***On a global scale, 1998 appears to be the single warmest year of the past millennium (with 2001 a close second), the 1990s the warmest decade, and the 20th century the warmest 100 year period.***

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Canada

- ***Across Canada, temperatures have warmed by about 1°C during the past century, 6 of the 15 warmest years since 1948 (the time when complete Canadian temperature data coverage started) have occurred during the past decade, 1998 was the single warmest year, and (as of summer 2002) 19 of the past 20 seasons have experienced above normal temperatures.***
  - Global and regional climate can vary dramatically from one year to the next and one decade to the next due to natural fluctuations within the climate system. However, the preponderance of warm years and/or seasons during the past decade is unusual and increasingly difficult to explain on the basis of such natural variability.
  - These changes are consistent with climate model simulations of human influence on the climate system to date.
  - IPCC experts conclude that "most of the warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations".
  - Global temperatures are projected to continue to rise at an average rate of 0.1 to 0.2°C/decade in the next few decades, and to warm by between 1.4 and 5.8°C by 2100. Average temperatures across Canada can be expected to warm at twice this rate. Allowing for natural variability, this suggests that extremely warm years and seasons under current climate regimes will become much more frequent in the decades to come, and extremely cold ones less frequent.

Sources: Folland *et al* (2001); Mitchell *et al* (2001); MSC Trends and Variations Bulletin; NOAAa; Watson *et al.* (2001); Zwiers and Zhang (2002).

b) Mild Winters

- ***In the Great Lakes – St. Lawrence River Basin, the winter of 2001-02 was 4.8°C warmer than average, setting a new record. The low snowfall amounts during the winter saved the insurance industry millions of dollars in reduced road accident claims and helped dramatically reduce provincial and municipal snow removal and road salting costs. A similar warm winter in 1994-95 reduced road maintenance costs for Ontario provincial highways alone by $14 million.***
  - Over the past century, there has been a significant trend towards fewer extremely low temperatures and more frequent extremely high temperatures in southern Canada during the winter and spring seasons.
  - The number of road accidents in Canada tend to increase by 50 to 100% during precipitation events, with snowfall having greater effects than rainfall.
  - As climate warms, mild winters are expected to occur more frequently and cold ones less so. For the Great Lakes Basin, for example, a winter like that of 2001-02 can be expected to be a normal winter by the late 21st century.
  - Under such winters, space heating energy demands are expected to decline by about 30% across southern Canada and 20% in northern regions.
  - Warmer climates could also significantly reduce road salt use in eastern Canada. For example, preliminary estimates for a doubled CO_2 type climate for Metropolitan Toronto suggest reductions in use of between 17 to 71%.

Sources: Andrey *et al.* (2001); Andrey and Snow (1998); Anisimov *et al.* (2001); Bonsal *et al.* (2001); Cohen *et al* (2001); Mercier (1998).

c) Summer Heat Waves

- ***During the summer of 2001, the number of days in central and eastern Canada with maximum temperatures in excess of 30°C was about 2 to 4 times the 1961-90 average. Coupled with dry weather and continuing emissions of smog producing gases, this resulted in one of the hottest, haziest and smoggiest summers in the region since 1988.***
  - During the summer, the Toronto Pearson airport recorded 24 days above 30°C, and authorities issued an unprecedented 23 smog advisories for the southern Ontario region. Two of these smog events lasted five straight days.
  - By 2050, hot summer days in excess of 30°C are projected to occur on average about once every two days in southern Ontario and once every four in Calgary. This frequency is more than four times current rates.
  - Extreme heat waves that now occur once every 80 years are projected to occur at least once every 10 years by 2050.
  - Summer space cooling costs will increase in southern Canada. In southern Ontario, for example, the number of cooling degrees may almost triple by 2090, relative to current values.
  - For each degree of apparent temperature (actual temperature adjusted for humidity effects) above 32°C, mortality rates amongst elderly in the Toronto-Niagara region increases by between about 0.9 and 1.3 per 100,000. This suggests that, within the next 25 years, more frequent heat waves could cause some 170-450 additional deaths among the elderly in the region.

Sources. Cohen *et al* (2001); Chiotti *et al.* (2002); Kharin and Zwiers (2000); Phillips (2002)

d) Longer Growing Seasons

- ***Aspens in Alberta now bloom some 26 days earlier than they did a century ago. Satellite data also indicate that the onset of the annual growing season in mid-Northern Hemisphere latitudes has advanced by more than one week since 1970.***
  - From 1900 to 1998, most of southern Canada progressively moved towards fewer days with extreme low temperatures during winter, spring and summer, longer frost free periods and an increase in growing degree days.
  - By the latter half of the 21st century, growing degree days across much of southern Canada are expected to be some 40 to 100% higher that today (depending on the region and climate scenario considered).
  - However, many plant species will be unable to migrate rapidly enough to adapt to these changes without major ecological disruptions. Some indigenous species risk disappearing. Further, the changing composition of future ecosystems will, at least initially, favour weedier species, which generally respond more quickly to changing environments.

Sources: Bonsal *et al.* (2001); Brklacich *et al.* (1998); Cohen *et al* (2001). Myneni *et al.* (1997); Penuelas *et al* (2001); Walther *et al*, (2002).

ii) Water Related Events

a) Extreme drought

- ***During the summer of 2001, much of southern Canada experienced one of the worst drought years in many decades. Particularly hard hit were southern Alberta and southern Saskatchewan, which have been under drought conditions for the past three years. Montreal experienced a record 35 days without significant rainfall. Estimates suggest that the cost of the 2001 drought to the agricultural economy of the Prairies was about $4-5 billion, while losses in Quebec were estimated at $200 million.***
  - A similar drought across much of central Canada in 1988 resulted in a loss of $4 billion in grain exports alone.
  - Such events have also occurred in the past. Hence, recent droughts may be entirely due to natural variability.
  - Most model outputs suggest that severe droughts are likely to become more frequent in mid-latitude continental interiors in the future. For example, one study suggests that, without efforts to reduce greenhouse gas emissions, regional droughts in central North America with 30 consecutive days without rain, projected to occur about once every 50 years today, may occur once every 15 to 20 years by 2070.

Sources: Arnell *et al.* (2001); Garnett (2002); Nyirfa and Harron (2001); Gregory (1997); Cohen *et al* (2001); Cubasch *et al* (2001)

b) Lake/River levels and flows

- ***During the past several years, levels in the Great Lakes, the St. Lawrence River and many other lakes in central and eastern Canada reached low levels that were unprecedented in the previous three decades. Although levels have increased again during 2002, most remain at below normal levels.***
  - The recent rapid drop in Great Lakes water levels appear to be linked to a sequence of unusually warm seasons and shorter winter ice seasons that both contribute to increased evaporation, and to several seasons of below normal precipitation.
  - Past records suggest that Great Lakes levels have experienced previous low levels below that of today in the early 1960s and in the 1930s, largely due to natural climate variability.
  - Average stream flows have decreased across southern Canada during the past 50 years.
  - Various studies using climate model projections suggest that, by 2050, average levels of the Great Lakes may be at or near the lowest levels of the past century.
  - As water levels fluctuate around these lower averages, periods of low lake levels can be expected to set new records in future decades that will be significantly below the extremes of the past. Conversely, high water levels are unlikely to reach historical record levels.
  - Such changes will have major impacts on water quality, freshwater fish populations, and competition for water use.

Sources: Arora and Boer (2001); Cohen *et al.* (2001); Mortsch *et al.* (2000); Nijssen *et al.* (2001); Schindler *et al.* (2001); Zhang *et al.* (2001a).

c) River Flooding

- ***The 1996 Saguenay flood, caused by extremely large volumes of rain falling over several days on already saturated landscapes, resulted in damages in excess of $1 billion.***
- ***The 1997 Red River flood, caused by (among other things) deep snow packs in the head waters region, forced the evacuation of some 25,000 people.***
  - There is no evidence that the total number of extreme precipitation events has increased across all of Canada in recent decades. However,

intense spring rainfall events have become more frequent in eastern Canada.

- As with severe droughts, intense floods occur from time to time as part of natural climate variability, and individual events cannot be directly attributed to global causes.
- However, an analysis of CCCma climate model projections suggests that the frequency of intense precipitation events across Canada could more than double by 2090. For example, an intense precipitation event that might now be expected once every 80 years could occur more frequently than once every 40 years.
- Other studies project that heavy summer rainfall events (>25 mm/day) over central North America may increase in intensity by about 150%. These have led IPCC to conclude that more intense rainfall is very likely over many areas, and that flood magnitude and frequency are likely to increase in most regions.
- A study for southern Alberta, using future climate projections, suggested a 30-40% increase in the magnitude of 100 year return period flood intensities for a $2xCO_2$ type climate

Sources: Arnell *et al.* (2001); Cohen *et al.* (2001); Kharin and Zwiers (2000); Muzik (2001); Zhang *et al.* (2001b)

d) Coastal Flooding

- ***On January 21, 2000, an unusually high storm surge caused extensive flooding and significant damages in Charlottetown. Insurable losses are estimated at almost $1 million.***
  - Over the past century, there has been a 32cm rise in mean sea level measured in Charlottetown, PEI. This is due to the combined effects of global sea level rise and land subsidence, and has caused the loss to the sea of more than 15 hectares of coastal land valued at about $900,000.
  - Flood damage occurs in Charlottetown whenever sea levels exceed 3.6 meters above chart datum, a threshold that now occurs about once every 7 years. These events usually occur when the meteorological influences from storms over the ocean (storm surges) enhance local high tides.
  - The January 2000 storm surge reached 4.23 m above chart datum, a level that occurs less than once per century.
  - IPCC provides a mean estimate for additional global sea level rise by 2100 of 48cm, although this could be as high as 88 cm or as low as 9 cm. Because of regional differences in the changes in the climate system and in local tectonic behavior (subsiding and lifting of the land mass), regional rates of sea level rise may be significantly higher or lower than such global means.
  - Under these scenarios, flooding of Charlottetown could become a yearly event, with large storm surge events like that of January 2000 expected to occur about once per decade.
  - Future erosion rates along PEI coastlines as sea levels rise are projected to increase by 1.5 to 2 times that for the last century. At the upper end of this range, almost 10% of the present coastal properties in the study area will be lost within the next 20 years and almost one-half in the next 100 years.

Sources: Cubasch *et al* (2001); McLean *et al* (2001); McCulloch *et al.* (2001).

iii) Storms

a) Convective storms

- ***In July, 2000, an F3 tornado ripped through a camping ground beside Pine Lake Alberta, killing 12 and leaving some 130 injured. A similar tornado event in Edmonton in 1987, which reached F4 intensity, killed 27, hospitalized 132, injured several hundred additional people and caused $330 million in property damage.***
- ***On August 21, 2001, a Winnipeg hailstorm generated $20 million in insurance claims for damaged cars alone. In 1996, hailstorms in Edmonton caused $400 million in damages.***
- ***In summer, 2002, four people were killed in eastern Canada by lightning strikes under unusual circumstances.***
  - Southern Canada experiences some 60 tornadoes every year. However, few reach the intensity of category 3 or higher
  - There is no evidence to suggest that thunderstorms, hailstorms or lightning are occurring more frequently.
  - However, a Canadian study of tornadoes in the Canadian Prairies indicate that these are now occurring earlier in the year, consistent with warmer spring temperatures.
  - A related study suggests an increase in Prairie tornados under warmer climates.
  - GCMs are unable to resolve convective storms and hence provide little conclusive guidance on future response of such storms to warmer climates. However, some empirical studies suggest

increased storm intensity, and an increase in thunderstorm lightning activity of 6% for each degree of warming.

Sources: Cohen *et al.* (2001); Cubasch *et al.* (2001); Etkin (1995); Etkin *et al.* (2001).

b) Winter storms

- ***In 1998, a winter ice storm left some 3 million people in eastern Canada without electrical power and cost the regional Canadian economy some $6 billion.***
- ***In December 1996, a series of brutal winter storms blasted Canada's west coast with up to 85 cm of snow, paralyzing infrastructure and commerce.***
- ***During the winter of 1998-99, total snowfall dumped on St. John's was almost 650 cm, the largest amount of snow in one season in over 130 years of record-keeping. That April also set a 24 hour snowfall record of 68 cm.***
  - There is evidence that extreme winter storms have actually become less frequent in southern Canada in recent decades, but more frequent in northern Canada.
  - There is no consensus on response of mid-latitude winter storm behaviour under warmer climates. One Canadian study suggests the frequency of intense winter storms in the Northern Hemisphere may increase by about 30%, although much of this increase occurs over oceans. Snow seasons are projected to become much shorter in a warmer world.
  - While severe ice storms often involve multiple factors, one key factor is the presence of moist air slightly above the freezing point over-riding cold air near the surface. Another is persistence. Under warmer climates, the frequency of warm moist air masses in southern Canada in mid winter is likely to increase. However, while this may contribute to a change in the risks and seasonality of freezing rain events, it remains uncertain how climate change will affect the likelihood of severe ice storms.

Sources: Cohen *et al.* (2001); Cubasch *et al.* (2001); Lambert (1996); Zhang *et al.* (2001b).

c) Tropical storms

- ***In 2001, four consecutive tropical storms each delivered in excess of 100mm of rain to eastern Newfoundland. The worst of these, Post-Tropical Storm Gabrielle, dumped more than 160 mm of rain on Cape Race within 10 hours, and a record –setting 90mm on St. John's within a six-hour period. Damage from flooding in the Avalon Peninsula during that storm is estimated a $5.5 million. During the passage of Tropical Storm Karen, offshore winds near Halifax gusted to over 100 km/hr, and 46 mm of rain fell in Yarmouth within a few hours.***
- ***In September 1999, tropical storm Gert caused more than $14 million in flood damages in new Brunswick and PEI and an additional $2 million surf damage to coastal infrastructure and boats on the southern Avalon Peninsula.***
  - Statistically, tropical cyclones make landfall in Newfoundland about once every 1.4 years, and in Nova Scotia about once every 2.4 years.
  - Intense hurricanes in the Atlantic Ocean have increased in frequency in recent years relative to preceding decades, contributing to large increases in economic losses relative to those for preceding decades. Hurricane Andrew (1992) alone caused ~$25 billion in damages.
  - However, there are indications that the recent increase in intense North Atlantic hurricanes may be a return to conditions similar to that observed in the first half of the 20th century, and may be part of a long term natural oscillation related to ocean circulation changes. Hence there is no evidence to suggest the increase is due to climate change. Experts suggest that this heightened level of activity may continue for several decades, regardless of any future effects due to climate change.
  - It is as yet uncertain how climate change will affect the total number of tropical storms. Some studies indicate that the maximum intensity of hurricanes may increase by 3 to 10% relative to today.

Sources. Knutson *et al.* (2001).; Elsner *et al.* (2001); Goldenberg *et al.* (2001); Environment Canada Atlantic Region; OCIPEP (2001).

iv) Oceanic and Sea Ice Behaviour

a) El Niño/La Niña

- ***During the very intense 1997-98 El Niño, winter temperatures across southern Canada were 2 to 7°C above long term average, and large areas of the Canadian Prairies and eastern Canada received less than 50% of normal winter precipitation. The great ice storm of 1998 was at least partly attributable to the influences of that El Niño.***
  - The 1997-98 El Niño event was the most intense of its kind in at least the past century.
  - The displacement of normal global weather patterns caused by the 1997-98 event also contributed to major weather disasters around the

world. Southern USA experienced major floods, winter tornado outbreaks and storms that cost up to $1 billion in damages. Peru lost almost 1000 km of coastal highways to mudslides. Many other countries experienced a range of extreme weather events. Some impacts, such as reduced space heating during the warm winter and reduced frequency of Atlantic tropical cyclones, were very beneficial. The net global costs of this extreme El Niño event are estimated at 24,000 deaths and $34 billion in damages.
- While few studies have yet been conducted into the impacts of climate change in El Niño-La Niña behaviour, some studies suggest both intense El Niños and La Niñas will become more frequent. Others suggest little change.

Sources: Timmermann (2001); Collins (2000); Folland *et al.* (2001); NOAAb.

b) Arctic sea ice

- ***During the summer of 1998, the Canadian Arctic experienced an abnormally warm summer, the southern edge of the Arctic ocean ice pack in the Beaufort Sea set new records for distance from shore, and the Canadian Arctic Archipelago experienced record minimum amounts of ice cover.***
- ***During the fall of 2001, a delay on ice freeze-up caused polar bears to migrate onto the ice in Hudson Bay for their winter feeding more than a week later than normal.***
  - Over the past 50 years, Arctic ice cover has decreased in extent by 10-15%, and its average thickness has also decreased substantially.
  - The health of female polar bears in the Hudson Bay region is reported to be in decline, and fewer cubs are being born. This is attributed to the shorter feeding seasons caused by delayed ice freeze-up and earlier break-up.
  - The Canadian climate model projects that the Arctic Ocean could be entirely ice free in late summer before the end of the next century.
  - Decreased ice cover has important implications for Arctic animal species dependent on such ice (e.g., polar bears and seals), for traditional Inuit lifestyles, and for Canadian sovereignty in the north.

Sources: Anisimov *et al.* (2001); Cohen *et al.* (2001); Huebert (2001); Nelson (2001); Stirling *et al.* (1999).

v) Ecological and Social Infrastructures

a) Permafrost decay

- ***Residents of the western Canadian Arctic are reporting decay of permafrost causing large-scale slumping on the coastline and along the shores of inland lakes and rivers. For example, in Sachs Harbour (Banks Island) the melting of permafrost has already caused one inland lake to drain into the ocean, killing the freshwater fish, and is causing building foundations within the community to shift.***
  - Temperatures in the Mackenzie District have warmed by 2°C since 1948, and the Canadian tundra region by 1.1°C. 1998 was the warmest single year, registering 3.9°C and 3.3°C above the long-term average, respectively.
  - Permafrost underlies 24.5% of the northern hemisphere land area. Many land slides in the Arctic are triggered by the effects of extreme climate events on ground thaw depth or permafrost stability. However, there is an absence of good data on long-term trends in the frequency of such slides.
  - An increase in snow cover and/or a rise in air temperatures will increase the decay of permafrost. The area of permafrost in the northern hemisphere could eventually decrease by 12-22% under typical climate change scenarios for the next century. That for Canada could decrease by as much as 50%.
  - Much of the high Arctic will be at risk of permafrost degradation, causing increased land instability and related damages to socio-economic infrastructure such as oil pipelines, sewage pipes, roads and buildings. For example, approximately 40% of communities in the Mackenzie Basin are located over extensive discontinuous permafrost. In Norman Wells, which is particularly vulnerable, a 2xCO_2 type climate could cause land subsidence over permafrost pockets of 0.5 to 1.25 meters.

Sources: Anisimov *et al.* (2001); Ashford and Castleden (2001); Aylesworth and Duk-Rodlin (1997); Bone *et al.* (1997); Malcolm *et al.* (2001).

b) Ecological impacts

- ***In 1998, coincident with the warmest annual temperatures on record in Canada and dry conditions in many of the forested regions, large forest fires consumed some 3.7 million hectares of Canadian forests. By mid season of 2002, forest area destroyed by fire was already 70% higher than the average for the past decade.***

- ***A major outbreak of mountain pine beetle now progressing across B.C. threatens to cause major damage to large areas of B.C. and Alberta forests. By spring 2002, estimated value of infested B.C. forests alone was in excess of $4 billion . Experts relate this outbreak to the lack of cold winters in the region in recent decades.***
- ***Residents in western Nunavut have noted the arrival of new species of birds such as barn swallows and robins, and an influx of flies and mosquitoes that are making life difficult for humans and animals.***
  - Average annual forest losses in Canada due to wildfire since 1980 is about 2.4 million ha. This appears to be a significant increase from the average losses in the decades prior to 1980, at least partly due to a long term natural cycle involving an aging Canadian forest more prone to fire. However, there is also evidence that climate may be an important factor. Annual loss rates vary considerably from year to year, largely due to changes in fire weather conditions. For example, the worst fire years in 1989 and 1995 resulted in losses in excess of 7 Mha per year, while low fire years such as 1978 and 2000 resulted in losses of 0.5 Mha per year or less.
  - Projections suggest that, as climates warm over the next half-century, average future fire weather severity in western and central Canada will increase by 50%, and the fire season is expected to lengthen by 3 weeks. Risks in northeastern Canada could decrease because of increased precipitation.
  - Warmer winters and longer reproductive seasons are projected to significantly increase the risk of outbreaks of insect infestations and of invasion by exotic insect species. For mountain pine beetles, absence of winter temperatures below –40°C is critical.
  - As forests die because of insect infestations, they also become more vulnerable to fire.
  - Warmer climates are also expected to expand the distribution of many species of plants, birds, animals, marine and aquatic life and insects northwards. On the other hand, changes in sea ice cover will negatively affect many of the traditional northern species such as polar bears, seals and walruses.

Sources: Anisimov *et al.* (2001); CFS National Fire Situation Report; Canadian Council of Forest Ministers; Cohen *et al.* (2001); Flannigan *et al.* (2 001); Malcolm *et al.* (2001); Skinner *et al.* (1999); Smith *et al.* (2001); Stirling *et al.* (1999).

c) Community Impacts

- ***Local citizens in Sachs Harbour report changes in local climate and environment that are very unusual for their culture. They note that autumn freeze-up is now occurring up to a month later than usual and the spring thaw seems earlier every year. The multi-year sea-ice is smaller and now drifts far from the community in the summer, taking with it the seals upon which the community relies for food. In the winter the sea-ice is thin and broken, making travel dangerous for even the most experienced hunters. In the fall, storms have become frequent and severe, making boating difficult. Thunder and lightning have been seen for the first time.***
  - The above changes are consistent with the already noted dramatic 2°C+ warming since 1948 in the Mackenzie District, and the more modest 1.1°C in the Canadian tundra region.
  - The impacts of future climate change will be particularly disruptive for indigenous peoples following traditional lifestyles, affecting hunting and gathering practices. However, there will also be new economic opportunities associated with easier access to remote communities such as those in the Arctic.

Sources: Ashford and Castleden (2001); Aylesworth and Duk-Rodkin (1997); Bone *et al.* (1997); Bonsal *et al.* (2001).

d) Aggregate social costs of weather related disasters

- ***During the 1990s, a total of 2000 some major weather disasters around the world killed about 330,000 people and displaced 1.9 billion others.***
- ***End of year report by Munich re-insurance industry for 2001 indicates that a total of 700 natural disasters world-wide caused 25,000 human fatalities and economic losses of $US 36 billion, of which 11.5 billion was insured. 91% of the record $US 11.5 billion in insurance payouts were due to windstorms and floods.***
- ***Property damage in Canada during the 1990s exceeded $Cdn 6 billion. The 1998 ice storm alone resulted in the deaths of 28 Canadians and payments by governments and insurers to storm victims of an estimated $Cdn 2.5 billion.***
  - Global economic losses due to natural disasters have increased 10-fold during the past 40 years, rising to an average of $US 40 billion per year in the 1990s (1999 US$). Similar trends are apparent in North America.
  - Much of this increase is due to demographic factors (growing and wealthier population in vulnerable areas, decreasing government investment in infrastructure, etc.). However, disaster

experts also suggest that there is evidence for a significant increase in the number of extreme weather events in recent decades. The number of weather-related disasters around the world has risen three times as rapidly as non-weather related disasters.

- Projected increases in many types of extreme weather events due to climate change are expected to have further adverse effects on national economies. In developed countries, the insurance industry may respond by reducing the range of perils it will cover. In developing countries, where few people have access to insurance or the resources required to adapt, the human costs may be much greater.

Sources: Berz *et al.* (1999); Kovacs (2001); Munich Re (2002); Rice (2001); Smith *et al.* (2001).

e) Environmental refugees/disasters

- ***In November, 2001, the small, low-lying island state of Tuvalu sought agreement from Australia and New Zealand for acceptance of Tuvalu citizens as environmental refugees should expected impacts of future sea level rise force evacuation of the island.***
  - Local sea rise has already caused significant erosion of the shorelines of Tuvalu and other Pacific small island states.
  - A UK study suggests that global populations vulnerable to storm surges could rise five fold by a 40 cm sea level rise (estimated for 2080), affecting up to 200 million additional people.
  - Up to 3 billion more people could live in water stressed countries by 2080.
  - 80 million more people could be malnourished by 2080
  - Canadian studies suggest that many conflicts between nations arise because of lack of life support resources. Such conflicts can be expected to increase in response to projected impacts of climate change in developing regions of the world.
  - Canadians are respected for their peace-keeping in conflict regions, their aid to international victims of natural disasters, and their provision of sanctuary to refugees. These roles are likely to rise dramatically as climate change impacts displace large populations and increase resource conflicts.

Sources: Homer-Dixon (1999); McLean *et al.* (2001); Arnell *et al.* (2001); Gitay *et al.* (2001).

CONCLUDING OBSERVATIONS

Collectively, the above examples of recent unusual weather and related impacts and disasters generate a number of observations that have direct relevance to assessments of social and economic vulnerability to future climate change. These include the following:

- Weather events beyond the expected range of weather behaviour to which local ecosystems and socio-economic infrastructure have adapted over time can have major ecological, social and economic impacts. Some of these impacts can be beneficial, but most are deleterious.Some of the recent climate trends and events, internationally and within Canada, cannot as yet be distinguished from those that could occur due to natural climate variability. Hence it is not possible to attribute these directly to human induced climate change. Other events, such as recent warm temperature events and related ecological changes, are unprecedented in recorded meteorological history and/or in native cultures, and are increasingly difficult to explain on the basis of natural causes alone. There is compelling evidence that these are already indicative of a changing climate caused by human influences. Most of the above events are consistent with those that can be expected more frequently in a warmer world, and hence provide good examples of important aspects of future climate change. They are effective reminders of how such change may affect our future well-being.

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