Climate change: the science and implications for life in Canada.

David R. Greenwood
Environmental Science
‘global warming’ is topical

Mean Annual Temperature

Last 30 yrs 1.2°C warmer than 1902-1933

Global average warming of 0.63°C
0.2°C / decade

Brandon & Winnipeg have warmest Jan since 1941
2006 Canada’s 2nd hottest summer

Saskatoon

Last 30 yrs 2.0°C warmer than 1902-1933

Global warming at level not seen for millennia

WASHINGTON — The Earth’s temperature has climbed to levels not seen in thousands of years, warming that has begun to affect plants and animals, researchers report in today’s issue of Proceedings of the National Academy of Sciences.

The Earth has been warming at a rate of 0.2 degrees Celsius per decade for the last 30 years, according to the research team led by James Hansen of NASA’s Goddard Institute for Space Studies in New York. That brings the overall temperature to the warmest in the current interglacial period, which began about 12,000 years ago.

The researchers noted that a report in the journal Nature found that 1.700 plant, animal and insect species moved poleward at an average rate of about 6.5 kilometres per decade in the last half of the 20th century.

The warming has been stronger in the far north, where melting ice and snow expose darker land and rocks beneath allowing more warmth from the sun to be absorbed, and more over land than water.

Water changes temperature more slowly than land because if its great capacity to hold heat, but the researchers noted that the warming has been marked in the Indian and western Pacific Oceans. Those oceans have a major effect on climate and warming there could lead to more El Nino episodes affecting the weather.

“This evidence implies that we are getting close to dangerous levels of human-made pollution,” Hansen said in a statement.

Few scientists doubt that the planet has warmed, though some question the causes of the change.

— Associated Press

Winnipeg Free Press, Sept. 26, 2006
The science of climate change

- Greenhouse effect - combined effects of *natural processes and human activities* (fossil fuels, biomass, agriculture).

- Not ‘global warming’, but *climate change* - yes, global average temp. changes, but also changes in precipitation amounts & seasonality.

- **Climate models** beset with uncertainty – complex & chaotic systems, but getting better; forecasts for 2020 to 2050.

- Consequences for Canada:
  - *Arctic sea ice*; rising sea levels and other effects.
  - *Altered climate zones* will affect what we grow and where, and the distribution of plants and animals *and* our water supply.
‘greenhouse’ – a poor analogy

1. *Radiation from the sun* either reaches the surface, or is *reflected* back into space by *clouds*, and also by *dust* in the upper atmosphere and by *high albedo land surfaces* (grasslands, ice, snow).

2. *GHGs absorb* (or ‘trap’) short-wave radiation and *re-radiate it as long wave radiation* (= heat).

3. *At night, the land and ocean re-radiate heat into the atmosphere*. This radiation may be reflected back to the surface by clouds or dust, be lost into space (on clear nights). Some is absorbed by GHGs and retained in the atmosphere.

4. *A natural process* - in its absence, the earth’s oceans would be frozen solid and life would not be possible.

Dearden & Mitchell, 2005
Greenhouse: an old idea

• Fourier, 1824: hypothesized the atmosphere blocks outgoing radiation, and warms it by reradiating some of this radiation.

• Arrhenius, 1896: CO₂ traps and reradiates heat.

• Callendar, 1938: since 1880 the Earth has warmed by 1°F, and will warm by double this in next 100 years.

• Revelle & Suess, 1957: the oceans could not absorb human emissions of CO₂ as fast as they were produced – “Human beings are now carrying out a large-scale geophysical experiment ... we are returning to the atmosphere and oceans the ... carbon stored in the sedimentary rocks over hundreds of millions of years.”

Source: Coward & Weaver (eds), 2004. See ch. 2.
Linkages between climate change and other environmental issues

- Stratospheric ozone depletion
- Air quality
- Desertification
- Water
- Biodiversity
- Forestry

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Variation in CO$_2$ at different time scales

- CO$_2$ levels (pCO$_2$) have varied due to natural processes (e.g. volcanoes, tectonics).
- Past $\Delta$ pCO$_2$ have caused climate change (↓ cooler; ↑ warmer).
- Current rate of $\Delta$ pCO$_2$ is $>$ than in the past.
## GHGs affected by human activity

<table>
<thead>
<tr>
<th></th>
<th>CO₂ (ppm)</th>
<th>CH₄ (ppb)</th>
<th>N₂O (ppb)</th>
<th>CFC-11 (ppt)</th>
<th>HFC-23 (ppt)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-industrial</strong></td>
<td>~280</td>
<td>~700</td>
<td>~270</td>
<td>zero</td>
<td>zero</td>
</tr>
<tr>
<td>atmos. conc.</td>
<td>(180-300)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>1998</strong></td>
<td>365</td>
<td>1745</td>
<td>314</td>
<td>268</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>(380)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>(2005)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rate of change</strong></td>
<td>1.5</td>
<td>7.0</td>
<td>0.8</td>
<td>-1.4</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>ppm/yr</td>
<td>ppb/yr</td>
<td>ppb/yr</td>
<td>ppt/yr</td>
<td>ppt/yr</td>
</tr>
<tr>
<td><strong>Atmospheric</strong></td>
<td>5 - 200</td>
<td>12</td>
<td>114</td>
<td>45</td>
<td>260</td>
</tr>
<tr>
<td>lifetime (yrs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* pre-1860s

† last 650,000 yrs

© IPCC – Climate change 2001: Synthesis report.
Canadian sources of GHGs

- fossil fuels as an energy source the primary source of GHGs in western society
- Canada one of the top GHG sources, per capita & national (USA #1)
  - cold winters require heating
  - A/C in summer
  - big cars, SUVs & pick-up trucks

74.4% from fossil fuel:
- ~25% vehicles, most from power generation
GHGs – not just carbon dioxide

GHGs vary in concentration and the amount of heat absorbed per molecule of gas.

1. Fluorocarbons
2. Water vapour
3. Nitrous oxide
4. Methane
5. Carbon dioxide

© Canada’s Greenhouse Gas Inventory 1990-2002
Indicators of the human influence on the atmosphere during the Industrial era

- Carbon Dioxide concentration
- Nitrous Oxide concentration
- Methane concentration
- Sulfate aerosols deposited in Greenland ice

© 2001, IPCC / WMO
Change in methane abundance

Last 1000 Years

Global average and deseasonalised methane abundance 1983 - 1999

Annual Growth Rate
Anthropogenic and natural forcing of the climate for the year 2000, relative to 1750

Global mean radiative forcing (Wm⁻²)

Warming

- Greenhouse gases
  - Halocarbons
  - N₂O
  - CH₄
  - CO₂

- Tropospheric ozone
- Black carbon from fossil fuel burning
- Mineral Dust
- Aviation (Contrails, Cirrus)
- Solar

Cooling

- Stratospheric ozone
- Sulphate
- Organic carbon from fossil fuel burning
- Biomass burning
- Land use (albedo only)
- Aerosol indirect effect

The height of a bar indicates a best estimate of the forcing, and the accompanying vertical line a likely range of values. Where no bar is present, the vertical line only indicates the range in best estimates with no likelihood.

LEVEL OF SCIENTIFIC UNDERSTANDING

High Medium Medium Low Very low Very low Very low Very low Very low Very low Very low
Temperature is naturally variable at several scales.

- decades
- millennia &
- geological (ice ages & longer)
- $\Delta T^\circ$ last 60 yrs exceeds past 1000 yrs
Sources of climate variability (forcings)

- GHG levels (volcanoes & forest fires emit GHGs and also produce dust)
- Solar output varies (sunspot activity)
- Orbital changes (earth’s distance from the sun; axial tilt)
- El niño / la niña
Comparison between modeled and observations of temperature rise since the year 1860

(a) Natural forcing only

(b) Anthropogenic forcing only

(c) Natural + Anthropogenic forcing

Model results
Observations

© 2001, IPCC / WMO
Mann et al. 1998;

Effects of climate change

Some of the expected consequences of climate change are already being observed.

1. Receding mountain glaciers.
2. Early and longer break-up of Arctic & Antarctic sea ice.
3. Rising sea level.
4. Plants flowering earlier (earlier spring).
5. The 1st two have affected sea levels, but also wildlife populations.
The annual sea level at Charlottetown (PEI) between 1911 and 1998 above the lowest expected low tide level.

- Charlottetown (PEI) is seriously threatened by rising sea levels.
- Its historic core lies just a few m a.s.l., and over the past 100yrs the city’s average sea level rose by ~ 30 cm.
- ~20 cm probably due to local sinking of the land after the last ice age.
- rest can be linked to global sea level changes resulting from a warmer climate.
The development of climate models, past, present and future

- Mid-1970s: Atmosphere, Land surface, Ocean & sea-ice
- Mid-1980s: Atmosphere, Land surface, Ocean & sea-ice
- Early 1990s: Atmosphere, Land surface, Ocean & sea-ice, Sulphate aerosol
- Late 1990s: Atmosphere, Land surface, Ocean & sea-ice, Sulphate aerosol, Non-sulphate aerosol
- Present day: Atmosphere, Land surface, Ocean & sea-ice, Sulphate aerosol, Non-sulphate aerosol, Carbon cycle
- Early 2000s?: Atmosphere, Land surface, Ocean & sea-ice, Sulphate aerosol, Non-sulphate aerosol, Carbon cycle, Dynamic vegetation, Atmospheric chemistry

© 2001, IPCC / WMO
Diagnostic Plots from CRCM
Change in screen (2m) temperature in 2040-49 vs. 1975-84 (°C)

DJF (winter)  
JJA (summer)
Diagnostic Plots from CRCM
Change in precipitation in 2040-49 vs. 1975-84 (mm/day)

DJF (winter)  JJA (summer)

© 2003, Canadian Centre for Climate Modelling & Analysis / Environment Canada
GCMs forecast a median annual increases of 2 to 5°C and 2-12% in precipitation; with the exception of a few scenarios for the 2020s, all models forecast climates that outside the range of natural variability.

- Increase in temp. and precipitation mostly in winter and spring in both forest and grassland regions, with increases of close to 4°C and 15% in winter.
• Changes in the availability of water resources represent the most serious climate risk.

• Lower summer stream flows, lake levels, retreating glaciers;
  • increasing soil and surface water deficits, as more water is lost by evaporation.

• Higher forest, grassland & crop productivity from increased heat and CO₂ limited by available soil moisture.
• Major ecosystem changes are expected.

• Most visible in isolated forests and forest fringe areas.
  - Cypress Hills and Moose Mtn (SK), Spruce Woods (MB), Turtle Mtn (MB, ND).
  - Trees will give way to shrub or grassland landscapes.
  - Major loss of forests in the southern boreal forest is possible.

• We will see new ecosystems develop.

Soil moisture: light blue to red excludes conifers.
Consequences in Canada

Changes in forest & grassland boundaries due to doubling of CO$_2$

- reduction in tundra;
- loss of boreal forest across much of the Prairie provinces;
- expansion of semi-arid areas & grasslands, and;
- expansion of temperate deciduous forests.

Dearden & Mitchell, 2005
## Consequences in Canada

- “(January) Average temperatures 10°C warmer than normal.”

<table>
<thead>
<tr>
<th>place</th>
<th>Jan. 2006</th>
<th>Year of 1st record</th>
<th>30 yr mean (1971-2000)</th>
<th>anomaly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brandon</td>
<td>−7.3°C</td>
<td>1941</td>
<td>−17.9°C</td>
<td>↑ 10.6°C</td>
</tr>
<tr>
<td>Winnipeg</td>
<td>−7.5°C</td>
<td>1938</td>
<td>−17.8°C</td>
<td>↑ 10.3°C</td>
</tr>
<tr>
<td>Dauphin</td>
<td>−7.4°C</td>
<td>1942</td>
<td>−17.3°C</td>
<td>↑ 9.9°C</td>
</tr>
<tr>
<td>The Pas</td>
<td>−11.2°C</td>
<td>1943</td>
<td>−20.6°C</td>
<td>↑ 9.4°C</td>
</tr>
<tr>
<td>Thompson</td>
<td>−17.3°C</td>
<td>1967</td>
<td>−24.9°C</td>
<td>↑ 7.6°C</td>
</tr>
<tr>
<td>Churchill</td>
<td>−21.5°C</td>
<td>1943</td>
<td>−26.7°C</td>
<td>↑ 5.2°C</td>
</tr>
</tbody>
</table>
Consequences in Canada

- 1901-1997 the *average flowering date shifted ~26 days* – early May to early April.
- *Warmer and earlier springs on the Prairies.*
- During the 20th Century *daily spring high T°C increased by > 2°C*, and overnight lows increased even more.
- The earlier flowering of the trembling aspen in Edmonton *may have been in part due* to an *‘urban effect’* (or *‘heat island’*) – greater urban warming than in nearby rural areas because Edmonton has less green space and more asphalt and buildings.
Consequences in Canada

- Seals and polar bears need sea ice to breed or to hunt.
- The extent and persistence of Arctic sea ice is affected by a number of factors, but mainly air temperature.

Seal pups are born on the ice and must stay there until they can swim. In early 2002, many harp seal pups were lost in the Gulf of St. Lawrence when a mild winter resulted in a lack of sea ice.
• Permanent sea ice doesn’t melt in summer.
• has decreased by 25% since 1969.
• only 25-year record, so some uncertainty whether due to climate change or natural variation … but seems to be accelerating.
Consequences in Canada

- The decline since the early 1980s appears to be caused by the trend towards earlier breakup of the sea ice (previous slide).
- Related to a 0.2–0.3°C increase in spring T°C per decade since 1950.
- Only 25-year record, so some uncertainty whether due to climate change or natural variation.

The body condition index measures the relationship between weight & body length. It provides good evidence of the general health of polar bears.
Consequences in Canada

- The average freeze-up date for Lake Simcoe (ON) is about 13 days later than it was 140 years ago, and the average break-up date is about 4 days earlier.
- For Swift Current Creek (SK) freeze-up is now about 24 days later and break-up about 14 days earlier than 115 years ago.
- These results are what might be expected from the temperature record of the past century, which shows more warming in southern Saskatchewan than in southern Ontario.
Consequences in Canada

- Winter roads rely on permafrost & lake ice
- Shifting vegetation zones
  - Loss of tundra, change in resource base for Arctic people
  - Loss of boreal forest / forest ‘islands’ in Prairies?
- Pests / new species further north
  - e.g., pine bark beetle in BC
  - New diseases / disease vectors (e.g., malaria)
- Water flowing down rivers (e.g., Saskatchewan R)
  - dependent on glacial melt and Rockies snow-pack / effect of erratic rainfall patterns (can’t rely on flows)
  - Water-supply AND hydroelectricity
- North-west passage
  - geopolitical tensions, cost of sovereignty & sea route
Consequences for North America

• US plant hardiness zones were adjusted in Dec. 2006 to compensate for climate change since the 1990 maps were made (see National Arbor Day Foundation website)
• Much of Illinois, Indiana & Ohio have shifted from Zone 5 to 6.
Summary

• Climate is naturally variable, and can sometimes shift dramatically within a few hundred or thousand years (climate change is not ‘new’).
  ❖ Past climate change is linked to ↑↓GHGs and other forcings.
  ❖ However, over the past 60-100 years, the rate at which climate has been changing appears to exceed the natural rate of change.
• Scientific evidence for global climate change includes:
  ❖ increasing concentrations of greenhouse gases (CO₂, CH₄, NOₓ, CFCs) in the atmosphere due to human activity;
  ❖ shrinking glaciers, sea ice & snow cover throughout the world;
  ❖ and increases in sea level.
• Climate models are used to explore past and present climate trends.
  ❖ There are many limitations associated with the models, and much uncertainty under different scenarios.
• The impacts of climate change will be variable around the globe.
  ❖ Impacts are already being felt in the Canadian Prairies and Arctic.
  ❖ Many US states have shifted at least one full plant hardiness zone. Some areas around the US have even warmed two full zones.
Information Sources

- Intergovernmental Panel on Climate Change: 3rd Assessment Report - [http://www.grida.no/climate/ipcc_tar/](http://www.grida.no/climate/ipcc_tar/)
- National Arbor Day Foundation (USA). [http://wwwarborday.org/media/mapchanges.cfm](http://wwwarborday.org/media/mapchanges.cfm)
- NOAA (USA) - [http://www.ncdc.noaa.gov/oa/climate/climateextremes.html](http://www.ncdc.noaa.gov/oa/climate/climateextremes.html)
- Paleoclimates and global warming: FAQs - [http://www.brighton73.freeserve.co.uk/gw/paleo/paleoclimate.htm#ghg_cause](http://www.brighton73.freeserve.co.uk/gw/paleo/paleoclimate.htm#ghg_cause)