2.0 AIR QUALITY, CLIMATE AND CLIMATE CHANGE

2.1 INTRODUCTION TO AIR QUALITY AND CLIMATE CHANGE

The Arctic Climate Impact Assessment (ACIA) is a comprehensively researched, fully referenced and independently reviewed evaluation of climate change and its impacts for the region and for the world. The Overview Report entitled "Impacts of a Warming Arctic" (November 2004) concludes that:

"The Arctic is now experiencing some of the most rapid and severe climate change on Earth. Over the next 100 years, climate change is expected to accelerate, contributing to major physical, ecological, social and economic changes, many of which have already begun. Changes in arctic climate will also affect the rest of the world through increased global warming and rising sea levels."

The variability of the earth's climate has been the subject of much debate over the past decade as a result of the observation that emissions of air pollutants (greenhouse gases and ozone depleting substances) from human activity have had an observable effect on the chemical composition of the earth's atmosphere. It has been suggested that this change in chemical composition may have already produced simultaneous physical changes in the atmosphere with respect to meteorological variables such as temperature, precipitation and cloud cover, and that even greater changes can be expected over the next century as the atmospheric concentrations or loadings resulting from anthropogenic emissions continue to increase.

Air pollution is caused by both natural and anthropogenic (human-induced) emission sources. Pollution is defined as "the presence in the atmosphere of substances that are toxic, irritant, or otherwise harmful to people or damaging to vegetation, animals, or property." This pollution has a number of manifestations on various scales: regional and local – smog and acid rain; continental – transport of persistent toxics (e.g., mercury and PCBs) and global - climate change, ozone layer depletion.

A principal source of pollution is the combustion of fuels to produce heat and/or energy. Major sources of anthropogenic emission sources include:

- transportation;
- stationary fuel combustion (e.g., electrical utilities, industrial and residential heating);
- industrial processes (e.g., mining, oil and gas extraction, solvent use); and
- other (e.g., forest fires, agriculture).

Emission sources can have three different configurations, which have significantly different atmospheric dispersion characteristics:

- point sources (emissions from well-defined stacks/exhausts or vents within industrial plants and electric utilities);
- line sources (emissions from vehicles along a highway); and
- area or volume sources (emissions that come from a relatively large area such as wind-blown dust, emissions from furnaces in a residential area).

Factors that affect the concentration of air pollutants in the atmosphere include:

- the geometric configuration (e.g., point/line/area source), and geography in the vicinity of the emission site (e.g., lakes, valleys);
- the total amount of pollutant emitted;
- the meteorological conditions; and
- the amount of pollutant emitted.

Air quality is determined by the concentrations of pollutants in the atmosphere, which are, in turn, affected by the dispersion of pollutants from emission sources. Emission sources can be primary or secondary, where primary sources include stack emissions and volatilization from equipment, and secondary sources generally refer to the reemission of contaminants from large environmental reservoirs. Secondary sources are very important for legacy POPs, like PCBs, and help explain why they will be with us long after their production has ceased.

Weather plays an important role in the dispersion of air pollutants. Meteorology is a vital part of predicting both the current air quality as well as developing any strategies to improve the future situation. The parameters of particular importance are wind speed and direction, and atmospheric stability. The amount of sunshine also directly influences photochemical production of secondary pollutants.

Air quality issues such as regional scale smog, acid deposition, and the concentration of hazardous air pollutants in the lower levels of the atmosphere are linked to climate through temperature, precipitation, humidity, solar radiation, cloudiness and the large scale circulation of the atmosphere which acts to re-distribute air pollutants through long range transport.

The following sections describe the Air Quality, Climate and Climate Change in the Northwest Territories (NWT), with particular emphasis on:

- current monitoring/research programs and data;
- trends in the data and the significance of these trends; and
- information gaps and recommendations for additional monitoring/research.

2.2 AIR QUALITY

2.2.1 Introduction to Air Pollutants

Emissions of air pollutants result in environmental and health impacts through issues such as smog and acid rain. Smog refers to a noxious mixture of air pollutants - including vapours, gases and particles - that can often be seen as a haze in the air. The two main ingredients of smog that affect our health are ground-level ozone and fine airborne particles. Ground-level ozone is a colourless and highly irritating gas that forms in the lower atmosphere. It is called a “secondary” pollutant because it is produced when two primary pollutants - nitrogen oxides (NO_x) and volatile organic compounds (VOC) - react in sunlight through a process known as photochemistry.

Airborne particles are microscopic solid and liquid particles that remain suspended in the air for varying lengths of time. Primary particles are predominantly produced by fuel combustion, industrial processes, as well as natural processes such as wind blown dust. Secondary particles are formed in the atmosphere by gas-to-particle conversion processes of originally emitted gaseous compounds.

Sulphur dioxide (SO_2) is a colourless gas that can be chemically transformed into acidic pollutants such as sulphuric acid and sulphates (sulphates are a major component of fine particles). The main sources of airborne SO_2 are coal-fired power generating stations and non-ferrous ore smelters. Sulphur dioxide is also one of the main causes of acid rain, which can damage crops, forests and whole ecosystems.

Nitrogen oxides (NO_x) are nitrogen-oxygen compounds that include nitric oxide (NO) and nitrogen dioxide (NO_2). NO_2 is a toxic, irritating gas emitted by all combustion processes. It is both a separate component of smog and a pollutant that contributes to the formation of ground-level ozone and particulate matter. In combination with water, NO_2 can form the nitric acid component of acid rain.

Volatile Organic Compounds (VOCs) are carbon-containing gases and vapours such as gasoline fumes, with the major exceptions of carbon dioxide, carbon monoxide, methane and chlorofluorocarbons. Anthropogenic sources of VOCs are mainly fuel combustion and the evaporation of liquid fuels and solvents. Carbon monoxide (CO) is a colourless and odourless gas that is a product of incomplete combustion.

The Environmental Protection Service (EPS) of the Department of Resources, Wildlife and Economic Development (RWED; now Environment and Natural Resources (ENR)) monitors air quality in the NWT. The network consists of four monitoring stations located in Yellowknife, Fort Liard, Norman Wells and Inuvik. In 2003 the NWT air quality monitoring network was significantly upgraded and expanded. In Yellowknife and Fort Liard, the existing equipment was relocated to climate-controlled trailers, some aging monitors were replaced and additional monitors were added to measure other pollutants and meteorological parameters. New stations were installed in Norman Wells and Inuvik, using climate-controlled trailers, housing state-of-the-art continuous monitoring equipment. Pollutants monitored vary by station but include sulphur dioxide (SO_2), hydrogen sulphide (H_2S), fine particulate matter ($PM_{2.5}$), ground level ozone (O_3), carbon monoxide (CO) and nitrogen oxides (NO_x), as well as wind speed, wind direction and temperature (GNWT 2004).

The GNWT has adopted a number of ambient concentration limits for the protection of air quality in the NWT. The limits for SO_2, ground-level ozone, TSP and $PM_{2.5}$ are listed in the *Guideline for Ambient Air Quality Standards in the Northwest Territories* (RWED 2002). These standards are used in the assessment of air quality monitoring data as well as in determining the acceptability of emissions from proposed and existing developments. Where NWT standards are not available for a particular pollutant the Canadian National Ambient Air Quality Objectives (Environment Canada 1981) or limits established in other jurisdictions are used.

The “2002/2003 Northwest Territories Air Quality Report” (GNWT 2004) concludes that overall, the air quality in the NWT continues to be good. With increased development it is important to continue monitoring to ensure that there are no negative impacts on air quality. RWED is continuing to explore opportunities to upgrade and expand the existing air quality program.

2.2.2 Air Quality Indicators

The key indicators of air quality addressed in this initial SOE and the rationale for their selection are presented in the Table 2.2-1.

TABLE 2.2-1
RATIONALE FOR SELECTION OF INDICATORS
FOR AIR QUALITY VALUED COMPONENT

Valued Component	Key Indicators*	Rationale
Air Quality	• **Particulate Matter concentrations**	• Primary air quality contributor to local human health issues • Emitted from local sources • Monitored by GNWT and private companies at various locations
	• **SO_2/NO_x concentrations**	• Emitted and measured locally • Potential local health and ecosystem effects • Also transported from long-range sources • Chemically converted in the atmosphere to acid rain • Precursor to ground level ozone

*key indicators are in bold type.

2.2.2.1 Particulate Matter

Airborne particulate matter consists of particles ranging in size from 0.005 to 100 µm in diameter. For convenience in air quality assessment and regulation, the various size fractions are generally subdivided into several distinct size categories. These include total suspended particulate matter (TSP) consisting of all particles with a mean diameter less than 30 µm, inhalable particulate matter (PM_{10}) consisting of particles with a mean diameter less than 10 µm, and fine particles ($PM_{2.5}$) consisting of particles with a mean diameter less than 2.5 µm. In part, the distinctions between these size categories reflect the changing focus of regulations over the past three decades from coarser to finer size fractions of particulate matter.

Monitoring levels of inhalable particulate matter (PM_{10}) is important because inhaling particulates can aggravate asthma and other cardiac and respiratory disorders, damage plants and cause corrosion and soiling of buildings and cars. Fine particulate matter ($PM_{2.5}$) consists of solid or liquid particles with diameters less than or equal to 2.5 micrometres (1 micrometre = 1 millionth of a metre) in size. They can penetrate deep into the lungs and pose the highest risk to human health.

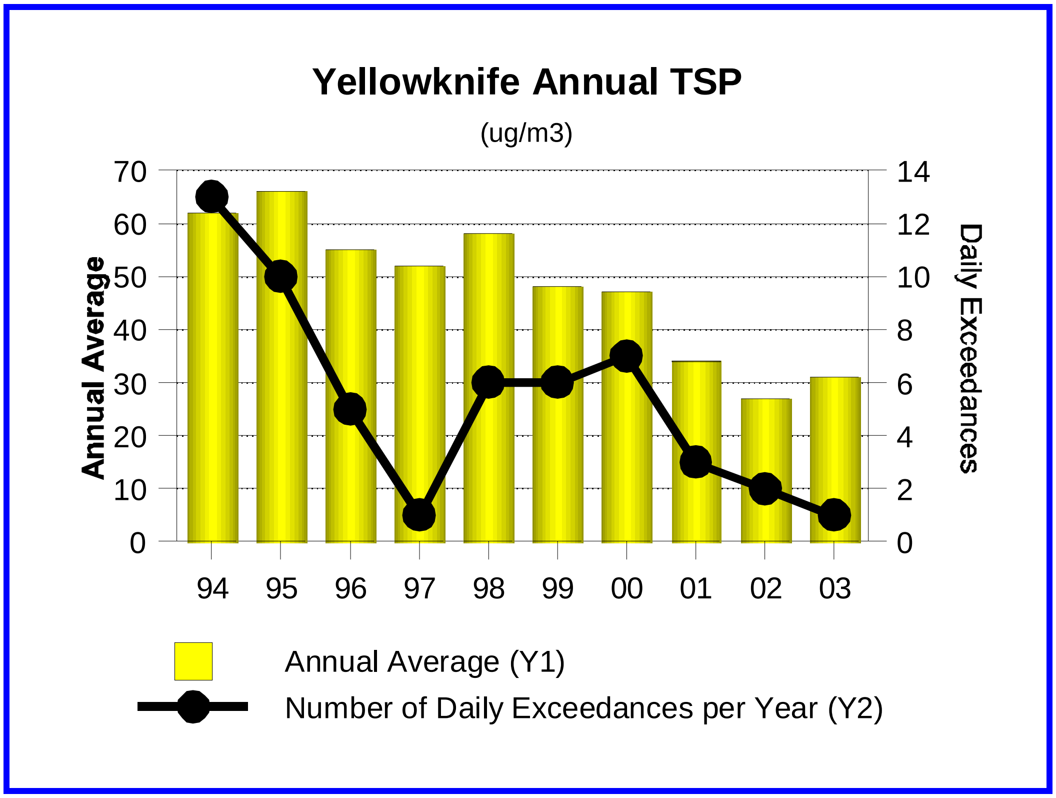
i) What is Being Measured?

TSP, PM_{10} (since 2000) and $PM_{2.5}$ (since 1999) are measured in Yellowknife. In mid-November 2003, a Beta Attenuation Monitor (BAM) was installed in Fort Liard to provide continuous monitoring of $PM_{2.5}$. A similar monitor was installed in Inuvik in December 2003.

ii) What is Happening?

Figure 2.2-1 shows the trend in annual average TSP levels in Yellowknife over the last decade. The graph shows a downward trend, with a slight increase in 2003, although the level of 31 $\mu g/m^3$ is well below the NWT annual standard of 60 $\mu g/m^3$. The line in Figure 2.2-1 shows the number of times during the year that the NWT 24-hour TSP standard (120 $\mu g/m^3$) was exceeded. The number of exceedances in 2003 continued the downward trend with only 1 of 52 samples exceeding the 24-hour standard.

FIGURE 2.2-1
ANNUAL AVERAGE TSP IN YELLOWKNIFE
AND NUMBER EXCEEDANCES OF DAILY STANDARD



Source: Figure 1 from 2002/2003 Northwest Territories Air Quality Report (Veale 2005).

Maximum 24-hour PM_{10} concentrations coincide with high April TSP values, confirming that PM_{10} concentrations are heavily influenced by the effects of road dust. Low PM_{10} concentrations are seen during the winter months when snow cover suppresses wind blown dust.

The annual average of $PM_{2.5}$ in Yellowknife has remained consistently low, ranging from 3 to 5 $\mu g/m^3$ since monitoring began in 1999. In 2003, the maximum 24-hour $PM_{2.5}$ values occurred between July 25 and August 6, and coincided with forest fires south of Great Slave Lake. Limited sampling in 2003 at Fort Liard and Inuvik showed very low concentrations of $PM_{2.5}$.

iii) Why is it happening?

Since the early 1990s, dust conditions in Yellowknife have improved, largely due to the City of Yellowknife's efforts to clean roads throughout the spring and summer, as well as ongoing paving of gravelled areas.

iv) What does it mean?

The greatest source of TSP in Yellowknife is dust from roads, especially in the spring. Forest fires, mining activities and combustion products from vehicles, heating and electricity generation also contribute to TSP levels. PM_{10} concentrations are also largely influenced by road dust. $PM_{2.5}$ concentrations are consistently low, with the greatest short-term influences being smoke from forest fires and extreme spring dust events.

v) What is being done about it?

The data emphasize the need for diligent and timely road sweeping by the City of Yellowknife during spring to minimize road dust sources. Ongoing road maintenance (e.g., sweeping and paving of dirt roads) and dust suppression activities on exposed areas throughout the summer are also important.

To address the health impacts of fine particulate matter, $PM_{2.5}$ monitors have been installed in Yellowknife, Fort Liard and Inuvik. A fourth monitor was installed in Norman Wells in 2004. PM_{10} concentrations are only measured at Yellowknife. It would be beneficial to complement the fine particulate monitoring being conducted at the other locations with PM_{10} monitors, in order to capture the coarser fraction of fine particles, which are associated with different sources and effects.

At the national level, the Canadian Council of Ministers of the Environment (CCME) endorsed Canada-Wide Standards (CWSs) for ground-level ozone and fine particulate matter ($PM_{2.5}$) in 2000. These standards set targets for ambient concentrations that have to be achieved by the year 2010. Slightly coarser particulate matter, particles with diameters less than or equal to 10 micrometres (PM_{10}), has been added to the Toxic Substances List under the *Canadian Environmental Protection Act, 1999.* (Environment Canada http://www.ec.gc.ca/soer-ree/English/Indicator_series/)

vi) What are the Information Gaps?

Current monitoring data (from the four operating stations) will provide a good baseline for air quality in the NWT, for future oil and gas and other industrial development projects. The four permanent stations have significant distances between them. A fifth station would be very valuable within the vicinity of Fort Simpson/Wrigley, to capture potential air quality impacts from pipelines/compressors in the area.

The mandate of GNWT's air quality monitoring network is the protection of community health. GNWT does not have jurisdiction over industrial developments that are not located on community lands, and therefore has no enforcement capability in the event of AQ impacts from such developments.

2.2.2.2 SO_2/NO_x Concentrations

Sulphur dioxide (SO_2) can cause breathing difficulties, is toxic to vegetation and is a precursor of acid rain causing acidification of natural ecosystems and damage to buildings. Measuring sulphur dioxide (SO_2) is important because of the health effects caused by exposure. SO_2 is linked to an increase in daily respiratory hospital admissions and an increase in cardiac and respiratory mortality.

Nitrogen oxides are toxic to plants and nitrogen dioxide can cause breathing difficulties in humans. Nitrogen oxides are one of the main precursors of ground level ozone, which can also affect breathing and damage crops and vegetation. Deposition of oxidized nitrogen causes acidification and eutrophication.

i) What is Being Measured?

Continuous monitoring of SO_2 has been conducted in Yellowknife since 1992. Significant oil and gas development in the Fort Liard region prompted the establishment of an air quality monitoring program in 2000. SO_2 and H_2S analysers were installed in March and October, respectively. In March 2003, both analysers were relocated to a climate-controlled trailer to provide improved operating conditions. In February 2003, a climate-controlled trailer housing continuous SO_2 and H_2S analysers was installed in Norman Wells. A similar station was brought on-line in September 2003 in Inuvik.

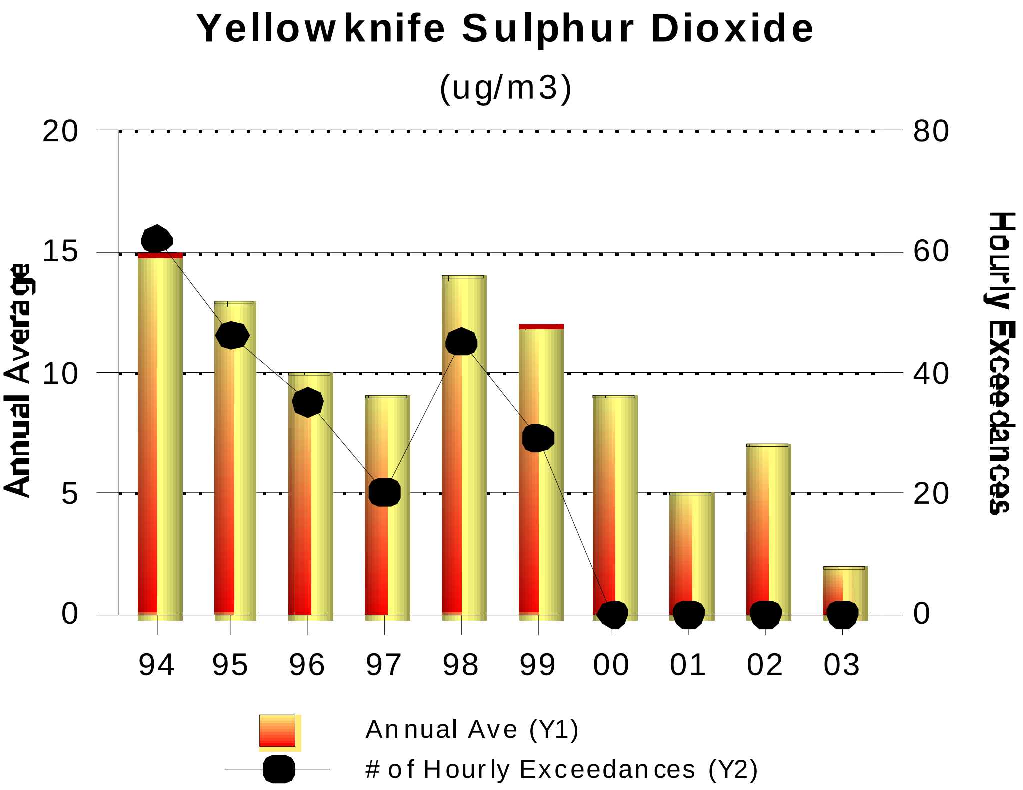
A NO_x analyser was installed in Yellowknife in November 2003. A NO_x analyser was added to the Inuvik station in mid-October 2003.

ii) What is happening?

Figure 2.2-2 shows the trend in annual SO_2 concentrations measured over a ten-year period in Yellowknife. The line shows the number of times in each year that the NWT 1-hour standard 450 $\mu g/m^3$) was exceeded. The number of exceedances have fallen to zero since the closure of Giant Mine in 1999. The annual averages indicate only background levels of SO_2 exist in ambient air in the Yellowknife region.

SO_2 concentrations measured in Fort Liard are within the expected range of background values and there appears to be no impact on community air quality from oil and gas development in the area, at the present time. SO_2 concentrations measured in Norman Wells and Inuvik in 2003, were also well below the NWT ambient standards.

FIGURE 2.2-2
ANNUAL AVERAGE SO_2 IN YELLOWKNIFE
AND NUMBER OF EXCEEDANCES OF HOURLY STANDARD



Source: Figure 10 from 2002/2003 Northwest Territories Air Quality Report (Veale 2005).

The limited NO_x data collected in 2003 indicate no exceedances of the 1-hour (400 $\mu g/m^3$) and 24-hour (400 $\mu g/m^3$) national acceptable limits for NO_2 More detailed information and analysis should be available in the 2003/2004 Air Quality Report, which is expected to be released in June 2005.

iii) Why is it Happening?

Following the closure of Giant Mine in late October 1999, SO_2 levels in Yellowknife have decreased significantly. The concentrations measured in 2003 reflect naturally occurring SO_2, usually in the range of 3 to 4 µg/m^3, and small amounts from the burning of fossil fuels. Similar background levels were noted in Fort Liard, Norman Wells and Inuvik.

iv) What does it mean?

Current SO_2 concentrations measured at four stations in the NWT indicated background (naturally occurring) levels of SO_2. Preliminary measurements from the recently established NOx analysers indicated similar background levels. Longer monitoring records are required to establish trends in these monitoring data. These stations will serve to monitor potential air quality impacts from proposed industrial developments that will be operating in the future.

v) What is being done about it?

The EPS has acquired a new computerized data management and warehousing system, which is intended to automatically download data from the monitoring network on an hourly basis, perform a series of validity checks, calculate the appropriate data averaging periods and store the data. The system also has the capability to post the calculated averages to a web page, providing public access to almost real time air quality data for each monitoring location (GNWT 2004).

Since the Acid Rain Annex was developed as part of the original Air Quality Agreement in 1991 to address SO_2 and NO_x emissions, the United States and Canada have taken significant actions to address acid rain. This Annex specifically targeted emissions from electric power generation, with the intention of protecting visibility, preventing air quality deterioration in clean areas, and monitoring emissions to ensure reductions. Both countries have established objectives for emission limitations or reductions, programs to implement these objectives, as well as timetables for implementation.

On June 23, 1999, the federal government passed regulations limiting the amount of sulphur in gasoline. In 2005, low-sulphur gasoline (that is gasoline with an average sulphur level of less than 30 mg/kg) is required throughout Canada. As an interim step, gasoline with an average sulphur level of not more than 150 mg/kg was required in 2002. The final level reduces the sulphur content of gasoline by more than 90% from current levels.
(http://www.ec.gc.ca/energ/fuels/regulations/sulreg_e.htm)

vi) What are the information gaps?

Current monitoring data (from the four operating stations) will provide a good baseline for air quality in the NWT, for future oil and gas development projects. The four permanent stations have significant distances between them. A fifth station would be very valuable within the vicinity of

Fort Simpson/Wrigley, to capture AQ impacts from pipelines/compressors in the area. The air quality monitoring infrastructure is established. Future improvements should include the monitoring of additional contaminants such as VOCs/methane for oil and gas developments (Veale 2005).

2.2.3 Other Air Quality Issues

The movement of air currents in the Northern Hemisphere is such that the air gravitates towards the Arctic and eventually carries pollutants into Northern Canada. Subsequently, these pollutants become trapped in the cold temperatures and can enter the food chain. Local sources of air pollution in the Northwest Territories include electrical power generation from diesel engines, residential emissions from home heating, motor vehicle emissions, and dust from gravel roads.

2.2.3.1 POPs and Heavy Metals

The Northern Contaminants Program (NCP) was established in response to studies that showed the presence of contaminants in the Arctic ecosystem. Many of these contaminants have no Arctic sources and yet some are found at high levels in animals at the top of the Arctic food chain and in humans. The three main contaminants groups of concern are persistent organic pollutants (POPs), heavy metals and radionuclides.

The NCP is managed by the Department of Indian Affairs and Northern Development in partnership with other federal departments (Health, Environment, Fisheries and Oceans), the three territorial government departments, Aboriginal organizations (Council of Yukon First Nations, Dene Nation, Inuit Tapiriit Kanatami, Inuit Circumpolar Conference) and university researchers.

Phase I of the NCP (1991-1997) focused on determining the main sources of contaminants and their transport pathways and fate in the Arctic, as well as their levels and spatial and temporal distribution within Arctic ecosystems and humans. The results were used in international negotiations to control contaminants. Education and communication of contaminants information with Northerners was a major emphasis of Phase I, led by the Aboriginal organizations. The NCP produced an extensive assessment in 1997, entitled Canadian Arctic Contaminants Assessment Report.

The NCP Phase II was a five-year program (1998-2003) that funded research on northern contaminants issues, in addition to supporting the Centre for Indigenous Peoples' Nutrition and Environment (CINE) and the participation of Aboriginal organizations in the NCP. The emphasis of Phase II was on expanding human health research, developing effective community dialogue, and continuing work on international agreements to control contaminants.

The NCP works closely with the Arctic Council's Arctic Monitoring and Assessment Programme (AMAP). The goal of this cooperative program among the eight Arctic countries, Arctic Aboriginal organizations and a number of observer countries and organizations is to monitor and assess anthropogenic pollution in the circumpolar Arctic. The results of NCP projects represent the main Canadian contribution to AMAP, and those of NCP Phase I formed an integral part of the comprehensive AMAP Assessment Report: Arctic Pollution Issues, published in 1998.

In March 2003 the second Canadian Arctic Contaminants Assessment Report, reporting on research under phase 2 of the NCP, was published. Phase 2 results also made a substantial contribution to the second AMAP assessment reports published over the past three years.

NCP findings have provided substantiation for the calls for action on international controls of contaminants. POPs and Heavy Metals Protocols under the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CRTAP) have been signed by 36 countries, including Canada, since June 1998. Negotiations for a legally binding global instrument on POPs under the United Nations Environment Programme have now also been completed with the signing of the POPs Convention in Stockholm, Sweden on May 23, 2001. Both of these conventions entered into force in 2004.

i) Highlights of the Canadian Arctic Contaminants Assessment Report II

In general, the Canadian northern atmosphere contains lower levels of POPs and heavy metals than those found over most other circumpolar countries. Levels of most contaminants are declining slowly right across the circumpolar Arctic. However, it is still too early to tell whether mercury levels are increasing or decreasing. Most POPs are declining in the Canadian northern atmosphere, with the exception of dieldrin and endosulfan. Decreases in the hexachlorocyclohexanes (HCHs) and toxaphene are undoubtedly a result of international controls on their use. Lindane is expected to continue to be transported northward for some years from residues in Canada, France and China.

Several new contaminants not previously studied under the NCP are now being found in the Canadian northern atmosphere but it is still too early to tell whether levels are increasing. These include the brominated flame retardants, chlorinated paraffins and chlorinated phenols. The flame retardants are widely used and may be of concern in the future as they easily enter the food web. More research is required in this area.

The federal government now gives special attention to the ways in which northern Aboriginal children are exposed to contaminants, and to the levels and effects of these contaminants on their health. The NCP continues to provide direct input and direction to both the federal and NAFTA initiatives. NCP research played a significant role in the development of the domestic voluntary agreement to stop using lindane.

The Canadian Arctic Indigenous Peoples against POPs (CAIPAP) group was formed in 1997 to influence Canada's position in the UN/ECE LRTAP and UNEP Global POPs negotiations. The NCP Aboriginal Partners formed the members of (CAIPAP). CAIPAP participated actively and very successfully in the global POPs negotiations, due in part to the support of the NCP.

Summary of Recommendations

- It is important to monitor the levels of the new POPs in the physical environment, e.g., brominated flame retardants, chlorinated paraffins and chlorinated phenols.
- Continued research on the properties of contaminants will help identify which are more likely to travel to the Canadian North from southern sources.
- Older POPs should continue to be monitored in the atmosphere, as there is not enough data as yet to determine long-term trends.
- More work is needed on the routes taken by heavy metals (especially mercury) to the Canadian North.
- Continued research is required to assess the importance and nature of mercury depletion events.
- Studies on levels of contaminants in lake water and sediments should continue as these are very sensitive to changes in inputs from the atmosphere, runoff and rivers.
- Research is needed to increase understanding of the importance of microbes in removing contaminants from the physical environment.
- POPs in seawater should continue to be monitored, as ocean currents are now recognized as being more important transport routes than previously thought.
- The role of sea ice in moving contaminants from one part of the environment to another needs to be better understood – this is particularly important given climate change may change sea ice patterns.
- Research using radionuclides to "trace" ocean currents may provide information on the routes used by contaminants in seawater to reach the Arctic.
- More research on the properties of contaminants will provide useful information on what is likely to happen to them once they reach the Canadian North.
- Although snow is known to be important for bringing contaminants to the surface, more needs to be understood about how this happens, and what happens to the contaminants once they reach the surface.

- Climate change is expected to have a profound effect on the Canadian North and more research is needed to increase understanding of the effects of climate change on contaminants.
- Studies are needed on how melting permafrost will affect the flow of contaminants.
- It is important to look closely at the links between human behaviour worldwide (e.g., energy consumption, and international policies), and contaminants in northern Canada.

Global and regional gridded emissions inventories have been created for some OC pesticides such as HCH and toxaphene. Declines in the global use and emissions of technical HCH are consistent with observed declines of alpha- and gamma-HCH in Arctic air, results that are helping to refine global mass balance models. These results also provide strong evidence that international action to reduce global POPs use can have a direct impact on levels in the Arctic.

Decreasing atmospheric trends in most "legacy" persistent organic pollutants (POPs) over the last 5–10 years. The concentration of most POPs which were reviewed in the first CACAR and which have received international attention through the United Nations have been declining in Arctic air. Observations at Arctic monitoring stations, in particular at Alert, Nunavut, have confirmed this trend for POPs such as PCBs, DDT, chlordane, and HCH.

The observation of "new chemicals" in the Arctic abiotic environment. A new generation of POPs has been measured in Arctic air, seawater, and freshwater sediments that includes brominated flame retardants (in particular polybrominated diphenyl ethers, PBDEs), perfluorinated alkane compounds (PFA), short chain chlorinated paraffins (SCCPs) and polychlorinated naphthalenes (PCNs). Some pesticides currently used in the circumpolar countries were also identified: endosulfan, trifluralin and methoxychlor. PBDEs have concentrations that are rising. Unlike most other organochlorine pesticides, concentrations of endosulfan in Arctic air have not declined over the last 7 years.

Relatively stable atmospheric concentrations of anthropogenically derived heavy metals including copper, lead and zinc. Twenty-years of weekly mean concentrations of metals (not including mercury) in Arctic air reveal no significant increasing or decreasing trends for metals derived from anthropogenic sources.

ii) Mercury

Mercury is listed as a "toxic substance" under the Canadian Environmental Protection Act. It is a liquid heavy metal that can volatize into the air and be carried by the atmosphere all over the world. In Canada, airborne mercury emissions come mainly from coal-fired power plants in the United States and base metal smelting plants and incinerators in Canada.

Scientists have concluded that in Canada and the United States, mercury originates from both domestic and international sources and is deposited in sensitive ecosystems. Mercury is found in many lakes, streams, forests and fields. It can convert to a very toxic and bioaccumulative form known as methylmercury -- a substance that can affect both humans and wildlife. For example, methylmercury levels in traditional foods in northern Canada are rising above those established as acceptable by the World Health Organization.

Canada's actions on mercury include (http://www.ec.gc.ca/air/mercury_e.html):

a. The signing and ratification of an International United Nations Protocol, United Nations Economic Commission for Europe Convention on Long Range Transboundary Air Pollution, Heavy Metals Protocol, obliging Canada to control emissions of mercury, cadmium and lead from major stationary sources and some products.
b. The signing of the Phase II North American Regional Action Plan on Mercury by Canada, the United States and Mexico under the North American Commission for Environmental Cooperation on June 12, 2000. The Plan is an indication of North America's commitment to control mercury, and to demonstrate to other countries the need for global cooperation in dealing with long range transport of air pollutants.
c. The agreement by federal, provincial and territorial governments at the meeting of the Canadian Council of Ministers of the Environment in Quebec City on June 5 & 6, 2000 to ratify the Canada-wide Standard on Mercury, paralleling similar actions in the United States to minimize the risks from mercury in air emissions and products. Additional Canada-wide Standards were also accepted in principle to reduce emissions of mercury in fluorescent lamps and dental amalgam wastes.

Canada's continued implementation of mercury management options under the Canada/United States Great Lakes Bi-national Toxics Strategy in order to virtually eliminate mercury from human activities into the Great Lakes.

2.2.3.2 Stratospheric Ozone

The depletion of the stratospheric ozone layer in the past two decades has been mainly caused by the increase in emissions of chlorine- and bromine-bearing compounds such as chlorofluorocarbons (CFCs), bromofluorocarbons (halons), hydrochlorofluorocarbons (HCFCs), carbon tetrachloride, methyl chloroform and methyl bromide. In addition, however, emissions of gases such as methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) can have both direct and indirect effects on the ozone layer. Since the ozone layer is largely responsible for filtering out the solar UV-B radiation, projected long-term trends in decreasing concentrations of ozone in the atmosphere have led to concerns about potential future increases in skin cancers and cataracts, as well as concerns about ecological effects such as decreased primary production in terrestrial ecosystems, altered plant species composition, altered secondary chemistry with implications for herbivory, litter decomposition and biogeochemical cycles (Caldwell and Flint 1994)

In 2000, Canada signed the Ozone Annex under the 1991 Canada-U.S. Air Quality Agreement to reduce the flow of air pollutants across the Canada-U.S. border. Consequently, the Government of Canada announced a commitment of $120 million over 4 years as part of a 10-year program to invest in new measures to accelerate action on clean air by focusing on cleaner vehicles and fuels, initial measures to reduce smog-causing emissions from industrial sectors, improvements to the cross-country network of air pollution monitoring stations, and expansion of the public reporting on pollutant releases by industry.

2.2.3.3 Acid Deposition

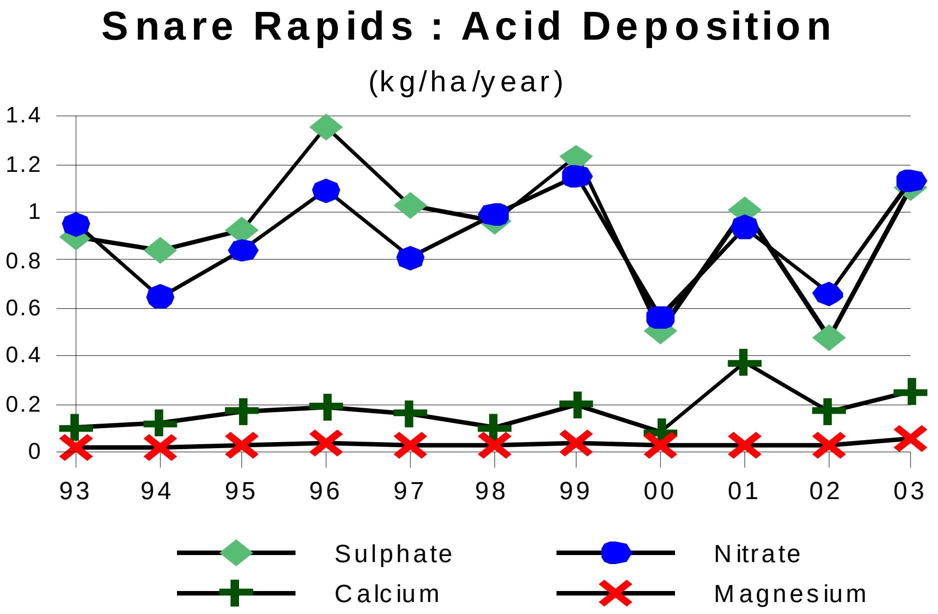
Acid deposition refers to the dry deposition of acidic compounds (in gaseous or particulate form), as well as the wet deposition of acidic compounds in rainwater, fogwater and snowfall. Since 1989, RWED has operated a Canadian Air and Precipitation Monitoring (CAPMoN) station at the NWT Power Corporation's Snare Rapids hydro site.

SO_2 and NO_x emissions can result in an increase in acidic compounds in the atmosphere, often in areas far removed from the original emission sources. The removal of these sulphur and nitrogen compounds through atmospheric washout is reflected in the increased activity (lower pH values) of precipitation. Calcium and magnesium ions, mostly from natural sources, act to neutralize acidity in precipitation. Assessment of acid precipitation is usually based on deposition to an area over a specified time period (e.g., kilograms per hectare per year, kg/ha/yr) (GNWT 2004).

Figure 2.2-3 shows the deposition rates of certain ions measured in Snare Rapids precipitation between 1993 and 2003. While calcium and magnesium deposition rates have remained relatively constant, both sulphate and nitrate deposition rates show an increase in 2003. However, these values are within the historical range for sulphate and nitrate, and reflect an annual variation noted in previous years. Sulphate and nitrate deposition rates remain well below levels that could cause an environmental effect in sensitive ecosystems (GNWT 2004).

GNWT's funding for this station may not be renewed in the new fiscal year due to budget constraints. This is the only acid precipitation station in Canada's North, and shutting it down will prevent detection of potential acid deposition effects from new oil and gas developments in the future (Veale 2005).

FIGURE 2.2-3
ANNUAL AVERAGE ACID DEPOSITION AT SNARE RAPIDS



Source: Figure 18 from 2002/2003 Northwest Territories Air Quality Report (Veale 2005).

2.3 CLIMATE

Climate is usually described in terms of the familiar elements that describe the weather. Temperature and precipitation are the essential indicators, but other parameters include sunshine, wind, cloud cover, atmospheric pressure, humidity and evaporation, to provide a more complete picture.

2.3.1 Climate Monitoring in Canada

Canada's national (atmospheric) Climate Network is, in practice, the composite of several rather distinct sub-networks:

- A Daily Temperature and Precipitation (T&P) Network, operated by cooperating agencies, volunteer and contract observers and including an increasing number of automatic stations;
- A Principal (Hourly) Network of automated and manned real-time reporting stations established primarily to support weather forecasting;
- An Upper Air (Radiosonde) Network, of manned stations to support weather forecasting;

- Supplementary Networks established to acquire observational data on variables such as:
    - Rate of Rainfall;
    - Wind Speed and Direction;
    - Ozone;
    - Evaporation (Pan);
    - Soil Temperature;
    - Sunshine;
    - Snow Cover/Depth;
    - Radiation;
- Air Quality and Precipitation Chemistry Networks.

2.3.2 Climate Indicators

The key indicators of climate that are addressed in this initial SOE and the rationale for their selection is presented in Table 2.3-1.

TABLE 2.3-1
RATIONALE FOR SELECTION OF INDICATORS
OF CLIMATE VALUED COMPONENT

Valued Component	Key Indicators*	Rationale
Climate	• **Temperature**	• *Long temperature record available in the North (50+ years)* • direct local impacts on humans and the ecosystem
	• **Precipitation**	• *reasonable precipitation record (not as reliable as temperature record)* • direct local impacts on humans and the ecosystem

*key indicators are in bold type.

2.3.2.1 Temperature

The near-surface temperature controls the reaction rate of contaminants as well as how fast the surface drys out. If the temperature is low, the moisture in the surface may stay there or it may even freeze, sealing the surface from the effects of wind erosion, thereby reducing wind-blown dust. Temperature near the surface also controls the buoyant component of turbulence (vertical motion). Heat from the earth's surface heats the air near the ground, causing it to rise. This mechanism reaches a maximum in the early afternoon, and a minimum near sunrise.

i) What is being measured?

Temperature records date back to about 1930 for most of the Canadian Arctic (some stations began in 19th century or early 20th century, e.g., Hay River, Fort Selkirk and Fort Simpson, Northwest Territories). Records from explorers, the Hudson's Bay company, and the gold rush are often sporadic, but offer information dating back several centuries (Kahl 1996). The stations in Canada's northern territories that have temperature records in the Historical Canadian Climate Database are widely and irregularly spaced (MSC 1999). Temperature records for the lower troposphere over the Arctic Ocean date back to 1950 (Kahl 1996). Climatic data is also measured at all Ecological Monitoring and Assessment Network (EMAN) sites in the NWT.

The Upper air monitoring program (conducted by Environment Canada since 1948) is comprised of instrumented weather balloons that are released twice daily from upper air stations at Fort Smith, Norman Wells and Inuvik to gather quantitative information about the vertical structure of the atmosphere over the NWT. The data include atmospheric pressure, temperature, moisture and winds from ground level to about 15 km.

The Global Energy and Water Cycle Experiment (GEWEX) is an international effort of the World Climate Research Programme aimed at improving our understanding and prediction of the water cycle and its relationship to climate. As a major contribution to GEWEX, the Mackenzie GEWEX Study (MAGS) focuses on understanding and modeling the flows of energy and water into and through the atmospheric and hydrological systems of the Mackenzie River Basin. The Mackenzie GEWEX study included a climate data-gathering phase which ended in 1999. However, several of the remote meteorological stations have been integrated into the surface weather monitoring network.

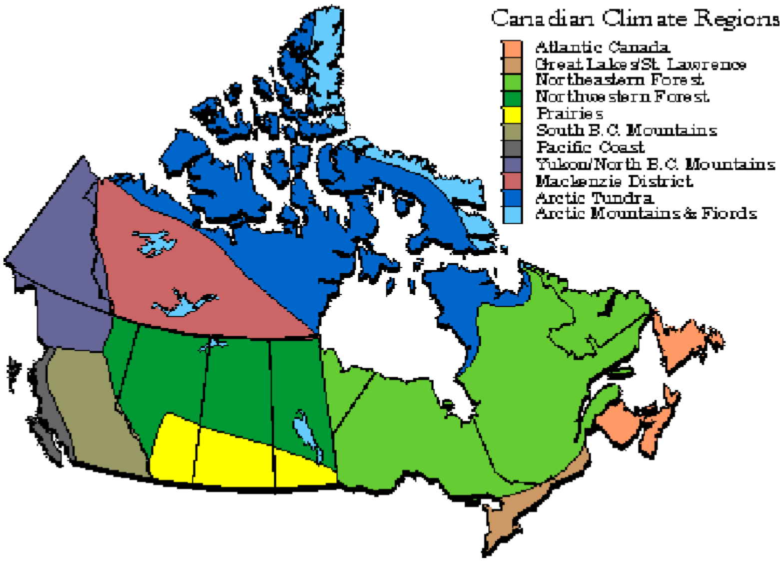
Lightning monitoring program (GNWT since 1987, Environment Canada since 1998) is comprised of a real-time lightning detection network that was established to detect the occurrence of lightning strikes as art of the forest fire management strategy. The current network of 14 stations operates continuously between May and September. The network senses the electromagnetic fields radiated from cloud-to-ground lightning flashes. There are varying degrees of uncertainty associated with the location accuracy of the lightning data and the detection efficiency of the network (DIAND 2002).

ii) What is happening?

The following information was adapted from an article by J.M. Bullas from Environment Canada's Prairie and Northern Region entitled : Recent Climate Trends in the Canadian Arctic" (http://yukon.taiga.net/knowledge/resources/yellow_bullas_07.html). Bullas described three Climate zones for the Arctic (Figure 2.3-1): a large tundra region, a somewhat smaller region bisected by the Mackenzie River, and the mountains and fjords of the far northeast. The results for the Mackenzie District and the Arctic Tundra district are applicable to the NWT.

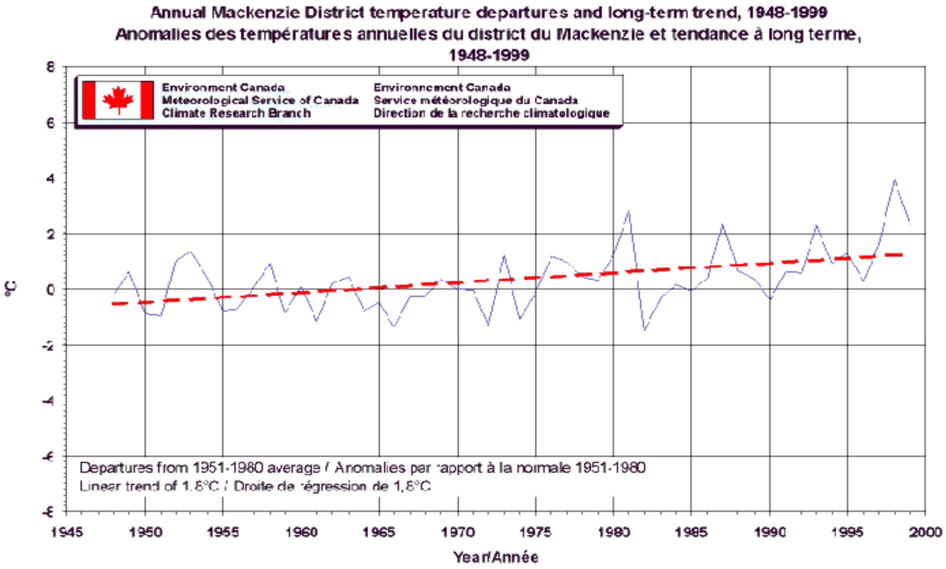
Figures 2.3-2 and 2.3-3 show the average trend in annual mean temperature for the Mackenzie District and the Arctic Tundra districts, respectively. The Mackenzie District (Figure 2.3-4) exhibits a clearly identifiable overall positive trend (about 1.5 degrees/century), comprised of a weak cooling trend into the seventies followed by a warming trend to 1999. The Arctic Tundra (Figure 2.3-5) shows a weak positive trend, but since the region is so large and variable in climatic influences, this trend probably does not apply to the whole district.

FIGURE 2.3-1
CANADIAN CLIMATE REGIONS



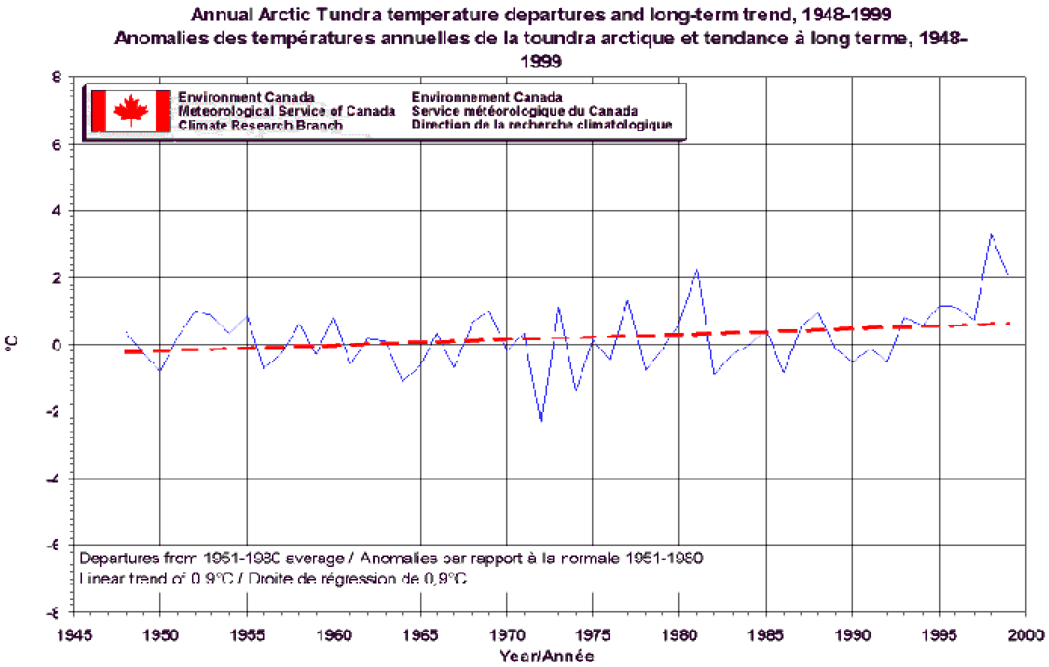
Source: Bullas 2000.

FIGURE 2.3-2
ANNUAL MACKENZIE DISTRICT TEMPERATURE TREND



Source: Bullas 2000.

FIGURE 2.3-3
ANNUAL ARCTIC TUNDRA TEMPERATURE TREND



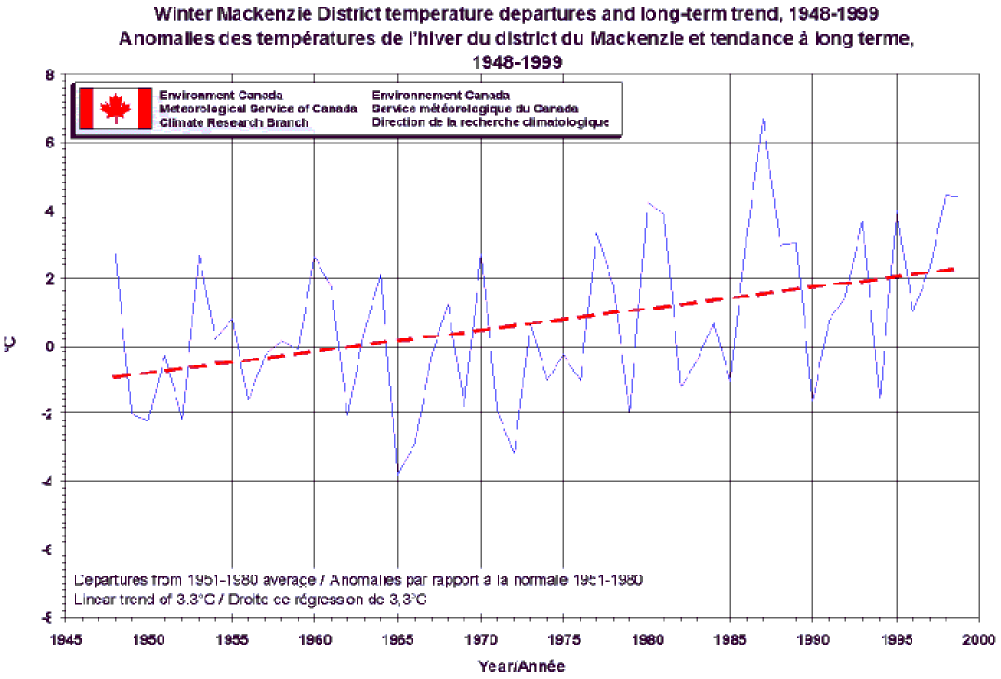
Source: Bullas 2000.

In the Mackenzie District, warming has occurred mainly in winter and spring. There is a very weak warming trend exhibited in the summer, and temperatures in autumn have been gradually decreasing. Elsewhere in the Territories, no significant seasonal variations are evident, although recent autumn seasons have been the warmest on record. Figures 2.3-6 to 2.3-7 show the seasonal trends for the Mackenzie District.

The warming in the winter in the Mackenzie District has been accompanied by a decrease in winter precipitation, while summer precipitation is somewhat higher and apparently more variable. The increase in precipitation over the Tundra region has been relatively evenly distributed throughout the year.

To summarize, prior to the mid-1940's, there were few observing sites in the Canadian Arctic. Since 1945, the western half of the Northwest Territories has exhibited a warming trend, mostly in the winter and spring. There is evidence to suggest that in the Mackenzie region, this trend may go back to the late 1900's or before. Precipitation has shown an increase in the Tundra portion of the Canadian Arctic since 1945.

FIGURE 2.3-4
MACKENZIE DISTRICT WINTER TEMPERATURE TREND



Source: Bullas 2000.

FIGURE 2.3-5
MACKENZIE DISTRICT SPRING TEMPERATURE TREND

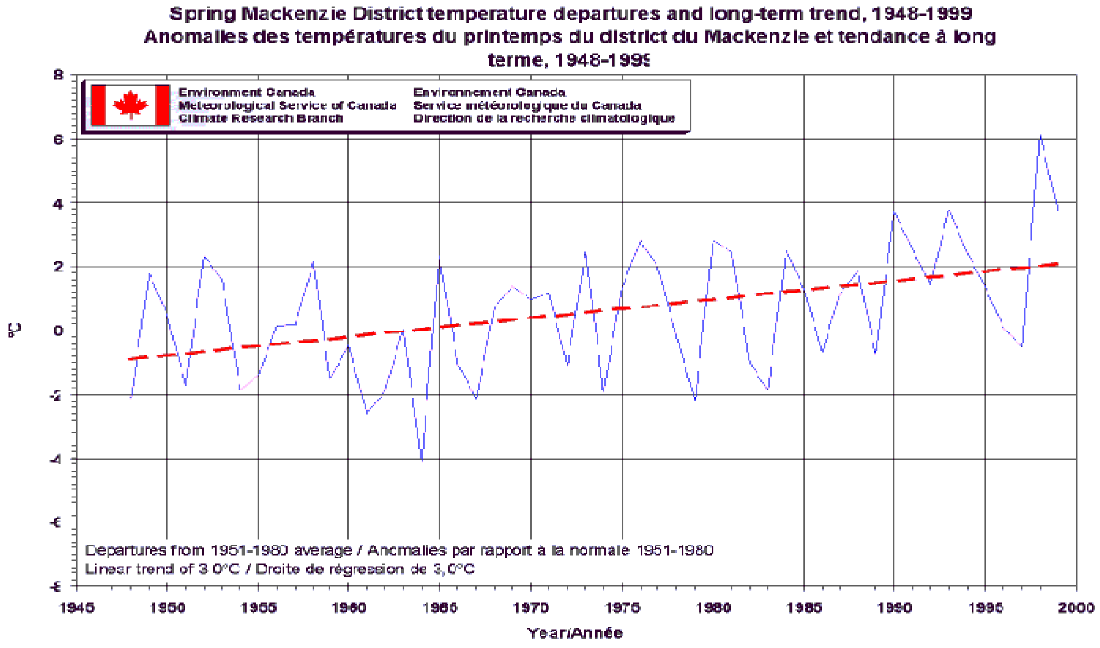
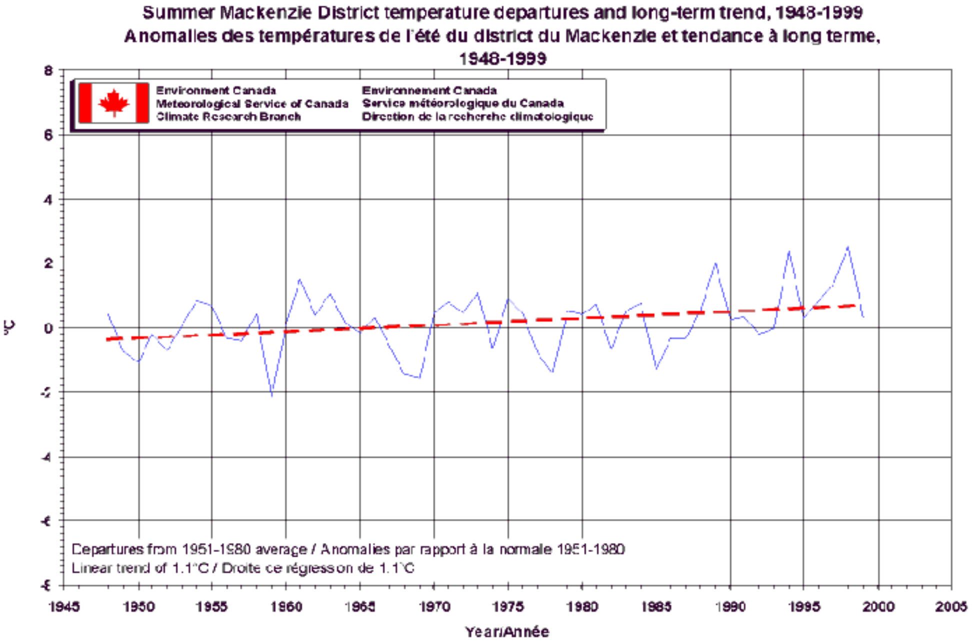
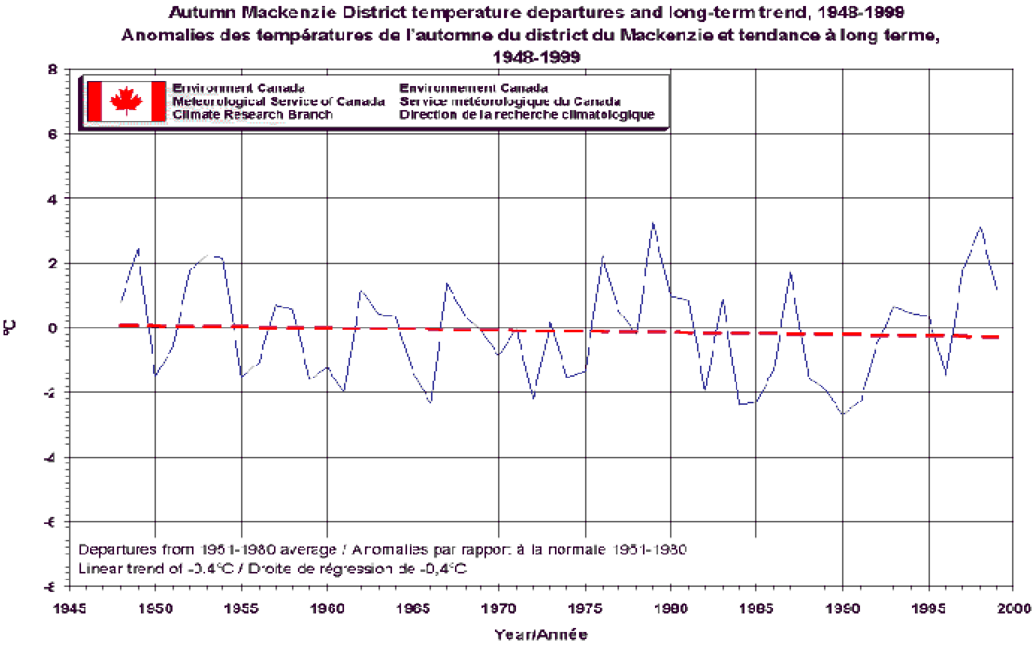


FIGURE 2.3-6
MACKENZIE DISTRICT SUMMER TEMPERATURE TREND



Source: Bullas 2000.

FIGURE 2.3-7
MACKENZIE DISTRICT AUTUMN TEMPERATURE TREND



Source: Bullas 2000.

ii) Why is it happening?

Increases in global mean temperatures have been predicted as a result of increases in atmospheric greenhouse gases generated by human activities. These changes have been predicted to be greatest in the polar region. Temperature changes may also result from natural climate variations, such as the decrease in temperatures that brought about the "Little Ice Age" cooling period in the 19th century for much of the northern hemisphere.

iii) What does it mean?

Changes in global and regional climate have important implications for many aspects of the environment. In the North, temperature warming may bring about changes in sea, lake and river ice, snow conditions, permafrost, habitat for plants and animals, and other changes. For human communities, this may mean changes in agricultural productivity, sustainable hunting levels, heating fuel consumption, and patterns of land use. These effects may be both positive and negative, and are likely to vary from region to region.

iv) What is being done about it?

Annual variability in mean temperatures is often large, and the detection of trends in climate generally requires long-term data sets. Reliable, consistently measured long-term climate records are required for the analysis of climate trends and for the validation of climate change models. In addition to the restoration of instrumental records, researchers are re-constructing historical climate records in the Arctic using lake sediments, ice cores and tree-ring analysis.

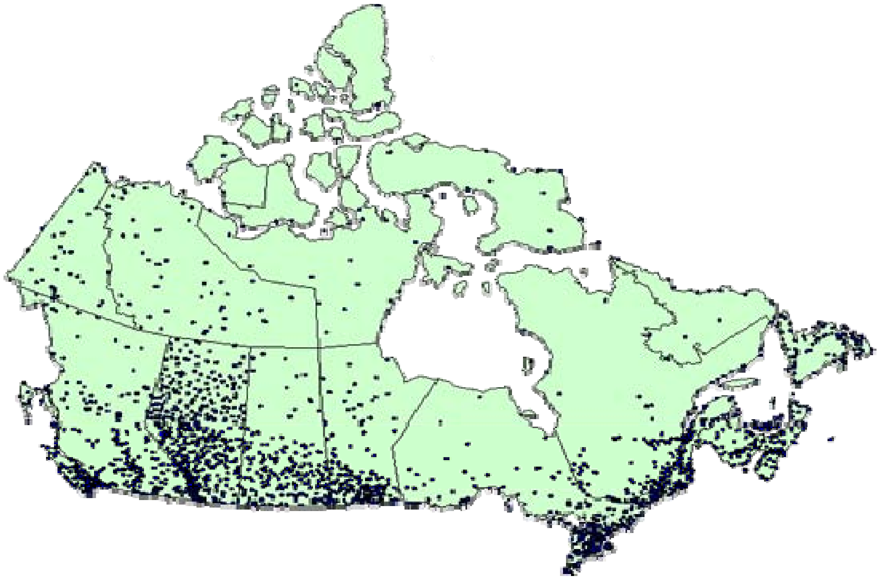
v) What are the information gaps?

Several stations have been closed recently due to budget cuts, and automated stations are replacing manual stations. Automatic stations can never be as accurate as manual stations, for example when mixed precipitation occurs (total precipitation is recorded but the breakdown of liquid versus solid precipitation is unknown) or when blowing snow is measured as false accumulation.

The CIMP VC report (DIAND 2005) identified particular areas with data gaps: the Mackenzie Mountains, Mackenzie River east bank, north of Great Bear Lake, Coppermine River basin, North Slave and South Slave.

The extensive national climatological network of temperature and precipitation stations has undergone significant, budget driven, reductions over the past decade and now totals 2147 stations. Station distribution is illustrated in Figure 2.3-8, reflecting a bias towards lower and more populated latitudes and elevations.

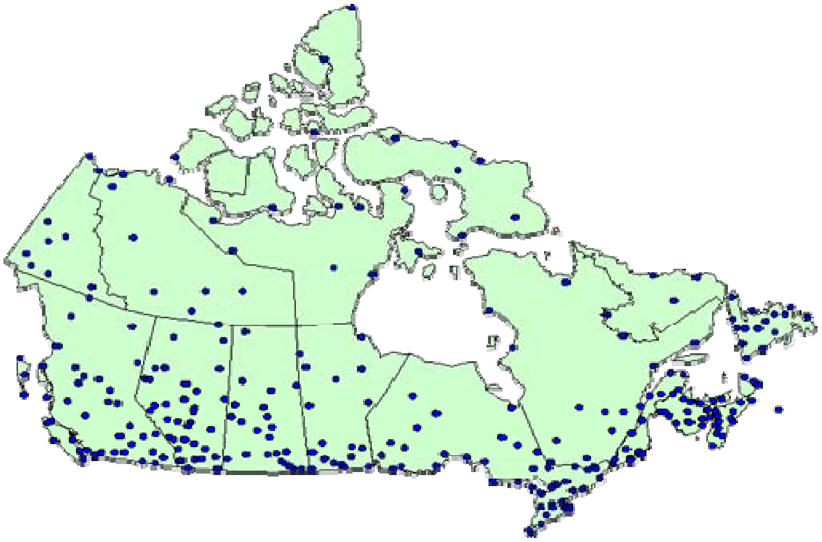
FIGURE 2.3-8
THE CANADIAN TEMPERATURE AND PRECIPITATION NETWORK



Source: http://www.ec.gc.ca/climate/CCAF-FACC/Science/nat2002/toc_e.htm.

Recent efforts to address the attrition in this network and its uneven distribution have focussed on the identification of a Reference Climate Station (RCS) Network of about 300 of the best stations and targeting these for long-term maintenance and enhancement through automation, addition of variables and other measures. These efforts will continue to be a priority during the coming decade. Figure 2.3-9 illustrates the RCS Network.

FIGURE 2.3-9
THE CANADIAN REFERENCE CLIMATE STATION NETWORK



Source: http://www.ec.gc.ca/climate/CCAF-FACC/Science/nat2002/toc_e.htm.

2.3.2.2 Precipitation

Precipitation plays a role in both control of emissions, and removal of pollutants from the air. For example, low precipitation will leave a soil surface mostly dry, and susceptible to wind erosion, whereas a lot of precipitation effectively seals the surface. Dew will effectively hold dust on the ground in the early morning. The contaminants in the air are washed out by precipitation - more precipitation produces more washout.

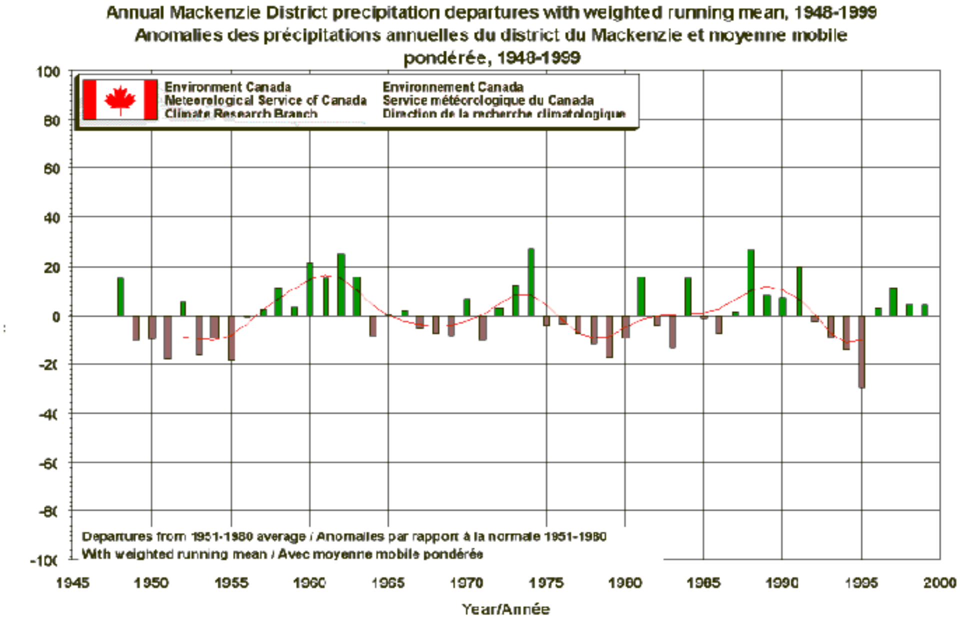
i) What is being measured?

About 65 precipitation gauges throughout Northwest Territories and Nunavut are monitored by Environment Canada (Isaac 1998); precipitation records go back to 1893 for Hay River, Northwest Territories.

ii) What is happening?

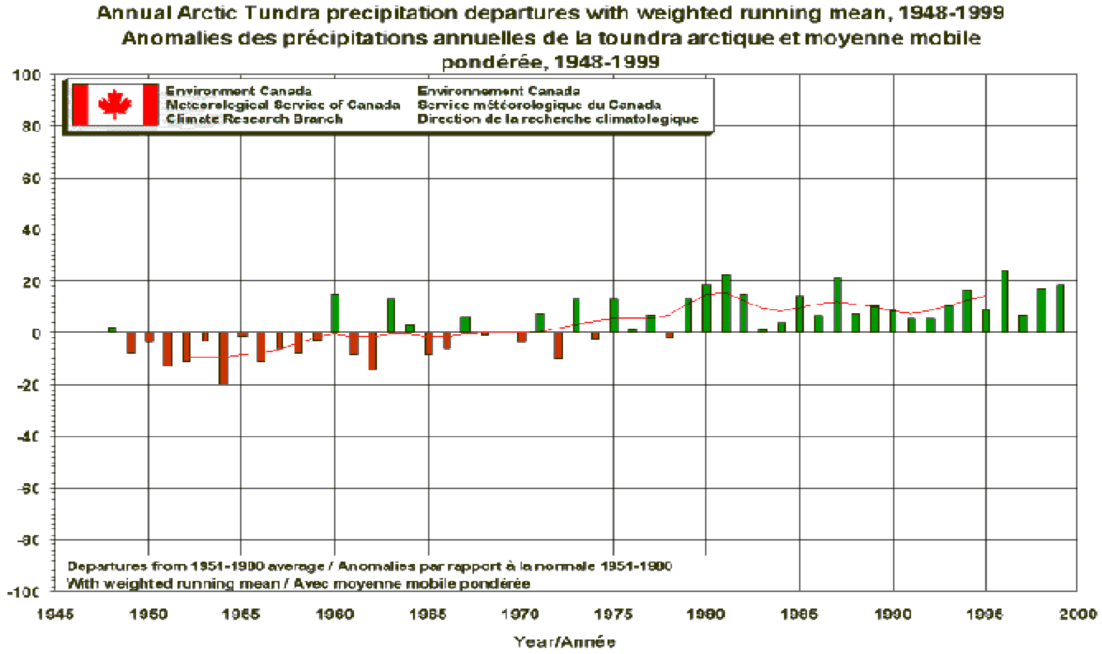
Because of the year-to-year variability, precipitation trends are more difficult to discern. Figures 2.3-10 and 2.3-11 show the trend in precipitation for the Mackenzie and Arctic Tundra districts. Mean annual precipitation has increased somewhat in the Arctic tundra region since 1945. There is no clear trend on an annual basis in other regions of the NWT.

FIGURE 2.3-10
MACKENZIE DISTRICT PRECIPITATION TREND



Source: Bullas 2000.

FIGURE 2.3-11
ARCTIC TUNDRA ANNUAL PRECIPITATION TREND



Source: Bullas 2000.

iii) Why is it happening?

Detecting changes in precipitation trends is difficult because precipitation varies widely across even small geographic areas. Although most of the changes are not statistically significant, an increasing precipitation trend has been measured for some areas of the NWT.

iv) What does it mean?

Human activity aside, surface and groundwater quantity is driven by the balance between atmospheric input from precipitation, and losses due to evapotranspiration. The impacts of changes in precipitation are described in other sections of this report.

v) What is being done about it?

Significant errors have been recognized in the measurement of cold season precipitation. The inherent nature of snow (e.g., varying density and wind effects) and snow cover (sublimation, the effects of land cover, temporal metamorphosis and redistribution by the wind) makes snow very difficult to measure. Snow makes up 60% to 70% of total annual precipitation in the NWT, with a chance of snowfall every month of the year. Because of this, accurate measurements of snowfall are very important for quantifying the water resource.

Both municipal and industrial demands for water are tempered by the ability of water managers to quantify water supply. Also, international research programs such as GEWEX (Global Energy and Water Experiment), WCRP (World Climate Research Program) and ACSYS (Arctic Climate System Study) require accurate long term precipitation measurements. In response to these needs, the Atmospheric Environment Service (AES) and Water Resources, Department of Indian and Northern Affairs (DIAND), developed a corrected historical precipitation archive for selected NWT climate stations. Methods used to correct the precipitation archive accounted for wind, wetting effects and trace measurement errors. As well, more accurate assumptions of snow density and snow ruler precision were applied. Research into precipitation measurement correction is still on-going. Known biases have been accounted for. However, verification of these corrections is needed in order to confirm the accuracy of the new archive (Spence 1997).

vi) What are the information gaps?

The Northern Climate Exchange Knowledge Site (http://yukon.taiga.net/matrix/) notes there is a marked lack of precipitation recording stations in the north relative to southern Canada (e.g.: 1 station per 50,000 km^2 in NWT, versus 12.5 stations per 50,000 km^2 in the rest of Canada) (Lukawesky 1994). There are often significant errors in measuring precipitation, particularly when snow falls in trace amounts, due to factors such as wind and wetting.

2.4 CLIMATE CHANGE

2.4.1 Introduction to Climate Change

The meaning of the term "climate change" within this report is consistent with its definition by the United Nations Framework Convention on Climate Change:

> *"a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."*

Within the context of this definition, climate change refers to any human-induced changes that are superimposed onto a background of natural climate variability that results from either internal instabilities in the ocean-atmosphere system, or triggering influences such as the El Niño -Southern Oscillation phenomenon, major volcanic eruptions or solar variability. Human-induced changes in climate are assumed to occur over time scales ranging from several decades to centuries.

The Arctic has some special features that make it an important focus for climate research. Physically, the Arctic islands are entirely snow-covered for more than half the year, and the region contains mountain glaciers, ice caps and extensive areas of permafrost. Arctic waters are also covered with sea ice for most of the year. Changes in the amount of sunshine are extreme since the Arctic experiences periods of 24-hour sunlight and 24-hour darkness at different times of year. Also, while large parts of the Arctic are essentially desert-like, large expanses of open water do occur during the short summer, making the Arctic a significant source for moisture and clouds. Northward-flowing rivers such as the Mackenzie empty their waters into the Arctic Ocean, influencing the ocean's physical characteristics. There are also important large-scale climate patterns, such as the Arctic Oscillation, where atmospheric pressure in the Arctic switches between high and low, causing shifts in climate and weather patterns in the Northern Hemisphere. These factors produce a complex interplay among climate processes in the Arctic.

The Intergovernmental Panel on Climate Change (IPCC) has been established by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP), to assess scientific, technical and socio-economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation.

To determine how the composition of the atmosphere, and consequently how climate may change in the future, it is necessary to construct scenarios of greenhouse gas and sulphate aerosol emissions for the next 100 years and beyond. This requires assumptions to be made about how society will evolve in the future. These emissions scenarios are then used in global climate models to simulate the evolution of climate over time. The IPCC has recommended a series of emissions scenarios, which describe plausible future changes in atmospheric composition. These are known as the SRES emissions scenarios after the IPCC's Special Report on Emissions Scenarios (IPCC 2000).

General Circulation Models (GCMs), and in particular, coupled Atmosphere-Ocean GCMs are the primary tools used to generate global-scale scenarios of climate change at broad spatial and temporal scales. Although there has been much progress in the refinement of GCM projections in recent years, the accuracy of GCM predictions is still uncertain, even with respect to representations of current climate conditions. Moreover, GCMs differ in their internal parameterizations so that, for any given scenario, there exist a range of possible outcomes depending on which model is used. Nevertheless, data from currently available GCMs project increasing global average temperatures in response to increases in greenhouse gas concentrations.

The lives of many Canadians are closely tied to the land. This is especially true for aboriginal communities, who get much of their food from hunting and fishing and the harvesting of edible plants and berries. These traditional activities are also an important part of aboriginal culture, which contains a large amount of knowledge about climate and how it affects these activities and the environment that it supports (CCME 2003).

Climate change is a major concern throughout Canada's arctic and sub-arctic regions, and many communities have begun to record their observations of how climate change is affecting their environments and their lives. These observations generally agree with the scientifically measured trends, although the scientific record gives a stronger impression of cooling in the eastern Arctic than the reports of local observers. This may be because local observers have given more emphasis to recent years, which have been unusually warm. The scientifically measured trends, on the other hand, cover a span of 50 years and include a greater number of cold years (CCME 2003).

Changes in Northern Canada's climate are affecting many aspects of the environment, such as ice and terrain conditions and the supply of game, wild plants and fresh water. As a result, native peoples are finding it harder to rely on the traditional knowledge and practices they have used for so long to survive in a region that is usually frozen for more than half the year (CCME 2003).

In recent years the Kitikmeot Inuit have noticed dramatic changes in the local climate and environment. Winters and summers have become warmer, and sea and lake ice have been melting earlier in the spring. Fall freeze-up, which occurred in August or September a few decades ago, now happens mostly in October or November. The weather has also become more variable, and short-term temperature swings that cause repeated thawing and freezing have become more common. With a more variable climate, weather and ice conditions have become harder to predict, and that has made it more difficult and dangerous for hunters and others traveling on the land and ice (CCME 2003).

People in most parts of the North are noticing the arrival of birds, fish and animals that have not been seen in their regions before. They are also noticing more unusual weather and more storms. Thunder and lightning, once very rare in the Arctic, are now being experienced more often, and in 2001, the Mackenzie Delta got its first tornado warning (CCME 2003). Most communities in the Mackenzie River Basin reported an overall increase in temperature and some comment that elders have a difficult time dealing with extreme summer heat (MRBB 2004).

Traditional knowledge has provided a broad perspective on the issue of climate change. Not only has it reported warmer temperatures, a more variable climate and unpredictable weather, but it has also indicated that the environment has changed in response to these changes in climate.

Some of the environmental changes could threaten or impose upon subsistence lifestyles (MRBB 2004).

2.4.2 Climate Change Indicators

The earth's climate has always changed. During the last ice age, glaciers covered much of Canada and temperatures were much colder than today in the Arctic. Rapid warming followed the ice age and global temperatures were 2°C warmer than in the early 20th century. The key indicators of climate change and the rationale for their selection are presented in Table 2.4-1.

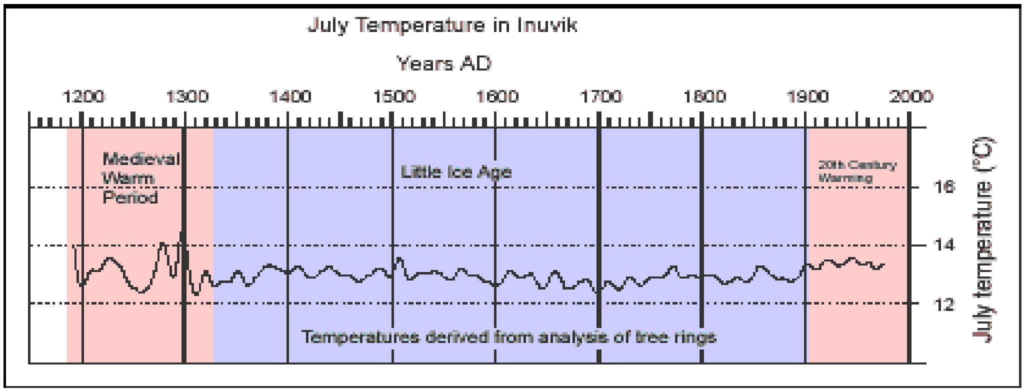
TABLE 2.4-1
RATIONALE FOR SELECTION OF INDICATORS OF CLIMATE CHANGE

Valued Component	Key Indicators	Rationale
Climate Change	• **Changes in Temperature and Precipitation**	• demonstrated changes in the North due to climate change • directly linked to climate change predictions in Global Climate Models • direct local impacts on humans and the ecosystem
	• **Atmospheric CO_2 Concentrations**	• measured in Alert, NWT since 1976 • strongly linked to increasing greenhouse gas emissions and hence the greenhouse effect • concentrations have increased dramatically since industrialization

2.4.2.1 Temperature and Precipitation

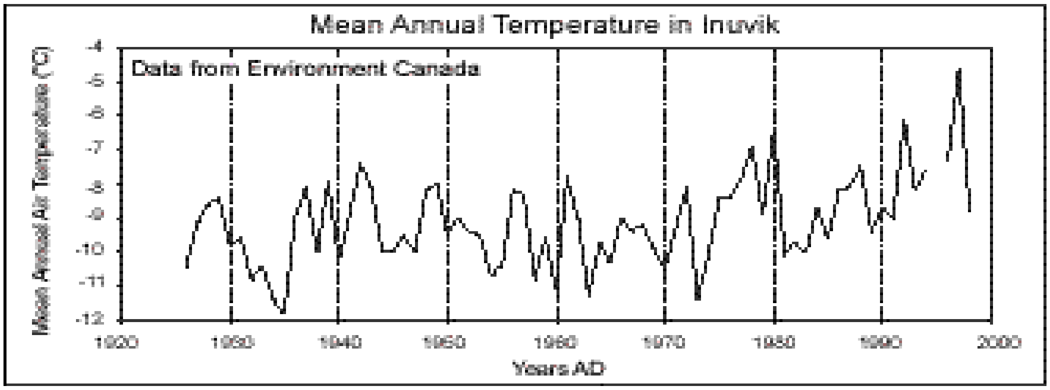
Data from Inuvik shows that air temperatures have changed over the last 800 years (Figure 2.4-1). During the Medieval Warm Period (1200 to 1300 AD), temperatures were higher than today. A cool period called the Little Ice Age followed this, ending only about 100 years ago. Warming has generally occurred over the last 100 years with average annual air temperatures for the western Arctic increasing by 1.5°C (Figure 2.4-2).

FIGURE 2.4-1
HISTORIC RECORD OF JULY TEMPERATURES IN INUVIK



Source: http://adaptation.nrcan.gc.ca/posters/articles/wa_02_en.asp?Region=wa&Language=en.
Adapted from: Begin, C., Michaud, Y. and Archambault, S. 2000.

FIGURE 2.4-2
MEAN ANNUAL TEMPERATURE IN INUVIK



Source: http://adaptation.nrcan.gc.ca/posters/articles/wa_02_en.asp?Region=wa&Language=en.

i) What is being measured?

Atmospheric observations are needed to monitor climate, detect and attribute change, improve understanding of the dynamics of the climate system and its natural variability and provide input for climate models. Several global observational networks have already been identified for the atmospheric component of the GCOS (Global Climate Observing System) Initial Observing System (IOS). In particular, a geographically representative GCOS Global Upper Air Network (GUAN) has been specified, a GCOS Global Surface Network (GSN) has been defined and the Global Atmosphere Watch (GAW) network is now considered a component of the GCOS. It is also recognized that other networks will be needed to address additional variables and that satellite observations of the atmosphere can make an important contribution to GCOS. (Source: http://www.ec.gc.ca/climate/CCAF-FACC/Science/nat2002/toc_e.htm).

Systematic observations of atmospheric constituents are needed to simulate the climate system, initialize and evaluate models and monitor the effectiveness of emission controls. The Global Atmosphere Watch (GAW) system, established in 1989, addresses this requirement and is a coordinated network of global and regional stations, along with associated infrastructure. Canada currently operates 43 GAW stations. Notably, the station at Alert (Nunavut) has been designated as a primary global background GAW station. Alert's baseline measurement program includes trace gas measurements of the greenhouse gases (CO_2, CH_4, CFC-11 and I_2, O_3, N_2O), along with aerosol measurements of black carbon, condensation nuclei and aerosol chemistry.

Additional measurements of atmospheric constituents are provided by two Canadian programs - CORE and CAPMoN. The "CORE" network of 6 stations has been developed to provide long-term, high quality, observations of atmospheric composition and radiation at locations representative of major atmospheric regimes and geopolitical regions. The Canadian Air and Precipitation Monitoring Network (CAPMoN), consisting of 22 stations, was created to study the regional patterns and trends of acid deposition in Canada and is an integral component of the GAW network.

The historical Climate Information and Monitoring Network in Canada’s North is comprised of:

- The longest running climate stations, which have recorded basic information since the late 19th century;
- The large Beaufort Sea and Mackenzie Valley climate database that dates back to the 1940s;
- Coastal Distant Early Warning (DEW) line stations that have monitored temperature, wind and precipitation since late 1950s;
- Central Northwest Territories monitoring stations that were installed with mineral exploration activity in the 1970s (Lukawesky 1994); and
- A few eastern stations that began monitoring as early as 1920s and 30s (Fox 2000).

Documentation of local observations of climate change is increasing throughout northern Canada. Examples include:

- A video of Inuit observations of climate change and its impacts (Banks Island, Northwest Territories) (Riedlinger 1999);
- Collection/documentation of traditional knowledge of climate change impacts in Baffin Island (Fox 2000); and
- Other projects such as the Mackenzie Basin Impact Study or the Hudson's Bay and Northern Basins Study incorporate traditional knowledge (GeoNorth Ltd. 2000).

There are four EMAN-North sites in the NWT: Yellowknife, Daring Lake, Mackenzie Delta and Nahanni National Park. The Arctic Borderlands Ecological Knowledge Co-op is also partially located in the NWT. Long-term ecological monitoring of avian and terrestrial wildlife, vegetation, water quality and quantity, snow, permafrost and climate occurs to varying degrees at one or more of these sites.

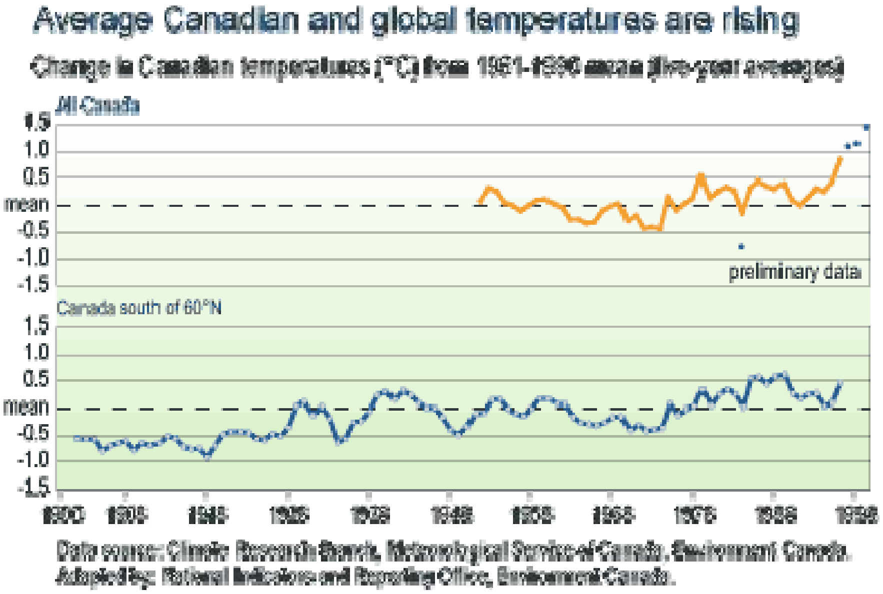
ii) What is happening?

In the past 40 years, annual temperatures in the western Arctic have climbed by 1.5°C. The average temperature in the Arctic has risen at almost twice the rate as the rest of the world in the past few decades. As the world's climate changes, temperature changes are anticipated to be greater in the North and greater in winter than in summer. According to recent climate models run by Environment Canada, annual temperature increases of greater than 5°C in the Arctic are possible by the year 2100. Figure 2.4-3 shows changes in Canadian temperatures versus the 1961-1990 climate normal period. Temperature records in the North are shorter than temperature records in the South of Canada, hence the longer trend for areas south of 60°N.

In the Mackenzie River Basin, winter precipitation has increased over much of the northern part of the basin but has decreased in the southwestern part of the basin. In contrast summer precipitation has increased in the south but has decreased somewhat in the far north. These changes, if extended over a long period of time, could have profound effects on the terrestrial and aquatic ecosystems of the basin (MRB SOAER 2003).

Additional evidence of Arctic warming comes from the widespread melting of glaciers and sea ice, and a shortening of the snow season. Increasing precipitation, shorter and warmer winters, and substantial decreases in snow cover and ice cover are among the projected changes that are very likely to persist for centuries (ACIA 2005).

FIGURE 2.4-3
ANNUAL AVERAGE CANADIAN AND GLOBAL TEMPERATURES



Source: http://www.ec.gc.ca/soer-ree/English/Indicator_series/.

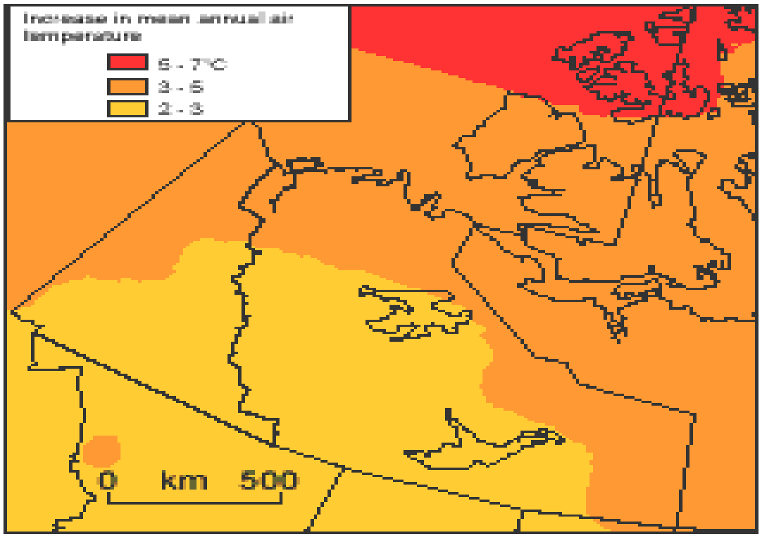
iii) Why is it happening?

Increasing global concentrations of carbon dioxide and other greenhouse gases due to human activities, primarily fossil fuel burning, are projected to contribute to additional Arctic warming of about 4-7ºC over the next 100 years (ACIA 2005).

iv) What does it mean?

Scientists use models called General Circulation Models (GCM) to predict future climate. Figure 2.4-4 shows how much warmer average annual air temperatures are expected to be in the middle of the 21st century compared to those in the last 30 years of the 20th century. The Canadian Climate Centre model predicts that average air temperatures in the western Arctic will be between 2 and 5°C higher.

FIGURE 2.4-4
PREDICTED INCREASE IN MEAN ANNUAL TEMPERATURES
IN CANADIAN NORTH BY 2050



Source: Data for map from Canadian Climate Centre for Modelling and Analysis Coupled GCM. http://adaptation.nrcan.gc.ca/posters/articles/wa_02_en.asp?Region=wa&Language=en.

v) What is being done about it?

The Arctic Climate Impact Assessment (ACIA) is an international project of the Arctic Council and the International Arctic Science Committee (IASC). It is focused on the evaluation and synthesis of knowledge on climate variability, climate change and increased ultraviolet radiation and their consequences in the circumpolar Arctic. The aim is to provide useful and reliable information to governments, and to the Arctic Peoples and their organizations.

The Government of Canada created the Climate Change Action Fund (CCAF) in 1998 (http://www.ec.gc.ca/climate/CCAF-FACC/Science/fact/arctic_e.htm). The CCAF identified the Arctic climate system as a priority area of study. Several research projects were funded following a national workshop held in 1999 to identify specific Arctic climate science issues. The work supported fell into two broad areas:

- Advancing our knowledge of the climate system (ocean, atmosphere, land and cryosphere - primarily ice in all its forms, snow and permafrost) for Arctic Canada;
- Rescuing and maintaining long-term data sets of importance to determining variations in the climate of Arctic Canada.

Several studies funded by the CCAF focused on the maintenance and rescue of relevant sets of climate data. These data sets will now be available for future research studies.

- Researchers compiled an inventory of High Arctic data, including the locations of more than 600 field camps, oil industry sites, historical expeditions and automated station sites within the High Arctic islands. The data sets provide snapshots of the climate at times and places not represented by the permanent observation network.
- Several databases of importance to climate change, such as permafrost and peatlands, are now accessible through the online National Arctic Geoscience Database (NAGD), providing information on the evolution of climate systems in the Canadian Arctic over the past several thousand years.

Since the late 1980s, various researchers have been gathering climate-related data (such as tree ring information) at a network of about 70 stations across northern Quebec. This study has put in place a method to transfer raw data collected at various sites into an interactive database. Federal departments are working with Canadian universities and provincial and territorial agencies on such activities as:

- Expanding Canada's contribution to atmospheric monitoring as part of the international Global Climate Observing System Surface Network, particularly in the North;
- Deploying a series of ocean floats to measure temperature and salinity in Canadian waters, and a series of tide gauges in Canadian Arctic waters; and
- Enhancing and/or establishing Canadian monitoring systems for snow, permafrost, glaciers, and sea and freshwater ice.

The second phase of the CCAF is currently underway, and includes continued improvements to climate models, including better representation of the Arctic climate system. Projects are also being funded to address aspects of the Arctic climate system that are not well understood, including aspects relating to the Arctic sea ice and Arctic Ocean dynamics, clouds and aerosols, and snow-covered ground.

The Northern Climate Exchange (NCE) is a Yukon-based center acting as an exchange point for climate change studies in the circumpolar north. The NCE's goal is to conduct research and education on the impacts of, and adaptations to, climate change in the North; and to facilitate exchange of scientific and traditional and local knowledge, technology and expertise.

The Arctic Monitoring and Assessment Program (AMAP) was established in 1991 through the Arctic Council with responsibilities to monitor the levels of, and assess the effects of, anthropogenic pollutants in all areas of the Arctic environment, including impacts on humans. Climate change remains one of the ongoing concerns of AMAP.

Numerous programs have been initiated across Canada to study climate change and to develop plans to reduce Canadian emissions of greenhouse gases. For example, the Mackenzie River Basin Impact Study's objective was to assess the potential impact of climate change on the land, water and communities within the Mackenzie River Basin.

vi) What are the information gaps?

At the global level, climate in the Arctic is a result of the general circulation of the atmosphere and heat transfer by the oceans. It is generally agreed that fluctuations in the upper atmosphere control or influence surface conditions. The factors that influence high-latitude energy fluxes including the Arctic Oscillation (AO) are fundamental science questions that need to be addressed (http://www.ec.gc.ca/climate/CCAF-FACC/Science/reports/arctic_e.htm#16).

The magnitude, frequency, and causes of extreme events in Arctic weather, stream flow, lake and sea ice, snow cover and other climatic-related variables need careful study in order that trends in global climate change are correctly interpreted and understood. Understanding of the magnitude and speed of past and ongoing climate change in the Arctic also needs to be improved through continued monitoring and the analysis of already existing time-series data.

2.4.2.2 Atmospheric CO_2

A small group of greenhouse gases, mainly carbon dioxide, methane, nitrous oxide, and water vapour, help to regulate the Earth's climate by trapping solar energy that reradiates from the Earth's surface as heat. Emissions from human activities enhance this natural process. Since industrialization, human activities such as burning fossil fuels have increased the amount of greenhouse gases emitted into the atmosphere. It is widely believed that increased emissions have enhanced the greenhouse effect, causing the atmosphere to warm and the climate to change.

Since the industrial revolution in the late 1700s, atmospheric concentrations of carbon dioxide have increased by 31%, methane by 151% and nitrous oxide by 17%. Increases in CO_2 have been especially pronounced in the last fifty years (MRBB 2004).

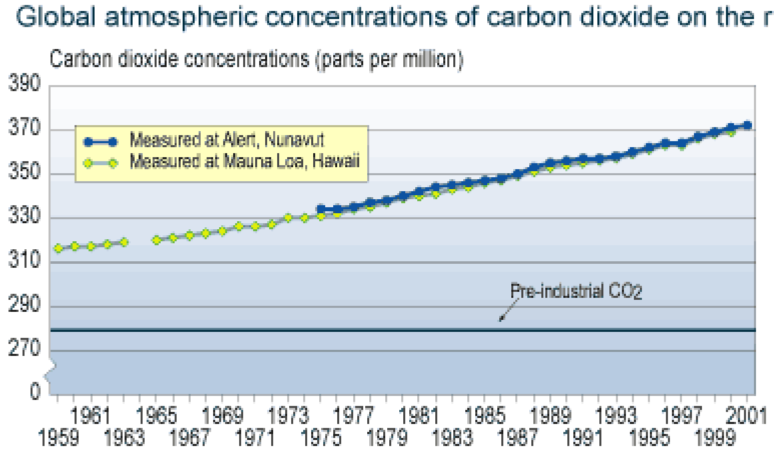
i) What is being measured?

Global concentrations of carbon dioxide have been measured since the mid-1950s. Carbon dioxide flask data has been collected on a weekly basis at 4 points in Canada (1 in the Arctic) since data collection started at Canadian stations between 1975 and 1979. The station in Alert, Nunavut, switched to more comprehensive continuous measurements in 1988. These data are comparable to that measured in Hawaii (longest running and most credible carbon dioxide measuring station in world) (McIlveen, N. and R, Desjardin 1998, Welch 2000). Historical concentrations of carbon dioxide, methane, and nitrous oxides are determined for past millennia based on study methods such as ice core analysis.

ii) What is happening?

Increased emissions of carbon dioxide are reflected in global atmospheric carbon dioxide concentrations, which have increased by 33% since the beginning of the industrial age (Figure 2.4-5). Since carbon dioxide is a well-mixed gas in the atmosphere, measurements made at any place on the globe are considered representative.

FIGURE 2.4-5
TRENDS IN ATMOSPHERIC CARBON DIOXIDE LEVELS AT MONITORING STATIONS IN HAWAII AND NUNAVUT



Data sources: Meteorological Service of Canada, Environment Canada; Carbon Cycle Group, National Oceanic and Atmospheric Administration, USA.
Adapted by: National Indicators and Reporting Office, Environment Canada.

Source: http://www.ec.gc.ca/soer-ree/English/Indicator_series/.

iii) Why is it happening?

Globally, carbon dioxide emissions from energy use have quadrupled since 1950. In 1998, Canada's share of these emissions was approximately 2%. Canadian emissions of six key greenhouse gases have grown 20% since 1990.

iv) What does it mean?

While there is no conclusive scientific evidence supporting a link between weather extremes and greenhouse gas-induced climate change, there is little debate that Canadians have experienced recent changes in weather patterns and a substantial increase in the number of weather-related disasters.

v) What is being done about it?

In 1992, Canada ratified the United Nations Framework Convention on Climate Change, which set out a framework for action to limit emissions of greenhouse gases. In 2002, Canada ratified the Kyoto Protocol to the Convention, committing to reduce its greenhouse gas emissions to 6% below 1990 levels by 2008-2012.

In 2001, The NWT Greenhouse Gas Strategy was developed to identify and coordinate northern actions to begin to control greenhouse gas emissions, and to assist in developing and contributing a northern perspective as part of Canada’s national Climate Change implementation strategy. The NWT Greenhouse Gas Strategy does not specify emission reduction targets or goals. Northern CO_2 emissions are approximately 30 tonnes per person compared to the national average of 21 tonnes per person. Per capita emissions are higher in part due to larger demands for space heating and other energy consuming devices to deal with colder temperatures. The long distances between communities have also made the NWT dependent on transportation and the use of refined petroleum products. CO_2 emissions and population growth in the NWT are both increasing at higher rates than the national average. Current greenhouse gas emissions in the NWT are in the order of 1600 kilotonnes of CO_2-equivalents per annum. Compared to Canada’s total of 731,000 kilotonnes of CO_2-equivalents in 2002, the NWT contributes less than 0.5% of Canada’s total greenhouse gas emissions.

The GNWT is organizing a workshop in Spring 2005 to evaluate progress to date and identify additional measures to reduce greenhouse gas emissions (Sparling 2005).

It is important to note that reductions in emissions from fossil fuel combustion will not only reduce greenhouse gases, but will have a positive impact on local and regional air quality by directly reducing emissions of sulphur dioxide, nitrogen oxides, and volatile organic compounds and indirectly reducing levels of ground-level ozone and inhalable airborne particles formed in the atmosphere. Reductions in emissions of sulphur dioxide and nitrogen oxides can also be expected to reduce acid rain.

vi) What are the information gaps?

There is greater knowledge and confidence concerning baseline information and predicted changes to temperature than for other climate components like rain, snow and extreme events

The next stage of CCAF-Arctic should include the development of better coupled atmospheric models, the validation of such models against both paleo- and current time-series data sets, and the identification and understanding of regional variability in Arctic climate change. The latter can be approached through the continued study of sea ice, the response of northern terrestrial ecosystems, and the monitoring of critical, climate-responsive, cryospheric variables.

2.4.3 Other Climate Change Issues

2.4.3.1 Effect of Climate Variability on Contaminant Pathways

Remarkable changes occurred in the Arctic's climate during the 1990s including wind and weather patterns, ice cover, ice thickness, ice drift patterns, permafrost, hydrology, ocean-currents, precipitation and temperature patterns. These changes have significant consequences for contaminant pathways. These changes have altered the physical pathways that transport contaminants, for example diverting Russian river inflow into the Canada Basin thence to flow out through the Archipelago and altering the drift trajectories of ice within the Arctic. However, even more consequential changes are likely to occur in contaminant magnification pathways including cryoconcentration, attachment to organic-rich particles, and food-web biomagnification. Recent change in the Arctic's ice climate and ecosystem structure require a great deal of caution in interpreting contaminant trend data collected for the past couple of decades (Source: Highlights of the Canadian Arctic Contaminants Assessment Report II).

2.4.3.2 Arctic Ozone Layer

Extensive ozone losses have occurred over the Arctic in the 1990s, and there is some concern that serious depletion episodes could become even more frequent over the next 10 to 20 years. Concentrations of ozone-depleting chemicals will be at or near peak levels during that time, and changes to the Arctic stratosphere arising from global warming could create more favourable conditions for depletion processes.

Deep ozone losses over both the Arctic and Antarctic are the result of special conditions that occur over these polar regions in the winter and early spring. As winter arrives in each hemisphere, a vortex of winds develops around the pole and isolates the polar stratosphere. Without milder air flowing in from the lower latitudes and in the absence of sunlight, air within the vortex becomes very cold. At temperatures of -80°C or less, clouds made up of ice, nitric acid, and sulphuric acid begin to form in the stratosphere. These are called polar stratospheric clouds (PSCs), and they give rise to a series of chemical reactions that destroy ozone far more effectively than the reactions that take place in warmer air. The destruction of ozone begins with the return of sunlight in the spring and continues rapidly until the vortex dissipates and warmer temperatures prevent the formation of PSCs.

Arctic ozone depletion could be further enhanced over the next few decades, however, by increasing accumulations of greenhouse gases in the atmosphere. By trapping more heat near the earth's surface, these gases cause the stratosphere to become cooler. Since temperatures in the Arctic stratosphere often come within a few degrees of the threshold for PSC formation, further cooling of the stratosphere could cause PSCs to form more frequently and increase the severity of ozone losses. Preliminary studies with atmospheric models suggest that this effect could delay the recovery of the Arctic ozone layer by a decade or more.

Continued monitoring and research are essential if we are to reduce present uncertainties in our understanding of depletion processes and improve our capability to predict how the ozone layer is likely to respond to changing atmospheric conditions and stresses in the future. The future of the Arctic ozone layer will depend primarily on our success in ridding the atmosphere of ozone-depleting chemicals, but our ability to control greenhouse gases will also be important. The linkages between these issues mean that we cannot treat either of them in isolation. Instead, they indicate the importance of developing a comprehensive strategy for moderating the human impact on the atmosphere (http://www.ec.gc.ca/press/arctoz_b_e.htm).

REFERENCES

AMEC 2004. *EIS for Mackenzie Gas Project.* August.

Arctic Monitoring and Assessment Programme (AMAP) 1998. *AMAP Assessment Report: Arctic Pollution Issues, Arctic Monitoring and Assessment Programme*, Oslo, Norway.

Arctic Climate Impact Assessment (ACIA) Secretariat 2004. Statement by Dr. Robert W. Correll, Chair. 16 November.

Barry, Roger C. 1986. *Impacts of CO_2 Doubling on Snow and Ice in the Canadian Arctic. In* Proceedings- Impact of Climatic Change on the Canadian Arctic, Environment Canada. As cited by NCE.

Begin, C., Y. Michaud, and S. Archambault. 2000. *Tree-Ring Evidence of Recent Climate Changes in the Mackenzie Basin Northwest Territories, Canada; in the Physical Environment of the Mackenzie Valley, Northwest Territories; A Baseline for the Assessment of Environmental Change*, L.D. Dyke and G.R. Brooks (eds.); Geological Survey of Canada Bulletin 547, 212 p.

Bullas, J.M. *Recent Climate Trends in the Canadian Arctic*. Presented at the Yellowknife CCAF Workshop, February 27-29/ http://yukon.taiga.net/knowledge/resources/yellow_bkgd_04.html

Burn, C.R., E. Barrow, B. Bonsal 2004. *Climate Change Scenarios for Mackenzie River Valley.*

Canadian Council of Ministers of the Environment (CCME) 2003. Climate, Nature, People: Indicators of Canada's Changing Climate.

Department of Indian Affairs and Northern Development (DIAND) 2003. Canadian Arctic Contaminants Assessment Report II. *Sources, Occurrence, Trends and Pathways in the Physical Environment*. Northern Contaminants Program.

Department of Indian and Northern Affairs Canada (DIAND) 2002. *A Preliminary State of Knowledge of Valued Components for the NWT Cumulative Impact Monitoring Program (NWT CIMP) and Audit.* Final Draft. (edited September 24, 2003).

Fox, S.L. 2000. *Arctic Climate Change: Observations of Inuit in the Eastern Canadian Arctic. In Arctic Climatology Project, Environmental Working Group Arctic Meteorology and Climate Atlas.* Fetterer and V. Radionov (Eds.). Boulder, CO: National Snow and Ice Data Center. CD-ROM. As cited by NCE.

GeoNorth Ltd., 2000. *Climate Change Impacts and Adaptation Strategies for Canada's Northern Territories: Final Workshop Report.* February 27-29, Explorer Hotel, Yellowknife NT. Natural Resources Canada and Environment Canada. As cited by NCE.

GNWT 2001. *NWT Greenhouse Gas Strategy.*

GNWT 2004. *2002/2003 Northwest Territories Air Quality Report.*

Hawking, J., Canadian Wildlife Service, Whitehorse, 1999. Personal Communication. As cited by NCE.

Hengeveldt, Henry, 2000. *The Science of Climate Change.* Internal Document, Environment Canada, as cited by J.M. Bullas.

Huntley, B. 1997. *The Responses of Vegetation to Past and Future Climate Changes*. In Global Change and Arctic Terrestrial Ecosystems. W. C. Oechel *et al* (Eds.): 290-311. As cited by NCE.

Isaac, G, 1998. *Research Project Description: FIRE III: An Arctic Cloud Study.* Cloud Physics Research Division, Atmospheric Environment Service. As cited by NCE.

Kahl, Jonathan D. 1996. *Long Term Variability in the Low-Level Inversion Over the Arctic Ocean.* In International Journal of Climatology 16: 1297-1313. As cited by NCE.

Lukawesky, A.L. 1994. *Northern Weather and Climate Networks.* In Mackenzie Basin Impact Study (MBIS), Interim Report 2. Stewart Cohen (Ed.): 97-105. As cited by NCE.

Mackenzie GEWEX Study http://www.usask.ca/geography/MAGS/index_e.htm.

Mackenzie River Basin Board 2004. *Mackenzie River Basin State of the Aquatic Ecosystem Report 2003.* June.

Maxwell, Barrie 1997. *Responding to Global Climate Change in Canada's Arctic,* Vol. II of the Canada Country Study: Climate Impacts and Adaptation, Environment Canada AES, Downsview Ontario. As cited by NCE.

McIlveen, N. and R. Desjardins 1998. *Canada's Emissions Outlook - An "Events-Based" Update for 2010*. Energy Forecasting Division, Energy Division, Natural Resources Canada. As cited by NCE.

Metcalfe *et al,* 1994. *Corrected precipitation Archive for the Northwest Territories.* In Mackenzie Basin Impact Study, Interim Report No. 2. Stuart Cohen (Ed.) As cited by NCE.

Riedlinger, D. 1999. *Climate Change and the Inuvialuit of Banks Island, Northwest Territories- Using Traditional Environmental Knowledge and Western Science.* In Arctic 52(4): 430-432. As cited by NCE.

Sparling, J. 2005. GNWT-RWED. Personal Communication, 17 February.

Spence, C. 1997. *The Accuracy of a Corrected Precipitation Data Archive for the Northwest Territories In: Project Reports 1995-96: Arctic Environmental Strategy NWT Water Component / Northern Affairs Program (Canada).* Water Resources Division. - Yellowknife, N.W.T.: Water Resources Division, Indian and Northern Affairs.

Sly, P.G., L. Little, R. Freeman and J. McCullum 2001. *Updated State of Knowledge Report of the West Kitikmeot and Slave Geological Province*. Final Report May 30th.

Treloar, Norman and B. Lawson 1998. *Climate Trends Over Northern and Western Canada, Environment Canada* (unpublished manuscript), as cited by J.M. Bullas.

Veale, G. 2005. GNWT-RWED. Personal Communication, 17 February.

Welch, David, Science Advisor, Parks Canada 2000. Personal Communication As cited by NCE.

Whitewood, Bob 1999. *Climatic Perspectives, Environment Canada,* as cited by J.M. Bullas.

Websites

Arctic Borderlands Ecological Knowledge Co-op http://www.taiga.net/coop/indics/co2territ.html

Arctic Climate Research and Monitoring, Hugh French, Peter Johnson and Fred Roots http://www.ec.gc.ca/climate/CCAF-FACC/Science/reports/arctic_e.htm#16

Arctic Monitoring and Assessment Programme
http://www.amap.no/

Environment Canada:
- http://adaptation.nrcan.gc.ca/posters/articles/wa_02_en.asp?Region=wa&Language=en
- http://www.ec.gc.ca/climate/CCAF-FACC/Science/fact/arctic_e.htm
- Canadian National Report on Systematic Observations for Climate
- http://www.ec.gc.ca/climate/CCAF-FACC/Science/nat2002/toc_e.htm

Meteorological Service of Canada, 1999. Climate Data and Archives- Climate Station Catalogue. http://www.cmc.ec.gc.ca/climate/ As cited by NCE.

National Climate Data and Information Archive
http://www.climate.weatheroffice.ec.gc.ca/Welcome_e.html.

NCE Knowledge site http://www.yukon.taiga.net/knowledge/.