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# "A PERSPECTIVE ON CLIMATIC CHANGE"



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# "A PERSPECTIVE ON CLIMATIC CHANGE"

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# TABLE OF CONTENTS

# A PERSPECTIVE ON CLIMATIC CHANGE

## I. INTRODUCTION

The weather is possibly the most talked about subject in the world. Its influence can change the mood, ability to travel, and capacity to function of almost everyone. Climate can best be described as the "average" or "most likely to be expected" weather. When the weather deviates from normal climate, it is seen as an unexpected event and becomes an instant topic for conversation.

The climate itself can change. There is an abundance of evidence to suggest that some deserts were once thriving agricultural regions. In the distant past Canada was covered with ice. Throughout geological time, the climate has cycled through periods of warmth and cold. There is a growing realization that natural causes may no longer be the only force acting on the weather machine. Man's activities, the release of pollutants, dust, waste heat, and carbon dioxide, may also change climate.

The importance of the problem lies in the fact that man's social and economic structure is very vulnerable to climatic change. Transportation, energy and agricultural infrastructures, for example, are designed to operate within certain assumptions concerning temperature, precipitation, and days of sunlight. Even short-term deviations from the normal can be seriously disruptive. Last winter's heavy snowfall in the northeastern U.S. is an example.

It is one thing to be concerned about climatic change. It is completely another matter to "do something" about it. Any decision that might be made concerning changes in climate is hampered in two ways: first, not enough is known about climatic

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processes to usefully predict how a change might come about; second, the impact of the change could be so dramatic that it is not certain that existing social institutions could adequately implement any solutions. What could be done, for example, if it were known that western Canada would have 5 years of drought. The dry years of the 1930's brought more than just a decline in grain production. They also brought unemployment, social migration, destruction of communities, poverty, and, as often happens, oppression of those who lost their farms and livelihood by those who had not.

It is not a glacial advance that threatens us. Such a devastating change would take thousands of years to evolve. The main threats lie in persistent changes of temperature or rainfall in areas which are agriculturally marginal or environmentally delicate. Frost-free days for the northernmost Canadian and Siberian farmlands, and ocean temperatures in regions of high nutrient and oxygen production, for example, are of more immediate concern.

The limits of present knowledge of climatic processes represent the first hurdle to be overcome. The U.S. National Academy of Sciences, in a report on climatic change, made the following statement. "Although we have considerable knowledge of the broad characteristics of climate, we have relatively little knowledge of the major processes of climatic change. To acquire this knowledge it will be necessary to use all the research tools at our disposal. We must also study each component of the climatic system which includes not only the atmosphere but the world's oceans, the ice masses, and the exposed land surface itself. Only in this way can we expect to make significant advances in our understanding of the elusive and complex processes of climatic change."

The concern of the National Academy of Sciences has led to a research action plan. This plan is now being debated as a bill before the House of Representatives (H.R. 783).

A national climate research program must have four main thrusts. The first is the establishment of a wide monitoring network to gather data and detect trends. Observations are essential for the development of theories and testing of models. Although much work has already been done to organise and make widely available climatic data there is still much room for improvement. A large, and perhaps crucial gap in our knowledge of climate is in the area of oceanography. It is known that heat, moisture and momentum exchanges that occur at the sea surface and the corresponding transports that occur within the ocean exert a powerful influence on the earth's climate. Oceanographic data are insufficient to accurately model these influences.

The second important research thrust deals with the advancement of our understanding of natural climatic variability. Our knowledge of the mechanisms of climatic change are so fragmentary that in many cases we do not know enough to pose the key scientific questions, let alone answer them. The search for order in the climatic record is necessary if we hope to recognise the first phases of a truly significant climatic change should it occur.

The third research need is for the improvement of monthly, seasonal, annual and longer-range predictions of climate parameters. The ability to forecast short-term changes in the weather has greatly increased the safety and reliability of air travel. There is no comparable capability at this time for forecasting the persistence of climatic anomalies or longer-term changes. While this capability has not been necessary over the last few decades of stable climate, the almost universal prediction that climatic variability will increase creates a need for the development of forecasting models.

The fourth research need is for an assessment of the economic, agricultural, energy and other impacts of climatic variability on human activities. No one doubts that large scale impacts exist. Even so, we cannot answer the question: What is a change of climate worth to the farmer, industrialist, forester, or fisherman?

The following three sections of this report consider: (1) the theories of climatic change; (2) possible scenarios for Canada; and (3) some impacts of change on the Canadian environment.

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## II. Theories of Climatic Change

The theory of climate change is generally sketchy. While there is still considerable debate in the scientific community on this issue, a number of observations are generally accepted.

(1) Climate can and does change.

(2) When it does change, it is more likely to change rapidly than gradually. Interannual oscillations are often greater than the gradual trend.

(3) Even small variations in the average annual temperature can result in significant environmental changes. Some researchers have observed a slight cooling trend of about 0.3° C over the past forty years. This, they claim, has shortened the growing season in the middle latitudes by a week to ten days.

(4) The "normal" weather of the past twenty five years has been in fact a balmy spell when compared with long-term trends.

(5) Past changes in the earth's climate have been accompanied by social and economic upheavals.

. . ./6

Climatic History

The changing nature of climate can be seen in figure 1 (from C. Emiliani, University of Miami). This graph shows water temperature in the Caribbean for the past 700,000 years. The chart indicates major ice ages occurring in 100,000-year cycles. It further shows that the last 6,000 years, during which our civilization has taken form, has been the warmest time in 100,000 years. Figure 2, prepared by P. Bergthorsson, reconstructs the decadal variation from the mean temperature in Iceland.

Some of the more important climate-regulating phenomena are linked together in feedback loops such that when change occurs it can occur very quickly. Some studies indicate that a change from a full-glacial period to non-glacial can take less than 100 years in terms of temperature. It takes much longer for the biota to fully recover. More time seems to be necessary to move from non-glacial to full-glacial patterns.

The climate does not have to return to full-glacial in order that the change be important. The "little ice age" (1550 to 1900 AD) was enough to destroy the once thriving wine industry in England and to cover under ice the pastures of Greenland. The Arctic expansion of 1900 BC caused monsoon failures which eventually wiped out the agricultural empires of Harappa and Mohenjo-Daro in what is now north-west India and Pakistan.

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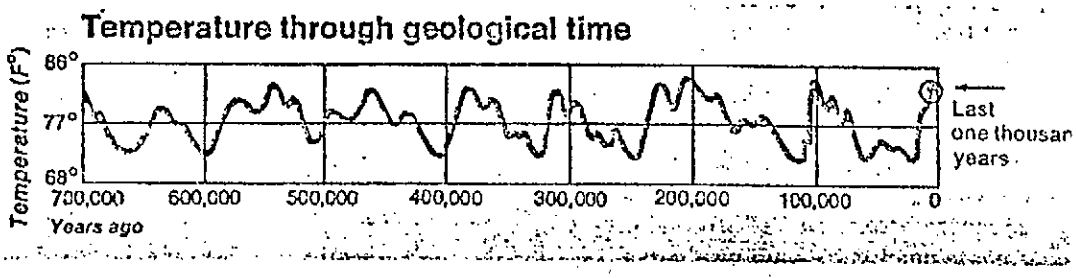



Figure 1

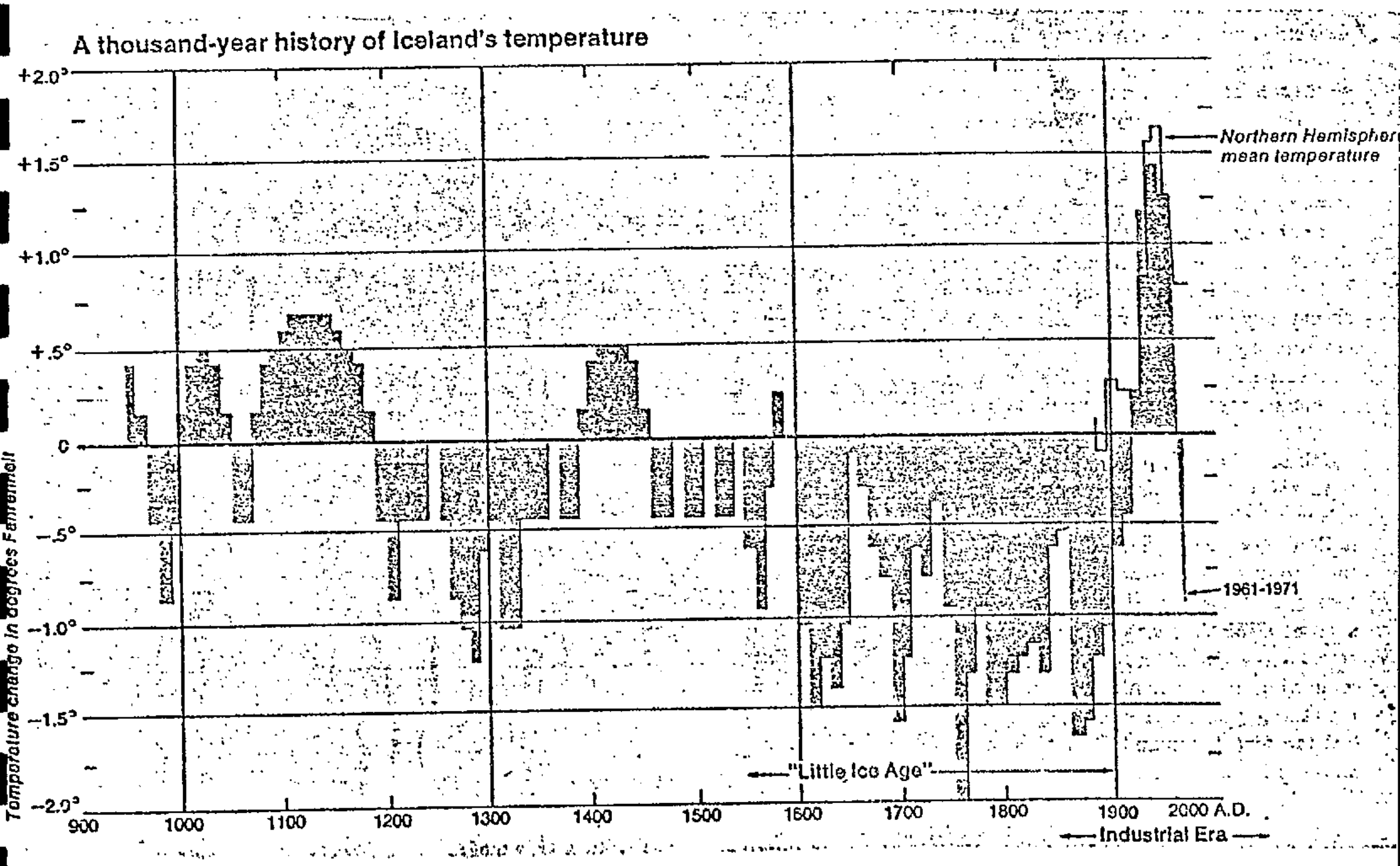



Figure 2

Theories of Climate Change

There are many hypotheses which purport to explain the origin of climatic change. While some are better than others, none are entirely satisfactory. It is in the nature of climatic change that the chains of events, from original cause to ultimate effect, are far too long and intricate to be easily understood in terms of a few interacting physical processes. Some of the events which might cause climates to change are described below.

Sunspots

The energy put out by the sun is generally assumed to be constant. Indeed, changes of total variation, even in the order of one percent, have not been firmly established. Large variations in the sun's output at the x-ray and UV end of the spectrum have been observed, however. These variations correspond to periods of extreme solar activity (sunspots). There is not a significant change in the visible and infra-red area of the spectrum.

The number of sunspots exhibit a cyclic trend with an 11.5 year cycle. Increased sunspot activity appears to correlate with more severe storms in the middle latitudes. More extreme temperatures appear during periods of low activity. The theory behind this correlation is that sunspots increase the solar wind -- that is, solar particles and radiation that fan the earth. The solar wind determines the amount of cosmic and galactic radiation that strikes the earth. This radiation, it has been hypothesised, has the potential to change the weather.

. . ./9

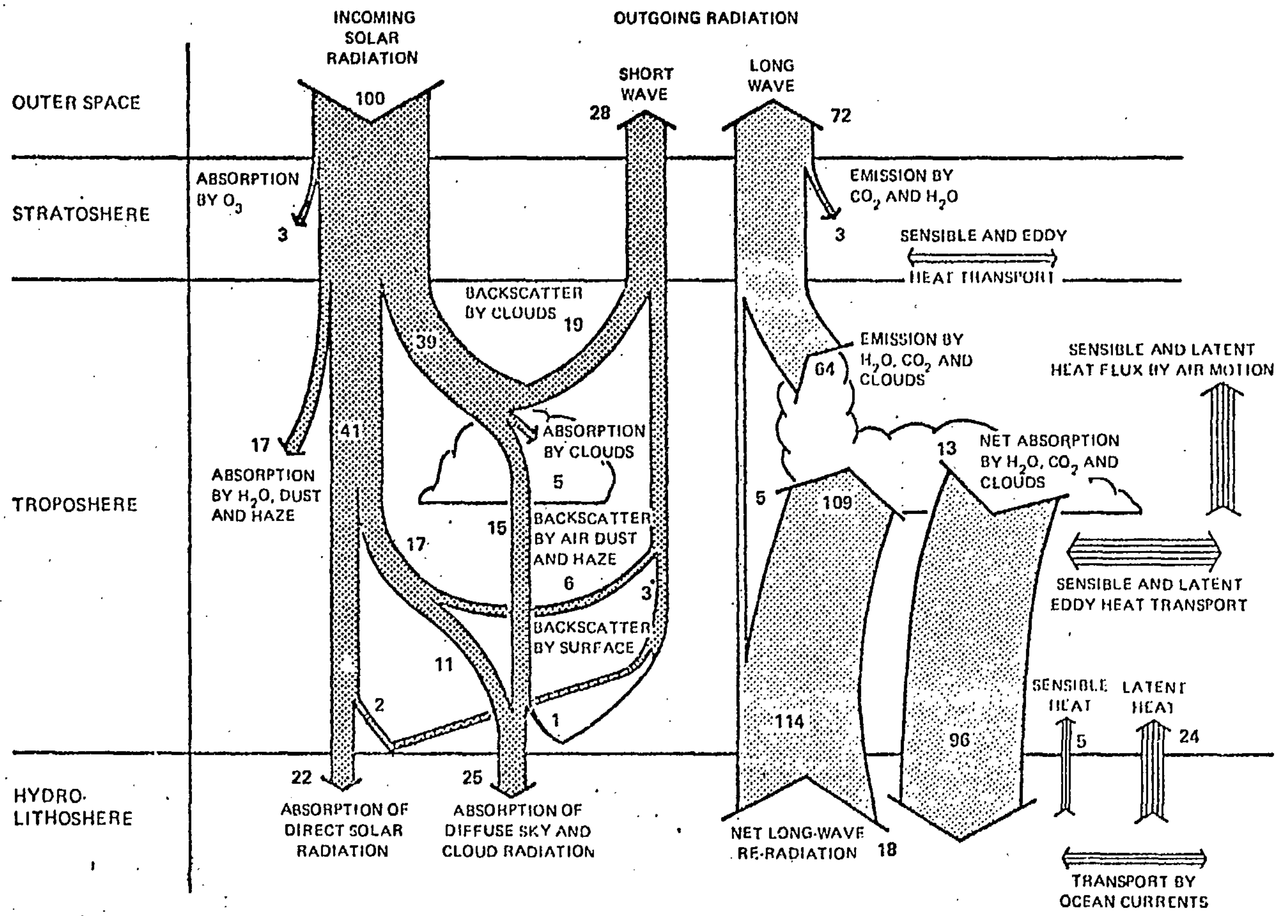
Orbital Variations

The shape of the earth's orbit has a profound influence on climate. It is the elliptical shape of the orbit and the tilt in the earth's axis that cause the seasons to change. Theorists have pointed out, however, that there are small deviations from the regular path taken by the earth as it moves around the sun. These deviations are themselves cyclic. The cycles vary in length. There is a 42,000-year cycle in the variations of the obliquity of the earth's axis. The precession index is quasi-periodic (23,000 and 19,000-year cycles). Orbital eccentricity varies in a 100,000-year cycle. These orbital variations correlate so well with observed climate cycles that some scientists have concluded that changes in the earth's orbital geometry are the fundamental cause of the succession of Quaternary ice ages.

A model of future climate based on the observed orbit - climate relationships, but ignoring man-produced effects, predicts that the long-term trend over the next several thousand years is toward extensive Northern Hemisphere glaciation.

Atmosphere

After travelling through space, solar energy must pass through the atmosphere before reaching the surface. The atmosphere changes incoming radiation both quantitatively and qualitatively. The atmosphere can reflect energy and absorb it. Energy is also transported by air from the equator to the poles. Figure 3 shows the energy flows in the atmosphere. The totality of atmospheric interactions is the subject matter of the science of meteorology. The relevant literature is much too extensive to be dealt with here. Only those phenomena which could lead to climatic change are discussed.




[redacted] Schematic diagram of the complex disposition of absorbed solar energy in the earth-atmosphere system. The potential climatic consequences of any human activities will be proportional to the relative disruption these might cause to the natural energy flows shown on the diagram (after Rotty and Mitchell).

Figure 3

Stratospheric Ozone

Much solar energy is absorbed by the atmosphere as it travels to the earth's surface. In the thermosphere (altitude 80 km and higher) gamma rays and "hard" x-rays are absorbed by molecular oxygen. The thermosphere has net gains in radiant energy and gets warmer with increasing altitude. Radiation slips through the mesosphere (50 km to 80 km). This layer has net radiation losses and cools with increasing altitude. In the stratosphere (10 km to 50 km) more energy is absorbed, this time soft x-rays and ultraviolet rays. Temperatures in this layer increase with altitude.

Energy absorption in the stratosphere is largely due to the presence of ozone. Since ozone is a relatively unstable combination of oxygen atoms, the total amount of ozone depends on the balance between the rate at which it is created and the rate at which it is destroyed. Its creation rate is dependent on incoming radiation and is therefore relatively constant. Its rate of destruction is influenced by the presence of chemicals which act as catalysts in the ozone depletion process. Two such catalysts, nitrogen oxides ($NO_x$) and chlorofluorocarbons, are introduced by man.

Nitrogen oxides are produced by automobile exhausts, aircraft emissions and fertilizer applications. Most of these emissions get washed out by rain in the troposhpere (altitude less than 10 km). Enough remains, however, to drift up into the stratosphere where it controls up to 70 percent of the normal ozone budget.

Because the stratosphere is a very stable layer of air, it takes a long time for particles and chemicals in it to return to the ground. High-flying aircraft (such as SST's) inject nitrogen oxides directly into the stratosphere. It is feared that commercial fleets of SST's could significantly deplete ozone concentrations.

Chlorofluorocarbons (CFM's, Freon) are a relatively new source of catalysts which destroy stratospheric ozone. CFM's are used extensively to power spray cans used for cosmetics and deodorants. They are also used as refrigerants. They are relatively inert and do not break down or get washed out in the troposphere. Eventually, they drift up into the stratosphere where they are broken up by high energy radiation. When CFM's dissociate, they release chlorine ions. It is the chlorine that catalytically reacts with ozone.

If the ozone barrier is depleted, more high-energy radiation will travel to the surface. This will likely mean cooler temperatures in the stratosphere and warmer temperatures in the troposphere. This could change global circulation patterns although it is not known what form the change would take. An increased temperature difference between the upper and lower troposphere implies increased turbulence and storminess. Increased exposure to ultraviolet radiation could also cause serious harm to plants and animals.

Carbon Dioxide

Carbon dioxide is one of the three most important radiation-absorbing constituents of the atmosphere (the other two are water vapour and ozone). The atmosphere allows about half of the incoming solar radiation to reach the earth's surface. The earth, being much cooler than the sun, emits radiation from the longwave end of the spectrum (infrared). Water and carbon dioxide effectively absorb longwave radiation so that less than one tenth of the radiation from the surface escapes directly into space. This phenomenon effectively traps heat in the lower atmosphere and is called the "greenhouse effect". Because of it the earth is about $14^{\circ}$ C warmer than its effective radiative equilibrium temperature.

Up to 1900, $CO_2$ levels remained constant. Since the turn of the century, however, concentrations have been increasing. This is largely due to the burning of fossil fuels. The $CO_2$ level is rising by about 0.7 ppm per year and it has been estimated that this has caused the average temperature to rise by $0.5^{\circ}$ C. It has been suggested that, by the year 2000, $CO_2$ levels could increase to 375 ppm and that this would mean an increase in temperature of $1.5^{\circ}$ C.

Particle Loading

Dust and other small particles in the atmosphere play an important role in global thermal balance. Air, dust and haze reflects (backscatters) about seven percent of incoming radiation. Along with atmospheric water, dust and haze absorb seventeen percent of radiation. Reflection results in energy loss while absorption causes an increase in temperature.

. . ./14

Nature is the main source of air-born particles. Volcanoes, sea spray, and pollen are examples of natural air pollution. Man contributes significantly to the particle load through slash-and-burn agricultural methods as well as by plowing the land and leaving it bare to the wind. Human activity may contribute up to thirty percent of the total atmospheric load.

Until recently it was believed that increased particle loads lead to overall cooling. It is now known that, under certain conditions, atmospheric dust can lead to warming. For example, "grey" dust over a reflective surface (such as ice) will lead to warming but over a dark surface (such as a plowed field) will lead to cooling. Temperature gains or losses due to particles are dependent on such things as particle size, residence time in the atmosphere, location, and reflectivity of the underlying surface. It is now suspected that large increases in atmospheric dust, uniformly distributed over the planet would result in overall warming of the earth. This is the opposite of what was previously believed.

## Albedo Variations

The albedo of the earth is the fraction of incident solar energy reflected back to space. The albedo varies, especially with changing cloudiness, but is on the average equal to 0.36 or 36 percent. The amount of reflection also depends on the type of surface, some examples of which are:

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| | |
|---|---|
| water surfaces | 3 - 8% |
| dark coniferous forests | 10 - 15% |
| deciduous forests | 10 - 25% |
| snow and ice | 30 - 70% |

The global albedo is largely determined by the relative proportions of land, sea, and polar ice. Man-produced surface changes such as dams and agricultural projects change the overall albedo only slightly. Such activities can, however, have important local effects.

A special case of albedo change coupled with thermal pollution is the urban heat island. Heat is released into the atmosphere by industrial, transportation, and domestic sources and into rivers, lakes, and oceans by industrial sources. This, along with landscape modification due to large structures and paved surfaces results in a three-dimensional heat island. The maximum intensity of the heat island is reached on a still night when the surrounding areas are cooling under the effect of net outgoing radiation. The minimum intensity occurs around noon when the heat flux of the surrounding areas more or less equals the input of artificial heat. Under stable conditions with light winds the effect is limited to a shallow layer of a few hundred metres with surface warming of 2 - 6$^{\circ}$ C. Local showers and thunderstorms can be produced, especially if extra water vapour is being introduced by cooling towers and hot water channels.

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Polar Ice

By far, one of the most important possibilities for modifying the albedo lies in the melting of polar ice. There is a great difference between the reflectivity of ice and of open water. As sea ice melts, more water is exposed. This leads to warmer surface temperatures which leads, in turn, to the melting of more ice, and so on. Such a positive feedback relationship can go in the other direction leading to colder temperatures.

Because positive feedback loops are inherently unstable, the role of sea ice in climatic change causes some nervousness among climatologists. It is argued, but not proven, that certain "trigger" mechanisms, insignificant by themselves, can have a greatly magnified effect by causing polar ice to advance or recede. Arctic oil spills, diversion of rivers which flow into the Arctic Ocean, and restriction or damming of the Bering Strait could all act as "trigger" events.

The significance of polar ice extends far beyond the economics of northern activity, argues R. Bryson of the University of Wisconsin. The extension of ice caps is definitely related to the extention of the polar front and the seasonal movement of the inter-tropical convergence zone (see figure 4). This zone determines how far north the monsoons will move. This is of crucial importance for the agriculture of such highly-populated areas as India and south-east Asia.

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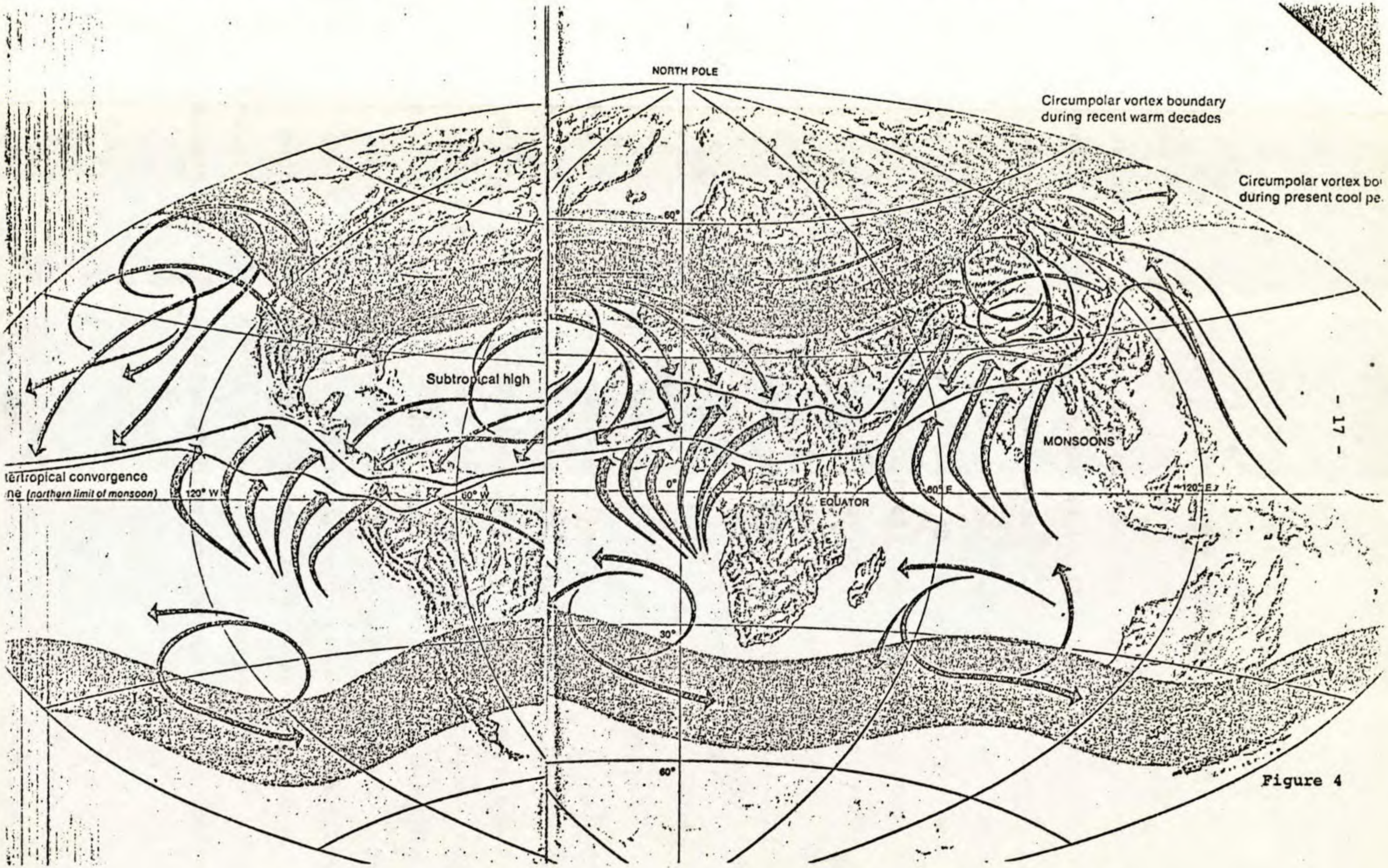

NORTH POLE
Circumpolar vortex boundary
during recent warm decades
Circumpolar vortex bo
during present cool pe
60°
30°
Subtropical high
MONSOONS
tertropical convergence
ne (northern limit of monsoon)
120° W
60° W
0°
60° E
120° E
EQUATOR
30°
60°


Figure 4

## III. Scenarios for Canada

There is no agreement among climatologists as to the direction of future climate change. Some claim that the planet is getting warmer, others that it is getting cooler. Most climatologists, however, feel that a climate with greater variability, or less stability, is likely. Since the planet has gone through many of these cycles before, it is possible to use geological and historical records to write scenarios for Canadian climate. The following three scenarios, prepared by G.A. McKay of the Atmospheric Environment Service, look at the implications for Canada of a warmer, a cooler, and a more variable climate.

### A Warmer Climate

A review of climatic records shows that Canada was warmer in the period of the Climatic Optimum (ca. 5000 B.C.), and again about 1940. How did the climate differ in those times, and what were its effects? The study of indirect evidence indicates that global temperatures were $2^{\circ}$ to $3^{\circ}$ warmer about 5000 B.C. At that time the Arctic was more humid, but the Great Plains were arid, the aridity extending eastward to the Great Lakes region. The boreal forest extended into the Arctic islands. Sea levels were not much different than at present. One would assume then that warmer means a northward displacement of the region climatically suited for agriculture, but more drought; diminished heating

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bills, diminished water levels on the Great Lakes, etc., but not necessarily a major disaster. The process of change would be sufficiently gradual that society would adapt without catastrophic consequences. The 1930's typify the most recent warm interval. They were disastrous; a major continental drought occurring at a time of great economic depression.

Droughts have affected the cereal production areas since the beginning of settlement. Stories of deserts and lush vegetation in the North American interior have alternated because that was the nature of the climate. Settlers moved in when the land was green, and emigration followed in the ensuing dry intervals.

The droughts of the 1880's and 1890's in western Canada led to the implementation of irrigation, summer fallowing and fodder storage. The "dirty thirties" showed this technology to be ineffectual against massive drought. A quarter million Canadians left the prairies. The 1937 average crop yield harvested in Saskatchewan was 2.6 bushels per acre. There were massive losses of livestock, at give-away prices, because there was no water or feed to maintain them. Market prices were greatly depressed, valuable top soil was severely damaged by erosion, and many wildlife populations were reduced to pitiful levels. The strong smell of sewage in the Red River at Winnipeg presaged a major water quality problem in our day should serious drought return.

The problem wasn't confined to the plains. Muddy rains stopped automobiles in New York. The level of the Great Lakes was reduced to very low stages - a problem that would greatly reduce vessel loading, access to ports, and the use of the lakes for recreation. The loss of trade and the cost of assistance was an additional levy on the Canadian economy which was already in serious straits.

A warmer climate would tend to push agricultural frontiers northward - if there were suitable soils. This would be of little value for most of the Canadian Shield, but the warming climate in Europe, this century, did allow the USSR to extend its agriculture northward to the Arctic Ocean. However, the warm climate in the USSR came to an abrupt end. Northern development in Canada would have to be based on similar uncertainty as to future changes.

Increased drought would adversely affect our ability to respond to or capitalize on food-trade opportunities and would contribute to inflationary trends. Price stability presently is highly dependent on world climate - further stressing of the production in any major producing country would lead to escalating food prices with consequences rippling down throughout the Canadian economy.

Warmer, drier weather would seriously stress inland water resources, reducing shipping, hydro power production, irrigation and water-based recreation. Forest fires would be more numerous, water rationing would be more frequent in cities, and the pollution of water courses and lakes would be greatly aggravated. Another effect is evident from the lack of sales of cold-winter clothing, snow removal equipment, etc., that occurred in the western provinces this year because of the mild winter.

Cooler Climates

The climate late in the 1800's was about 0.5°C colder than at present. Canadian agriculture evolved in this climate, and it is reasonable to assume the Canadian economy would survive its return. However, a cooler climate would stress many institutions. The growing season, which in many areas is just adequate for wheat and corn, would be about a week shorter. Substitute crops such as barley would have to be used in these areas, but they are not as attractive for export. Marginal areas would be most severely affected for they would become uneconomical from an agricultural viewpoint. Cooler climates are usually wetter. Eastern agriculture requires drainage tiles during wet seasons. The clay soils of the Red River Valley are poorly drained and pose a major problem to farmers, as well as contractors in earth work. Poor drainage alone would greatly reduce the opportunity to work on otherwise highly productive lands.

Heating costs would rise proportionally. A drop of $1^{o}C$ would increase domestic heating costs and energy sales about 7%, increase shortages and dispatch problems.

Cool climates are often snowier in maritime areas. It is perhaps more than coincidental that the record cold year of 1972 produced record snowfall over southern British Columbia and along the Gulf of St. Lawrence. This means not only increased energy use, but also a snarled and more costly transportation, increased traffic accidents, insurance rates, greatly increased construction costs, deficits in municipal budgets, and time losses by employees en route to work. Cold, snowy climates can also mean factory shut-downs due to natural gas shortages and problems of access. Along the east coast and in the Arctic, colder weather means heavier ice, a longer ice season, a shorter fishing season, greater shipping hazards, etc. Cool weather in summer equates to a major dropoff in recreation and tourism and their supporting enterprises. The installation of swimming pools, the sales of summer sports equipment, refreshments, use of resorts, travel - most recreation oriented activities would be curtailed.

On January 20, 1972, the Vancouver Sun reported that "Heavy snow slides have plugged all road and rail links between British Columbia and the rest of Canada, with the exception of a

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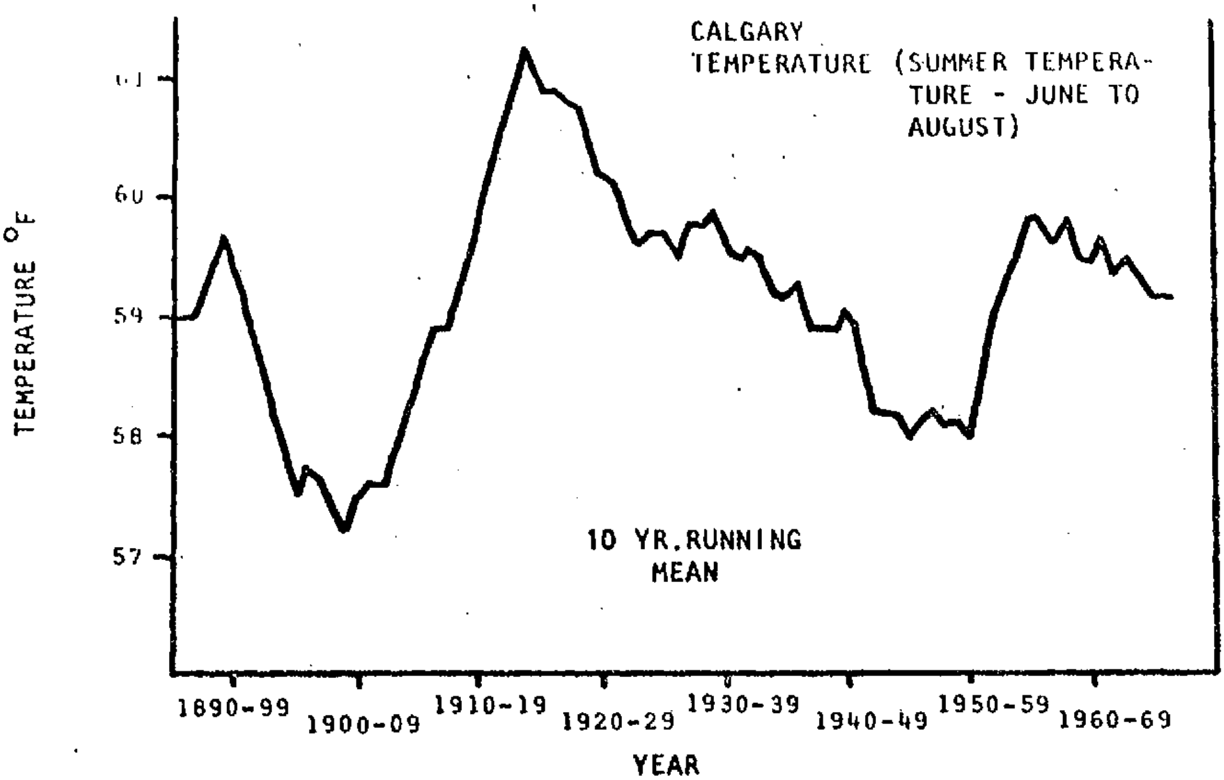
single lane on the Hope/Princeton Highway. Thousands of travellers were trapped, cargo deliveries to ships waiting in harbours were stopped, and due to a concurrent air traffic controllers' strike, southern British Columbia was, in essence, isolated from the rest of Canada." The same storm caused the collapse of transmission towers and lines; the loss to British Columbia Hydro estimated at $3 million. That year avalanches and snow depths reached record proportions and Rogers Pass was closed for 583 hours, compared to an average of 194. The aggregate effect of this type of climate is a drop in the Gross National Product. Overcoming the cold is a charge against productivity. It can be shown a decrease in mean annual temperature of $1^{o}C$ would effectively reduce the GNP by about 1%. Recent cooling in Iceland led to a 43% currency devaluation as fisheries failed due to ice, and the agricultural production was cut by 15%. Losses of over $6 billion were attributed to the extreme cold of Jan-Feb/77 in the USA.

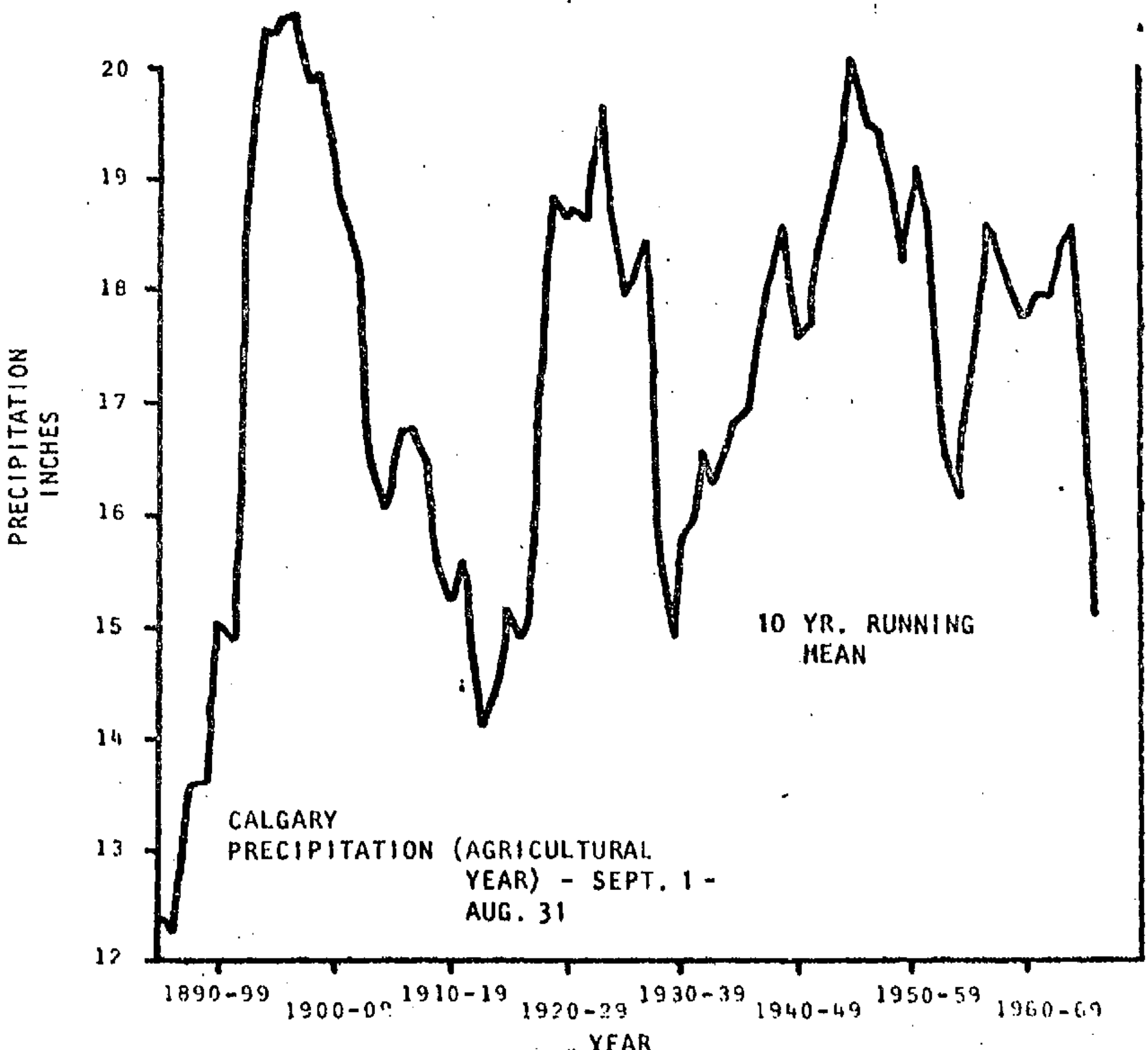
## A More Variable Climate

Climate assumes many forms. Since the 1930's the Canadian climate has been relatively favourable for agriculture, as it has been in the U.S. mid-West since 1957. This duration of a relatively suitable climate is remarkable and a more agriculturally unstable climate is likely to follow. The major climatic anomalies throughout the globe in the 1970's show how variable and extreme climate can be.

The short-term variations and anomalies are of extreme importance to investors. Year-to-year variations greatly exceed in magnitude the gradual long-term trends in climate - such as may lead toward an ice age. Man can adapt reasonably well to such gradual change, but he is highly vulnerable to abrupt, unexpected change. This vulnerability is particularly marked when economic operations are carried out near a critical threshold. Marginal agriculture and fisheries provide examples. Too often plans are set on the basis of recent periods of favourable climate, only to result in failure as a shift to unfavourable climate occurs. Corn production near Montreal was a disaster in 1976 because of that year's cold climate, but the losses were magnified because the varieties used were selected on the basis of a very warm summer in 1975. Ski resorts are built in areas because snowfall was reasonably good over the past few years, only to fail when variability brought warm, relatively snow-free winters.

Variability, in a relative sense, is most marked in arid areas - the oceans act as regulators in the more humid zones. The variability of rainfall at Calgary (Fig. 5) shows how changeable climate can be. In the 1890's Alberta turned to irrigation in response to prolonged severe drought. In the early 1900's it experienced a wet cycle. Flooding was rampant. Rivers changed their courses and roads were in desperate condition. The Calgary


CALGARY
TEMPERATURE (SUMMER TEMPERATURE - JUNE TO AUGUST)
10 YR. RUNNING MEAN
TEMPERATURE °F
60
59
58
57
1890-99
1900-09
1910-19
1920-29
1930-39
1940-49
1950-59
1960-69
YEAR


CALGARY
PRECIPITATION (AGRICULTURAL YEAR) - SEPT. 1 - AUG. 31
10 YR. RUNNING MEAN
PRECIPITATION INCHES
20
19
18
17
16
15
14
13
1890-99
1910-19
1920-29
1930-39
1940-49
1950-59
YEAR

.../26

statistics show a highly variable climate, but also one in which there is persistence of dry or wet for considerable periods of time. Plans or designs based on the climate of one interval could be seriously wanting for the next. While this effect is marked at Calgary, it can also be demonstrated to exist at other locations across Canada.

Variability also exists on the spatial dimension as was clearly demonstrated in the winter of 1976-77. Here, a weather pattern that might be normal for any one day or week, was extremely unusual because it prevailed over 4 months in much the same form right across the North American continent. The effects on the economy were enormous. Warm weather and the absence of storms caused a lack of snow and runoff across British Columbia, and kept lakes and reaches of rivers open in mid-winter in the Yukon. Skiing and hunting were severely hit, as were water supplies. The warm weather kept heating bills down on the prairies, but the drought caused farmers to avoid fertilizing, and cut purchases of winter clothing and equipment. The lack of water cut hydro generation and greatly increased the haulage of coal by rail to power plants. Dryness caused wells to dry up, water mains to break, and peat fires to persist throughout the winter, and threatened to cut trapping by 50%. Persistent cold near the Great Lakes greatly strained American energy resources and adversely affected agriculture, fishing and transportation. (Fig. 6).

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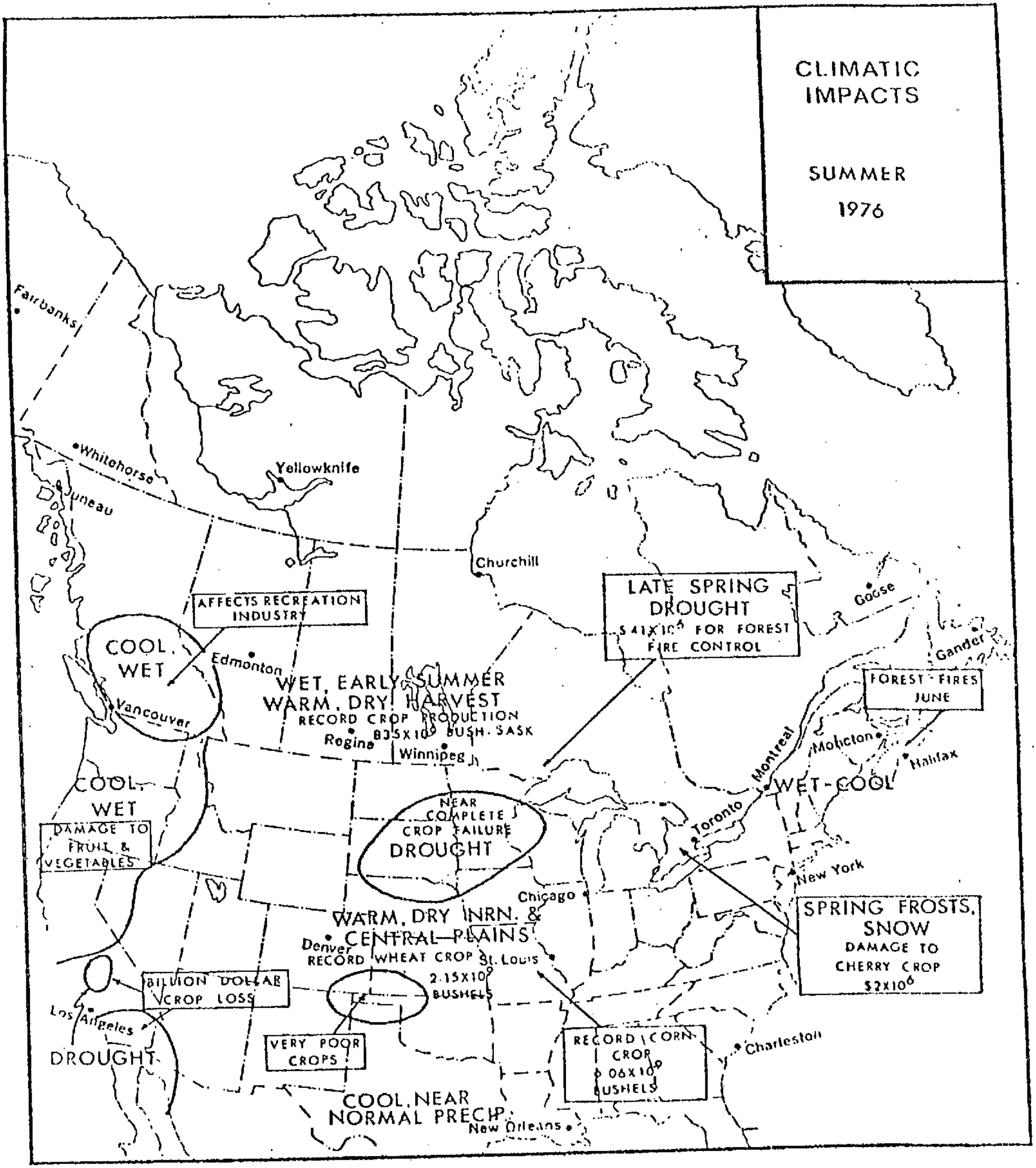
CLIMATIC IMPACTS
SUMMER
1976
Fairbanks
Whitehorse
Juneau
Yellowknife
Churchill
Goose
Gander
Edmonton
Vancouver
Regina
Winnipeg
Montreal
Moncton
Halifax
Toronto
New York
Chicago
Denver
St. Louis
Los Angeles
Charleston
New Orleans
AFFECTS RECREATION INDUSTRY
COOL, WET
WET, EARLY SUMMER
WARM, DRY HARVEST
RECORD CROP PRODUCTION
LATE SPRING DROUGHT
FOR FOREST FIRE CONTROL
FOREST FIRES JUNE
WET-COOL
COOL, WET
DAMAGE TO FRUIT & VEGETABLES
NEAR COMPLETE CROP FAILURE
DROUGHT
WARM, DRY NRN. & CENTRAL PLAINS
RECORD WHEAT CROP
BUSHELS
SPRING FROSTS, SNOW
DAMAGE TO CHERRY CROP
BILLION DOLLAR CROP LOSS
DROUGHT
VERY POOR CROPS
RECORD CORN CROP
BUSHELS
COOL, NEAR NORMAL PRECIP.

FIGURE 6.

Just a few months earlier the situation was quite different. Timely rains and a phenomenal summer resulted in Canada's largest wheat crop. Prairie farm incomes were high, but in the Ottawa and St. Lawrence valleys the cool, wet weather prevailed, depressing agriculture and recreation. In western Ontario, spring drought sent the cost-plus loss estimates attributable to forest fires to over $40 million, the highest in Ontario's history. From an economic viewpoint, it's an ill wind that blows no one good, and fire fighting was a profitable enterprise involving the use of 118 aircraft. Sour cherry prices in Ontario were up 86% in July because of a bizarre spring that brought fruit trees bloom at Easter, this followed by cold weather that kept pollinating insects from fertilizing the flowers. The climatically thinned fruit that resulted were a prime size, but cherries burst as the weather remained cool and rainy in July. Later in the year the British Columbia logging industry was in difficulty as a cool, wet autumn curtailed operations (Fig. 7).

Back in July 1976, beer was being rationed in Britain, and wine in France, as much of Europe experienced their worst drought on record. British farm income was off 30 to 40%, and industry curtailed by water shortages. In both countries inflation was rampant and currencies weakened. These overseas events are of great significance to Canada, since they influence

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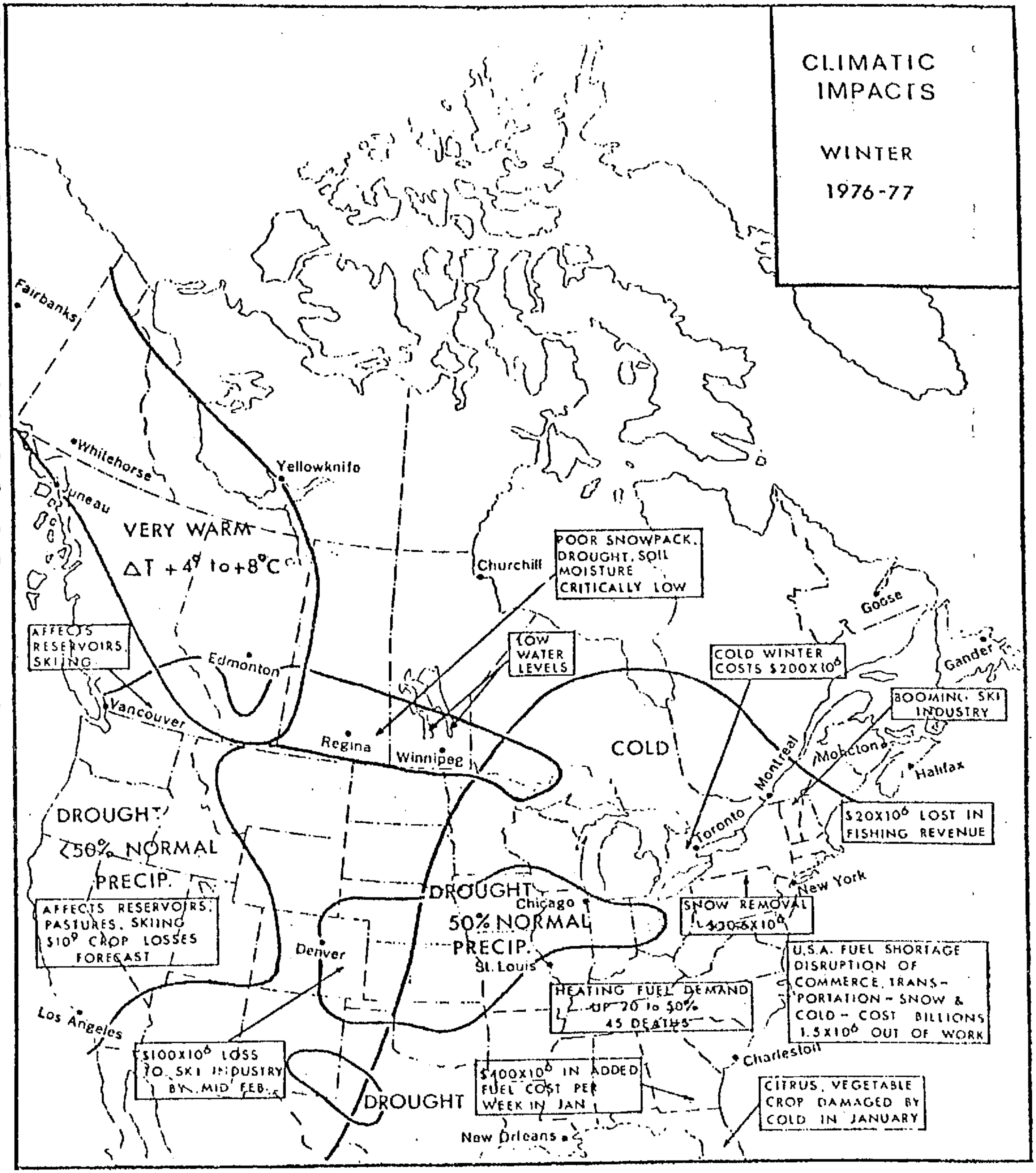
CLIMATIC IMPACTS
WINTER
1976-77
Fairbanks
Whitehorse
Juneau
Yellowknife
VERY WARM
ΔT +4° to +8°C
AFFECTS RESERVOIRS, SKIING
Edmonton
Vancouver
Regina
Winnipeg
Churchill
POOR SNOWPACK, DROUGHT, SOIL MOISTURE CRITICALLY LOW
LOW WATER LEVELS
COLD
COLD WINTER COSTS $200X10⁶
Goose
Gander
BOOMING SKI INDUSTRY
Moncton
Halifax
Montreal
Toronto
$20X10⁶ LOST IN FISHING REVENUE
DROUGHT
<50% NORMAL PRECIP.
AFFECTS RESERVOIRS, PASTURES, SKIING $10⁹ CROP LOSSES FORECAST
DROUGHT
50% NORMAL PRECIP.
Chicago
Denver
St. Louis
New York
SNOW REMOVAL
U.S.A. FUEL SHORTAGE DISRUPTION OF COMMERCE, TRANSPORTATION - SNOW & COLD - COST BILLIONS 1.5X10⁶ OUT OF WORK
HEATING FUEL DEMAND UP 20 to 50% 45 DEATHS
Los Angeles
$100X10⁶ LOSS TO SKI INDUSTRY BY MID FEB.
DROUGHT
$100X10⁶ IN ADDED FUEL COST PER WEEK IN JAN
Charleston
CITRUS, VEGETABLE CROP DAMAGED BY COLD IN JANUARY
New Orleans

FIGURE 7.

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trade and market prices. The droughts of 1972 contributed to a tripling of wheat prices. The Brazilian frost of 1975 has sky-rocketed coffee prices. Apart from these interdependencies, knowledge of climatic impacts abroad can be of enormous value to the investor, both as an index of general economic conditions abroad and the opportunity for export sales.

## IV. Impacts and Research Needs

It is known that climatic anomalies have dramatic and costly impacts on the economy as well as on society. Such simple things as the Braziliam coffee failure have resulted in cost increases in the order of many billions of dollars. Nevertheless, because of the great variety and scale of possible impacts, it is impossible to assess in any specific terms the cost of climatic changes.

It is however possible to delineate specific concerns. These range from the fear of the dangers in using monocultures at key points in the food production cycle to the uncertainties involved in energy planning within a variable climatic regime.

Because perceived impacts are hypothetical they are presented side by side with an assessment of the research needed to be more definitive about risks and options. The survey of concerns for impacts was undertaken by G.A. McKay and M.K. Thomas

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of the Atmospheric Environment Service and represents the state-of-the-art of this type of analysis.

The several pages that follow contain information and opinions gleaned from contacts and visits with many professionals in other Services of the Department of Fisheries and the Environment. To complete the survey, officials of other government departments, private businessmen, university professors, farmers, etc., were also contacted. In analyzing the information obtained, the investigators were able to draw on many years of experience in meteorological applications.

Such specific sector headings as land resources, agriculture, forestry, etc., have been used in the survey of needs that follow. To complete the report, headings such as "the Canadian economy" and "the Canadian environment" have beed added to ensure that the survey was complete. The "considerations" and "concerns" paragraphs in each sector contain information volunteered by the interviewees as a preamble to expressing and discussing their specific needs.

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These paragraphs have been included to allow a full appreciation of the expressed needs in each sector. The needs have been organized into sentences or paragraphs having to do with data, forecasts, and research and scenarios. While data and forecast services will most certainly be considered to be functions of a national meteorological service, the role of such a service, in attempting to meet the needs for research and scenarios, is perhaps more open to discussion. Certainly there is responsibility for a national meteorological service to promote and ensure that such studies are undertaken but at some point in applying meteorology to a specific sector, the user agency or industry must assume prime responsibility.

1. LAND RESOURCES

Considerations-

The Canadian topography is a legacy from thousands of years of geological, atmospheric and biological action. Similarly, soils have been formed over the most recent hundreds of years but, unhappily, they are subject to serious damage by man in such short periods as years, seasons, or even days, through ill-advised land use. In recent years the Canadian public has become aware that agricultural lands are not limitless, that many of our economic activities are polluting the environment, and that perhaps land-use studies, leading to regulations, are essential for a balanced

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economy and a healthful and pleasing environment. Short-term climatic anomalies have little effect on land use but longer term changes, say over three years or more, do. Climatic change over decades and centuries alters land use gradually as society and the ecosystem adapt without major stress.

Concerns-

There is a growing opinion that Canadians must preserve their basic land resources while making the best possible use of them today. Various government agencies are working towards a national land-use policy which might well be invalidated by climatic anomalies and change unless consideration is given to these factors. Specifically, DFE is concerned with land budgets and land-use requirements over the next 25 or so years; climatic anomalies will play a significant role in the scenarios that are being developed.

Needs-

(a) Data

While periodic current climatic anomaly information would not be of too great value, historical and statistical data over long periods or record would be most useful.

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(b) Forecasts

Specific climatic outlooks for periods ranging from 3 to 25 years and general outlooks for longer periods are needed.

(c) Research and Scenarios

1) There is a need for the development of a climatic variability index.

2) Better understanding of the role of land management in maintaining air quality is required.

3) Studies of the effects of climatic change on such land-based activities as agriculture, recreation and tourism, transportation, etc., are needed.

2. AGRICULTURE

Considerations-

Despite the advances of technology in recent decades, climate remains the most important factor in the success or failure of any type of agriculture. Climatic anomalies ranging from 1 to 12 months are important in tactical farming operations, those ranging from 1 to 5 years are important for crop strategies, while periods from 5 to 10 years are important in equipment investment decisions.

Concerns-

Farmers' concerns range from whether or not next month's weather will be suitable for planting, harvesting or some other field operation, whether or not next year's weather will be good for a particular crop, to whether or not investment should be made in specific equipment which will be used over a decade or more. Agro-business people are concerned with the types of agricultural chemicals and farm equipment to manufacture and stock. Governments are concerned whether or not to proceed with drainage or irrigation proposals, large scale land clearing and development proposals, and other long-term developments which have an impact on economics and society.

Most agricultural planning is based on personal experience and the lessons of history are too often not put into practice. Thoughtful planners, however, are concerned with -

a) whether or not the climatic record used in any planning is representative;

b) the probabilities of reoccurrence of major scale climatic hazards, and

c) how vulnerable an area is to specific hazards, especially those areas along the northern frontier of agriculture.

Needs-

(a) Data

Current information on the extent of climatic anomalies is needed for short-term planning especially in the absence of short-term forecasts. Historical and statistical anomaly data are required for agro-business planning.

(b) Forecasts

1) One month forecasts are required during the spring season to aid in scheduling cultivation and planting operations.

2) Three-month forecasts especially over the crop season are needed to plan planting, cultivating and harvesting operations.

3) Eighteen-month forecasts are required to aid in making decisions about crop selections one and two years in advance.

4) Five to ten-year outlooks are needed to aid in long-term planning for investments in farm equipment, drainage and irrigation facilities, grain storage and drying facilities, capital expenditures for the transport of agricultural products, etc.

(Note: In addition to the specific forecast needs noted above for farmers, other groups such as commodity dealers, retail and wholesale merchants, manufacturers, etc., require the same information for their decision making inthe agricultural sector.)

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(c) Research and Scenarios

1) Improved methods of providing the information that is currently available in weather offices to farmers and agro-business people are required.

2) There is a need for improved understanding of the role of climate and weather in land-use potential for agriculture.

3) The development of methods for the preparation of real-time advisories on the probable impact of climatic anomalies on operational strategies and markets is required.

4) The preparation of improved definitions of climatic risks involved in different agricultural activities is needed.

5) The development of functional relationships to evaluate risks and to develop strategies and warning systems should be attempted.

3. FORESTRY

Considerations-

Silvaculture is analogous to agriculture and, in many instances, is associated with agriculture in the consideration of needs for meteorological services. But time and space scales are different. Trees require about 60 years to mature in southern Canada and a hundred years in the northern boreal regions, while physical growth is usually an order of magnitude or more greater in forestry than in agriculture which results in different "micro" concepts in the "boundary layer" between the earth's surface and the atmosphere.

Concerns-

While climatic anomalies appear to be relatively unimportant to mature forests, they are important in the general response of an ecosystem when attempts are made to regenerate forests. A long-term climatic anomaly is important in altering the production rates and the reproduction capabilities of forests. Climatic anomalies are also important as they pertain to the prediction, response and control of diseases and insects, and longer term climatic change with regard to changes in ecological zones, the movement north and south of the treeline, etc. To date, however, climatic anomalies have been of greatest importance to forestry in the forest fire control and prevention sector.

Needs-

(a) Data

Up-to-date climatic anomaly information is of particular value in forest fire prevention and forest regeneration work. Statistical and historical climatic anomaly data are important in the selection of new species.

. . ./ 39

(b) Forecasts

Climatic anomaly predictions in time scales of one to 100 years (commensurate with the tree life span) are of value. Shorter climatic outlooks in time scales relative to such hazards as the spruce budworm are also needed. Seasonal forecasts are required for forest fire protection planning.

(c) Research and Scenarios

1) More study is required in monitoring and developing functional relationships between silvaculture and climatic anomalies.
2) Land-use capability zonation studies should be developed.
3) Study leading to a better understanding of the adaptability of breeding stocks from other areas is required.

4. FISHERIES

Considerations-

Fisheries are analogous to agriculture in that success in any year depends on the fishing season length and the presence or absence or climatic anomalies during the fish growth and harvesting seasons. Some fish live all year in Canadian waters and require a specific range of marine climate while others are migratory and move into Canadian waters in season when suitable marine conditions occur. The spread of fish diseases, in many instances dependent upon climatic anomalies, can be catastrophic. DFE is moving towards a

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real-time capability for forecasting waves, sea swells and other oceanographic parameters in support of fisheries but is primarily concerned with the social-economic aspects of fisheries. Forecasts of climatic anomalies and long-term climatic change are essential in setting quotas for fish harvest and for adjustments to social inequalities arising from the inadequacy of fishing incomes over specific periods.

Concerns-

Any climatic anomaly which might alter environments that are critical to fish reproduction and development are of concern. Anomalies over a watershed have considerable influence on the coastal marine climate. Specific short-term concernd involve the presence of ice in spring, which interferes with fishing by blocking ports, damaging equipment, etc. Medium to long-term climatic change has a marked effect on wind and current patterns, thus changing the marine environment and the varieties of fish that develop or migrate into it.

Needs-

(a) Data

There is apparently no need for information on short-term climatic anomalies but historical and statistical anomaly data are of value.

. . ./ 41

(b) Forecasts

1) Forecasts of short-term climatic anomalies are required to improve real-time capability for forecasting waves, sea swell and other oceanographic parameters. In turn these forecasts are used to forecast fish population according to year class.

2) Forecasts of 3 to 6 months are desired to aid in seasonal planning, particularly with regard to the presence or absence of ice.

3) Forecasts for 10 to 30 years would be valuable as an aid in setting long-term fish-catching quotas, in designing coastal engineering works, as an aid in the timing of expensive marine and oceanographic surveys and in planning for socio-economic legislation and action.

(c) Research and Scenarios

Monitoring and study is required to develop functional relationships between climatic anomalies and fish population. Too little is known about relationships between anomalies in the oceanographic environment with aquatic populations and such semi-meteorological parameters as basin runoff, sea-ice, etc.

5. <u>WATER RESOURCES</u>

<u>Considerations</u>-

Most aspects of the hydrologic cycle and of the physical qualities of water are controlled by the atmosphere - qualities of water are

are controlled by the atmosphere - precipitation and thus total water supply, timing and extent of runoff, floods, drought, ice cover, evaporation, water quality resulting from air pollution, etc. Fluctuations in the atmospheric processes are thus reflected in the hydrologic processes, although these are modified by a temporal lag and even more so by water storage.

Concerns-

Water resource planners are concerned with the impact of climatic anomalies on the water available for hydro production, water levels in lakes, rivers and harbours with regard to shipping regulations and the supply of water for irrigation. DFE is concerned that not enough attention is paid to coupling precipitation and runoff data. Federal and provincial authorities are concerned with the effect of climatic anomalies on plans for massive water diversions, while provincial and municipal authorities are concerned with the possibility of the need for water rationing on one hand and improved flood-prevention schemes and water control facilities on the other.

Needs-

(a) Data

Water resource operators are particularly in need of up-to-date climatic anomaly data to assist in their operational work. In addition there is a need for improved historical and statistical data for correlation with streamflow data in modern times and with paleoclimatological data of earlier eras.

(b) Forecasts

Seasonal forecasts are required for regulating water levels and power production. Climatic outlooks for 10 to 100 years would be of immense value in planning the siting and design of dams and other water control structures.

(c) Research and Scenarios

1) A reconstruction of climatic history using such paleoclimatological methods as the study of sediment cores from lakes is required.
2) Additional study and scenario preparation showing the influence of urbanization and industry on the hydrological cycle is needed.
3) Further research into the implications to soil conservation of erosion caused by heavy rainfall should be undertaken.
4) Additional study to gain better understandings of the impact of climatic anomalies on the hydrological balance, groundwater levels, etc., is necessary.

6. ENERGY

Considerations-

At present, the prime concern of governments in relation to energy and climatic change relate to long-term aspects. Forecasts of

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climatic change over decades and centuries would allow a better preparation of national energy policies than is possible today. On an operational basis, however, energy requirements for heating and air-conditioning, and to a lesser extent transportation, are quite dependent upon short-term monthly and seasonal climatic anomalies.

Concerns-

For periods of decades and centuries in the future there is widespread concern about the effect of (a) large-scale energy parks; (b) the increasing use of coal which may increase $CO_2$ levels sixfold over the next 200 years; (c) the heating effects of $CO_2$ will be three times greater at the Poles than the average for the globe, and what the resulting hotter climates would mean. Energy policy makers are also concerned about the need for additional energy to provide residential heating and whether or not it is necessary to invest in more pipelines, fossil fuel liquification plants, tar sands mining facilities, etc., in the next decade to allow for possible colder conditions in the decades and centuries to come.

Over shorter periods of seasons and years, coal, gas and energy suppliers, pipeline and transportation companies and distributors are greatly concerned with climatic anomalies since these have a

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marked influence on the demand for energy. In addition, severe climatic anomalies produce heavy winter snow and ice impeding transportation, wet harvesting weather requiring grain drying facilities, etc., which all have direct effects on the demand for energy.

Needs-

(a) Data

Energy producing and distributing organizations have a marked need for up-to-date climatic anomaly data in order to better manage their day-to-day operations. Comparative historical and statistical data are of immense value to the energy sector for planning year-to-year operations and capital investments in manufacturing facilities, pipelines, icebreakers, etc.

(b) Forecasts

Short-range climatic anomaly forecasts of one to three months would be of immense value to the energy industry. Climatic outlooks for periods of three months to two years would allow better planning of minor capital expenditures, while outlooks for three to a hundred years would be of great assistance to national energy planning.

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(c) Research and Scenarios

1) Research and the preparation of scenarios on the functional relationships that identify impacts of climatic anomalies on regional and provincial bases are required.

2) There is need for the preparation of design values and scenarios to achieve economy in energy consumption through improved architecture, traffic artery design, etc.

7. CONSTRUCTION

Considerations-

Long-term climatic change is relatively unimportant to the general construction industry. Buildings are no longer built to last "forever" and safety factors are often over subscribed. Failures of buildings, dams, etc., credited to weather are usually associated with the occurrence of extremely unusual events. Over shorter periods, however, contractors need advice and information pertaining to seasonal climatic anomalies.

Concerns-

Changes in permafrost, water levels and currents are of importance in the design and construction of buildings and other structures. Changes in the frequency of such major storms as hurricanes, tornadoes, severe thunder-storms, etc., are of concern to building designers. Such design values as snow loads, wind loads, design

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temperatures, precipitation intensity values, etc., must be based on periods of records that are applicable to the period for which the structure is being designed. In the past, building designers and engineers, in designing structures, have frequently abused the climatic normal concept by not allowing for marked climatic anomalies and the possible occurrence of extremely unusual events.

Needs-

(a) Data

There is little or no need for current climatic anomaly information but historical and statistical data are of great value to designers in the preparation of design values.

(b) Forecasts

Seasonal forecasts of 1 to 3 months ahead would be valuable to contractors for tactical planning. Climatic outlooks covering several years and decades would be of value to building designers.

(c) Research and Scenarios

Studies are required to develop functional relationships between climatic anomalies and building design. In addition considerable pioneering work should be done on site, specific type studies to garner a better understanding of the effects of unusual climatic anomalies on the construction and design of buildings.

## 8. TRANSPORTATION

Considerations-

The needs of the transportation industry for operational meteorological services have been so evident that very little attention has been paid to needs for climatic change services. The design of aircraft and airports, ships and harbours, trucks and roads, depend to a marked degree on climate and hence climatic anomalies. Any prospect of significant climatic change is of great importance to the entire transportation industry.

Concerns-

Are today's harbour facilities and ships designed to withstand winter storms of greater intensity and frequency than have occurred over the past few decades? Should increasing attention and resources be used for winter highway maintenance if winters continue to be severe? Should Canada invest more money in the design and construction of icebreakers or will the climate improve to such an extent they will not be needed?

Needs-

(a) Data

In general, current climatic anomaly information would be of great value to the transportation industry. Specifically, marine transport in the winter season has a vital need for such information

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as an aid in forecasting ice formation. Statistical and historical information on past climatic anomalies is of value to transportation facility designers and planners.

(b) Forecasts

Climatic anomaly forecasts for periods of 1 to 3 months would be extremely valuable to air, land and water transportation operators before and during each winter season. Climatic outlooks for periods ranging from 1 to 30 years would be very valuable in planning investment in transportation facilities.

(c) Research and Scenarios

1) Study and development of scenarios relating climatic extremes to ship and harbour construction are required.

2) Extensive study and scenario preparation is required relating short-period climatic anomalies to the occurrence of heavy snow, severe ice formation, and the flood potential of river basins.

3) Full consideration has not yet been given to climate and climatic anomalies as they relate to transportation in the Canadian north. Extensive research and scenario writings are required in this area.

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## 9. THE CANADIAN ECONOMY

Considerations-

Separate needs statements have been prepared for eight specific sectors of the Canadian economy. This statement contains a brief overview and touches on a few sectors not previously covered.

The Canadian economy is exposed to climatic anomalies and climatic change as much as or more than that of most nations. Canadian settlement, agriculture and other outdoor activities are all located near the "northern fringe". A marked cooling would make it impossible to grow most crops in Canada, while further south in the United States such cooling would perhaps be beneficial to agriculture. The winter season is an economic liability to the transportation industry; a change to longer winters would add to this liability. Similarly, longer and more severe winters would produce worse ice conditions and shorter fishing seasons on both coasts than now occur.

Planning and policy making on a national level are too frequently based on short-period experience. Over the past several years, Canadian business has seen how anomalous periods of climate in other areas of the globe such as the general cool conditions of 1972, the frosts of 1975 in Brazil (coffee) and in southern United States (citrus and fresh vegetables), have had a marked effect on

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inflation, speculation, and other factors affecting international economy. Further, our cereal marketing has been severely affected by the droughts in the Sudano-Sahel of Africa, in the U.S.S.R. and in China during the early 1970s and possibly by the western European drought of 1975 and 1976.

Concerns-

The concerns of government and the business community include:

1) Should food reserve be stockpiled - where, when, how, by whom, etc.?
2) What is the future of international trade and assistance programs?
3) Can insurance protect industry in a period of uncertain climates?
4) How can markets (especially farm markets) be kept stable?
5) Are fixed price contracts and "futures" markets to become obsolete?
6) How inflationary are climatic anomalies?
7) What level of investment should be placed in climatic research?

Needs-

(a) Data

In addition to the regular historical data periodicals issues by the AES there is a need for a climatic anomaly information service by which information on existing anomalies could be made public at least once a week. Statistical and historical data should be readily available to all planners.

(b) Forecasts

There is a requirement for an integrated climatic anomaly and climatic outlook forecast service for periods from 1 month to 1 century.

(c) Research and Scenarios

1) Much research is required in developing functional relationships correlating the gross national product with climatic anomalies.

2) Relationships must be developed between climate and all outdoor activities such as those mentioned in special statements, tourism and recreation, general commercial activity, etc.

10. THE CANADIAN ENVIRONMENT

Considerations-

Previous statements have dealt with the needs of various sectors of the Canadian economy. Too often the public's concern stops with the economy without giving consideration to the effect of climatic anomalies and climatic change on our environment. Specific attention must be given to the atmospheric environment, although there are interrelationships with the aquatic environment.

Concerns-

How would a colder climate affect Canada's native wildlife and vegetation? How far would the treeline retreat southward for specific temperature decreases? How would the vegetation change with increased precipitation in coastal areas? What would increased drought do to the "native" prairie vegetation?

Needs-

(a) Data

Statistical and historical data from weather observations and proxy data from tree-ring analysis, lake bottom cores, bog cores, and ice cap cores would be most valuable in building long-term climatic series for use by environmental conservationists and planners.

(b) Forecasts

There is a need for climatic outlooks over periods from 3 to 50 years. Wildlife authorities would find seasonal forecasts of great value.

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(c) Research and Scenarios

Little has been done in correlating climatic anomalies with changes in the natural environment. Much research and scenarios preparation are required.

## V. CONCLUSIONS

There is no evidence in terms credible to government or industry to suggest that climate will change beyond recent historical fluctuations. Changes are essentially scientific curiosities. Concern for climate change at the highest policy levels is justified, however, because of the overwhelming implications which such changes would have.

There is a strong suspicion that fluctuations and anomalies on the scale of those experienced in recent years will become increasingly frequent. This is significant considering the environmental stress caused by these fluctuations.

The main concerns are as follows:

1) There is a possibility that land use plans and policies could well be sub-optimized by climatic anomalies and change.
2) Climate remains the most important factor in the success or failure of any type of agriculture. Anomalies can completely cancel the benefits of crop planning and investment. Agricultural planners need more information to determine: the value of the

climatic record for planning purposes; the probabilities of re-occurrence of major anomalies; the vulnerability of farm areas to climatic change; and the best way of preparing for such change.

3) While climatic anomalies are relatively unimportant to mature forests, they can be of great importance when attempts are made to regenerate forests. They also are of great importance in programs to predict and control insects, diseases, and forest fires.

4) Fish growth, migration, and harvesting seasons are highly dependent on climate and are potentially sensitive to climatic change.

5) Most aspects of the hydrological cycle are controlled b_ the atmosphere. Fluctuations in levels of precipitation have significant impacts on hydro power generation, water quality, and sewage treatment needs.

6) The demand for energy in Canada is greatly modified by the weather. Decreased annual mean temperatures result in an obvious increase in energy demand. The release of thermal pollution and $CO_2$, on the other hand, have the potential to change the climatic regime.

7) Changes in permafrost, water levels, frequency of major storms, and soil stability are of importance in the design of buildings and other structures.

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8) The effectiveness of all transportation systems is greatly decreased by adverse weather conditions.

9) The general concerns of business and government include:

   a) Should food reserve be stockpiled - where, when, how, by whom, etc?

   b) What is the future of international trade and assistance programs?

   c) Can insurance protect industry in a period of uncertain climates?

   d) How can markets (especially farm markets) be kept stable?

   e) Are fixed price contracts and "futures" markets to become obsolete?

   f) How inflationary are climatic anomalies?

   g) What level of investment should be placed in climatic research?

10) Environmental concerns relate to the effect of climatic change on vegetation and wild life.

The lack of firm evidence relating to climatic change and the importance of change, should it occur, suggest that more research in the area of climatology is necessary. This is a role which should be played by the Atmospheric Environment Service.

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It is accordingly recommended that MOSST collaborate with and encourage the AES to:

a) devote increased attention to the issue of climatic change;

b) improve their delivery system for climatic information so that data is more accessible to users and researchers;

c) develop a capability for forecasting the climate for periods between 1 month and 10 years; and

d) investigate the functional relationships between climate and various sectors of the economy, especially agriculture and energy.

25128