A PERSPECTIVE
ON
CLIMATIC VARIABILITY

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EXTRACTS
FROM REPORTS
ON
CLIMATIC VARIABILITY

PREPARED BY THE
ATMOSPHERIC ENVIRONMENT SERVICE
AND THE
MINISTRY OF STATE FOR SCIENCE AND TECHNOLOGY

DOWNSVIEW, 1978

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A PRESPECTIVE ON CLIMATIC VARIABILITY

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 is often 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 and does 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 and human history 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.

Of major importance, 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. The 1976-77 winter's cold and snowfall in the eastern United States is an example, causing a $20 billion loss to the U.S. GNP.

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 processes to usefully predict how a change might come about; second, it is possible that existing social institutions cannot adequately implement solutions in some instances. What could be done, for example, if it were known that western Canada would have five 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, perhaps 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 immediate threats lie in persistent changes of temperature, rainfall and snowfall in areas which are agriculturally marginal, heavily populated, that are major transportation corridors, or otherwise closely linked to food, supply, trade and commerce. Man may contribute to these problems by inadvertently or otherwise altering climate on a local or even global scale.

The limits to present knowledge of climate is a major hurdle to overcome is responding to climatic variability. Our knowledge of climatic processes and of how activities relate to climate is inadequate, as is our capability to forecast the future climate. But major steps can be taken to mitigate the adverse and optimize on the beneficial aspects of climate. The preparation of contingency plans to respond to cold spells in the eastern United States was ordered following the winter of 1976-77 - they should have existed and been implemented prior to and during that period. There is much useful technology on the shelf to aid in the mitigation of drought, but too frequently it is forgotten, social and economic circumstances have altered, and there is no plan for implementation when the next drought arrives.

Much useful information is ignored or not available in the time or form needed for economic decisions. A major goal of a national climate program is to ensure that existing information on weather and climate is made available to users (Senator A.E. Stevenson re U.S. National Climate Program Act). The object of this seminar is to present such information to you and to discuss how the information can and should be used.

This report attempts to outline some of the problems relating to climate and to suggest what might be done using available information. Press clippings and quotations are used to show the social and economic importance of climate. This is followed by a report on the climate-man relationships. The changes affected by man within society, the economy and the environment are shown to be of major importance and ways of reducing related losses and optimizing on benefical climates are suspected. Finally, aspects of climate change are presented in an appendix for those who wish a deeper appreciation of climatic theory.

CLIMATIC IMPACTS

Climate creates both hazards and opportunities. The hazards have been reported extensively in the press because their social and economic consequences were serious, and the frequency and magnitude of the losses is increasing. Their aggregated impacts can be enormous - for example, the cold winter of 1976 -77 caused a loss to the U.S. GNP estimated at $20 billion. On the fringe of the cold anomaly, costs to Ontario totalled $200 million by January 31, 1977 including $135 million in increased residential heating bills, $15 million in road maintenance extras, and $50 million in lost productivity. The same area of the United States was stricken in 1972 when Hurricane Agnes caused losses to property estimated at $3.5 billion. The losses frequently result from inadequate planning or design. The cost and our vulnerabilities are mounting steadily as our society and its investments grow and become concentrated in susceptible areas.

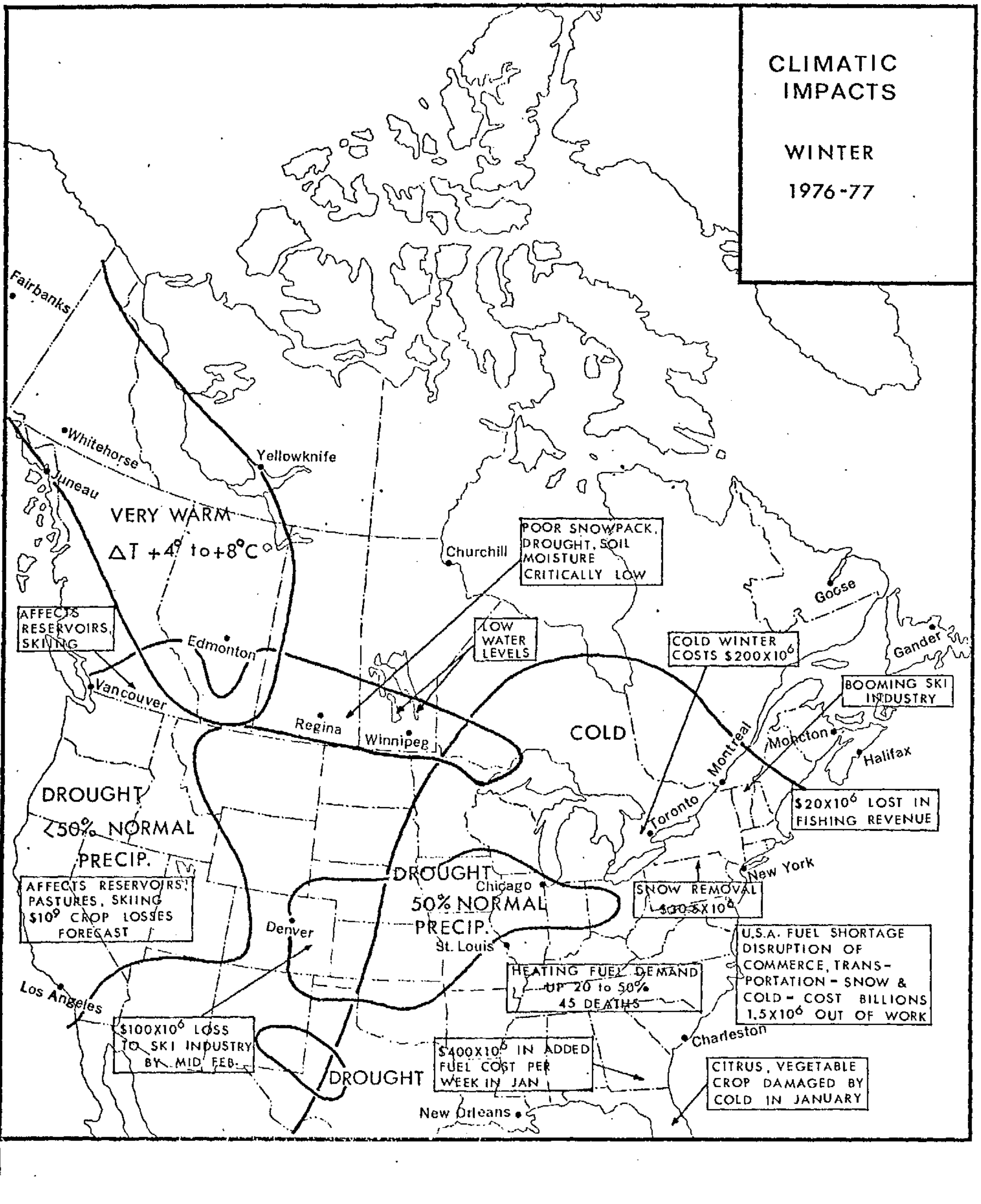
Climatic opportunities arise with equal frequency as the hazards. The Canadian snow manufacturing industry benefited substantially from the lack of snow that closed Rocky Mountain ski resorts in the winter of 1976-77. Snow removal equipment sales boom in snowy winters, and recreation and beer sales in hot, droughty weather. Opportunities also rise because of the market conditions created by anomalous climate in other countries. Arctic shipping and agriculture in northern Eurasia benefited substantially from the warmer climate of the 1930's and 1940's. Napoleon's and Hitler's bad fortune in selecting two of the worst winters on record to advance on Moscow were the good fortune of the Russians. It's an ill wind that blows no one good.

Perhaps the greatest benefit to society is in the less spectacular application of climatic information in commerce, trade, design, resource management - in almost every activity. Prudence and efficiency warrant its use and technology makes its use easy and inexpensive. Over a hundred years of climatic experience is available to guide Canadians in an almost infinite number of ways.

It requires preparedness to capitalize on the good and mitigate the adverse effects of climate. The U.S.A. was inadequately prepared for the cold winter of 1976-77, although history shows that such an event could be reasonably expected to occur. What of Canadian preparedness? A reactive attitude is simple to adopt, but it can be much more costly in the long run.

Whether climatic information is used or not depends on its proper shaping from data to information that can be understood and used by decision makers. Advice from the user on what data and the way it should be presented is urgently needed if the value of this resource is to be properly exploited. But above all, there must be appreciation of the problems and opportunities that exist.

The clippings that follow provide evidence of the opportunities and vulnerabilities that are perennially present.


CLIMATIC IMPACTS
WINTER
1976-77
Fairbanks
Whitehorse
Juneau
Yellowknife
VERY WARM
ΔT +4° to +8°C
Churchill
POOR SNOWPACK, DROUGHT, SOIL MOISTURE CRITICALLY LOW
AFFECTS RESERVOIRS, SKIING
Edmonton
LOW WATER LEVELS
COLD WINTER COSTS $200X10^6
Goose
Gander
BOOMING SKI INDUSTRY
Vancouver
Regina
Winnipeg
COLD
Moncton
Halifax
Montreal
Toronto
$20X10^6 LOST IN FISHING REVENUE
DROUGHT <50% NORMAL PRECIP.
AFFECTS RESERVOIRS, PASTURES, SKIING $10^9 CROP LOSSES FORECAST
DROUGHT 50% NORMAL PRECIP.
Chicago
New York
SNOW REMOVAL
Denver
St. Louis
U.S.A. FUEL SHORTAGE DISRUPTION OF COMMERCE, TRANSPORTATION - SNOW & COLD - COST BILLIONS 1,5X10^6 OUT OF WORK
HEATING FUEL DEMAND UP 20 to 50% 45 DEATHS
Los Angeles
$100X10^6 LOSS TO SKI INDUSTRY BY MID FEB.
$400X10^6 IN ADDED FUEL COST PER WEEK IN JAN
Charleston
DROUGHT
CITRUS, VEGETABLE CROP DAMAGED BY COLD IN JANUARY
New Orleans

Les experts s'interrogent Le Droit 2/2/77

Quel sera l'impact du froid sur la reprise américaine?

Toronto Star 2/2/77

Eggs $3 a dozen bread $2, milk $1 in Buffalo gouging

By LEE COPPOLA
Special to The Star

BUFFALO — Eggs at $3 a dozen; $2 for a loaf of bread; $1 for a quart of milk and up to $250 for a small hotel room — these are just some of the examples of price-gouging which have shamed this snow-paralyzed city.

The rip-... blizzard cov... ply trucks as ... "A frien... Macey, who ... the city said ... a quart of milk. ... City official ... gouging victims. ... "My heart ... said Erie County

WEATHER/COVER STORY

The Big Freeze

Why had the rain turned white? Startled millionaires wintering in their baronial mansions in West Palm Beach, Fla., peered closer last week at the miracle that was falling from the skies and discovered—could it be?—yes, the substance was snow, the first ever reported there. Since mid-November, pedestrians in Dallas, unaccustomed to such hazards, have been slipping on sleet-slicked sidewalks. Meanwhile, a series of blizzards has smothered Buffalo this winter with an astonishing 124.6 in. of

Globe and Mail 29/1/77

Thick ice causes halt to shipping

By ALBERT SIGURDSON

Unusually severe ice conditions have halted navigation in the St. Lawrence River at Quebec City and have caused commercial operators in Lake Superior to cut off their winter program.

Globe and Mail 10/2/77

Cold costs Ontarians $200 million so far

By THOMAS CLARIDGE

Abnormally cold weather has probably cost Ontarians about $200-million so far this winter.

Most of the bill comes from higher heating costs, but it also includes some big jumps in road-maintenance expenditures and higher transportation expenses.

...that is usually ...rmometer was ...ce was so soft ... canny and the ...ren then man-

him in a down ... blizzard to a ... the office crew

Wall Street Journal 26/1/76

Weathering Winter

For Many Americans, Soaring Price of Fuel Creates Real Hardship

Plants Lay Off Workers;

Business Week February 14, 1977

THE ECONOMY

A bad case of frostbite

Winter is devastating the statistics. How fast can they recover?

Globe and Mail 1/2/77

Snow-clogged roads cripple Eastern Ontario, Southwest

Ottawa Journal 1/2/77

Le vent, le froid et la neige

Ca n'est pas fini!

The Sun 5/3/1977

Prairie drought brings dustbowl

REGINA (CP) — Prairie dust storms, sending clouds as high as 10,000 feet, are reducing visibility in some areas of Saskatchewan to less than a mile.

The storms, a phenomenon which hasn't been seen here for many years, now are almost a daily occurrence.

The cause is a combination of strong winds and no rain, and the situation becomes particularly bad when the ground is warm and a cold air mass moves overhead.

Wind speeds over the weekend were up to 90 kilometres an hour, and yesterday they were still up to 60.

Bob Jacobs of the Regina weather office said such conditions combined Saturday to "boil up" the air, sending dust clouds 10,000 feet into the atmosphere.

They reduced visibility across the southern grain belt, roughly from Saskatoon

south to l

There
no snow
August.
winter
lack of
creating
many Pr
The
reminder

of the D
continue
the Gre
dustbowl

May 21, 1977 The Financial Post p 1

DROUGHT

Governments pray for rain as they mobilize task force

La Presse – 17 nov./75

Une partie des E.-U. menacée de sécheresse

Globe & Mail 18/5/1977

Food experts look for rain to put damper on inflation

THE SPREADING IMPACT OF WORST DROUGHT IN DECADES

Months without enough moisture are imperiling crops, cattle, bank accounts. Now danger is threatening new areas.

The drought th
tion from Illinois
one of the worst
As March began
etable crops were
Cattle herds were
pasture. Corn-ph
mented pos
The clear signal
food prices and p
months hence.
Shadow of dus
far below normal
even the rains an
much of the reg
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fall over the next
normal precipitat
to alleviate the bo
"Barring a mir
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Walter Orr Robert
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weather, told *U.S.*
Even as Robert

U.S. NEWS & WORLD REPORT, March 7, 1977

Winnipeg Free Press 11/2/77

Drought bill $3 billion

BERKELEY, Calif. (Reuter) — Drought could cost California up to $3 billion in lost crops and livestock this year, the California Farm Bureau said Wednesday.

The estimate was the latest sign that crop losses due to frost in Florida and drought in California will raise the cost of food to consumers.

Le Droit 25/5/1977

Une sécheresse presque sans précédent

BOUCHETTE — "En vingt-huit années de métier, je n'ai jamais connu un printemps aussi sec", de dire hier soir, le directeur-général de la Société de conservation de l'Outaouais M. Ghislain Ouellette.

La SCO qui est responsable de la détection et de la suppression des feux de forêts sur un immense territoire englobant tout l'Outaouais et la nord de Montréal, indiquait hier soir 73 feux actifs dont vingt hors de contrôle et les orages "secs" d'éclairs continuaient à se multiplier au nord de Mont-Laurier et à la hauteur de Parent et Clova.

Toronto Star 19/2/75

Farmers fear millions lost from drought

TIME Feb. 14, 1977 — THE NATION

THE WEATHER

The Icy Grip Tightens

LE DROIT 2/2/77

Quatre-vingt morts aux E.-U.

NEW YORK (AFP) — Le bilan de la vague de froid sans précédent qui se poursuit aux Etats-Unis s'aggrave de jour en jour: hier, on comptait près de 80 personnes mortes de froid, le nombre de salariés mis à pied à la suite de la pénurie de gaz naturel dépassait largement le cap des deux millions, des centaines de milliers d'écoliers sont restés chez eux, leurs écoles n'étant pas chauffées.

...oelectric power will de-...spring. Water is already ...in parts of California (see ...). In Oregon, forest fires

...saster areas because of snow or drought, thus making them eligible for some form of federal assistance.

...th the new President, ...passed Carter's plan ...l gas crisis, and be ...—his first. The mea-...ral Government the ...r natural gas supplies ...rplus to those where .... Just twelve hours ...dry on the bill, the ...rving from the Pa-...ough a series of con-...and then on to the ...theast. ...earth in the White ...President delivered ...t (see story, page 20) ...consumers and pro-...effort to deal with

Toronto Sun 8/2/78

We're about out of cheeks to turn

EVERYWHERE (UPI-Special) — Well, almost everywhere.

Places like southern Arizona and Miami made out all right, but the rest of North America struggled to cope yesterday with what many areas called the worst winter storms of memory.

A high-pressure system in Northern Ontario forced major storms westward as far as Alberta and eastward into Quebec and the Maritimes.

For the U.S. Midwest and Northeast, it was ... second straight ... lentless bl... brought ... and ...

MARITIME ... failures, road ... ferry service

THE GLOBE AND MAIL, SATURDAY, JANUARY 22, 1977 - B3

Globe and Mail 15/2/76

Heavy early snowfalls strain removal budgets

... fearing the worst ... ter for livest... able to ... drift...

Fresh fruit embargoed by Florida

LAKELAND, Fla. (AP) — ...he Florida Citrus Commis...n has placed an embargo on all shipments and sales of fresh citrus fruits, effective ...nday.

...mbargo will last 10 ... be followed by ...week period ...ts will ... into ... as concen... processing of the ... affected by the embargo.

The Florida Fruit and Vegetable Association said retail shoppers will begin to see the effects of record cold weather on Florida's vegetable crops late next week.

The Globe & Mail - 27/1/1978

Hurricane-force blizzard batters Ontario

Two die in storm, winds hit 93 mph

Snow and hurricane-force winds spawned by record low barometric pressure roared into Ontario yesterday, stranding travellers, knocking out hydro in many areas, closing schools and public buildings and causing heavy property damage. ...ared. ... powerful ... coastal areas, ...s of Boston and ...ing areas were with...ut power at various times.

... fo... O... easte... ince ... Highw... the Bro... scores of ... in conditi... a whiteout.

QUEBEC: Canada ... many other ... closed after m... centimetres of sn... winds made virtually imp... Flights and buses ... Montreal were canc... and schools across ... province closed.

The Vancouver Sun - 5/1/1978

Storm blocks highways, traps B.C. train travellers

Transportation in the B.C. Interior is getting back to normal today after a snowstorm virtually cut off rail and road traffic to the Lower Mainland on Tuesday.

New York Times 14/7/1977

Planet earth undergoes record weather extremes

By James P Sterba
New York Times Service

HOUSTON — The year began with a blizzard of superlatives — among the coldest winters in history in the East, driest in the West. People froze in New York, tomatoes glacified in Florida, streams ran dry in Oregon, and bears sweated in Alaska — in January.

Now, with winter emergencies forgotten, natural gas flowing, record crops forecast, and swimming pools brimming, many Americans have settled into the air-conditioned cocoons of summer, more oblivious than ever to the vagaries of weather.

Weather experts, meanwhile, have had time to soberly reassess the shrill pronouncements of winter. Their consensus: the weather was just as [illegible] and worrisome as they said it w[illegible] more importantly, it still is.

The United States, and muc[illegible] globe, is experiencing some of [illegible] extreme weather of the century. [illegible] and national security experts [illegible] come increasingly concerned. T[illegible] coldest, driest, hottest, and we[illegible] sprinkled daily in world weather [illegible] and their effects on grain harv[illegible] ergy useage, fisheries, water c[illegible] tion and even social unrest have [illegible] matters of day to day scrutiny by federal agencies.

The Pentagon, concerned with [illegible]

—THE GLOBE AND MAIL, WEDNESDAY, SEPTEMBER 8, 1976 3

U.K. farm income off 30% to 40%

LONDON — Britain's drought will cut farm incomes this year by up to about $720-million or an average of 30 to 40 per cent, a farmers' representative said yesterday. Prof. Asher Winegarten, deputy director general of the National Farmers' Union, said the union's recent survey gave the first real picture of the effects of the drought. He

La Presse 31/12/76

-les aérosols-

Les humains déclenchent la guerre contre le fréon, qui attaque la couche d'ozone

Globe and Mail 23/6/76

Fears for crops in Europe

Too hot or too wet

LONDON (AP) - The western part of the Soviet Union has just had its wettest weather since at least 1878 and more rain is forecast.

Britain, meanwhile is having its driest spell since 1727. Despite some recent showers, reservoirs and rivers remain several feet below their normal levels.

Across Europe, from too wet to too dry, the worry is the same—the threat of crop failure.

One of the countries worst hit by drought is France. Experts predict that if the drought continues, France will loose thousands of tons of wheat, barley and sugar beet and a large part of its vegetable crop.

Spain is also hit by drought. Oth[illegible]

Globe and Mail 3/2/77

Poor weather raises world crop doubts

La Presse 7/7/76

Les Parisiens en sont rendus à désirer les orages

PARIS (AP) — Les habitants de la région parisienne commencent à envier au sud-ouest, aux pays de Loire et à la Bretagne leurs orages parfois si meurtriers, mais qui atténuent la canicule.

La sécheresse poursuit ses

Globe and Mail 3/5/76

Britain suffers worst drought in 200 years, crops threatened

28 THE WALL STREET JOURNAL, Friday, Dec. 19, 1975

Soviet Uncertainties

Health of Russian Economy Is Dependent On Increase in Rainfall, Recovery in West

New Scientist 19/1/78

Cold winters and the economy

A winter as severe as that which Britain experienced in 1947 could possibly have even more disruptive consequences today. What conditions cause such prolonged cold spells? And is there any chance of anticipating them?

32156

—THE GLOBE AND MAIL FRIDAY AUGUST 19 1977

Public asked to water thirsty trees

Play spots closed, loggers laid off as heat wave broils B.C.

Le Nouvelliste 54e année, No 51 Trois-Rivières, vendredi 28 décembre 1973

Le bilan de la tempête de verglas

Pertes de $2.2 millions et 300,000 citoyens privés d'électricité

The Globe and Mail - April 5/76

Jammed ice floods St. John River valley, hospital evacuated

PERTH-ANDOVER, N.B. (CP) — About 500 people were taken from their homes ... Emergency Measures Organization.

Flooding was caused by an ice jam. At Woodstock, three of the five spans of the railway bridge across the Medu-

Globe and Mail 25/11/77

Frost damage to PEI potatos at $1.7 million

A snowstorm last weekend was the final blow in the loss of about 2,000 acres of potatoes still in the ground in Prince Edward Island, according to Paul MacPhail, potato specialist with the provincial Agriculture Department. He estimated that the frost damage resulted in loss to growers of $1.7-million, based

The Citizen 16/5/1977

Forest fire roaring down on cottagers

... ence Department.

At Hartland, where an ice jam caused havoc on Friday, residents were without drinking water until arrangements were made to have it trucked in by a local dairy.

The Trans-Canada Highway was blocked both below and above Perth Andover by two ice jams, forcing motorists to go through Maine.

La Presse - 21 avril 1976

Inondations: nouvelle crue printanière

Après une longue accalmie sur le front des inondations, les riverains de la région de Montréal doivent de nouveau ...

Les secteurs les plus susceptibles d'être touchés par cette deuxième crue provoquée par le dégel sont, outre la région de Montréal, la rive sud du Saint-Laurent, de la rivière Bécancour à Matane et la rive nord jusqu'au Saguenay.

Cependant, tout le secteur sud de la rivière Bécancour à la frontière américaine connaît des baisses de niveau d'eau, y compris la rivière Richelieu.

... rivière ... Saint ... rivière ... météorolo... un te ... main, locale ... Cette augmentation de température ... d'accroître la ... à la tête et causera ... tions.

Le Soleil - 14 juillet/76

125 millimètres de pluie depuis le début du mois!

par Denis ANGERS

Les Québécois goûtent à tous les caprices d'une météo imprévisible.

... progresser depuis jeudi dernier et atteignait hier matin 76.25 upieds, soit six pouces au-dessus de la côte d'inondation.

Le Droit - 5 avril 1975

La situation est désastreuse du côté américain

PERTH-ANDOVER, N.-B. (PC)— Les inondations ont légèrement ralenti, samedi, dans la plupart des régions le long du côté canadien de la rivière Saint-Jean supérieur, mais on a signalé que la situation était désastreuse du côté americain du même cours d'eau.

The Citizen 16/5/1977

Fires sweep northland in drought

By The Canadian Press

More than 200 forest fires raged across northern Saskatchewan, Manitoba and Ontario during the weekend, forcing evacuation of several communities and threatening acres of commercial timber, provincial officials said.

More than 400 Canadian Armed Forces personnel were called in Sunday to help fight at least 67 forest fires in Northern Saskatchewan

The Globe & Mail - Oct. 20/76

Trees uprooted, planes overturned

Hurricane winds smash buildings, boats in Newfoundland

The Sun 24/5/1977

Ontario a tinder box

Globe and Mail TORONTO, MONDAY, APRIL 26, 1976

Frost, brown rot feared

Fruit crops threatened as snow hits province

MAN AND CLIMATIC UNCERTAINTY *

by

G.A. McKAY

The "Climate Problem"

Uncertainty in climate equates to environmental uncertainty and uncertainty for mankind. That the climate is uncertain, there can be little doubt. The seventies have been punctuated by climatic crises. A seemingly endless parade of climatic extremes - typhoons, drought, floods, excesses of heat and cold have seriously stressed communities and economies. Death and famine in Bangladesh and the Sahel, market action and inflationary pressures connected with poor harvests in Europe and Asia, the social and economic aspects of sustained cold and water shortages in North America - these have made us acutely aware of our vulnerability to climate variations. These events have forced the questions: has the climate changed? Is there no escape from future climatic disasters of increasing severity and frequency? Has mankind done this to itself?

Man has always existed in a state of climatic uncertainty. Climatic variability is both a threat and a challenge, and a factor that has contributed to the evolution of the human species. The disappearance of cultures and the failure of major technologies in history have often had their origin in climatic change. Wisdom and technology have made man master of the globe despite climatic adversities, but the recent climatic events remind us that we have far to go to achieve immunity. Climatic uncertainty remains to compound the other uncertainties facing mankind; furthermore, man has now become a part of the climatic problem. Climates are being changed on the local scale, and it is within man's power to alter climate on regional and global scales. The issues relating to natural climatic variability are stressed here as the long-term effects are to be addressed by the next speaker.

Our present awareness of the "climate problem" is due mainly to a news media of unprecedented effectiveness. Analysis and logic tell us that the resulting famines, debility, speculation and inflation, have many non-meteorological roots. Populations have grown and expectations have changed. We have more material goods, more powerful technology, more investments, more need and more wants. These shifts have been largely in one direction - increasing pressures on the environment, on ecosystems, and on economic systems. New technologies have helped overcome the vagaries of the climate, but they have also increased demands so that in many respects we are more vulnerable. Societal change, outmoded defences, short memories and short-term vision leave us disaster prone.

*Presentation to the Third International Banff Conference
Man and his Environment - Our Future Options - May 1978

If only we could predict the future then one major uncertainty would be removed. But our ability to predict natural variations in climate is limited and we may never have forecasts with the detail and precision that are needed for many social decisions. On the other hand, defensive technologies exist, and available science and history do provide an excellent basis for planning for the future. The changes caused by man are gradual, observable, and in some respects, predictable. This type of prediction can help us avoid inadvertence and possibly assist mankind to mitigate the damage of natural climatic variations. Climatic uncertainty is unlikely to disappear and man's impact and vulnerability are increasing. However, the "climate problems" can be greatly diminished and advantage taken of the opportunities offered by climatic change and variability, by planning that allows for the variable, pervasive nature of climate.

What's Happening to the Climate? - Natural Variability

Over 225,000 died in the Bangladesh cyclone of 1970, but losses there and in the Sahelian drought will never be known with certainty. The failure of the anchovy fishery off Peru in 1972, the recent surges in prices of cereals, sugar and coffee, are all events with intimate climatic connections. In 1976 much of Europe experienced its worst drought on record. British farm income was off 30 to 40%. Forests burned and herds were drastically reduced for want of feed. Inflation was rampant and currencies weakened in both Britain and France. North America's economy also shuddered in the winter 1976-77 as a remarkably steady weather pattern brought a mild, dry climate to the west, and sustained cold to eastern United States. Prevailing drought conditions in California were extended into the Great Plains. Winter snow cover failed to materialized in the Canadian West where soils cracked and dust storms prevailed in the more arid sectors. Only a few months earlier, in the summer of 1976, eastern Canadian farmers were concerned about a cooling trend that was hurting agriculture - too cool for corn, and too wet for hay and the potato harvest. The upsets have continued on into 1978 with devastating rains in southern California, and another bitter winter over eastern North America and much of Europe. Long standing climatic extremes are being exceeded frequently. What is happening to the climate?

Is this normal? Obviously extremes are not everyday occurrences, or they would not be extremes. But the climate is normal in the sense that similar events have occurred before and will happen again, perhaps not in the identical manner and location, but assuredly there will be more extremes. A more severe cyclone struck Bangladesh in 1876 (Burton, et al), and droughts have occurred repeatedly over the last century in the Sahel. Droughts are well known in North America, although the pattern of earlier droughts may be quite different from those in the 1970's. Similarly sustained extreme cold has occurred elsewhere in North America. Only a decade ago, in 1969, Edmontonians were given certificates for surviving a record cold winter - 26 consecutive days with below zero (Fahrenheit temperature), and there have been colder winters; that was their fourth coldest since 1881. Locally and globally some years and decades are colder, warmer, or stormier than others. Variability is a normal characteristic of climate and cannot be construed in itself as a signal of harbinger or major long-term change.

Although the 1976-77 winter was billed as the worst of the century in England, other years such as 1918, 1940 and 1963, were only marginally less severe. The winter was within the bounds of expectancy, but the nation's energy supplies were precarious and expectations of mobility and comfort had risen so that both the scale of disruption and the public reaction to it were greatly magnified (Burroughs, 1978). In America sustained cold in the winter of 1976-77 caused similar disruption and suffering, and the losses estimated at a staggering several billions of dollars. History has demonstrated that such winters can happen; we simply have not planned for their occurrence.

Western Canada provides excellent examples of climatic varibility and the interaction between man and climate. Settlement and development were vigorous in relatively humid periods - it was the reverse in periods of drought. The 1860's were hot and dry, and in 1868, "an earnest appeal for aid for the virtually starving population was addressed to Canada, England and the United States" by the Red River Settlement. The 1870's were "as good for the North-West as the '60's had been bad - migration following civil war encouraged by increasing rainfall". This type of variation continued. Emigration and pessimism followed in the 1880's, peaking in 1894 as the drought intensified, but hope returned with the rains in the new century. The climate is warmer now than it was in the last century, but this sequence has not changed. Drought and stress are followed by good crops and development. But the periods between droughts are not constant, the character of each drought is different in its timing, location, intensity and duration, and <u>times have changed</u>.

Climatic variability has always been with us and man has reacted to it. But the sense of urgency that prevails in times of distress quickly dissipates when conditions return to normal. Paradoxically, remedial actions that are invoked occasionally enable a more productive base during the favourable years so that liabilities may increase before the next crises occur. Some buffering also results, such as when marginal lands are abandoned as a result of improved farming technologies and economic policies. But as memories fade and priorities change, the harried decision maker is inclined to accept that climate and society interactions are unlikely to change from what they were in the recent past. Accordingly productive epochs are frequently accepted as the norm, favouring levels of development that are unsupportable when the adverse climate returns.

Climatic Change and Man

The term "climatic change" embraces all types of climatic inconstancy on time scales that range from geological to weeks, and over areas ranging from global to local. Since the concern here is overall uncertainties that impact on man, critical shorter duration weather extremes (anomalies) are, of necessity, included in the following remarks.

Climatic change has occurred throughout our documented geological past. Over the past 500 million years the climate has generally been warmer than at present, but periodically ice sheets have appeared and covered large portions of the earth's surface. There is also evidence of tropical climates within what are now temperate zones, as well as more arid and pluvial epochs. It is fascinating to consider that the earth's equator may have once passed through Greenland and Antarctica, but this is of little consequence in the present consideration of man's future. Of particular importance is the documented period of the earth's history during which the distribution of land and water, and the astronomical relationships between the earth and the sun were similar to those found today. What has happened under these circumstances could happen again.

Recent investigations tend to support Milankovitch's (1941) theory that the ice ages identify with the earth's orbital eccentricity, obliquity, and seasonal precession which have periodicities of about 96,000, 41,000, 21,000 years (Hays, et al, 1976). Twenty-one thousand years ago the world was in the grips of the last ice age. During glacial periods the global average temperature was probably about 6°C below present values. Precipitation was presumably excessive along the southern periphery of the ice, but meagre in Arctic latitudes. Muskoxen inhabited central United States during the glaciation and spruce forests engulfed Florida and Texas (Sellers, 1965).

There is good evidence that at the end of the last glacial period precipitation was much greater in areas that are presently arid. Large lakes formed in East Africa during this time and remained until about 5000 BC. Saharan culture shifted from fishing to agriculture, and ultimately nomadism, as the climate became progressively drier. During the Climatic Optimum (5600 to 2500 BC) the mean global temperature was probably about 2°C warmer that at present, and the polar ice is considered to have retreated north of 80°N. North America's Great Plain was more arid, while the European climate was warm and humid. Forests moved northward reaching their northern limit between 3000 and 1500 BC (Lamb, 1974).

The present interglacial climate has continued for 10,000 years, but it can be described with reasonable accuracy only during the last century. Prior to that time the climate must be inferred from "proxy" information such as chronicles, soil profiles, tree rings and lake sediments. But some of the inferences are unmistakably clear. These suggest a relatively mild European climate a thousand years ago, the Viking Age, when grapes were cultivated in England and the Celtic missionaries reached Iceland. This was followed by a "little ice age" which lasted three hundred years, terminating in the 18th century. This was a period of glacier advance in mountain valleys that destroyed villages, and of cold wet weather that inhibited production on rain-soaked soils. By the late 19th century the global climate started to warm and the warming continued into the 1940's or 1950's, depending on the location. A period of cooling followed, but since 1960 the global temperature trend has been uncertain (Fig. 1).

Superimpossed on these gradual changes were variations in climate of a much shorter duration, but often of greater amplitude which has a major effect on man and the environment. It is this type of variation that is the cause of most of today's climatic concerns. Such variations have always been a cause for concern, but our memories areare short and we quickly forget the bad times of the past. For example, at least twenty serious droughts visited western Canada in the 19th century. Drought has occured with about equal frequency in the 20th century until World War II. The most memorable was the drought of the 1930's when the worst soil erosion ever observed on the Great Plains was recorded. Interspersed among the droughts have been wet periods that both encouraged and discouraged settlement. In the early 1900's the semi- arid area of Alberta experienced a very wet cycle. Floods were frequent, rivers changed their course, and both roads and railroads were seriously damaged. Rainfall statistics for this area show a highly variable climate, but also one which is persistently wet or dry for prolonged periods (Fig. 2). Land-use strategies based solely on the climate of one of these periods could be seriously in error at a later date.

Climatic anomalies occur on global to regional scales, and are more critical when several regions are affected at the same time. In 1972 drought was widespread over many important agricultural areas, an exception being the cereal producing areas of North America. Concurrently an extended drought in the Sahel reached peak intensity, while the occurence of unusually warm ocean water off Peru (El Nino) contributed to a major reduction of the anchovy fishery. Drought and the lack of snow cover led to greatly reduced cereal production of the Soviet Union, and either drought or excessive flooding severely reduced the rice harvest over much of southeast Asia. World food production decreased by 888.1 million tons, 9% less than in 1973, and 2% less than in 1971. The result was regional famine, a scramble for available grain reserves, market speculation, widespread inflation, and the trebling of cereal prices. Other anomalous climates caused global surges in the price of sugar in 1974, and coffee in 1975. These short variations in climate were not in themselves signs of major change in the climatic system, but just natural manifestations. Of particular interest was their pervasive or domino effects which resulted from the economic interdependence of nations. Droughts, frosts and wet harvest in one region of the globe had spectacular effects on prices in far-removed countries. The climate system was not perceptibly different but society had acquired new vulnerabilities and an awareness of the "climate problem". The assumption that climate is stable was recognized as being no longer valid for today's planning.

Societal Change and Vulnerability

Key factors in the "climate problem" are new technology and societies' increasing needs and wants. Their implications are numerous and complex. Studies of Sahelian drought have revealed the problems created by new technology and increasing populations. The more crowded society is not free to move about to sustain itself as before, and has become a captive victim of drought. In the case of the 1970 Bangladesh cyclone, technology enabled unprecedented levels of settlement in a deltaic area, but planning did not provide the necessary defences against floods. Mitigating technology was available but not used (Burton, et al, 1978) - a situation too often repeated and contributing to the "climate problem."

In the more developed nations life is relatively secure, but anomalous climate can cause great material losses. In some instances the loss is absorbed by a larger sector of society because of insurance, assistance, or market forces. Higher prices compensated Florida citrus producers for frost damage in 1977. North America food prices also rose rapidly in 1973, not because of poor North American crops, but because of widespread drought in the USSR, and southeast Asia in the preceding year. Instead of a policy of self-sufficiency, reliance was placed on imported feed grains. Attitudes had changed - not the variable nature of climate; but in combination the two had widespread reverberations.

The pervasiveness of climate means there is an infinite number of vulnerabilities. We are conditioned to accept and, at times, enjoy the more commonplace climate variations, but severe, unusual anomalies are to be feared. Of great concern to us are those adverse climatic occurrences which are likely to occur within our lifetime, or inadvertent changes that would inalterably disadvantage future generations. Some decisions such as the construction of dams and railways relate to long-time periods, but most of man's activities and decisions relate to short-time periods, usually less than ten, and frequently less than two years. This means that for most purposes we can ignore the gradual climatic change on the geological time scale. Similarly, many of the changes wrought by man are not immediately ominous because they too are very gradual. However, some with potentially large irreversible environmental consequences, such as changes in the atmospheric carbon dioxide, do require immediate attention.

Vulnerability is greatest when the climatic impact is direct and controlling such as on agriculture, water supplies, transportation, etc., and especially when these activities are the keystones of an economy. Diversity then provides a way of mitigating the adverse effects of climatic variability. As an example, in the 19th century, the United States' economy was based largely on agriculture, and national economic crises identified closely with crop failures. With 20th century industrialization the relationship has changed.

North Americans are not as vulnerable to climatic anomalies as are people in other continents because of their relatively small population and high agricultural productivity. Vulnerability at the farm level has been greatly reduced, partly by new technology, but also by risk speading through insurance, assistance, crop diversity, larger holdings, improved varieties and more selective land-use. Nevertheless, immunity is elusive and marketing practices have made profitability of agriculture highly dependent on climates not just in Canada, but also in other lands. The problem has not e disappeared - it is now spread over a larger economic base. This was evident in western Canada in 1977 when the threat of drought upset not just agriculture, but cities, industry and commerce. Farm implement and fertilizer purchases, as well as those of appliances and clothing, were postponed as the farming community waited apprehensively. Dependent on the farm system are manufacturers, distributors, wholesalers, retailers, hotel operators, food outlets and other institutions that serve the community.

The more sensitive and the larger the area affected the greater the overall impact. Climatic anomalies that affect vital food supplies or that cause the innundation of highly populated coastal zones or river valleys are obviously much more disastrous than those occurring in uninhabited areas. Droughts that are regional in scale are greater calamities than local droughts for which assistance can be mustered quickly and at relatively little cost. Some areas are highly sensitive because they are already climatically marginal. For example, a slight reducation in the frost-free period may not be serious in cereal producing areas of the United States, whereas in Canada it could be critical because the growing season is barely adequate for economic agriculture. Similarly a slight shift to a warmer, more arid climate could greatly reduce the suitability of semi-arid lands for crops and grazing. In Iceland the ice fields are never far away. Slight changes in the prevailing wind can bring the ice onto the northern coast with disastrous consequences for fisheries and agriculture. When such cooling occurred in the 1960's, as it had in previous centuries, the result was major social and economic stress with currency devaluation. During a preceding cold spell from 1870 to 1918 thousands of Icelanders emigrated to North America.

But it is an ill wind that blows no one good. During the 1976-77 western Canada drought, coal sales and shipments soared as "thermal" replaced hydroelectric power generation, and ski resorts invested heavily in snow-making equipment. In periods of excessive rain, high water levels may cause extensive property damage, but at the same time improve electrical power generation and navigation. Climatic variations do provide opportunities. Furthermore, not all climatic variations are adverse. The trend to warmer climate, 1880 to 1940, opened up Arctic sea routes and advanced the frontier of viable agriculture. Other variations can result in bumper crops, ideal conditions for tourism and choice wines.

Some uncertainty may be desirable. For example, it can be argued that the tourist resorts and travel system would have a much more difficult time if we knew precisely what the weather would be well in advance. Where vital food supplies are concerned, one can envisage foreknowledge of an adverse climate leading to belligerent actions. Asked what would he have done if a perfect climate forecast had been available for the Sahel in 1973, one respondent to a questionnaire stated his first action would be to increase the police force. In some instances we may not want to know the future. Knowledge of a completely bleak future would be totally demoralizing. Nevertheless, planning has its advantages in mitigating adverse effects and in achieving economies - and uncertainty most certainly complicates the planning process.

Man has altered local climates by tillage, deforestation, urbanization and other acts which may significally change the environmental balance. The effects have been both good and bad - among them increased heat stress and altered precipitation pattern and character near cities. Collectively these have great importance, affecting human health and regional ecosystems, planning and design. Projected urban and industrial development promises to augment these effects. The energy system, in particular the conversion and use of energy, has the greatest potential to alter climate. The generation of heat itself if concentrated in energy centres may cause regional climatic change. The production of carbon dioxide (10 - 20% increase this century) could produce global warming, accentuated in polar regions. Our knowledge of these man/climate interactions is insufficient and the planning for our future must proceed cautiously because of these uncertainties.

Defending Against Climatic Variability

The loss of billions of dollars from the gross national product as a result of a cold winter, the damage to agriculture, soils and forests occasioned by drought, and the ravages of famine occasioned by floods and regional drought, all provide overwhelming evidence of the need to develop defences against climatic variability. Many defensive options exist, and mixes of these options appear to provide the most rational approach to reducing their traumatic social and economic consequences.

Potential defensive actions include insurance, engineering works to modify climatic impacts, the modification or direct control of climate, and other tactical responses based on meteorological understanding. Each are subject to economic and social costs and to other constraints - consider for example that political and physical boundaries may limit applicability, and that climate control may pose more problems than it would overcome. On the other hand, the opportunities that these defensive measures can provide are enormous. Thompson (1977) has estimated that weather causes $5 billion preventable losses annually in the United States. From both an environmental and economic viewpoint the need to consider climatic variability is imperative. We need not passively take our losses. There are alternatives.

New technology is constantly being sought as means of overcoming climatic losses. Substantial technology already exists, but too frequently it is forgotten in the intervals that separate periods of climatic stress. Where it is "on the shelf" the need is merely to stay alert. There is also a tendency to develop technology that grapples with the immediate rather than the long-term response. The construction of a dam, the green revolution and similar advances only buy time, unless the remainder of the system changes. The removal of an immediate element of uncertainty leads to increased demand and thereby to an increased future uncertainty. The ultimate simple answer is adaptation to the variations in resources that are occasioned by climate.

More flexibility is essential; the alternative is greatly increased social, economic and environmental costs. Land use practices, the storage of supplies and the size of herds can be varied according to levels of climatic risk and other circumstances. The marshalling of transportation equipment can be modulated for greater economy when there is advance informmation on climate - induced supply and demand anomalies. The purchase of capital equipment, fertilizer, the viability of new industry, etc., is often climate dependent and would benefit substantially from the provision of timely advice on climatic conditions and risks. We intuitively consider the weather when planning picnics, but we often lack foresight concerning climatic risks that can endanger both life and property.

Climatic Information

What really practical information can the climatologists provide to planners? What are the chances of obtaining reliable climatic forecasts? Seasonal predictions are currently being made in several countries, but the level of skill is wanting from the decision standpoint. Longer-range predictions are highly speculative. Some promise for improved seasonal prediction exists and techniques such as the use of probability can improve their utility. However, much greater knowledge of the physical processes is urgently required.

There are other types of predictions of great utility. Climatological models can be used to predict the probable effects of man on climate. For example, models have been used to assess the effects of increasing carbon dioxide and other pollutants on the future climate. Present energy and land- use policies could lead to an increase in carbon dioxide of 15% by the end of the century, and models indicate this could cause an increase of about 0.5C in the global mean temperature. In addition, they show that the warming could be much greater at high latitudes where the snow and ice cover would be reduced. These predictions are of great utility in the critical examination of energy policy and options.

Another type of forecast is that provided by probability statistics. Climatic variability and climatic extremes can be considered in the same way as any other calculable risk. Statements of risk are basically forecasts for which the date of occurrence is not specified. They have a certain superiority over a conventional forecast in that they relate to precisely defined conditions. Long series of observations are needed for this purpose, but many Canadian climatological records go back over a century, and longer records can be deduced from natural evidence such as that given by tree rings, lake sediments and ice cores. We should be quick to recognize that past climatic variations may have led to designs and plans that are inadequate with today's climate, and that man too through urbanization and industrialization may be altering the planning basis. Careful climatic analyses are essential to verify the validity of plans that are critical to our future needs and that have climate sensitivity.

Closely related to risk estimates is the use of scenarios (Fig. 3). Scenarios may and should incorporate statistics, but by and large they provide a detailed description of extremes that can happen. From the climatological viewpoint well documented historical events provide credible scenarios by the mere fact that they have happened and, therefore, could happen again. The climate that produced the Alberta Wet Cycle (1902 - 15), or the "dirty thirties" can be used to test today's plans and operating systems. What would be the effect of another run of dry years, as occurred in the 1890's on a society that requires much more water to serve more and larger cities and industries, the gasification of coal and irrigation?

Many climatologists have analyzed climatological records in depth with the hope of finding cyclical patterns that could be used in predicting the future climate. The studies have generally shown that cyclical patterns have little predictive value. A 2.3-year pressure oscillation and an

11-year rainfall periodicity exist in tropical areas. There is good evidence that the 22-year sunspot cycle may correspond with the extent of the drought area in the North American southwest, but the predictive value is yet to be demonstrated. Other atmospheric processes are so dominant in shaping climatic variability that gradual trends and cycles are usually difficult to discern.

The inability of the meteorologists to accurately predict the future climate is sometimes used as an excuse not to use climatic information in decision making. It is not a valid excuse. Interestingly enough the answer to many of today's urgent problems exist in current information that does not require complicated analysis. The information needed by the United States for its grain marketing strategy in 1972 was available, but not fully exploited. The technology to plan and advise on evacuation during the 1970 typhoon in Bangladesh existed, but the developers did not have the foresight to insist on its acquisition. The information needed to avoid major ($50 to $100 million) loss in an East African groundnut program existed but was not used. The planners should have considered the drought hazard posed by the natural variability of climate - there was no need for a deterministic climatic forecast at the planning stage.

The Future Climate

The future climate is always a matter of great speculation. Although meteorologists have developed useful models for estimating how man might influence climate, prediction of the natural variability of climate has not been developed to the stage required for planning; and for many specific operations it may be impossible to develop adequate forecasts. Trends and cycles have been explored as predictive tools, but to little avail. The only certainty is that the future climate will be variable and that the variability experienced over the recent centuries probably provides the best indication of the future climate.

Most climatologists agree that eventually there will be a return to a period of colder climate; however, there remains some uncertainty as to how mankind might alter this natural change. Mason (1976) estimates the chances of 1:100 of the reversion to an ice age starting over the next hundred years, with the full effect (a drop of 10°C) being spread over 1000 years. He also expresses an opinion that is shared by most meteorologists: "...... fluctuations of climate will continue to occur with about the same magnitude, frequency and variability as in recent centuries, superimposed on long-term trends, the onset and reversal of which cannot yet be predicted in advance". As to trends, the Milankovitch (1941) theory suggests cooling, but the many and appreciable effects of man tend to favour climatic warming. At present no clear cut trend can be established; the climatic signals, if they exist, are obscured by the shorter term climatic variations.

Most of the influences of man tend to cause climatic warming and they could become dominant in the not too distant future. The major impact of man on climate will probably be due to the burning of fossil fuels. Since carbon dioxide is an excellent absorber of long-wave terrestrial radiation, it has the potential to influence the amount of heat retained near the earth's surface. As a result and other things being equal, conditions not unlike those in the Climatic Optimum could recur within the next 75 years if present models and energy scenarios are credible. This equates to a northward shift of present climatic boundaries and a more arid climate over much of the Great Plains. There would be both advantages and disadvantages to such a change. On the positive side, less energy would be required for heating, Arctic shipping could be greatly expanded, and new areas could be opened up for agriculture. On the negative side, increased drought would occur over established agricultural areas, and reduce inland waterway utility and water supplies for electric power generation. Such changes are, of course, speculative.

Planning for the Future

Superimposed on future trends there will continue to be climatic variability of the type that is now stressing countries in all regions of the world. Drought, wet, heat, cold and other manifestations of climate will occur with irregular frequency and intensity. Uncertainty will remain-how successfully can we adapt to climatic variability and what are the possible implications of man's activities?

Today's unprecedented awareness of interdependencies, and the need to share resources, has made the "climate problem" a matter for action. Plans are now advanced for a World Climate Conference to be held in Geneva in 1979. The object of the conference is to place the "climate problem" before economists and planners of the global community with a view to determining what action should be taken. In many countries plans are now being implemented to look at man/climate relationships and to develop strategies that will mitigate future stress and optimize on the opportunities that result from climatic variations.

Much has already been accomplished, for example, in the breeding of drought resistant and early maturing cereals. There is reason to believe that many plans now incorporate climatic information effectively. An interesting evaluation of decisions made with respect to Saskatchewan's 1974 crop indicated that they would not have been altered by the availability of accurate climatic forecasts. This suggests that climate has already entered the decision process to a high degree either directly or indirectly. A parallel study for the 1973 drought years in the Sahel disclosed a complex situation in which accurate climate forecasts would be of little utility unless numerous social, political and economic obstacles were removed. There as elsewhere, the "climate problem" has its roots in society.

Energy evaluation provides at least one response to the problem posed by atmospheric carbon dioxide. Programs that conserve fossil fuels by achieving greater efficiencies in energy use as well as by substituting renewable energy supplies, offer an opportunity to reduce the rate of CO_2 emmissions to the atmosphere. This could significantly extend the doubling time of CO_2 and provide needed additional time for more rigorous understanding and the development of appropriate alternative energy strategies and sources.

Climate, society and economics are inextricably intertwined. Writing about the French Revolution, Neumann (1977) described the preceding drought and famine which contributed to the timing and widespread violence, although they were not the primary cause of the revolution. Climatic stress is frequently only one factor among many in decision making and frequently it will be viewed as a minor factor among many imperatives and alternatives. The decision maker wants more concrete climatic evidence, but at times he incorporates climatic information unknowingly, as does the farmer who doesn't seed because the soil is too dry. Despite centuries of catastrophic experiences, mankind's vulnerability to climatic variability remains, and in many regions has increased, not necessarily because of climatic change, but rather because our memories are short and because society and its supporting systems are changing.

We have not profited fully from our past mistakes - nevertheless, there has been progress. The need to incorporate climatic knowledge into policy planning is being increasingly recognized. Integrated national and international climate programs are now evolving, and they involve most of the players - meteorologists, economists, agriculturalists, engineers, planners, etc. A major objective of these programs is improved communication, for much basic understanding exists - it just needs to be put to work. Another major objective is climatic prediction, a difficult scientific problem in which progress may be slow, but for which the benefits may be enormous. The resulting integrated environmental understanding, combined with the rapid strides being made in science and technology, place today's society in a position unparalleled in history to confront the climatic uncertainties of the future.

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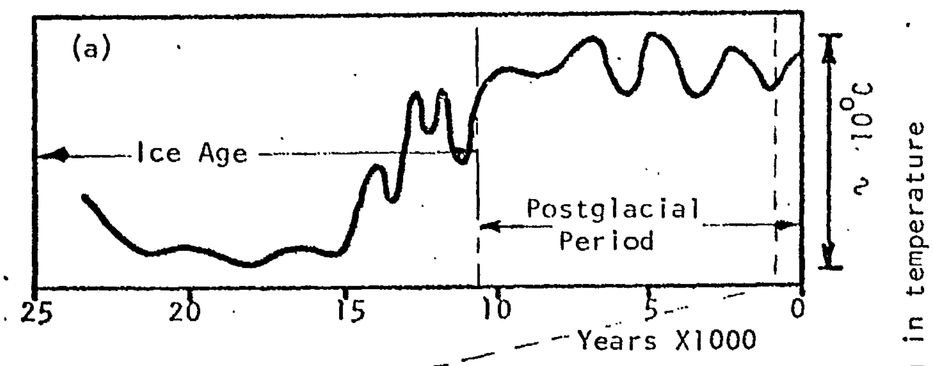
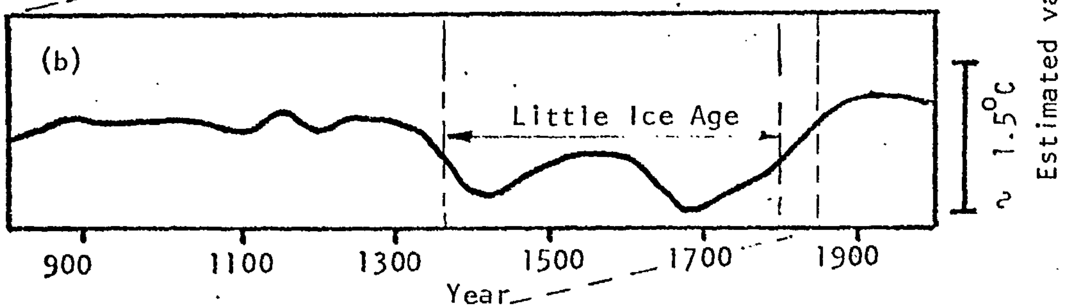
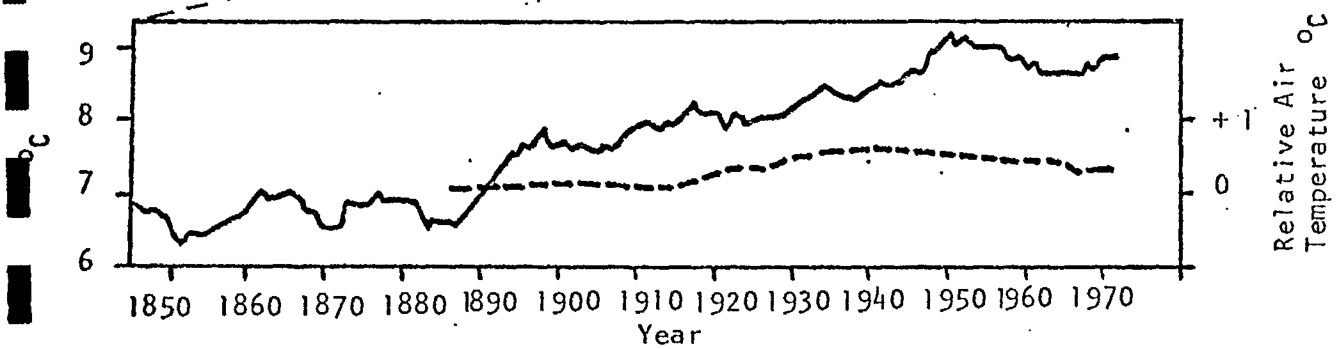


(a) Trend in global temperature last 25000 years

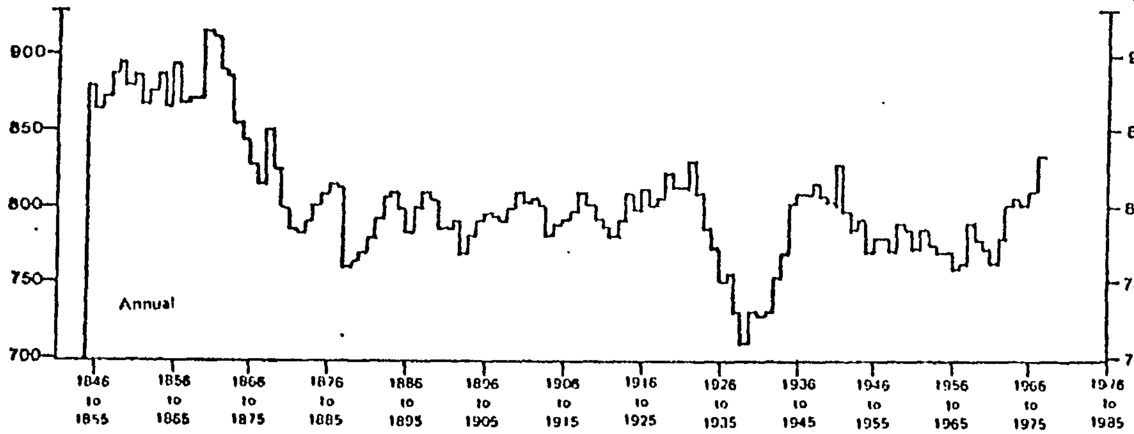


(b) Trend in global temperature last 1000 years



(c) Ten-year moving means of temperature at Toronto

Northern Hemisphere temperatures relative to that in 1885 - - -



TEN YEAR MOVING MEANS OF PRECIPITATION AT TORONTO

Fig. 1 Climatic Trends

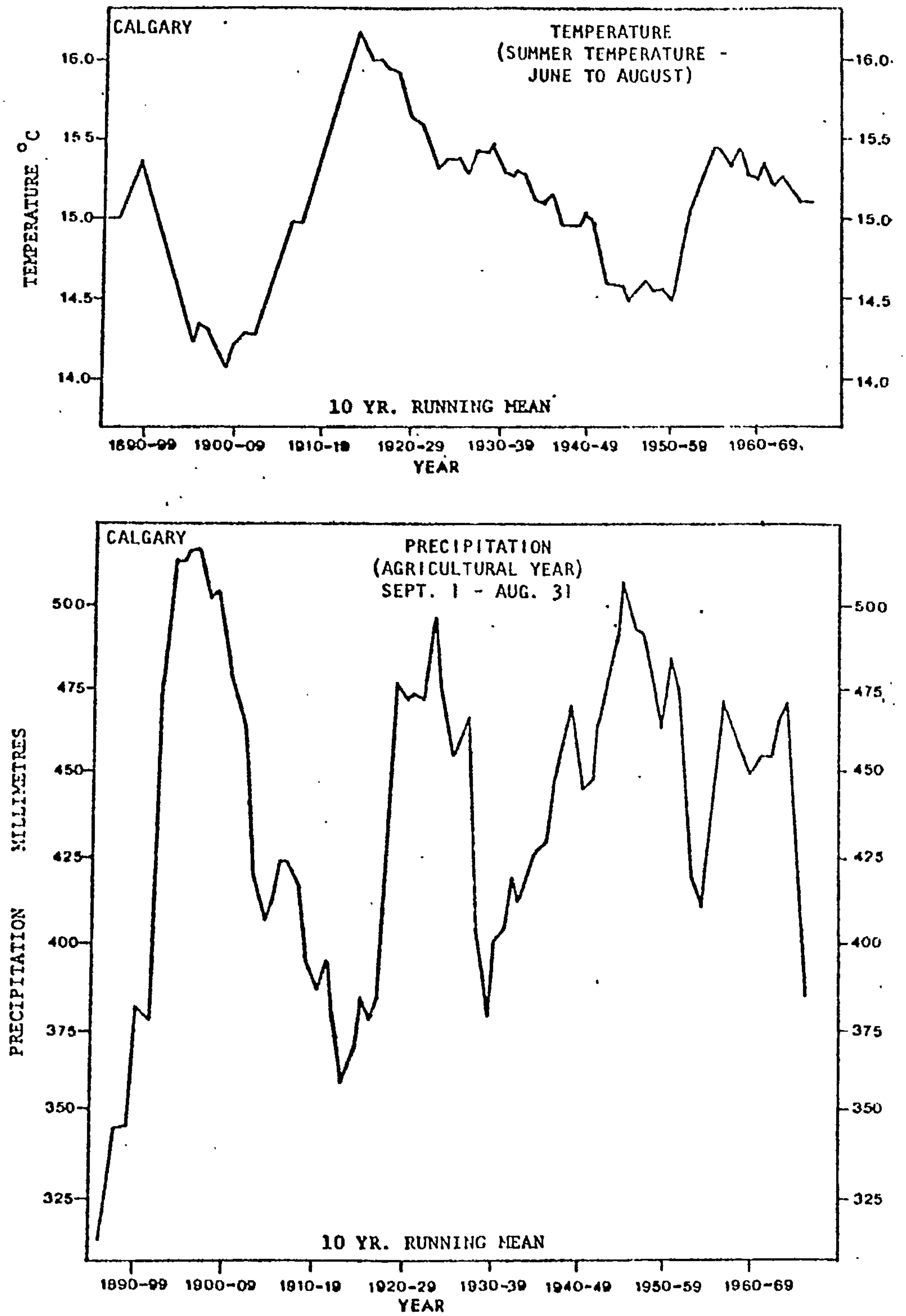
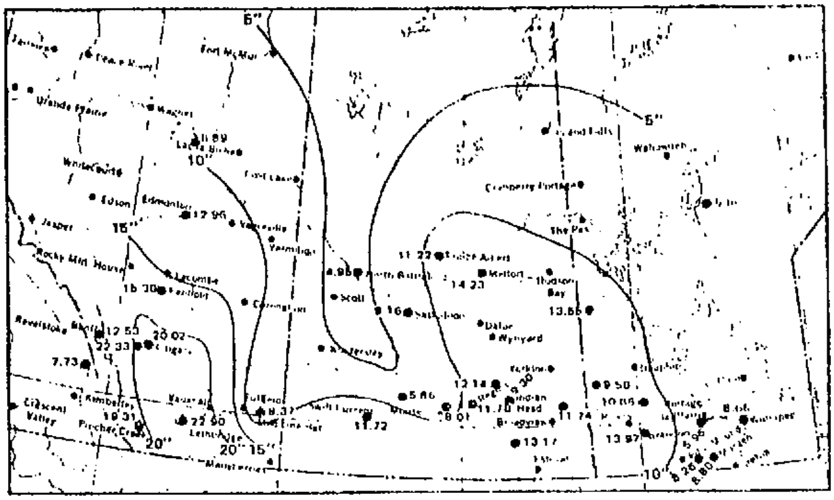


Fig. 2 Marked variation in decadal temperature and precipitation Calgary, Alberta.

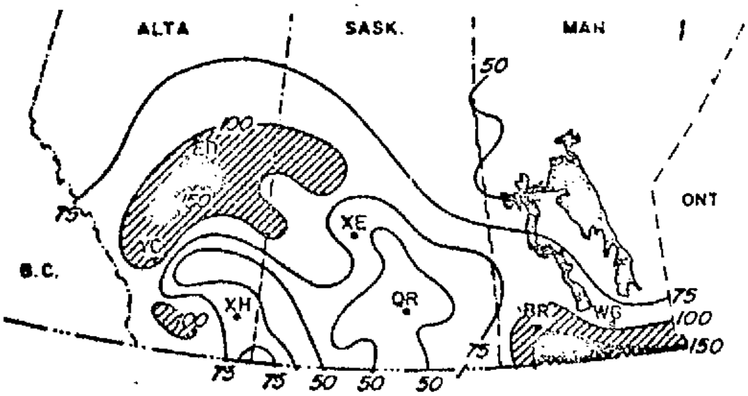
1902 Wet



MAY, JUNE AND JULY TOTAL RAINFALL (inches) - 1902

* 1902 - Heavy late spring rains in Alberta foothills produce major flooding - Bow & Oldman Rivers.
  1903 - Southern Alberta foothills - a "swamp" many roads rerouted to higher ground at great expense - railroad traffic disruption.
  1908 - Record flood on Oldman River at Lethbridge.

1937 Dry



PERCENT OF 1941-70 AVERAGE PRECIPITATION FOR MAY-JULY 1937

Harvested Crop Yields for U.S.A. and Canada for 1933-1937

Year	United States of America: Winter Wheat	United States of America: Spring Wheat	Corn	Saskatchewan Spring Wheat	Canada Spring Wheat
			(bushels per acre)		
1933	12.4	9.2	22.9	8.7	10.4
1934	12.3	9.8	15.7	8.6	11.3
1935	13.9	8.8	24.0	10.8	11.3
1936	13.8	9.6	16.5	7.5	8.1
1937	14.6	10.8	28.2	2.6	6.4
Average (1922-31)	15.2	12.6	25.0	16.4	11.8
Average (1933-37)	13.4	9.6	21.5	7.6	9.5

Fig. 3 Scenarios for wet and dry summers

THEORIES ON CLIMATE CHANGE

There are many hypotheses which purport to explain the origin of climatic change. While some are more plausible 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 processes which might cause climates to change are described below.

1. Solar Influences

The energy put out by the sun has been 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 definite observable change in the visible and infra-red area of the spectrum.

A number of studies have indicated some correlation between sunspot activity and weather. For example, in the American south-west, the areal extension of drought, appears to follow the 22-year double sunspot cycle. Correlations found for weather in some regions are not apparent in others and their utility in prediction is very limited. The question of the influence of sunspot ativity on weather has not been settled and no satisfactory theory has yet been proposed to link the sunspots to climatic variations.

Statistical studies have shown other relationships, such as between weather and solar magnetic field polarity. Although the associated changes in weather are small, they help the development of the theory and prediction of climatic change.

2. Orbital Variations

Small deviations from the regular path taken by the earth occur as it moves around the sun. These deviations are themselves cyclic. These cycles vary in length. There is 41,000-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 105,000-year cycle. These orbital variations correlate so well with observed climate cycles that some scientists have concluded that they are fundamental causes 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 more extensive Northern Hemisphere glaciation.

3. Atmospheric Composition and State

The composition of the atmosphere is very important in determining the climatic state of the earth. Any change in the physical or chemical state of the atmosphere will alter the energy balance. This, in turn, will be manifest as altered circulation, temperature and precipitation regimes. Three important atmospheric constituents which can be influenced by human activity are ozone, carbon dioxide, and airborne (dust) particles. Massive injection of heat and water vapour may also cause local and regional climates. This is apparent in the vicinity of large cities where the thunderstorm frequency, winds, temperature, and other atmospheric parameters have been altered. The earth, being much cooler than the sun emits radiation from the longwave end of the spectrum (infrared). Water and carbon dioxide effectively absorb radiation so that less than one-tenth of the radiation from the surface escapes directly into space, i.e., it is effectively trapped in the lower atmosphere causing the earth to be about 14°C warmer than its effective radiative equilibrium temperature.

CO_2 - Man may have already altered the carbon balance by deforestation prior to the year 1900. Since the turn of the century concentrations have increased more rapidly due to the burning of fossil fuels and altered land-use. The CO_2 level is presently 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°C above the level that would occur naturally. It has been suggested that by the year 2000 CO_2 levels could increase to 375 ppm, and that this would result in a global average increase in temperature of 1.5°C. The increase should be much greater at high latitudes because of the resulting decrease in snow and ice cover.

Particle Loading - Dust and other small particles in the atmosphere play an important role in global thermal balance. Air, dust and haze reflect (backscatter) 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.

Nature is the main source of airborne 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 highly reflective surface (such as snow) 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. Increases of stratospheric dust load due to major volcanic eruptions are statistically correlated with consequent lowering of the mean temperature around the world.

4. 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:

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

The global albedo is largely determined by the relative proportions of cloud, 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.

Urbanization - 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 and albedo modification due to large structures and paved surfaces results in a heat island. The maximum intensity of the contrast is reached on a long, still night with clear skies, when the surrounding areas are cooling under the effect of net outgoing radiation. The minimum intensity occurs around noon when the heat from the sun is much greater than 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°C. Shower and thunderstorm activity can be enhanced in and downwind of cities.

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 apprehension among climatologists. It is speculated that certain "trigger" mechanisms, insignificant by themselves, can have a greatly magnified effect by causing polar ice to advance or recede. The diversion of rivers which flow into the Arctic Ocean, and restriction or damming of the Bering Strait have been considered as possible "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 related to the position of major large scale air currents and determines how far north the monsoons will move. This is of crucial importance for the agriculture of such highly populated areas of India and south-east Asia.

5. Ocean-Atmosphere Interactions

Unquestionably the oceans exert a strong influence on weather and climate. They act as stable heat reservoirs and tend to moderate the temperature differences between the seasons. They interact in a very complicated way with the atmosphere - while they influence the atmosphere, their currents are mostly driven by the atmosphere itself through wind stress.

For numbers of reasons, persistent anomalies develop in sea surface temperatures. Because of the high heat capacity of water, such temperature anomalies can systematically alter the flow of heat into the atmosphere for extended periods of time. Some meteorologists have exploited the theory in attempts to produce monthly and seasonal forecasts of climatic anomalies. Others have found relationships between the oceans and the atmosphere which could partly explain interannual climatic variations.