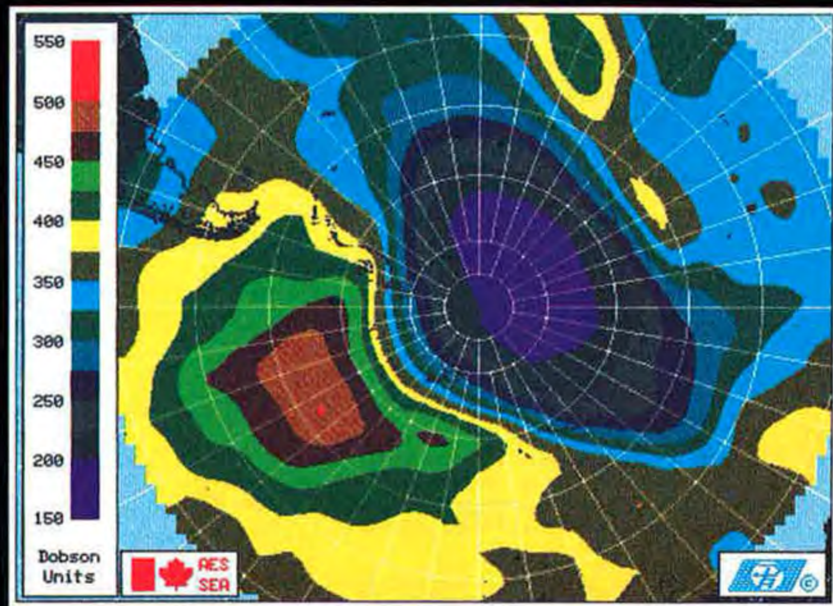
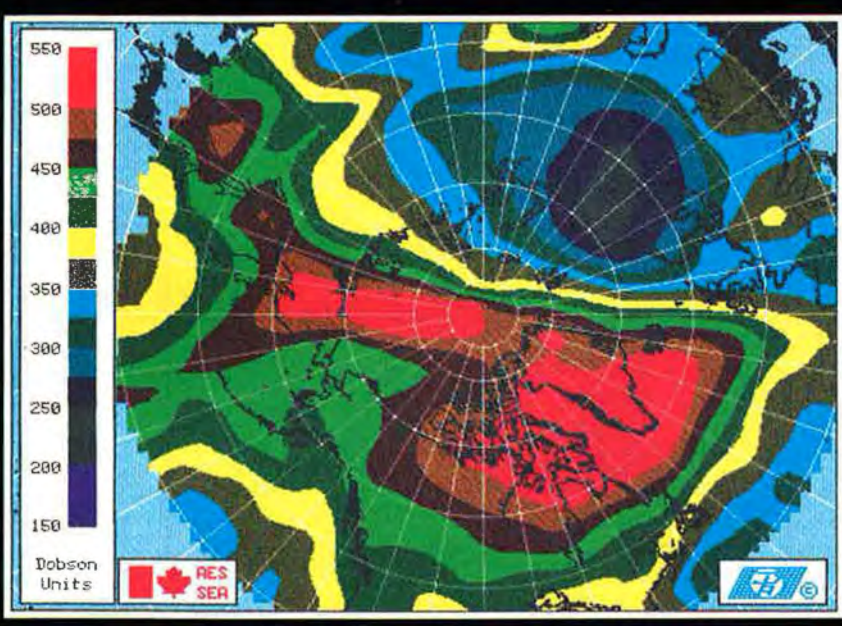
# Chinook

THE CANADIAN MAGAZINE OF WEATHER AND OCEANS

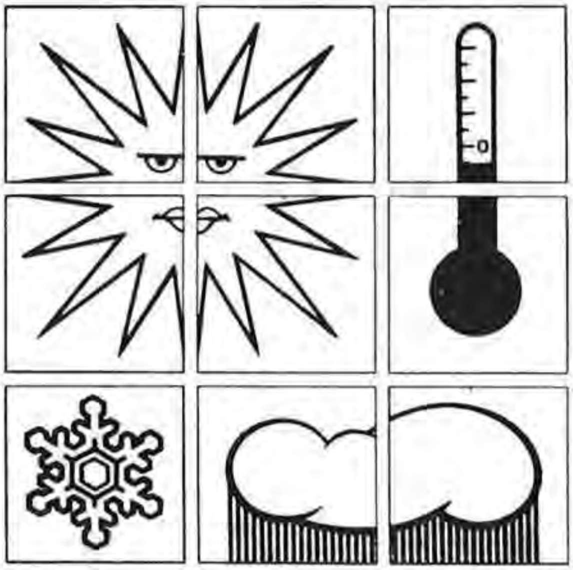
LA REVUE CANADIENNE DE LA MÉTÉO ET DES OCÉANS




VOL. 10 NO. 2

SPRING / PRINTEMPS 1988



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## COVER

A photograph of the ozone layer taken from the space shuttle separates coloured maps of ozone distributions derived from data recorded by the TOMS instrument on board the NIMBUS 7 satellite. For further details see the article on page 24.
*Top* Ozone map for the Southern Hemisphere showing the Antarctic ozone hole on October 12, 1986.
*Bottom* Ozone map for the Northern Hemisphere showing the Arctic ozone hole on March 16, 1986.

## COUVERTURE

La photographie de la couche d'ozone prise par la navette spatiale sépare les cartes couleur de la distribution d'ozone provenant de données obtenues à l'aide de l'instrument TOMS installé sur le satellite NIMBUS 7. Voir l'article à la page 24.
*En haut*: Carte de l'ozone de l'Hémisphère sud illustrant le trou d'ozone antarctique le 12 octobre 1986.
*En bas*: Carte de l'ozone de l'Hémisphère nord illustrant le trou d'ozone arctique le 16 mars 1986.

Canadian Meteorological and Oceanographic Society

La Société Canadienne de Météorologie et d'Océanographie

Contributions, enquiries, comments and suggestions from readers are welcome. They should be addressed to:
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Spring / Printemps 1988 Vol. 10 No. 2



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ISSN 0705-4572

Published by:
Canadian Meteorological and Oceanographic Society

Publié par:
La Société canadienne de météorologie et d'océanographie

Printed and produced in Canada and published quarterly by the Canadian Meteorological and Oceanographic Society, Suite 903, 151 Slater Street, Ottawa, Ont. K1P 5H3. Annual subscription rates are $10.00 for CMOS members, $12.00 for non members and $15.00 for institutions.  All correspondence including requests for special permission or bulk orders should be addressed to *Chinook* at the above address.

Second Class Mail Registration No. 4508
Spring 1988 Date of issue – August 1988

Edité et imprimé au Canada. *Chinook* est publié tous les trois mois par la Société canadienne de météorologie et d'océanographie, Suite 903, 151, rue Slater, Ottawa (Ontario) K1P 5H3. Les frais d'abonnement annuel sont de 10,00 $ pour les membres de la SCMO, de 12,00 $ pour les non-membres et de 15,00 $ pour les institutions.  Toute correspondance doit être envoyée au *Chinook* à l'adresse ci-dessus, y compris les demandes de permission spéciale et les commandes en gros.

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# SCIENCE OF THE OZONE LAYER

**by Wayne F.J. Evans**

In recent years there has been an increasing awareness of pollution problems that affect our environment. These range from local-scale problems such as garbage disposal, to regional-scale problems such as air pollution, to international-scale problems such as acid rain and water pollution in the Great Lakes. In the last decade we have become aware of several pollution problems that are of truly global scale, such as climate warming due to the carbon dioxide greenhouse effect. Another global problem with correspondingly long timescales is the threat posed by changes in the stratospheric ozone layer. This is the first global environmental problem that geophysical scientists have attempted to solve; what is learned may be of intrinsic value in the solution of other global problems for which we need scientific data.

Marc Garneau conducting an experiment, as fellow astronaut Dave Leesma watches, on shuttle mission 41G using a "sunphotometer" designed by Environment Canada scientists.

## IMPORTANCE OF THE OZONE LAYER

Our atmosphere consists of the troposphere, the lower portion in which we live, and the stratosphere, an upper layer that lies above 12 km. This region of the atmosphere contains the ozone layer, which is a vertically distributed layer of gas about 20 km thick starting about 25 km from the earth's surface. If compressed to surface temperature and pressure, the "effective thickness" of this layer would be only 3 mm. The front cover shows a photograph of the ozone layer taken from space, by astronauts on board the space shuttle. The top of the clouds marks the tropopause or upper boundary of the troposphere. The white band is caused by sunlight scattered by the stratospheric aerosol layer between 15 and 30 km. Above this, a faint violet band shows the upper levels of the ozone layer from 30 to 40 km. Above 40 km, the sky is black owing to the lack of Rayleigh scattering from atmospheric nitrogen. The actual ozone layer extends from 15 to 40 km and the resulting absorption of ultraviolet light makes the aerosol layer look even whiter. However, because ozone is a powerful absorber of ultraviolet light, this thin layer shields the surface from the damaging short-wavelength radiation coming from the sun. Without a protective ozone layer there would be no life on a planet such as earth. Despite our ozone shield, some ultraviolet light still penetrates to the surface and can cause skin cancer and eye-aging in humans and animals, retard the growth of many plant species including cereal crops, and result in reduced agricultural yields. It also affects the phytoplankton yield and the ocean food chain.

The ozone layer also plays a key role in the climate of the earth since it blocks heat radiation from escaping to space and causes heating in the stratosphere by absorbing short-wavelength sunlight; this absorption of sunlight produces a temperature rise with increasing altitude in the stratosphere. Future temperature changes due to changes in the ozone layer may well affect the surface climate significantly.

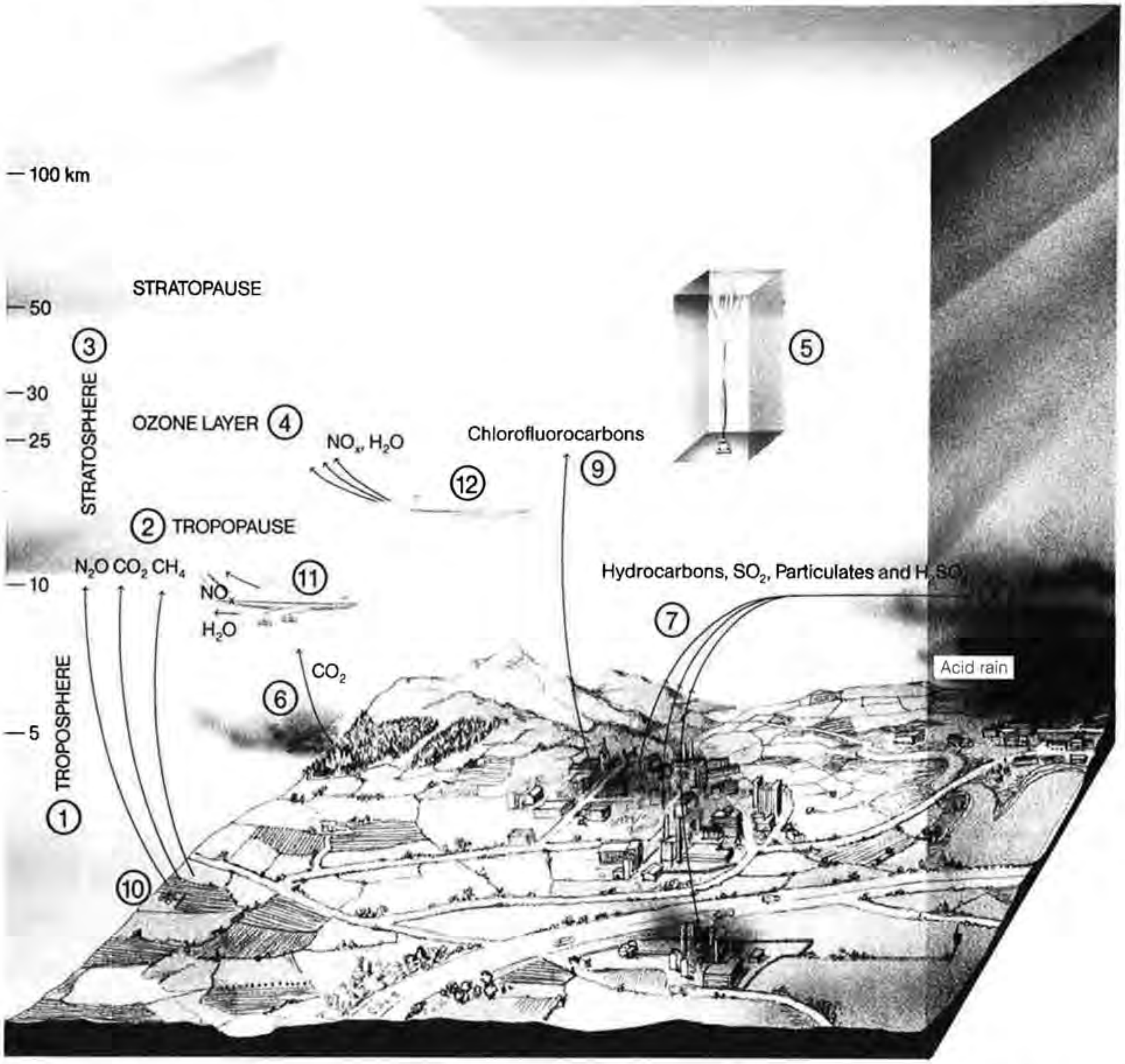
## CHEMISTRY OF THE OZONE LAYER

The amount of ozone in the stratosphere is controlled by a balanced set of chemical reactions. Ozone is created by the breakup of molecular oxygen by electromagnetic radiation in the ultraviolet region of the spectrum (reaction 1, on page 26) and is destroyed by nitrogen chemistry (reactions 4 and 5), by water chemistry (reactions 6 and 7) and by chlorine chemistry (reactions 8 and 9). Although this is a vast simplification of all the chemical reactions occurring, it is clear that any increase in nitrogen or chlorine compounds in the stratosphere can lead to a depletion of ozone.

Problems with the ozone layer were first anticipated when scientists began to worry that water vapour from the exhaust gases of supersonic transports would cause a decrease in the ozone layer. With the discovery that nitrogen oxides play a key role in the chemistry of the ozone layer, this concern was extended to include the nitrogen oxides that would be emitted in the exhausts of large fleets of supersonic transports proposed for the 1990s.

About 1972, scientists at the National Aeronautics and Space Administration (NASA) began to study the effects of

# ADDING TO THE ATMOSPHERE




## THE ATMOSPHERE

1 The troposphere (0–11 km above sea-level) is warmest at ground level and therefore thermally unstable. Pockets of warm and cold air constantly rising and falling produce the world's varying weather conditions.

2 The tropopause, where the air temperature passes through a minimum, marks the boundary between the lower and upper portions of the atmosphere.

3 The stratosphere (12–55 km above sea-level) is, in contrast, thermally stable and vertical mixing takes place mainly by diffusion.

4 Ozone is produced by the action on oxygen of ultraviolet radiation (UV) from the sun. This layer shields the earth from biologically harmful UV in the wavelength range 220 to 300 nanometres.

5 Balloon-borne spectrometers monitor many species including $O_3$, $H_2O$, $HNO_3$, $N_2O$, NO, $NO_2$ and CFCs to determine the effect of man-made pollutants on the ozone layer.

## POLLUTANTS

6 $CO_2$ emitted by industry and by forest clearance increases the natural level in the atmosphere and may eventually affect world-wide climatic conditions.

7 Industrial pollutants directly affect the local environment; hydrocarbons and oxides of nitrogen, for example, contribute to urban smog.

8 Some pollutants, e.g., $H_2SO_4$ and $HNO_3$, are carried by the wind, eventually falling, far from their source, as acid rain. This may result in harmful accumulations of acid in rivers, lakes, etc.

Certain pollutants can produce catalysts for the decomposition of ozone, for example:

9 Chlorofluorocarbons from aerosol propellants, refrigerants, etc. Catalytic species: Cl

10 Nitrogen compounds from fertilizers. Catalytic species: NO

11 Nitrogen compounds and water vapour emitted by subsonic aircraft. Catalytic species: NO and OH

12 Supersonic aircraft inject nitrogen compounds and water vapour directly into the stratosphere.

### Chemistry of the Ozone Layer

*Formation* by Photolysis of $O_2$

$$O_2 + \text{ultraviolet} \rightarrow O + O \quad \text{R1}$$
$$O + O_2 + N_2 \rightarrow O_3 + N_2 \quad \text{R2}$$

*Destruction*

Oxygen only

$$O_3 + O \rightarrow O_2 + O_2 \quad \text{R3}$$

Nitrogen Chemistry

$$O_3 + NO \rightarrow O_2 + NO_2 \quad \text{R4}$$
$$NO_2 + O \rightarrow O_2 + NO \quad \text{R5}$$

Net $O_3 + O \rightarrow O_2 + O_2$

Water Chemistry

$$O_3 + OH \rightarrow O_2 + HO_2 \quad \text{R6}$$
$$O + HO_2 \rightarrow O_2 + OH \quad \text{R7}$$

Net $O_3 + O \rightarrow O_2 + O_2$

Chlorine Chemistry

$$O_3 + Cl \rightarrow O_2 + ClO \quad \text{R8}$$
$$O + ClO \rightarrow O_2 + Cl \quad \text{R9}$$

Net $O_3 + O \rightarrow O_2 + O_2$

chlorine compounds that would be emitted by the space shuttle planned for the 1980s. It turned out that the amounts were too small to be significant. However, these calculations led to the recognition that large amounts of chlorine were being injected into the atmosphere by the use of freons (chlorofluorocarbons, CFCs as they are now called) which were used for propellants in aerosol spray cans, for refrigeration and for manufacturing foam. Professor Sherry Rowland at the University of California realized that because the CFCs were so stable, that any of them released in the air at ground level would eventually be transported upward into the upper atmosphere and be broken down by sunlight to release chlorine into the ozone layer.

The depletion of ozone by CFCs has now been studied for a decade, and current estimates of ozone depletion by CFCs are not too much lower than the original estimates by Rowland. However, it has been found that the overall problem is much more complex than originally estimated and that there are several other pollution sources for the ozone layer that have to be considered together because they interact with each other and the atmosphere. For example, increases in lower-atmosphere nitrogen oxides from jet traffic have actually led to *increases* in the amount of tropospheric ozone. Further, temperature changes in the high atmosphere that accompany the greenhouse effect produce ozone increases in the stratosphere. These and other gases are causing a partial compensation for depletion of the ozone layer due to the CFCs.

However, very recent developments in the knowledge of ozone-layer chemistry indicate a potential for a future disaster. In an effect called the "chlorine catastrophe," ozone would be depleted by only 5% at current usage rates of CFCs, yet if the global usage rate increased by only 4% a year, the ozone layer could deplete precipitously by more than 30% within 50 years! It might take more than 100 years after that to recover.

## GLOBAL OZONE DISTRIBUTION

In the last few years, satellite images from the NIMBUS weather satellite, which carries a remote-sensing instrument at an altitude of 600 km, have given us the ability to study actual global ozone distributions. The satellite image in Figure 1 provides an example of the kinds of images obtained and shows the distribution of ozone with latitude. It is apparent that the ozone layer is thin at the equator and thick at the poles. This ozone distribution has influenced the evolution of the human species; dark-skinned races are well-suited to live under the low ozone conditions in equatorial regions, while light-skinned people are better adapted to the northern regions. Skin cancer rates for example, are much higher among fair-skinned people living at tropical latitudes in places such as Australia. This is a graphic demonstration of our environmental dependence on the ozone layer. We also note that the ozone layer is strongly affected by the location of the jet stream, which we can easily see in the satellite image as a sharp gradient in the ozone field at mid-latitudes. Thus the ozone layer moves north and south with the daily motions of the jet stream.

Although the most recent calculations that attempt to account for the rather complex reactions involving many chemicals show that only small changes in the *total* column amount of ozone is expected over the next 5 years owing to the compensating effects of increases in several atmospheric gases, we do know that the altitude profile of the ozone layer has been altered especially over Antarctica in spring.

Ground-based remote-sensing measurements and satellite measurements of the 40-km level ozone indicate that the ozone layer over the globe at these upper levels has been depleted by about 5% at 40 km because of chlorine buildup from CFC usage. On the other hand, the ozone at lower levels below 10 km has increased by a small percentage, owing to ozone production by nitrogen oxides emitted in jet aircraft exhausts. Thus, although the total column amount of ozone has not changed much, its altitude distribution has been altered. Scientists are not certain what the climatic effects of the change will be; however, there is definite evidence that the ozone layer is being altered and will continue to change.

## BIOLOGICAL IMPACT

On the medical front, there is new evidence that ultraviolet radiation is more damaging than previously thought. A 1% ozone depletion will lead to at least a 4% increase in skin cancer. There is new evidence linking malignant melanoma to ultraviolet exposure and the discovery that ultraviolet exposure can lead to a depression of the human immunological system resulting in increased sensitivity to viral infections and carcinogenic factors such as toxic chemicals in the environment. It is also evident that the skin cancer rate is increasing because of the increased exposure of the general public to ultraviolet radiation resulting from such lifestyle changes as vacations in southern latitudes. Increases in ultraviolet light levels are harmful to many other life forms. Animals and small marine organisms have lower productivity. Plants and even agricultural crops may be adversely affected. Recent work indicates that wheat and soybean crop yields may be reduced, with a total annual agricultural loss estimated at over 3 billion dollars.

## THE GREENHOUSE EFFECT OF CFCs

Recently, we have heard many predictions that the increase of carbon dioxide concentrations due to the burning of fossil fuels will lead to a warmer climate within about 100 years. But CFCs have a more powerful greenhouse effect per molecule than carbon dioxide. The greenhouse effect is so powerful that if mankind deliberately wanted to warm up the global climate by 10°C, the current CFC production would only need to be increased by a factor of 10! It is expected that the greenhouse effect from CFCs will be at least half as large as that from carbon dioxide. Currently, the CFC greenhouse effect is estimated to be about one third of the carbon dioxide greenhouse effect; CFC concentrations are increasing at 6% per year whereas carbon dioxide concentrations are increasing at only 0.3% per year. This effect may be a compelling argument by itself for limiting CFC usage,

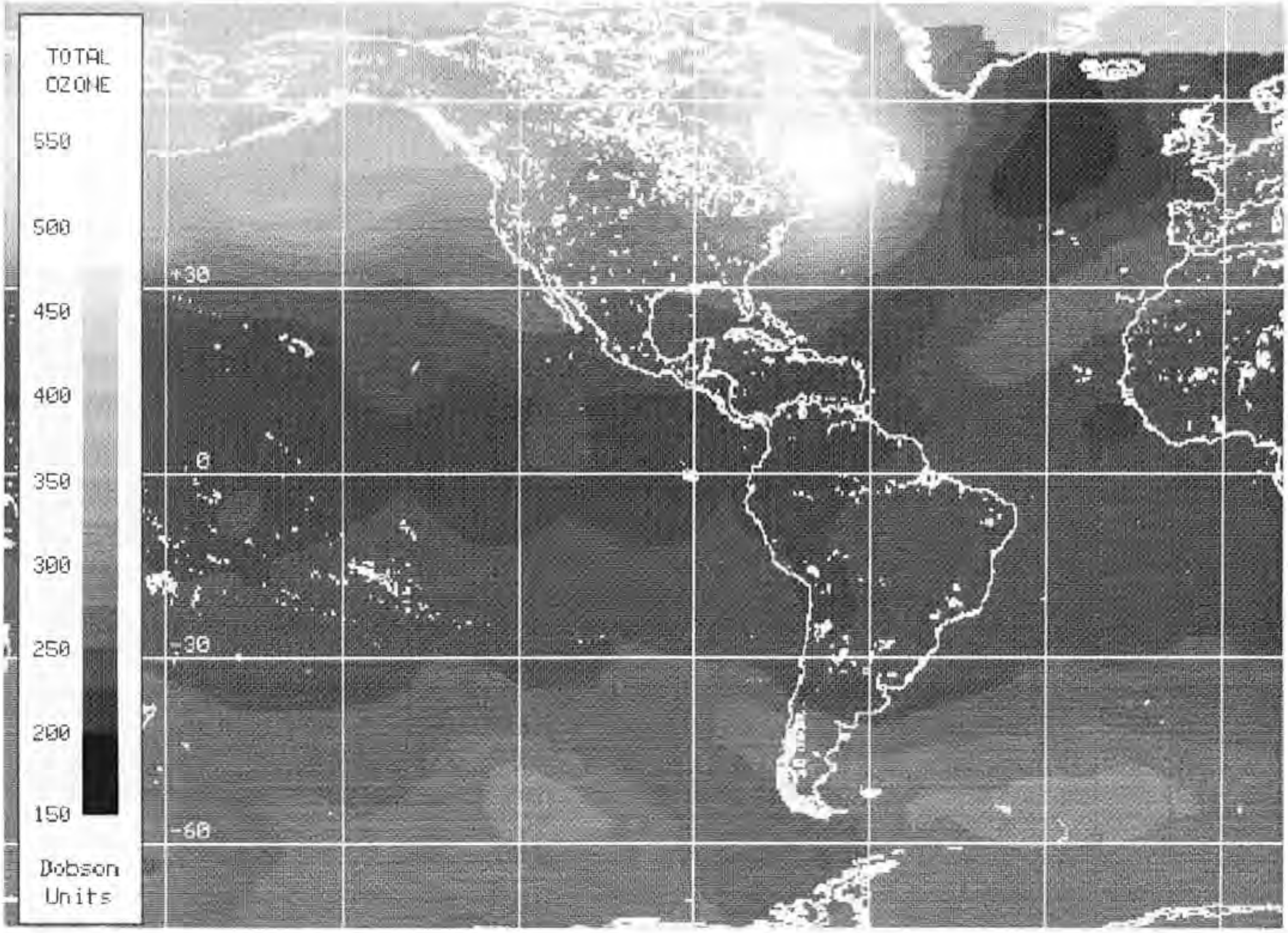



*Figure 1* Total ozone distribution for the Western Hemisphere on January 15, 1986, derived from data recorded by the TOMS (Total Ozone Mapping Spectrometer) instrument on the NIMBUS 7 satellite (data courtesy: Dr. Arlin Kreuger, NASA Goddard). Ozone amounts vary with latitude from about 2.5 mm in the tropics to over 4.5 mm at the poles. 100 Dobson Units (DU) = 1 mm.

quite aside from the ozone issue.

## GOVERNMENTAL CONTROLS

The regulatory action taken in the United States and Canada against the use of CFCs as propellants in aerosol spray cans has resulted in a stabilization of CFC usage at the 1977 levels. In the United States this regulation has the form of a total ban on propellant use, while in Canada, CFC use as a propellant has been banned only in hair sprays, antiperspirants and deodorants since these constituted the major uses. Most other nations, with the exception of the Nordic countries, have been much slower to discourage CFC usage. The most effective strategy for Canada and the United States now is to encourage other countries to limit their usage. However, if global usage continues to increase, we will have a serious long-term ozone depletion.

## THE ANTARCTIC OZONE HOLE

In 1985, scientists of the British Antarctic Survey at Halley Bay, Antarctica, noticed that the ozone column amount during the spring months, particularly October, had been decreasing since 1978 at a rate of 5% a year. When this station's data were checked against satellite data it was found that there was a crater-like structure in the ozone field over the Antarctic continent that had been getting progressively deeper since 1979, the first year for which satellite data were available. This crater or ozone "hole" as it is called is shown in the top colour map on the front cover. Ozone amounts range from over 4 mm (400 DU) in the rim at 55°N down to less than 170 DU in the floor of the crater in October 1986. This hole became even deeper in 1987 with ozone amounts below 130 DU in early October; over a factor of 2 deeper than in 1979! There is much debate about the cause of this hole, but the evidence now strongly implicates CFCs, since large amounts of free chlorine in the form of chlorine monoxide have been found in the altitude regions from 16 to 20 km where the hole is formed. It is thought that this free chlorine is produced by chemical reactions on the ice clouds that form in the cold temperatures of the winter polar vortex.

## THE ARCTIC OZONE HOLE

Canadian scientists have been searching for evidence of a similar phenomenon occurring in the Arctic during late winter. The bottom colour map on the cover is a satellite image for mid-March 1986, which should be compared with the other map; there appears to be a crater structure in the ozone field very similar to the Antarctic hole. Note that there is over 500 DU of ozone in the rim,

# MEASURING THE OZONE LAYER

One important facet of understanding the ozone layer is the measurement of the concentrations of ozone and the other gases that are important in the chemistry of the ozone layer. High-technology instrumentation is being used to study an environmental problem created by high-technology industry.

High-altitude aircraft, large stratospheric balloons, satellites and even the space shuttle are used as platforms on which to mount instruments to measure the ozone layer. Canada is one of the most advanced nations in the study of the ozone layer and the upper atmosphere. In 1976, a large atmospheric balloon was launched from Yorkton, Saskatchewan, carrying the Atmospheric Environment Service balloon payload which is part of Project Stratoprobe. This payload carries ten remote-sensing instruments up to 40 km above the earth's surface to measure the altitude distributions of many stratospheric gases including ozone, water vapour, methane, nitrogen dioxide, nitric acid and hydrochloric acid. The payload is brought back to earth on a parachute after a twenty-hour flight.

Environment Canada scientists launch a research balloon from Saskatoon in January to study the Arctic ozone layer (Photo: Lewis Poulin).

Both remote-sensing and *in situ* instruments are used to measure the stratospheric gases. Radiometers, spectrometers, interferometers, and photometers are some of the types of remote-sensing instruments flown. Gas chromatographs, mass spectrometers, absorption photometers, and tunable diode lasers are some of the *in situ* instruments flown on balloons and aircraft in the stratosphere.

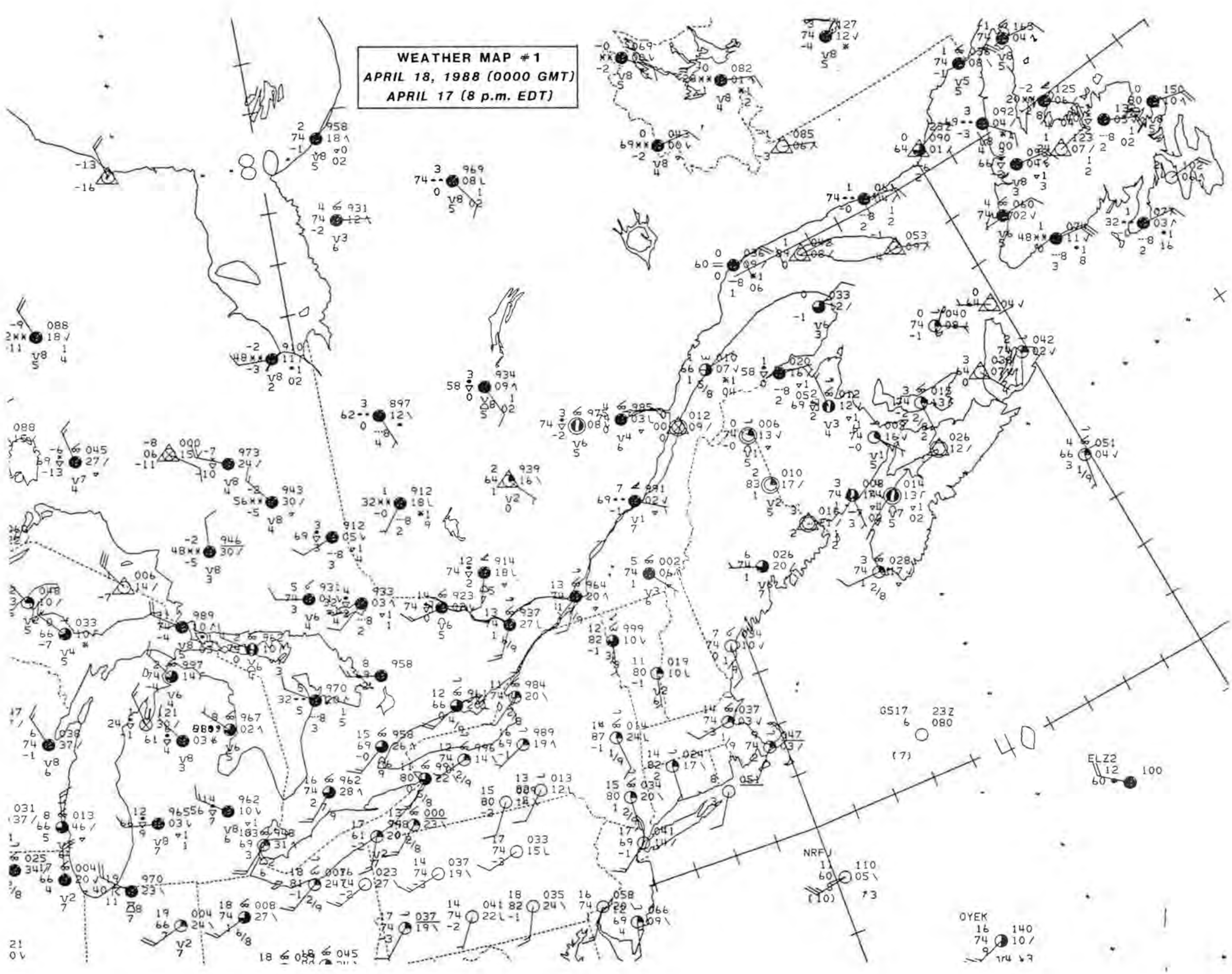
## MODELLING THE OZONE LAYER

Owing to the complexity of the chemistry and the motions of the stratosphere, scientists require the use of the most advanced supercomputers to predict future changes in the ozone layer. The chemistry of the ozone layer is extremely complex; there are over 100 species of molecules and over 300 reactions between these species. Most of these are incorporated in the large computer models used to study the stratosphere and the ozone layer. In addition to chemical reactions, models must include a representation of the atmospheric circulation and the transport of the gases including ozone. A range of sophistication of models is used, from simple "back of the envelope" models that can be run on personal computers to global climate models that must be run on supercomputers such as the Cray computer. One-dimensional models are frequently used, with altitude as the variable. Two-dimensional models have both altitude and latitude in their representation of the globe. The most sophisticated models represent the variations in the chemistry at various heights, latitudes and longitudes; these are usually derived from climate models called general circulation models.

Models may include time as a variable in order to simulate changes in the ozone layer over future decades, or they may simply be equilibrium models that assume the changes in the ozone layer are so slow that equilibrium would result.

The kinds of scientists that work on the ozone problem also have a wide range of skills; chemists, meteorologists, computer scientists, and physicists all work in this field.

Another development in the last four years has been the simulation of multiple scenarios; those in which the predictions of the increase of several atmospheric gases are included at the same time. In the past, scientists had considered only the increase in CFC usage or the increase in nitrogen oxides by themselves in model calculations. The result of these multiple-scenario calculations has changed the outlook for the depletion of the ozone layer during the next 20 years. Because of the combined effect of all the substances that affect the ozone layer, any decrease will be delayed for at least 20 years; this makes it difficult to use the monitoring of total ozone as an early warning for global long-term ozone depletion.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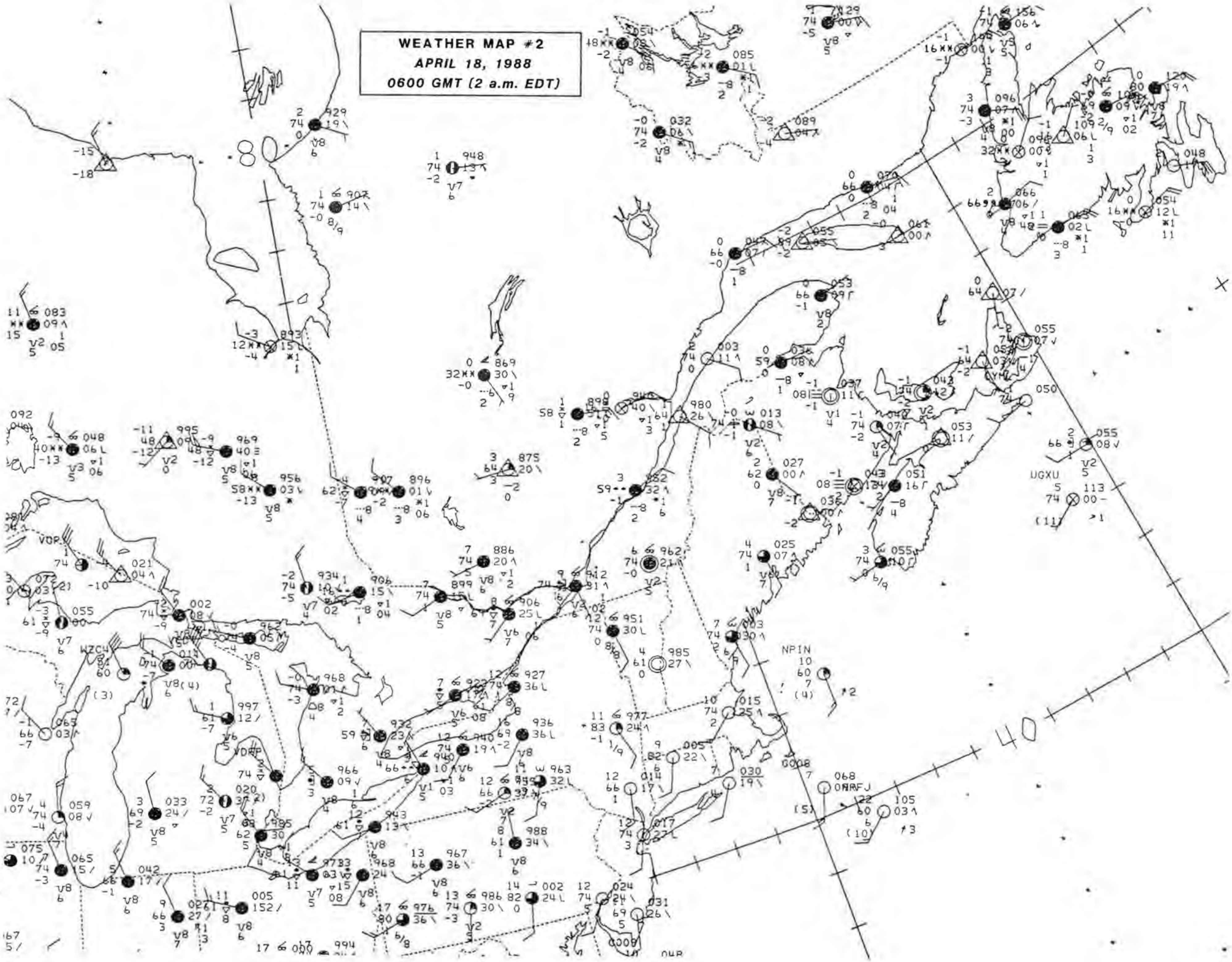
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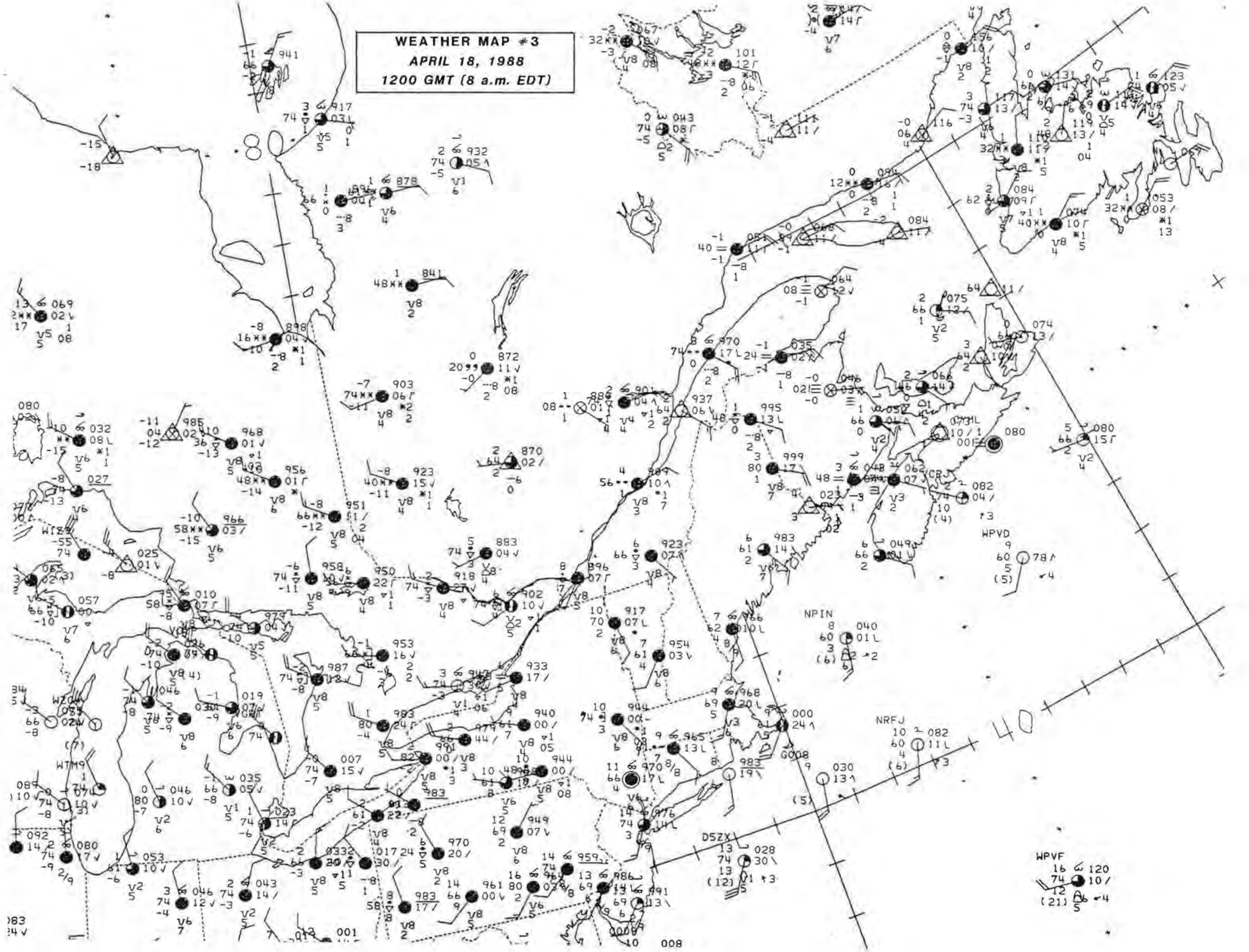
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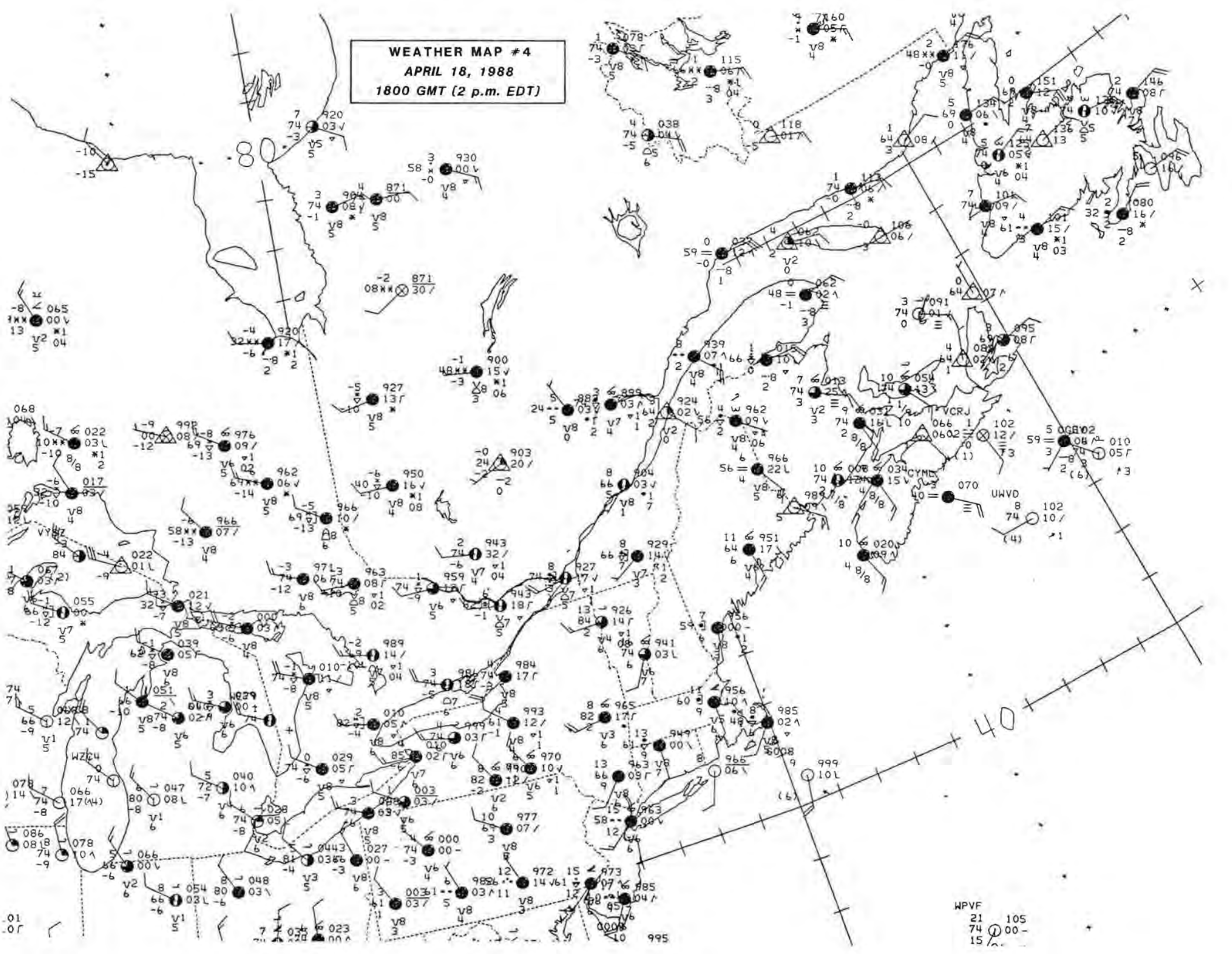

**WEATHER MAP #4**
***APRIL 18, 1988***
***1800 GMT (2 p.m. EDT)***

but less than 225 DU in the valley. A search of satellite data from other years has not revealed any structure as obvious as this, but similar phenomena are indicated in some other winters including 1984. Measurements of the ozone altitude profile from ozonesonde flights close to the floor of the crater have demonstrated notches or depleted layers in the profile similar to the notches discovered in the Antarctic and associated with the hole by American investigators from McMurdo Base. Hence it appears that a similar phenomenon may exist in the Arctic, although it only became obvious in 1986. We do not have definite evidence that a deepening hole exists in the Arctic, but its reappearance in the 1990s would lead to the likely conclusion that a hole is developing in the Arctic ozone layer.

## GLOBAL IMPLICATIONS

Although there is now concern that the Antarctic hole does permit more ultraviolet radiation to penetrate to the surface, there is little concern that the ultraviolet levels will be serious in the Arctic in late winter, since there is 15% more ozone in the Arctic to start with and the sun angle is low in late winter. The real concern is that the mechanism producing the hole represents a new chemical sink for the ozone layer; as a result the ozone levels at lower latitudes would be affected annually and allow more ultraviolet to reach the earth's surface in summer at the latitudes where most of the world's population lives. The analogy of adding another drain to your bathtub, so that the level of water in the bathtub is lowered, is appropriate. If the rate of disappearance of ozone in the Antarctic is scaled to a world level, then ozone depletion may occur at a rate 4 times faster than predicted in computer-model simulations of the effects of CFC usage using currently accepted schemes for ozone chemistry. Most of these scenario models predict a 2% depletion will not occur until the year 2030. If the Antarctic hole sink is included, the ozone change may be over 5% by the year 2000! This is why it is so urgent for scientists to understand the cause and mechanism for the hole.

## THE 1987 OZONE LAYER PROTOCOL AT MONTRÉAL

It is quite apparent that there is need for international action to limit global usage of CFCs to a safe level and provide the framework to protect the ozone layer against future threats as they occur. A United Nations Environment Program (UNEP) group had drafted an international convention for the protection of the ozone layer, which was signed on March 22, 1985 by 20 nations.

In September 1987 at Montréal, diplomats from over 40 countries met to negotiate a control protocol on CFC usage. On September 16, representatives of over 23 countries signed a UNEP protocol agreement. Over the next year, this will be legally ratified by the governments of these countries. As soon as 11 countries that produce over 67% of the world's CFCs have ratified it, the protocol will come into effect. Under the terms of the agreement, the signatory countries agree to reduce CFC consumption to 50% of the 1986 base year consumption by 1999. Halons, which are CFCs containing bromine used in fire protection, will be frozen at the 1986 level in 1992. Underdeveloped countries are allowed to increase their annual consumption to 0.3 kg per person (the United States uses 2 kg per person per year). The USSR is allowed to use 1990 as the base year. The European Common Market countries are permitted to pool their consumption for accounting purposes. The protocol will be reviewed every 4 years to see if the status of scientific predictions has changed; then if necessary, the consumption quotas will be adjusted in light of the knowledge at the review time. The first review will be in 1990, so that if harmful global effects can be detected to result from the ozone hole by that time, then consumption levels could be lowered. This treaty represents a unique example of international cooperation, and the Canadian Minister of the Environment, the Honorable Tom McMillan hopes that it may lead to a "Law of the Atmosphere Treaty" by the United Nations. This more general treaty could in principle provide a solution to the greenhouse and acid rain problems.

## CONCLUSION

It appears that the world's ozone layer is under more severe threat from CFCs than predicted 3 years ago. The Antarctic ozone hole and possibly an Arctic ozone hole have appeared. On the positive side, a global UNEP treaty has been signed to protect the ozone layer, and the level of knowledge has advanced. It has never been more true that more scientific research and monitoring of the ozone layer is needed urgently.

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## ACKNOWLEDGEMENT


This article, an updated and expanded version of "Ozone, Our Invisible Shield", which appeared in the May/June 1985 issue of *Bridges*, is published with the permission of Bridges Publications.



Wayne Evans is chief of the AES Experimental Studies Division in Toronto. He began ozone investigations in 1967 at the University of Saskatchewan where he discovered the mesospheric ozone layer. Dr. Evans joined the Atmospheric Environment Service in 1972 to start the balloon research project STRATOPROBE, and has conducted numerous studies of ozone layer chemistry. His research group has flown a shuttle experiment with Mark Garneau and developed a new instrument to monitor ozone – the Brewer spectrophotometer.



**RÉSUMÉ** *On examine les caractéristiques et la position de la couche d'ozone dans l'atmosphère. On pointe son importance pour la vie humaine car il protège la surface de la terre contre les rayons ultraviolets du soleil. On décrit les réactions chimiques qui s'effectuent dans la couche d'ozone et qui l'affectent, de même qu'on examine des modèles numériques qui prévoient son amenuisement par les chlorofluorocabones (CFC). On illustre des techniques de mesure de l'ozone et des gaz atmosphériques. Les efforts internationaux faits en vue de protéger la couche d'ozone sont mentionnés, particulièrement le nouveau Protocole de l'PNUE, signé par 23 pays à Montréal, pour réduire l'utilisation de CFC.*

*Le trou d'ozone de l'Antarctique, nouveau phénomène observé, est décrit, de même que les recherches canadiennes sur la possibilité d'un tel trou au-dessus de l'Arctique. On se penche surtout sur le travail exécuté par les Canadiens.*

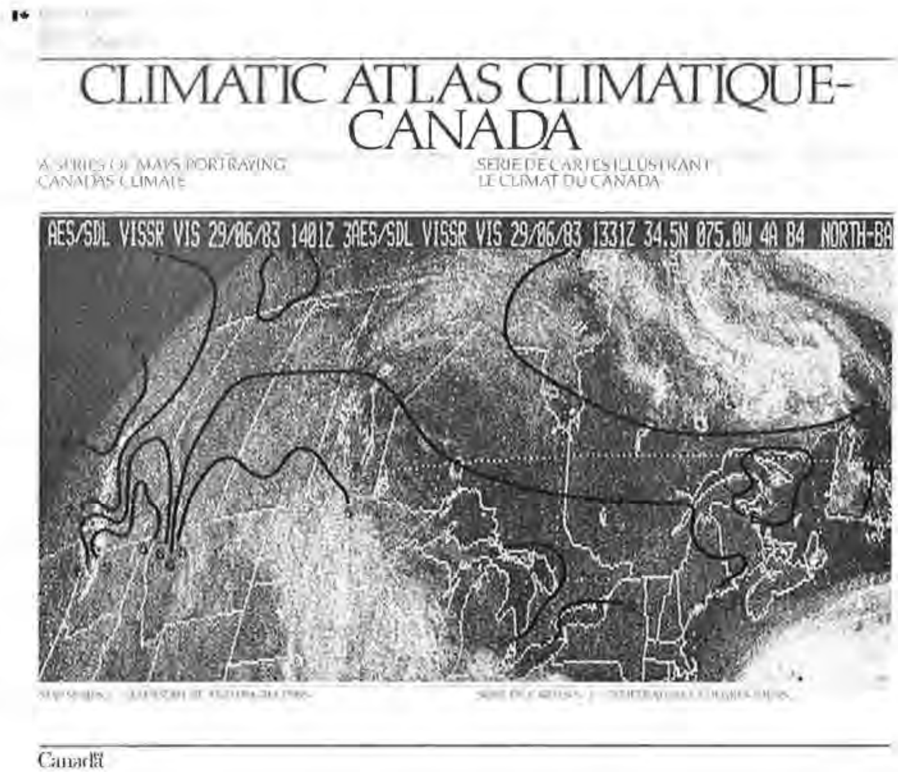
# A CLIMATIC ATLAS FOR CANADA

**by Donald W. Gullett**

How many days does it snow in an average January at Victoria? Are thunderstorms ever observed at Vancouver? Is Essex County, Ontario, really the "sun parlour" of Canada, or does Estevan, Saskatchewan, better qualify for such a distinction? Is St. John's really fog-enshrouded most of the time? These are but a few of the weather questions, facts and fantasies that may be confirmed or dispelled with the new climatic atlas of Canada. This latest series of national climatic maps depicts in visual form, many climatic elements, the aggregate of which make up the many climates of Canada. A climatic map represents a "bird's-eye" view of a climatic element (such as, temperature, precipitation or sunshine) "captured" permanently in time and space for use by all.

Mapping of climatic elements has been carried out since ancient Greek times when crude maps were first drawn to delineate the torrid and temperate zones of the earth. Climatic mapping, as we have come to know it, however, is a fairly new field that has been practised only for the past century and a half. One of the earlier known climatic maps, a chart showing the Northern Hemispheric distribution of temperature, was produced in the early 1800s by Alexander von Humboldt. Since then, climatic maps have become a widely accepted medium for summarizing and displaying huge quantities of data in a concise and easily interpreted manner. As well, there are many types of climatic maps, ranging from large- or medium-scale maps prepared on a local or regional basis, to small-scale national maps. Examples of the former are maps for fairly small geographic areas, such as provinces, river drainage basins and towns; and those of the latter are maps for large areas, such as Canada. Today, almost every major meteorological service produces a national climatic atlas.

Climatic mapping is still in its infancy in Canada, since it was a mere fifty years ago that Abraham Connor, the Dominion Climatologist, co-authored with Charles Brooks, for publication in the United States, a collection of climatic maps of North America. But the first




full-fledged "Climatological Atlas of Canada" came into being as recently as 1953. This very useful desk-size publication was produced by Morley Thomas to support his research on climate and building construction in Canada. As a result of this early work, Mr. Thomas is considered the "father" of climatic mapping in Canada. His work was later augmented with that of yet another well-known Canadian climatologist, George Kendall, when in the mid-1960s they produced, along with other government colleagues, the *Atlas of Climatic Maps*. This sixties version of the atlas was greatly expanded from the earlier edition and contained over 125 maps, pages measuring 17 inches × 22 inches and data from a growing post-war network of meteorological reporting stations. In addition, maps were now included for all months of the year and for 10 separate climate elements. The averaging period for the data was updated to the period 1931–1960, which coincided with the "normal" period at the time, as specified by the World Meteorological Organization (WMO). A WMO climatic normal is a long-period average of a climatic element, such as temperature, that is based on the most recent thirty-year period and is usually re-calculated every ten years. Normal periods include: 1931–1960, 1941–1970, 1951–1980, 1961–1990, 1971–2000. The "sliding" time-scale for calculating climatic normals was introduced by the WMO in the 1930s in an attempt to incorporate any climatic changes that may have occurred.

### CLIMATIC ATLAS CLIMATIQUE – CANADA

Five years ago, when the 1951–1980 Canadian climate normals were produced, it was decided to use these long-term averages further and at the same time, to take full advantage of the

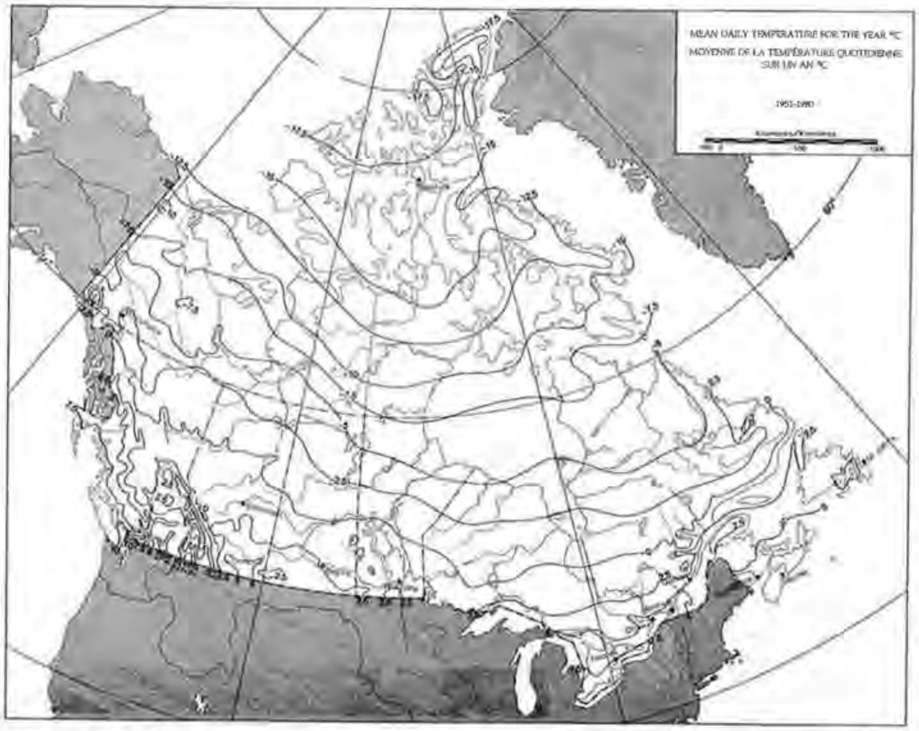



*Figure 1* Sample map from Series 1 showing Mean Daily Temperature for the Year.

*Table 1* Map Series 1 – Temperature and Degree-Days

| Climate Element | Period | Map Scales |
|---|---|---|
| *Mean* | | |
| maximum temperature | monthly, annual | 1:25 M, 1:12.5 M |
| minimum temperature | monthly, annual | 1:25 M, 1:12.5 M |
| temperature | monthly, annual | 1:25 M, 1:12.5 M |
| *Extreme daily* | | |
| maximum temperature | monthly, annual | 1:25 M, 1:12.5 M |
| minimum temperature | monthly, annual | 1:25 M, 1:12.5 M |
| *Mean number of days with* | | |
| maximum temp. > 30°C | annual | 1:12.5 M |
| minimum temp. ≤ 0°C | annual | 1:12.5 M |
| minimum temp. <−20°C | annual | 1:12.5 M |
| *Mean* | | |
| cooling degree-days >18°C | annual | 1:12.5 M |
| heating degree-days <18°C | annual | 1:12.5 M |
| growing degree-days > 5°C | annual | 1:12.5 M |
| freezing degree-days <0°C | annual | 1:12.5 M |

previously unavailable computer technology and produce a new, revised Canadian climatic atlas. The last such atlas had then been in existence for nearly twenty years. The *Climatic Atlas Climatique – Canada* was thus born with the impetus for the work coming from David Phillips of the Canadian Climate Centre. His devoted efforts in the design, layout, formatting and detailed planning of the project and in the analysis of large amounts of data resulted in the first series of maps in 1984. All maps were computer-plotted from digital data bases using routines either developed by Atmospheric Environment Service (AES) personnel or obtained from commercially available software. Automated plotting of the base data made it possible at times to plot data for more than 2000 stations on a single map. A colour-coded technique was used to rank and plot the data for stations with the longest periods of record. Some data for stations with shorter periods, and hence lower analysis priorities, were not plotted especially if they would overlap the data for longer period stations. In this way map congestion was minimized while station longevity was given the highest priority.

Map Series 1 – Temperature and Degree-Days, comprising some 60 maps, depicts the monthly and annual patterns of the maximum, minimum and mean temperatures, and the annual degree-day distributions for 4 different base temperatures (Table 1). This was followed soon after by Map Series 2 – Precipitation, an even larger edition with over 150 maps showing monthly patterns of rain, snow and total precipitation across Canada (Table 2). Late in 1986, Series 3, the largest to date, was published containing more than 280 maps of the spatial patterns of monthly mean atmospheric pressure, atmospheric moisture (relative humidity and vapour pressure), cloud cover, visibility, and days with eight separate climatic elements including thunderstorms, hail, smoke/haze, fog, freezing precipitation, blowing snow, frost, and snow on the ground (Table 3). Similarly, Map Series 4 – Bright Sunshine and Solar Radiation, issued in March 1988, shows monthly patterns of various aspects of the sunshine and solar radiation received at the earth's surface in Canada (Table 4). Map Series 5 – Wind (Table 5) has just been published. Two additional series are also being planned. Sample maps from Series 1 and 2 are shown as Figures 1 and 2, respectively.

## MAPPING AND ANALYSIS

The climatic mapping needed to produce a national climatic atlas is a complex undertaking. Such factors as map scales, map standardization, data consistency and reliability, and the temporal and spatial variabilities of the data must be borne in mind at all times during the process.

Map scales for climatic mapping are generally selected for specific purposes. Small-scale maps, usually 1:5,000,000 or less are most useful for general education. In the current atlas, the map scales were 1:7,500,000 for the full-page maps and 1:25,000,000 for the four-to-a-page layouts. These rather small scales are well suited for the broad-based depiction of major climatic patterns. The choice of a final base map for use throughout all series was made only after close consultation with map experts at Energy, Mines and Resources Canada (EMR). Map projections and scales were selected such that most maps would be compatible with those in the *National Atlas of Canada* published by EMR Canada (1985). All maps in the climatic atlas were photo-reduced to the final design size. Greater detail could have been provided by maps with larger scales, for example, 1:1,000,000 or larger. However, such maps are usually reserved for regional climate studies where a more detailed examination of the various climatic elements of a particular geographic area is desired.

The mapping of climatic elements should always be carried out in compliance with the international mapping standards recommended by WMO, which are specified in the *Guide to Climatological Practices* (1983). The guide gives criteria for standard map scales, and guidelines for legends, symbols and labelling; in addition specifications for national climatic maps include meridians and parallels drawn at 5° intervals; smooth isolines that are continuous and end uniformly just beyond international boundaries and just off coastlines; and clear identification of the period of the data analysed.

The climatic map analyst must be more than a geographer/cartographer. Climatic mapping is more involved than merely drawing lines between points of equal value. In addition to possessing a regional and national knowledge of the principles of physical geography, the analyst must also be apprised of the administrative details of the observing stations. In short, one must be intimately acquainted with the data being mapped. An awareness of such details as the origin of the data, the period of record, changes in observing and recording procedures, observing site changes, periods of missing data, and possible and probable errors in the data is essential.

The analyst must also be acutely aware of the temporal and spatial variabilities of the data. This requires a thorough understanding of the physical and dynamic behaviour of the relevant climatic elements. Many questions must be addressed: How do the elements change in time and space? How do they vary from month to month, from season to season, and with changes in topography, elevation, observing site orientation and exposure? How are they influenced by major climatic controls, such as latitude and longitude and nearness to large water bodies and physical barriers, and by numerous other factors?

All of these considerations must be foremost in the analyst's mind during the mapping and contouring exercise. Ultimately what is desired is a professional-looking isoline map that documents the temporal and spatial distributions of a climatic element in a clear, concise and easily comprehended manner.

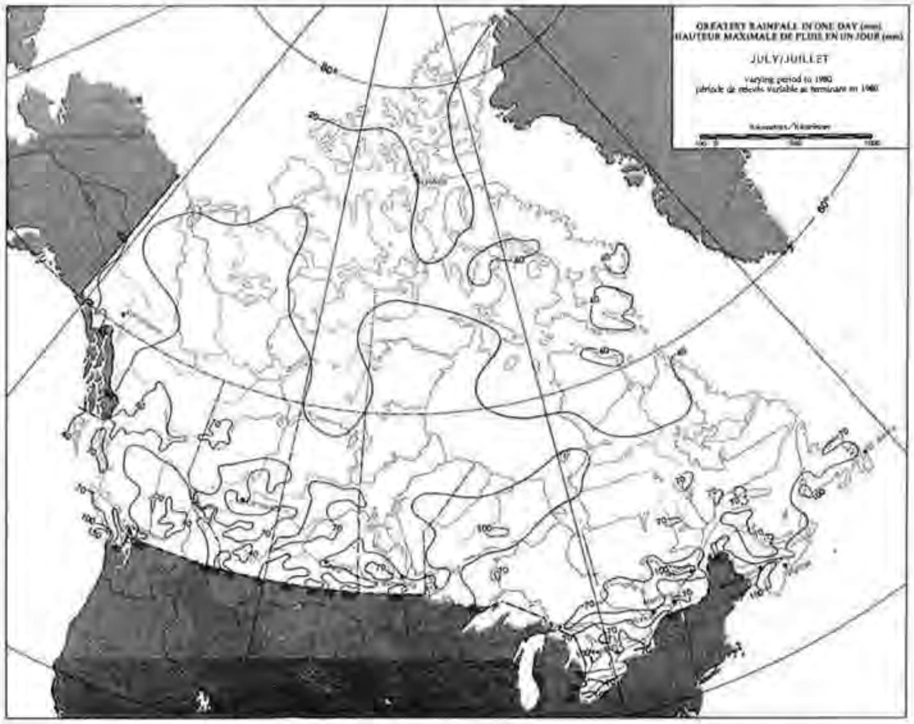



*Figure 2* Sample map from Series 2 showing Greatest Rainfall in One Day.

*Table 2* Map Series 2 – Precipitation

| Climate Element | Period | Map Scales |
|---|---|---|
| *Mean* | | |
| rainfall | monthly, annual | 1:25 M, 1:12.5 M |
| snowfall | monthly, annual | 1:25 M, 1:12.5 M |
| precipitation | monthly, annual | 1:25 M, 1:12.5 M |
| *Mean number of days with* | | |
| measurable rainfall | monthly, annual | 1:25 M, 1:12.5 M |
| measurable snowfall | monthly, annual | 1:25 M, 1:12.5 M |
| measurable precipitation | monthly, annual | 1:25 M, 1:12.5 M |
| rainfall ⩾ 10 mm | monthly | 1:25 M |
| snowfall ⩾ 10 cm | monthly | 1:25 M |
| precip. ⩾ 10 mm | monthly | 1:25 M |
| *Extreme one day* | | |
| rainfall | monthly | 1:25 M |
| snowfall | monthly | 1:25 M |
| precipitation | monthly | 1:25 M |
| *Mean rainfall* | | |
| 24 h extreme | annual | 1:12.5 M |
| 12 h extreme | annual | 1:12.5 M |
| 6 h extreme | annual | 1:12.5 M |
| 1 h extreme | annual | 1:12.5 M |
| 15 min extreme | annual | 1:12.5 M |
| 5 min extreme | annual | 1:12.5 M |

## FUTURE

Additional map series are planned to complete the *Climatic Atlas Climatique – Canada* project. Maps of the monthly mean patterns of soil temperature, lake evaporation and snow cover amounts will compose Map Series 6. A final series is planned to illustrate the upper-air climatology of Canada, including monthly maps of the means of selected climatic elements at different levels of the atmosphere, e.g., air temperature, dew-point temperature, relative humidity, mixing ratio, and wind speed and direction. The data to be mapped will be computer-processed and summarized for the 1961–1985 period using the historical data record from the AES national climatological digital archive.

*Table 3* Map Series 3 – Pressure, Humidity, Cloud, Visibility, and Days With ...

| Climate Element | Period | Map Scales |
|---|---|---|
| *Mean* | | |
| sea-level pressure | monthly, annual | 1:12.5 M |
| vapour pressure | monthly, annual | 1:12.5 M |
| vapour pressure at 7 a.m. | monthly | 1:25 M |
| vapour pressure at 1 p.m. | monthly | 1:25 M |
| relative humidity at 7 a.m. | monthly | 1:25 M |
| relative humidity at 1 p.m. | monthly | 1:25 M |
| *Extreme hourly* | | |
| sea-level pressure | monthly, annual | 1:12.5 M |
| vapour pressure | annual | 1:12.5 M |
| *Mean percentage frequency of* | | |
| clear skies at 7 a.m. | monthly | 1:25 M |
| clear skies at 1 p.m. | monthly | 1:25 M |
| cloudy skies at 7 a.m. | monthly | 1:25 M |
| cloudy skies at 1 p.m. | monthly | 1:25 M |
| good visibility at 7 a.m. | monthly | 1:25 M |
| good visibility at 1 p.m. | monthly | 1:25 M |
| poor visibility at 7 a.m. | monthly | 1:25 M |
| poor visibility at 1 p.m. | monthly | 1:25 M |
| *Mean number of days with* | | |
| thunderstorms | monthly, annual | 1:25 M, 1:12.5 M |
| hail | monthly, annual | 1:25 M, 1:12.5 M |
| smoke/haze | monthly, annual | 1:25 M, 1:12.5 M |
| fog | monthly, annual | 1:25 M, 1:12.5 M |
| freezing precipitation | monthly, annual | 1:25 M, 1:12.5 M |
| blowing snow | monthly, annual | 1:25 M, 1:12.5 M |
| frost | monthly, annual | 1:25 M, 1:12.5 M |
| >5 cm snow on the ground | monthly, annual | 1:25 M, 1:12.5 M |

*Table 4* Map Series 4 – Bright Sunshine and Solar Radiation

| Climate Element | Period | Map Scales |
|---|---|---|
| *Mean* | | |
| hours of bright sunshine (% possible) | monthly, annual | 1:25 M, 1:12.5 M |
| hours of bright sunshine | monthly | 1:25 M |
| number of days with some bright sunshine | monthly, annual | 1:25 M, 1:12.5 M |
| *Extreme monthly* | | |
| hours of bright sunshine | monthly | 1:25 M |
| *Mean daily solar radiation* | | |
| global | monthly, annual | 1:25 M, 1:12.5 M |
| diffuse | monthly, annual | 1:25 M, 1:12.5 M |
| direct | monthly, annual | 1:25 M, 1:12.5 M |
| *Extreme daily* | | |
| global solar radiation | monthly, annual | 1:25 M, 1:12.5 M |

*Table 5* Map Series 5 – Wind

| Climate Element | Period | Map Scales |
|---|---|---|
| *Mean percentage frequency of* | | |
| wind direction and speed | monthly, annual | 1:12.5 M |
| *Prevailing direction and speed* | | |
| at 7 a.m. | monthly | 1:25 M |
| at 1 p.m. | monthly | 1:25 M |
| all hours | monthly, annual | 1:25 M, 1:12.5 M |
| *Extreme speed and direction* | | |
| hourly wind | monthly, annual | 1:25 M, 1:12.5 M |
| gust | monthly, annual | 1:25 M, 1:12.5 M |

It is hoped that taken collectively the maps of the *Climatic Atlas Climatique – Canada* will provide a comprehensive, well-rounded, visual depiction of the many and varied climates of Canada.

Copies of the *Climatic Atlas Climatique – Canada*, Environment Canada, Toronto, 1984 to 1988, may be purchased from the Canadian Government Publishing Centre, Supply and Services Canada, Ottawa, Ontario K1A OS9. Map Series are individually priced and must be specified separately when ordering, quoting the appropriate catalogue numbers. Catalogue numbers and prices are as follows:

Map Series 1 – Temperature and Degree-Days, Catal. No. EN56-63/1-1984, $8.00

Map Series 2 – Precipitation, Catal. No. EN56-63/2-1986, $12.00

Map Series 3 – Pressure, Humidity, Cloud, Visibility, and Days With ..., Catal. No. EN56-63/3-1986, $19.95

Map Series 4 – Bright Sunshine and Solar Radiation, Catal. No. EN56-63/4-1987, $11.95

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Donald Gullett is a climatologist with the Canadian Climate Centre, engaged in climate product development. He has over twenty years of experience in meteorology and climatology, serving as a weather observer at many locations across Canada, including the Arctic before joining the climatology group at AES Headquarters in Downsview during 1975.



**RÉSUMÉ** *On décrit brièvement le nouvel atlas climatique canadien qui vient d'être publié par Environnement Canada. Cet atlas sera utile aux personnes vouées à l'éducation ainsi qu'à ceux et celles qui s'intéressent à la météorologie et à la climatologie. Il peut servir de rapide source d'informations pertinentes sur les différents climats du Canada et leurs variations. Il donne un aperçu visuel de plusieurs des éléments atmosphériques qui, ensemble, font notre climat. Les problèmes et les aspects uniques à la cartographie climatologique sont examinés afin de présenter aux usagers de l'atlas une idée de sa complexité.*

# FALL OF 1987 – A REVIEW

**by Alain Caillet**

*The arrival of fall saw a return of the trend towards warmer or, at least, milder than normal temperatures that began in late 1986 and continued throughout spring and most of summer. During the fall months, mean above normal temperatures were limited to the area west of Lake Superior. By late November, all indications forecast that this area would have an exceptional number of mean annual temperature records in 1987.*

The unusual climatic regime that had been keeping the country's temperatures well above normal following the winter of 1986–87 was severely disturbed in August. Only a few areas remained above normal, such as southwestern British Columbia, the Great Lakes Basin and southern Ontario. In September, a change in the general circulation aloft, marked by an intensification of the long-wave ridge over the Canadian West, brought mild air from the Pacific. With a few exceptions, mean monthly temperatures climbed back to above-normal levels across Canada.

### WARM WEATHER RETURNS TO WESTERN CANADA

In the West particularly, it seemed that summer had returned: In September, Penticton and Kelowna, B.C., recorded maximum temperatures of 37 and 35°C, respectively, while southern Alberta and Saskatchewan temperatures rose above 30°C. In October, Edmonton and even Fort McMurray in northern Alberta had temperatures over 28°C while Calgary and Lethbridge reached highs of 19°C. The effects of the ridge of high pressure continued irregularly across the country until mid-November: Alberta and British Columbia remained above normal for two additional months. However, October was cold in Ontario and western Quebec as November was in all of Quebec and the Atlantic Provinces.

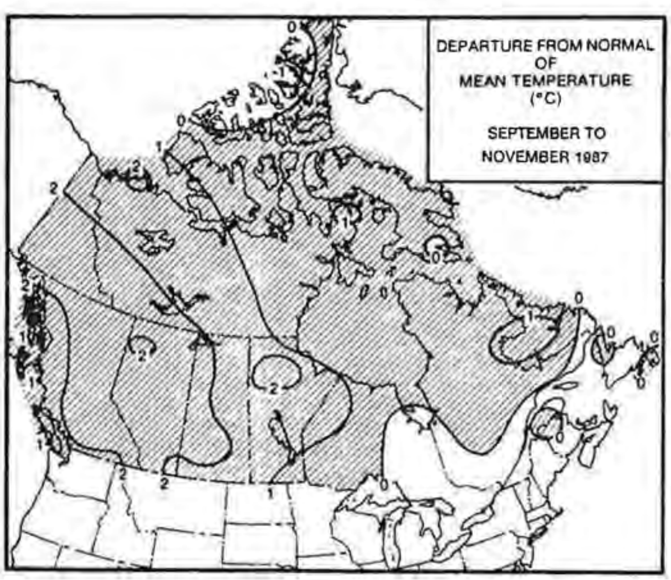
It would be hard to identify a definite period of "Indian summer", since although temperature swings were great enough, they were also too rapid and occurred too frequently.

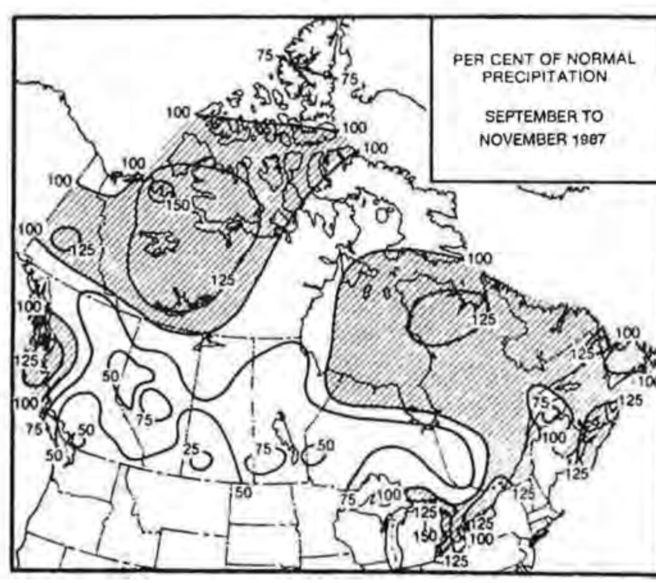
### SNOW COMES LATE TO THE WEST

The precipitation picture during the fall was in some ways the opposite of the temperature picture. Beginning in September, the Maritimes made up for much of their June and August precipitation deficits. In southern British Columbia, on the other hand, the lateness of the rainy season created a critical situation, with reports in late October of dry wells and of lake, river and reservoir levels so low that there was a risk of fish dying during the winter. At Calgary, no more than 5 cm of snow still lay on the ground in mid-November. On the Atlantic coast, seasonal storms arrived a bit late this year (in October). In the Maritimes, only Summerside, P.E.I., had a measurable quantity of snow, and then only 0.2 cm!

### IMPACTS

With the opening of the storm season on the East Coast, Newfoundland was hit by the biggest of the weather systems affecting the Atlantic Provinces, and some schools and roads had to be closed. Generally, however, climatic extremes were pleasant rather than unpleasant, and any deleterious effects on Canadians and on the economy were fairly mild. One exception was the severe thunderstorms that cost two people their lives when hit by lightning, one in Toronto and the other in Orillia, Ontario, on September 13. In Alberta, crops whose growth had slowed in August reached maturity thanks to the fine weather, and harvesting could proceed



at a good clip. By the end of November, British Columbia had experienced its sixteenth consecutive month of above-normal temperatures, but the rains finally arrived, eliminating the risk to sport fishing, fruit production and cattle raising threatened by the low water levels in lakes and rivers the previous month. On the Prairies, however, the lack of snow on the ground concerned not only the farmers but also the organizers of the Olympic Games, who could not depend on using artificial-snow machines because air temperatures were not cold enough, at least during the daytime.

Alain Caillet is a meteorologist with the Canadian Climate Centre and is a member of the editorial team of *Climatic Perspectives*.

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# DEFINITELY NOT BASEBALL WEATHER!

## Weather Map Series, April 17 and 18, 1988

### by Hans VanLeeuwen

The baseball season opened in southern Ontario under typical mid-April weather conditions. The "Boys-of-Summer", however, play their game preferably in more pleasant temperatures. During the 1988 opening series in Toronto, one game was cancelled because of extreme cold and the April 19 and 20 Blue Jays games were played in 1-degree (C) "too-cold-to-swing-a-bat" weather.

A deepening storm moved across central Ontario into Quebec. The associated cold front formed the leading edge of an invasion of cold Arctic air into the Great Lakes Basin. The accompanying snow, freezing precipitation and strong winds created havoc with the hydro power system in northern Quebec, which caused a massive blackout in the province and the northeastern United States.

The Weather Map Series starts with the 0000 GMT situation on April 18 (8 p.m. EDT April 17), and continues at 6-hourly intervals to 1800 GMT April 18 (2 p.m. April 18). The series thus illustrates the movement of the low-pressure system through Ontario and gives an excellent illustration of the cold front separating the reasonably mild air to the east (14 to 17°C) from the cold air to the west and northwest (below freezing).

In order to carry out a meaningful analysis of the weather data plotted on each map, the coded information must be understood. A previous issue of *Chinook* (Volume 8, Number 2) contains a detailed explanation of the synoptic map plot and also a list of publications recommended for reading. If a copy of the above issue is not available one can be obtained by mailing a stamped, self-addressed envelope to the CMOS office in Ottawa, attention: Editor, *Chinook* (Weather Map Series: Vol. 9 No. 2).

As in previous Map Series it is suggested that some of the following activities be performed: analysis of the pressure field (isobars), temperatures (isotherms), precipitation (types), weather (fog, mist) and cloud (amount, i.e. overcast versus clear skies; cloud types).

After a detailed isobar analysis at 4-mb (0.4-kPa) intervals on all four charts – and using the change in temperature (mild to cold) and wind direction (southerly to west and northwesterly) – try to locate the cold front on all four maps. You will notice that with the windshift-line there is also a significant change in temperature. Specifically the following interesting features should be noted in the series:

- thunderstorm and cumulonimbus cloud reported near South Bend (Indiana)
- strong falling pressures ahead of the advancing cold front (map 1 over southwestern Ontario and New York)
- snow showers in the west-northwesterly flow behind the cold front (maps 2, 3 and 4)
- fog in the easterly flow of mild air off the Atlantic along the Nova Scotia and New Brunswick shoreline (maps 2, 3 and 4)

The following questions and others could be posed:

- How would you describe the weather over Newfoundland that day?
- What overnight temperatures would you predict for the Ottawa-Montréal area?

Chinook

# THE CANADIAN MAGAZINE OF WEATHER AND OCEANS

**WHAT?** *Chinook* is a popular magazine concerned with two major components of the Canadian environment – the atmosphere and the oceans. It is published quarterly by the Canadian Meteorological and Oceanographic Society (CMOS).

Features in *Chinook* include articles, weather summaries, interpretations of satellite and other photographs, and news and notes. These appear in the language submitted (English or French). In addition, summaries of all articles appear in the other language.

**WHY?** The aims of *Chinook* are

- to increase public awareness of meteorology and oceanography in Canada and of their modern scientific and technological aspects and achievements
- to stimulate public interest in and understanding of the impact of climate, weather and oceans on Canadian society and economics
- to inform Canadians about the education, information and interpretative services available to them on climate, weather and oceans

**WHO?** Features in *Chinook* are chosen to appeal particularly to

- secondary school and community college students
- farmers, fishermen and foresters
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# LA REVUE CANADIENNE DE LA MÉTÉO ET DES OCÉANS

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On retrouve dans *Chinook* des articles, des sommaires du temps, des interprétations de photos satellitaires et autres, des articles d'actualité et des notes. Ces articles paraissent dans la langue originale, le francais ou l'anglais; tous les résumés sont rédigés dans l'autre langue.

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- éveiller la curiosité du public en ce qui a trait aux aspects de la météorologie et de l'océanographie au Canada et à l'informer des réalisations scientifiques et technologiques d'aujourd'hui;
- stimuler l'intérêt du public et l'aider à mieux comprendre les effets du climat, du temps et des océans sur la société et sur l'économie du Canada;
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