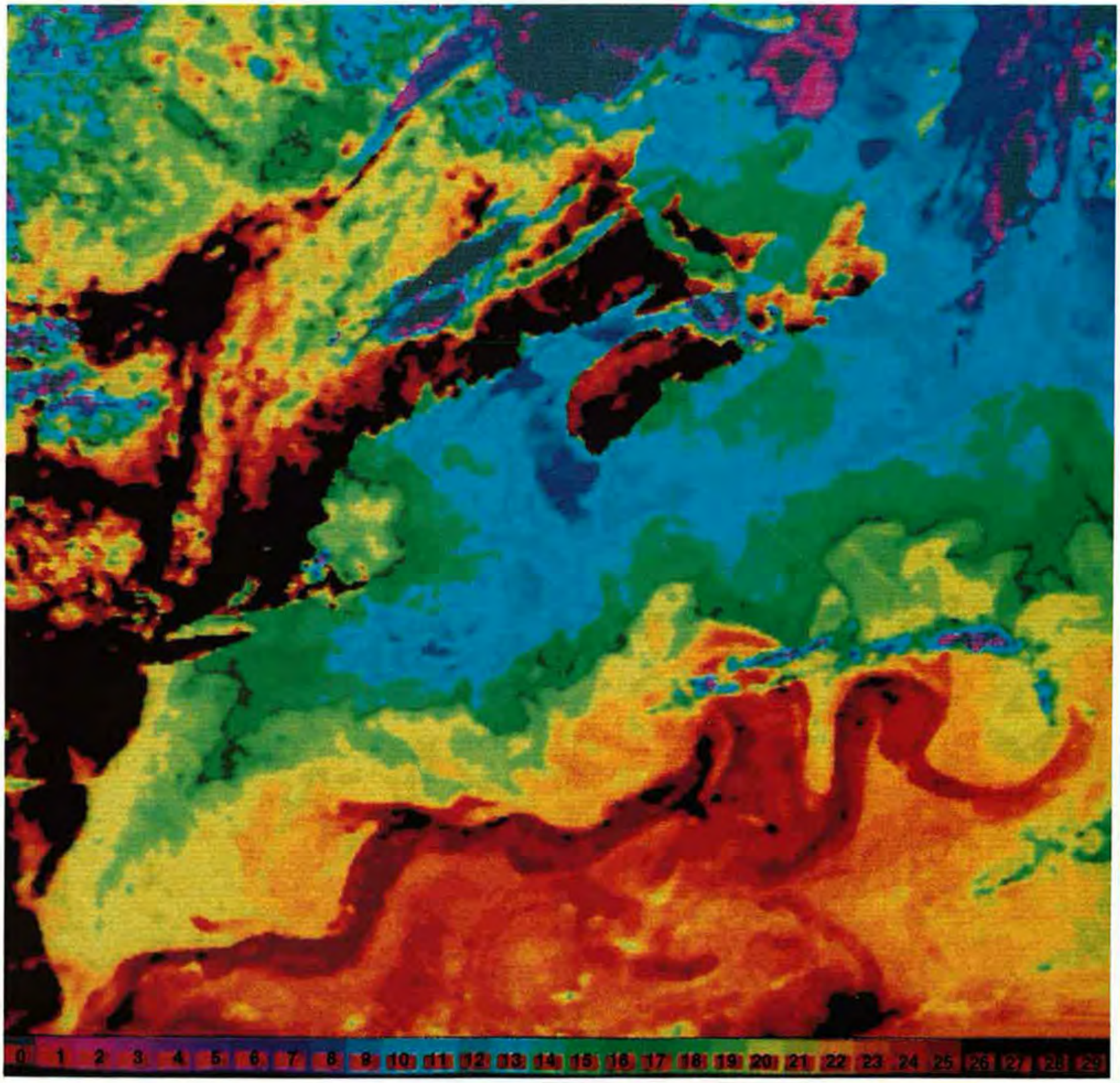
Chinook

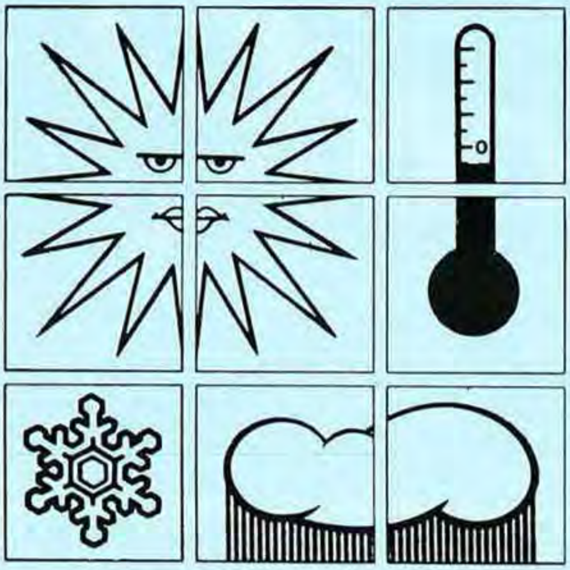
THE CANADIAN MAGAZINE OF WEATHER AND OCEANS

LA REVUE CANADIENNE DE LA MÉTÉO ET DES OCÉANS

VOL. 9 NO. 1

WINTER / HIVER 1987





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LETTERS

Icebergs Off Canada's East Coast

I have just finished reading this latest issue of *Chinook* [Fall 1986, Vol. 8 No. 4] and thought I would write to inform you that I thought it one of the best issues I have recently read.

In particular, I enjoyed not only reading "Icebergs Off Canada's East Coast", by Jerry E. Salloum, but was heartened to hear of Mr. Salloum's efforts in "exposing Canadian students to the existing developments on Canada's environment frontiers".

My compliments to you, your staff and your magazine. Keep up the good work in increasing the public awareness of meteorology and oceanography and their interest in same.

Ken G. Anderson
President
DOBROCKY SEATECH LTD.

COVER

The image on the cover shows the distribution of sea surface temperatures off eastern Canada and the United States on June 24, 1983, from measurements made by the NOAA-8 satellite of the U.S. National Oceanic and Atmospheric Administration. A more detailed description can be found on page 7.

COUVERTURE

On voit en page de couverture l'image de la répartition des températures de la surface de la mer au large de la côte est du Canada et des États-Unis prise le 24 juin 1983, à partir de données provenant du satellite NOAA-8 de la National Oceanic and Atmospheric Administration des États-Unis. Pour de plus amples détails, se reporter à la description de la page 7.

Canadian Meteorological and Oceanographic Society

La Société Canadienne de Meteorologie et d' Oceanographie

Chinook

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THE GULF STREAM AND THE CLIMATE MACHINE

by Ross Hendry

The Gulf Stream is a major ocean current and an important part of the world ocean circulation. Beginning with the Florida Current off the southeast coast of the United States, it grows into the eastward flowing Gulf Stream proper south of Nova Scotia, and rounds the Grand Banks to continue as the North Atlantic Current flowing across the northern North Atlantic Ocean towards Europe. The cover illustration shows the actual distribution of the sea surface temperature over part of the area shown, as measured during the satellite pass on June 24, 1983. The U.S. National Weather Service combined the data from several such passes with the scattered temperature measurements from ships at sea to derive the general path and shape of the Gulf Stream and the location of the eddies for the same date (Figure 1). To the physical oceanographer, the Gulf Stream is a fascinating dynamical puzzle. It is a mid-ocean jet with a maximum speed of more than 2 metres per second and a total water transport equal to 10,000 St. Lawrence Rivers, constantly twisting and meandering as it flows, casting off eddies that entrain up to 15,000 cubic kilometres of water and persist for months or even years. To the climatologist, the Gulf Stream is the northern and western boundary of an immense pool of warm water that supplies heat and moisture to the overlying atmosphere and plays a vital role in determining the climate of the North Atlantic Ocean and adjacent land areas. Changes in the position of this boundary and the temperature of the warm pool will inevitably be reflected by changes in the climate of this region. One long-term goal of the physical oceanographer studying the Gulf Stream is to understand the dynamics of the system so as to be able to predict such changes.

According to a noted ocean scientist, Henry Stommel, in his monograph *The Gulf Stream*, this major current system was first mentioned by Ponce de Leon who encountered the Florida Current in 1513 during his exploration of the New World. It was relatively familiar to American mariners in 1770 when Benjamin Franklin, then Deputy Postmaster General of the American Colonies, ordered a chart to be prepared depicting the course of the Gulf Stream so that mail packets sailing from England to New England would be encouraged to avoid the strong eastward currents in the Stream and thus speed their passage. As late as 1942, an influential oceanographer, Harald Sverdrup, could write in his classic textbook, *Oceanography for Meteorologists*, that most meteorologists of the day neglected the effect of such ocean currents as the Gulf Stream on the transport of heat from lower to higher latitudes. Sverdrup himself presented an example showing that oceanic transports could be significant in some regions, but he considered that the atmosphere played the dominant role in the overall process. In fact, modern studies have shown that the ocean circulation is vital to the global climate system, actually carrying more heat poleward in tropical latitudes than the atmospheric circulation itself.

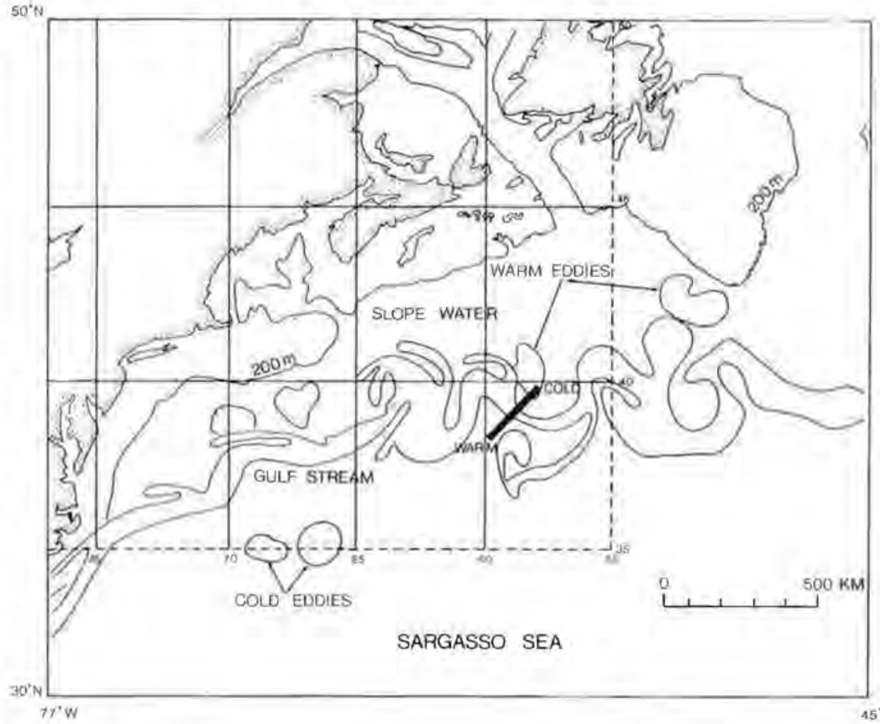


Figure 1 Chart of the western North Atlantic Ocean showing the meandering path of the Gulf Stream on June 24, 1983, according to an analysis by the U.S. National Weather Service. The Gulf Stream separates relatively cool Slope Water to the north from warmer Sargasso Sea waters to the south. Two cold eddies (south of the Stream) and four warm eddies (north of the Stream) formed by the pinching off of earlier Gulf Stream meanders are also shown. Such analyses depend heavily on satellite images of the sea surface such as the one shown in the cover illustration for this same date. The 200-m bottom depth contour representing the edge of the continental shelf is also indicated.

HEAT TRANSFER: OCEAN TO ATMOSPHERE

To discuss the influence of the Gulf Stream and Ocean circulation in general on the climate of the North Atlantic Ocean and adjacent land areas, we refer to Figure 2, which shows the net heat transfer from the atmosphere to the North Atlantic Ocean averaged over the annual cycle. South of about 30°N, the relatively cool surface waters gain heat from the overlying air, as well as from the sun's rays. North of a line running northeast from the Gulf of Mexico all the way to the Norwegian Sea, a broad ocean area releases heat to the atmosphere over the annual cycle. This transfer is partly sensible heat, or energy associated with molecular motions, but is mainly the latent heat of evaporation associated with the change from liquid water in the ocean to water

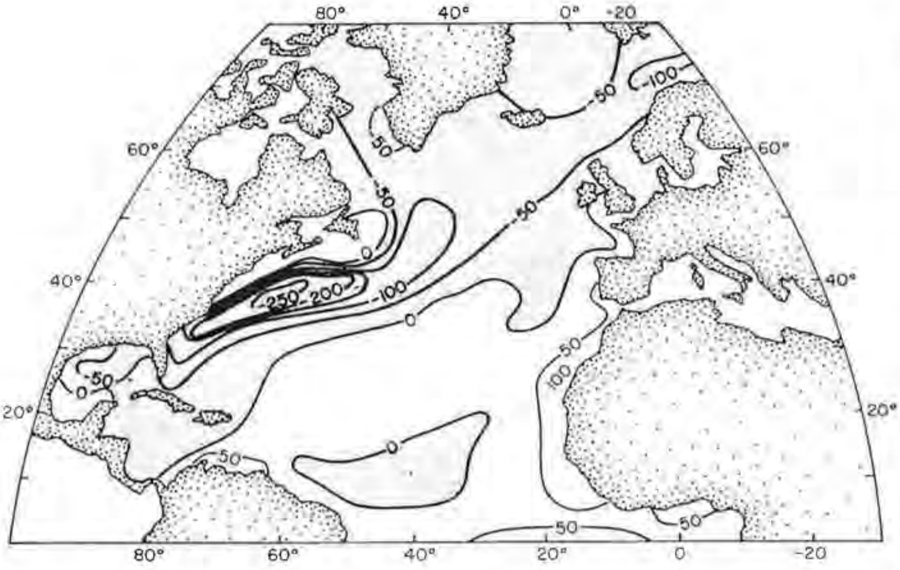


Figure 2 The net heat transfer from the atmosphere to the North Atlantic Ocean over the annual cycle. Contours are in watts per square metre. A negative value means the ocean is losing heat, i.e., the ocean is warming the overlying atmosphere. Adapted from Figure 1 in "Archived Time-Series of Atlantic Ocean Meteorological Variables and Surface Fluxes", by A.F. Bunker and R.A. Goldsmith, January 1979, Technical Report 79-3 of the Woods Hole Oceanographic Institution, Woods Hole, Mass., U.S.A.

vapour picked up by the moving air. The two areas of greatest oceanic heat loss are found just east of the United States near 35°N and just east of Newfoundland near 45°N, where relatively cooler and drier winds blowing off the North American continent first encounter the warmer ocean waters. The maximum rate of heat transfer is about 250 watts per square metre of ocean surface. At this rate, an area of ocean only 20 kilometres square loses heat energy to the overlying atmosphere faster than it could be replaced by the installed capacity of electrical power generation for the whole of Canada (Canadian Encyclopedia, 1981 figures). The energy transfers in the global climate machine truly dwarf the activities of man.

IMPACT ON CLIMATE

The heat energy absorbed by the atmosphere over the mid-latitude North Atlantic is carried to the east by the prevailing westerly winds and helps create the temperate climate of northwestern Europe. To quote an extreme example, the island of Lerwick at the northern tip of the British Isles near 60°N enjoys an annual temperature of about 7°C, some 10°C warmer than the annual mean temperature at Fort Smith, N.W.T., at a comparable latitude. Most of the heat carried by the moving air must be released by the condensation and precipitation of water vapour, giving a somewhat damp climate to these European countries as an unavoidable companion to their moderate annual range of temperature. During the period 1931–1960, Lerwick received an annual average of 1,129 mm of rain, more than three times as much as Fort Smith with its dry Arctic climate.

Referring again to Figure 2, the ocean waters immediately adjacent to northwestern Europe release relatively small amounts of heat to the atmosphere compared to the waters near the North American coast. Thus the ocean-wide atmospheric circulation is a vital link in this climate system. The Gulf Stream does not really bathe the shores of Europe as people naively suggest. Some readers might wonder why Canadian oceanographers should be so concerned with the climate of Europe, but it must be recognized that the study of large-scale ocean and atmospheric circulations is an international effort. Japanese oceanographers who are studying a similar system of large air-sea heat exchange associated with the Kuroshio Current in the western Pacific Ocean are contributing to the understanding of factors that shape the maritime climate of coastal British Columbia! To return to the basic theme of this article, just what is the role of the Gulf Stream in this large-scale process, and how can fluctuations in ocean currents change our climate?

OCEAN CURRENTS AND THEIR FLUCTUATIONS

A moment's thought will make it clear that if certain areas in the North Atlantic lose great quantities of heat to the atmosphere without themselves cooling drastically, then heat must also be supplied to these areas from some other source. Ocean currents accomplish this by transporting heat from tropical regions that enjoy a net surplus of solar energy input over a year. The maximum average poleward heat transfer by ocean currents in the North Atlantic has been estimated at about 3×10^{15} watts near 20°N, just at the upstream end of the Gulf Stream System. The poleward ocean heat transport decreases to the north as the ocean-borne heat is released to the atmosphere. The Gulf Stream and its continuation as the North Atlantic Current carry relatively warm waters to the north. In a steady state, an equal southward transport of water must occur somewhere in the ocean. A net heat transport results because the southward flowing currents generally carry water cooler than the northward flowing currents, just as in a domestic hot water heating system.

One component of the return flow is the cold Labrador Current, which flows southward along the eastern coast of Canada. Other return flows take place at abyssal depths. The structure and time variation of the North Atlantic circulation is the focus of study for oceanographers from many nations. The dynamical balances that control the circulation and maintain the distinctive warm-water gyres associated with the Gulf Stream and the North Atlantic Current are only partially understood. Specific mechanisms by which oceanic heat transport is accomplished are also being actively studied. One question still to be answered is the importance of time-dependent ocean eddies in the large-scale transport of heat.

SLOPE WATER

The warm Gulf Stream currents are important in determining ocean conditions in eastern Canadian waters, as well as in shaping the large-scale patterns of climate. A region called the Slope Water is found north of the Gulf Stream between eastern continental North America and the Grand Banks (Figure 1). This Slope Water is fed by an inflow of cold Labrador Current water from the north, and warmer waters from the Sargasso Sea south of the Gulf Stream which mix into the Slope Water. This mixing begins when the Gulf Stream meanders far to the north and then pinches off, leaving a warm-centred eddy trapped in the Slope Water. The Slope Water is separated from the warmer waters to the south by the Gulf Stream itself, which acts as a dynamical but, as we have mentioned, somewhat leaky boundary. We will return to the Slope Water below.

UNANSWERED QUESTIONS

Modern-day physical oceanographers are involved in international efforts to understand the physics of deep-ocean circulation, including the Gulf Stream System. Many very basic questions remain to be answered. How do the currents change with depth in the Gulf Stream? It now seems that the Stream extends from the surface of the ocean into abyssal depths as a coherent jet, with the deep currents somewhat reduced in speed. Figure 3 shows a representative cross-section of the flow in the Gulf Stream south of Nova Scotia based on recent work in our Laboratory. How energetic are Gulf Stream eddies at different locations? Recent field studies have begun to map out the answer to this question, showing that the current fluctuations decrease in speed but have longer time-scales while moving downstream in the system. How important are the cut-off meanders of the Gulf Stream (called Gulf Stream rings) in transferring heat across the Stream between the warm Sargasso Sea and the cooler Slope Water with its Labrador Current influence? There are hints that such processes may be a very significant part of the total transfer, but the final answer has yet to be found.

In the introductory remarks, I mentioned the possibility of climate change. Figure 4 gives an example of the type of long-term variability actually observed in the North Atlantic Ocean, based on an analyis made by the climatologist Jakob Bjerknes more than 20 years ago. It shows the trend in annual mean sea surface temperature during the first part of the present century in a 5° by 5° square centred in the Slope Water south of Nova Scotia and Newfoundland. There is convincing evidence for a net warming of these waters by at least 2°C over the 40 years of data. Explanations for this phenomenon are largely speculative, but one suggestion is that the warming is due to increased mixing with warm water from the Sargasso Sea as a result of more frequent and energetic meandering and eddy production by the Gulf Stream. The Stream itself is driven by the large-scale North Atlantic wind system. Changes in sea surface temperature and the consequent changes in air-sea heat exchange

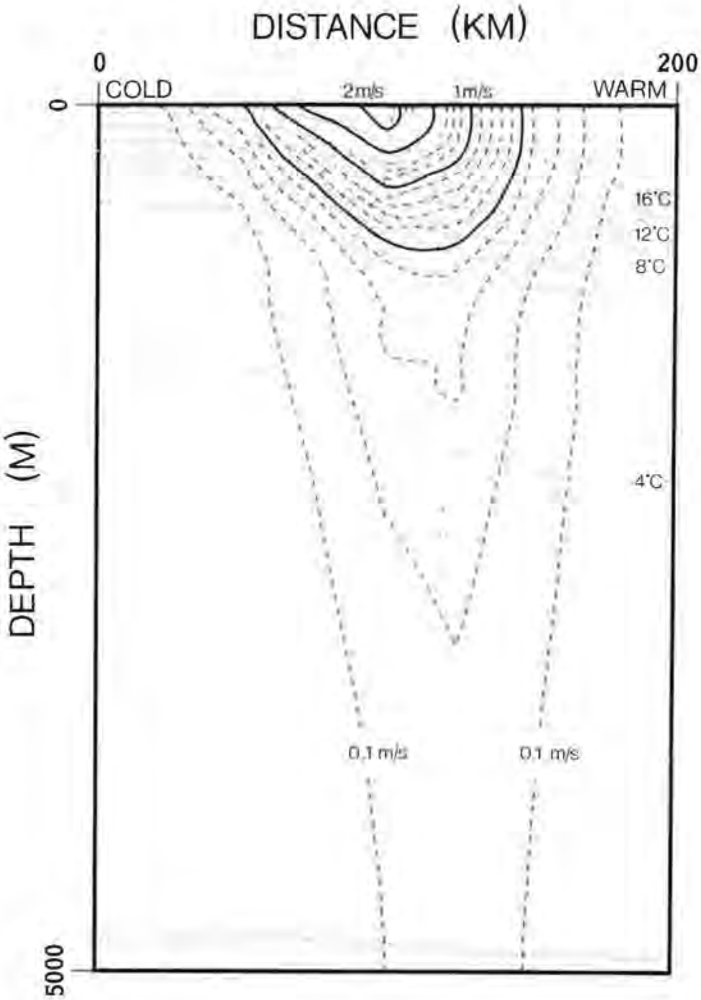


Figure 3 A representative vertical cross-section of flow in the Gulf Stream south of Nova Scotia across a 200-kilometre wide section such as the section indicated by the thick black line in Figure 1. The solid and dashed contours represent the speed of the downstream flow (eastward on average) in the Gulf Stream, showing speeds greater than 2 metres per second at the surface decreasing to about 0.1 metre per second at the bottom. The dotted curves represent constant temperature surfaces, which shallow on moving from the warm side of the Stream to the cold side. The Gulf Stream is a thermal transition region in conjunction with a strong current. These two facets of the Gulf Stream are fundamentally linked by the physics of ocean circulation.

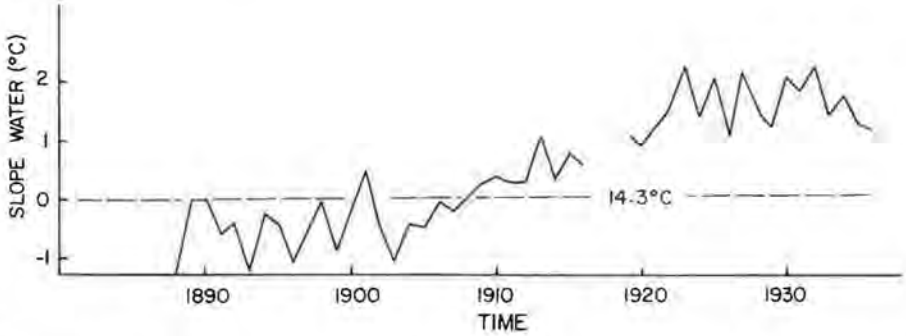


Figure 4 Time series of annual sea temperature anomalies (°C) in the Slope Water south of Nova Scotia (40–45°N, 55–60°W) (after Bjerknes, J.B., 1964: Atlantic Air-Sea Interaction. In: *Advances in Geophysics*, Vol. 10, p. 36).

affect the large-scale atmospheric circulation and can change the winds that drive the Gulf Stream. The result is a closed feedback loop that is typical of the entire global climate system.

By seeking to understand the fundamental dynamics of the Gulf Stream and its eddies, oceanographers hope to contribute to the eventual understanding of this complicated climate machine.

SUGGESTED READING

Bedford Institute of Oceanography, 1984: BIO Review '84. Dartmouth, N.S., 66 pp.

Dobson, F.W., 1985: The Oceans and How They Affect Climate. *Chinook*, Vol. 6, 88–91.

Woods Hole Oceanographic Institution, 1978: Oceans and Climate. *Oceanus*, Vol. 21, No. 4, 72 pp.

Woods Hole Oceanographic Institution, 1981: Oceanography from Space. *Oceanus*, Vol. 24, No. 3, 76 pp.

Ross Hendry is a research oceanographer with the Department of Fisheries and Oceans in the Ocean Circulation Division of the Atlantic Oceanographic Laboratory located at the Bedford Institute of Oceanography in Dartmouth, Nova Scotia. His research specialty is the study of deep-sea circulation and dynamics, with recent work focused on the Gulf Stream System.

RÉSUMÉ *Le Gulf Stream est un courant océanique fort qui constitue un élément important de la circulation des océans à l'échelle du globe et fait partie intégrante du système climatique. Le Gulf Stream transporte les eaux des régions chaudes des latitudes du sud jusque dans les régions froides situées plus au nord; le surplus de chaleur de l'eau se dégage dans l'atmosphère, phénomène qui tempère le climat du nord de l'Europe. Il existe un courant d'eau plus froide en direction sud à d'autres endroits de l'Atlantique Nord qui équilibre la circulation globale. Le Gulf Stream n'est pas un courant régulier : tournoyant et sinueux, il peut produire des tourbillons de 100 kilomètres de diamètre qui peuvent influer profondément sur les températures des endroits avoisinants, comme dans le cas de l'eau de pente au large de la côte est du Canada. Les océanographes de nombreux pays, y compris le Canada, étudient présentement ce système compliqué de courants.*

SEA SURFACE TEMPERATURES FROM SPACE

The cover scene shows sea surface temperatures on June 24, 1983, over a region extending from 35 to 50°N and 55 to 77°W, centred south of Nova Scotia. The picture was derived from measurements of infrared radiation in two spectral bands (Band 4, 10.3–11.3 μm; Band 5, 11.5–12.5 μm) by the U.S. National Oceanic and Atmospheric Administration (NOAA) satellite NOAA-8. The infrared energy sensed by the satellite radiometer is proportional to the temperature of the emitting body, in this case, the uppermost surface of the sea. Information from the two different spectral bands is combined to allow for correction of that part of the signal received by the satellite that originates in the atmosphere overlying the ocean.

The Gulf Stream appears as a warm (red) feature entering the scene at the lower left and following a meandering path to the northeast. Maximum sea surface temperatures in the Gulf Stream in this early summer period are about 25°C. Cooler temperatures (yellow to green to blue) are found inshore of the Stream, reflecting the widespread influence of the cold Labrador Current, while warmer temperatures persist to the south of the Stream in the Sargasso Sea.

Some areas to the north are totally obscured by cloud cover, so that the computed result is a measure of the temperature at the top of the cloud rather than that of the sea surface. The linear feature overlying the large double meander of the Gulf Stream near the eastern side also reflects an isolated cloud in what is an otherwise relatively clear scene.

The NOAA-8 satellites fly at altitudes of about 850 km in orbits that take nearly 100 minutes to complete and pass close to the North and South Poles of the earth. The orbits are specifically chosen so that the satellite remains synchronized with the local solar time of the point over which it is passing. The cover picture is an "afternoon" scene, taken when the satellite was travelling from south to north. The radiometer scans across the satellite's path and a succession of scan lines is assembled to create the image. The ground resolution of the NOAA radiometer is about one kilometre, and the accuracy of the temperature map shown on the cover is ±1°C. This map was produced in the Atlantic Oceanographic Laboratory's Image Analysis Centre using digital imagery obtained from NOAA.

BOOK REVIEW

OCEANOGRAPHY OF THE BRITISH COLUMBIA COAST. R.E. Thomson, 1981. Canadian Special Publication of Fisheries and Aquatic Sciences, No. 56 Department of Fisheries and Oceans, Ottawa, Ont., (reprinted in 1983, 1984; French translation, 1984) $21.00; outside Canada, $25.20.

To the Kwakiutl and other native tribes of the Pacific Coast, the sea was a bountiful but somber mother, generous with its gifts of sparkling salmon and giant halibut, but unpredictable in its moods, at some times calm as a mirror, at others foamy with destructive fury. To the sea, the B.C. Indians owed their existence and the leisure to develop their distinctive arts and crafts.

Today, the ocean continues to be the focus of life in coastal British Columbia. In summer, its shores are thick with bathers and beachcombers, its waters speckled with the sails and wakes of boats of all descriptions. In October, however, the sea turns angry, biting at the shores and drowning fishermen. All year, the ocean remains an object of love and hate, fascination and study. It is thus not surprising that Thomson's survey of the physical oceanography of the B.C. Coast should have been received with such enthusiasm.

Oceanography of the British Columbia Coast evolved from a series of articles first published in *Pacific Yachting*. Clearly written, well illustrated and dealing with phenomena of immediate interest, the articles were well received and the author was emboldened to gather and expand them in "a text that would be readily comprehensible to the intelligent layman without

Continued on page 15

A BIRD'S-EYE VIEW

by Philip Chadwick

The high-soaring members of the avian society enjoy a totally different perspective of the world around us. This view *was* beyond the reach of most Canadians. However, the poliferation of satellite imagery has changed that. The technology available with the current generation of satellites even surpasses the capabilities of an eagle's eye. Sensing of the earth and atmosphere in several spectral bands reveals information unseen by the hawk.

The accompanying satellite images are fine examples of the capabilities of today's technology. The careful use of the two spectral bands displayed allows the analysis of features beyond the scope of either band by itself. The application of basic satellite interpretation techniques will be illustrated by explaining the deduction of the features highlighted in the description below.

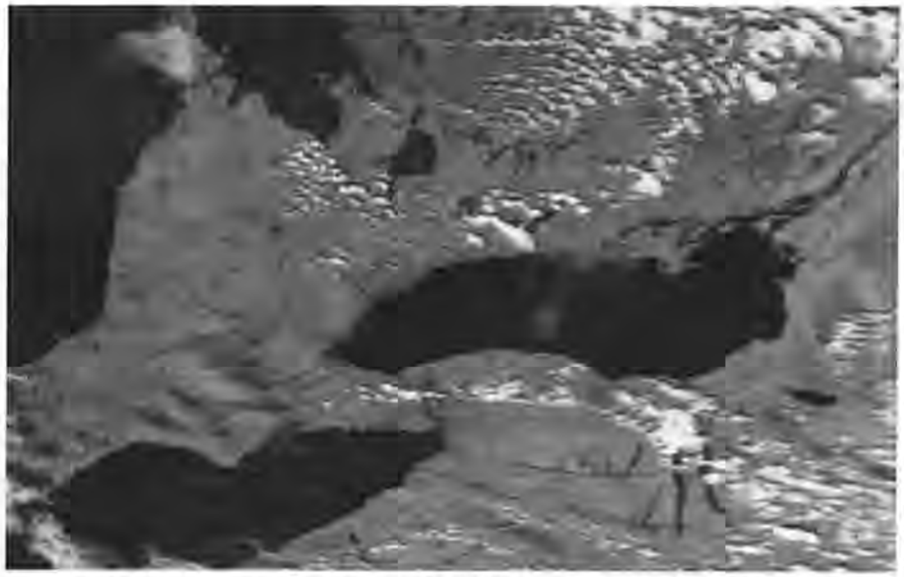

U.S. NOAA-9 polar-orbiting satellite

Figure 1 Near infra-red satellite image for 2022 GMT on September 24, 1986 (courtesy: AES Satellite Data Laboratory).

The satellite image labelled NIR (Figure 1) is achieved by sensing radiation in the Near Infra-Red Spectral band. A more appropriate name would be near-visible since the bulk of the radiation sensed is on the red fringe of the visible band with wavelengths near 0.7 μm (micrometres). Only a small portion of the band lies in the infra-red portion of the spectrum at wavelengths near 1 μm.

As a result, the NIR band observes mainly visible light reflected toward the satellite by clouds or the earth's surface. The more radiation reflected toward the satellite by a surface, the whiter that surface is mapped on the resulting image. Reflective clouds appear white in the image while water surfaces are dark. The NIR also observes the radiation reflected from the chlorophyll in green vegetation. Thus, green fields are lighter on NIR imagery than comparable brown fields.

The 11-μm imagery (Figure 2) is achieved by sensing radiation between about 10.5 and 11.5 μm wavelength. This is totally beyond the capabilities of the bird community. The 11-μm spectral channel was selected because it represents most of the radiation coming from the earth's surface and is only intercepted significantly by clouds in the atmosphere. In addition, by applying a fundamental law of physics, we know that the amount of 11-μm radiation sensed by the satellite is proportional to the temperature of the emitting surface. In the resultant image, the coldest surfaces are mapped as white while the warmest are black. As the temperature of the emitting surfaces increases, the corresponding areas are gradually assigned darker shades of grey. The image can thus be viewed as a temperature representation of the earth's surface and the clouds in the atmosphere. Clouds, being high in the cold atmosphere are typically white, while the warmer ground surfaces are shades of dark grey. Variations in the shades of white or grey correspond accurately to variations in the temperatures of the emitting surfaces.

A final complication to note is that the pictures appear to be composed of small squares. These squares are called "picture elements" or *pixels* for short. In the accompanying imagery, the pixels correspond to squares of the earth's surface with dimensions of 1.1 kilometres. The satellite is unable to resolve or see any feature smaller than a pixel. In fact, a feature should be "several" pixels in size before the resulting image can define the shape or structure which is characteristic to it.

The first features to note are the long white, fibrous streaks apparent on the 11-μm image. These are contrails (condensation trails) from the exhaust gases of jet aircraft flying high in the cold atmosphere. Jets typically fly between 30 thousand and 40 thousand feet in altitude. The thin layer of ice crystals composing the contrail is cold (roughly -50°C) and thus appears white on the 11-μm image. The shape, size and orientation of the contrail is unlike that of any other meteorological or atmospheric phenomenon. Its characteristics are unique!

The contrails on the NIR image are virtually invisible. This results because the thin layer of ice crystals is quite inefficient at scattering visible light back toward the satellite. With little back-scattered visible radiation the satellite cannot "see" the contrails. However, the contrail does cast a shadow on the ground as indicated. With less radiation reaching the ground in the shadow area there is less visible radiation to be scattered toward the satellite – hence the shadow.

The representation of the same feature is strikingly different on the 11-μm as compared to the NIR image. The 11-μm image depicts the cold contrail itself while the NIR image displays the shadow best. The use of both images together along with some knowledge of jet aircraft contrails yields a complete and accurate diagnosis of the feature.

A second noteworthy class of features is the "heat islands" on the 11-μm image, which correlate with the major and not-so-major cities in the field of view. The cities are identified in Figure 3.

The most noticeable characteristic of the "heat islands" is their warmth relative to the surrounding countryside. After a sunny day (the image time is 1622 EST) the dark pavement and building surfaces have warmed to their maximum values. Aided by the heat

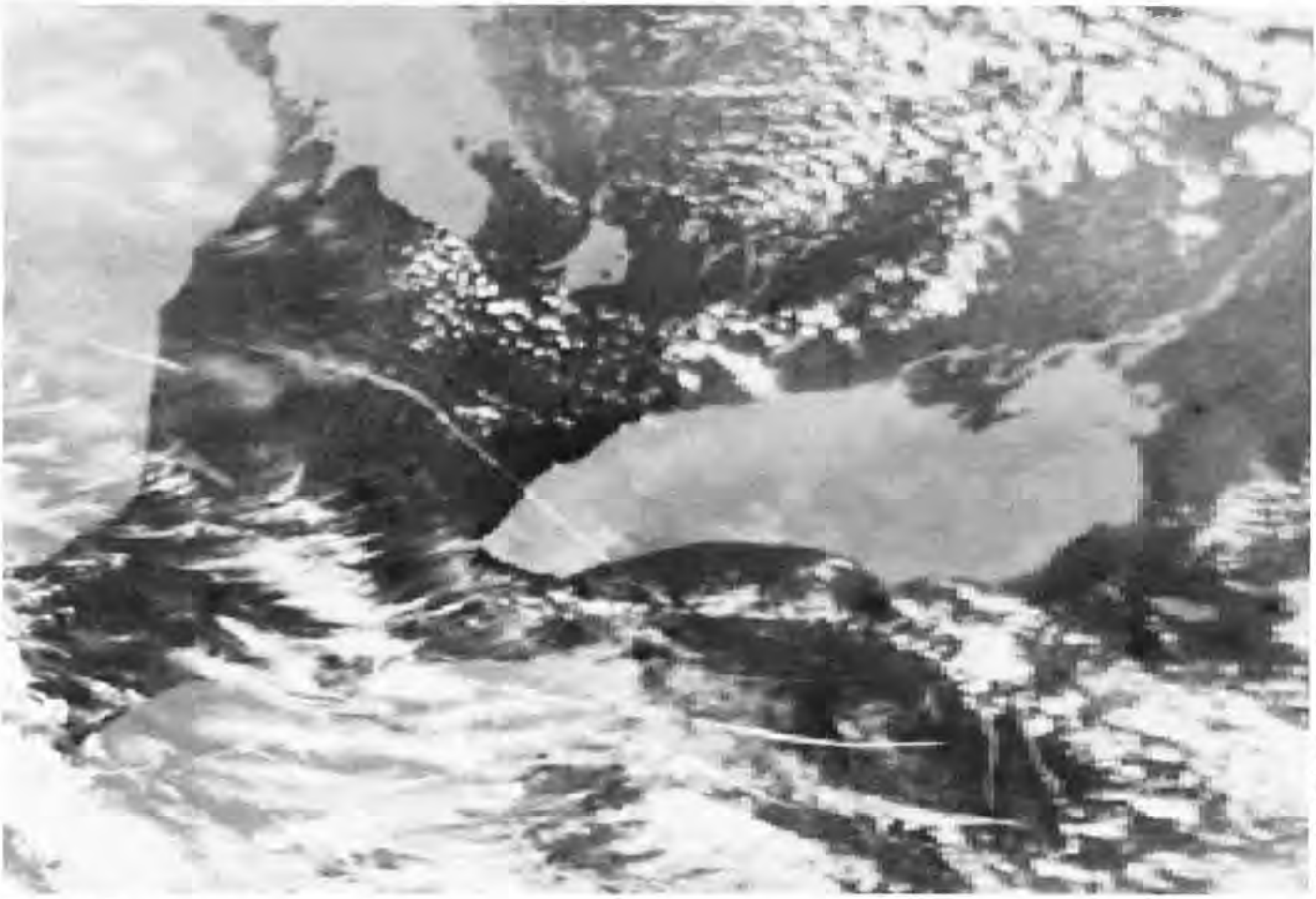


Figure 2 The 11-μm satellite image for 2022 GMT on September 24, 1986 (courtesy: AES Satellite Data Laboratory).

pollution from various industries, the city warms during the day. Naturally enough, the temperature of these heat islands contrasts with that of the cooler agricultural areas. This forms the basis for their identification on the 11-μm imagery. The largest heat islands observable are the Toronto and Hamilton metropolitan areas. This is not surprising given the huge population and high concentration of industry. However, even smaller centres are observable including Barrie, Brantford, Trenton and my home town, Brockville.

The portrayal of the heat islands on the NIR is *not* dramatic. The average reflectivities of the city buildings and pavement are not significantly different from that of the surrounding countryside. The green chlorophyll contribution to the NIR channel is insufficient to provide city–country contrast. Remember that in September, most crops are already fully ripe or harvested.

Figure 3 Locations of urban communities that appear as dark areas on the 11-μm satellite image (Figure 2).

A final point of interest is the 11-μm mapping of the temperatures of the Great Lakes – notably Lake Ontario. The lake is much colder than the land and is thus portrayed much lighter. As well, the surface temperature variations are clearly revealed. Warm pools of 16°C water are clearly depicted in the middle of the lake while the near-shore edges are typically cooler. An interesting exception is the warm pool offshore Toronto and Pickering. This reflects the heat pollution from the city and nuclear

Continued on page 15

RAIN, RAIN AND MORE RAIN!
Weather Map Series, September 29 and 30, 1986

by Hans VanLeeuwen

This is the second in the *Chinook* Weather Map Series. The first consisted of a sequence of four unanalysed surface weather maps (Volume 8, Number 2, pages 29–32).

September 1986 was for many localities in the Great Lakes region a near record-breaking wet month. Several observing sites in Canada and the United States reported precipitation amounts that exceeded not only the monthly normal totals, but also those for the summer season (see article on pages 21–23).

The map series offers the reader and weather amateur an opportunity to analyse and study the precipitation amounts reported over a two-day period during the latter part of September 1986. The maps also show the maximum and minimum temperatures recorded over various periods of the day. The details of the data plot are explained in the plotting model and decode guide.

The specific case illustrates the passage of a series of weak low-pressure systems from the Northern Plain States and the Midwest (September 28) to the Great Lakes (September 29) into central Quebec (September 30).

A cold front, extending southwestward from the low, moved slowly eastward through the area shown on the maps and is identified by the precipitation amounts reported on the 29th at 7 a.m. in Missouri, Iowa, Oklahoma and parts of Illinois and Wisconsin. The precipitation reported at that time in northern Ontario is mostly associated with the low centre and the warm front. During the next 36 hours one can observe the gradual end of the precipitation north of the Great Lakes.

The most important feature observed over the two-day period is the evolution of the cold front and its associated rain band, and the slow eastward movement through the Great Lakes region. Extensive amounts of precipitation are reported in many localities in Illinois, southern Michigan and southern Ontario. Most of the copious rainfall was a result of a southerly flow of warm, moist and unstable air ascending along the eastward moving cold front. Temperatures (°C) south of the front and south of the Lakes during the two days reached the high 20s and even the low 30s.

To assist in the analysis of the information it would perhaps be helpful to decode the data reported by one of the reporting sites. The Lester B. Pearson International Airport (Toronto, Ontario) is identified with the letters YYZ. Please note that these are the same three-letter identifiers that airlines use on baggage tags! The Toronto observations are decoded in Table 1. Furthermore, it is interesting to note the 24-hourly precipitation amounts reported by several of the observing sites:

Toronto, Ont.	(YYZ)	Sept. 30, 7 a.m.	51.6 mm
Springfield, Mo.	(SGF)	Sept. 30, 7 a.m.	132.6 mm
St. Louis, Mo.	(STL)	Sept. 30, 7 a.m.	83.8 mm
North Bay, Ont.	(YYB)	Sept. 29, 7 p.m.	12.8 mm
Muskoka, Ont.	(YQA)	Sept. 30, 7 a.m.	34.6 mm

Similarly we will notice some interesting 6-hourly amounts:

Chicago, Ill.	(ORD)	Sept. 30, 7 p.m.	26.0 mm
London, Ont.	(YXU)	Sept. 30, 7 p.m.	31.0 mm
St. Louis Mo.	(STL)	Sept. 30, 7 a.m.	55.0 mm
Syracuse, N.Y.	(SYR)	Sept. 30, 7 p.m.	33.0 mm

MAX - MIN - PRECIP PLOT

MAX TEMP. °C 0 — 70 — 6 HR PCPN - mm AND TENTHS 7.0 mm

304 — 24 HR PCPN mm AND TENTHS 30.4 mm

MIN TEMP. °C −4 — YPG — 25 — DEPTH OF SNOW ON GROUND WHOLE CM 25 cm

STATION IDENTIFIER

STATION CIRCLE

NO PCPN IN PAST 6 HOURS OR 24 HOURS

PCPN IN PAST 24 HOURS

PCPN IN PAST 6 HOURS

TR - IF PCPN IS NOT MEASURABLE

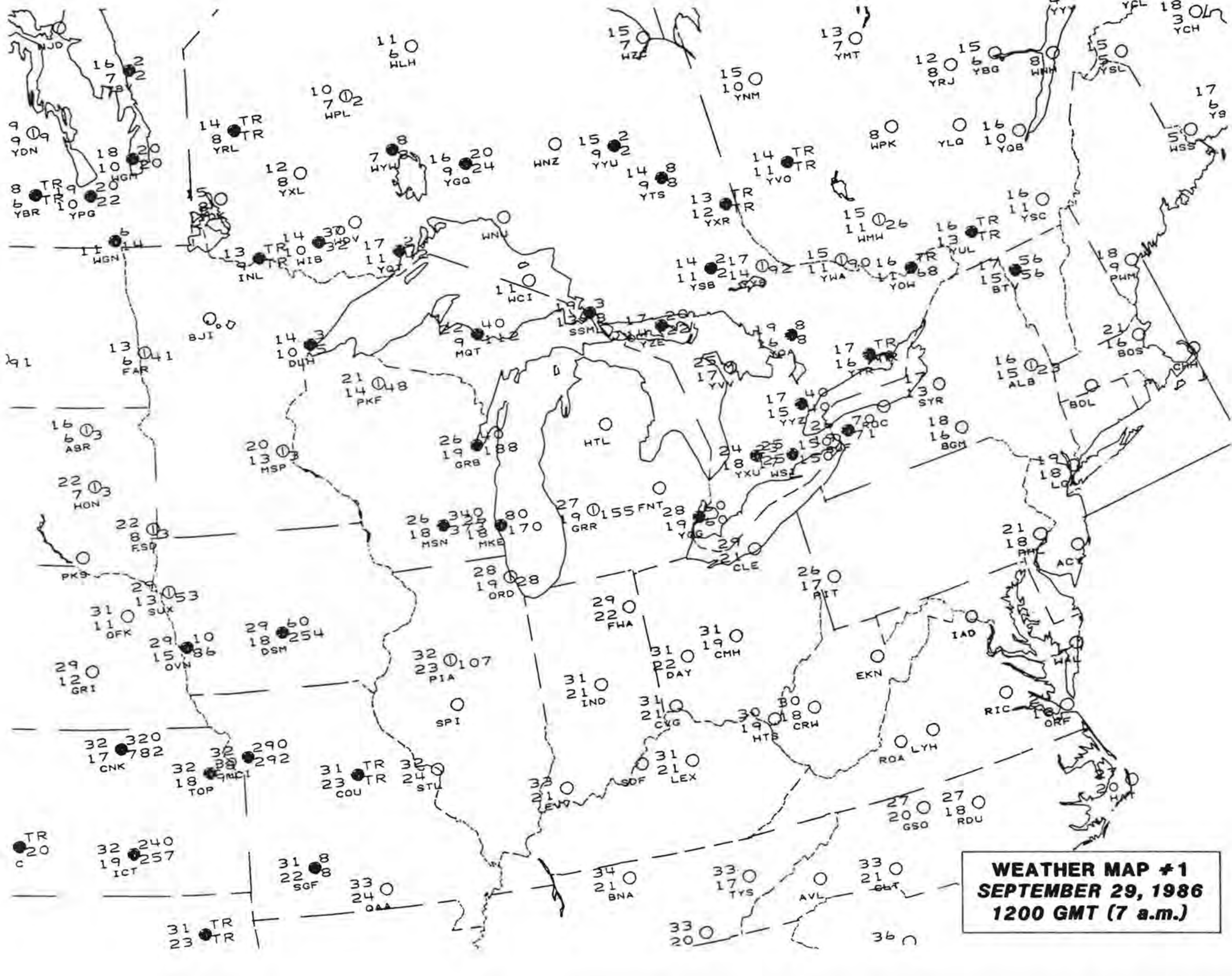
MAP TIMES	MAX. TEMP	MIN. TEMP
0000Z	12 HR	18 HR
0600Z	24 HR	24 HR
1200Z	24 HR - CARRIED FROM 06Z	12 HR
1800Z	12 HR	24 HR

Plotting model and decode guide for maximum and minimum temperatures and precipitation amounts.

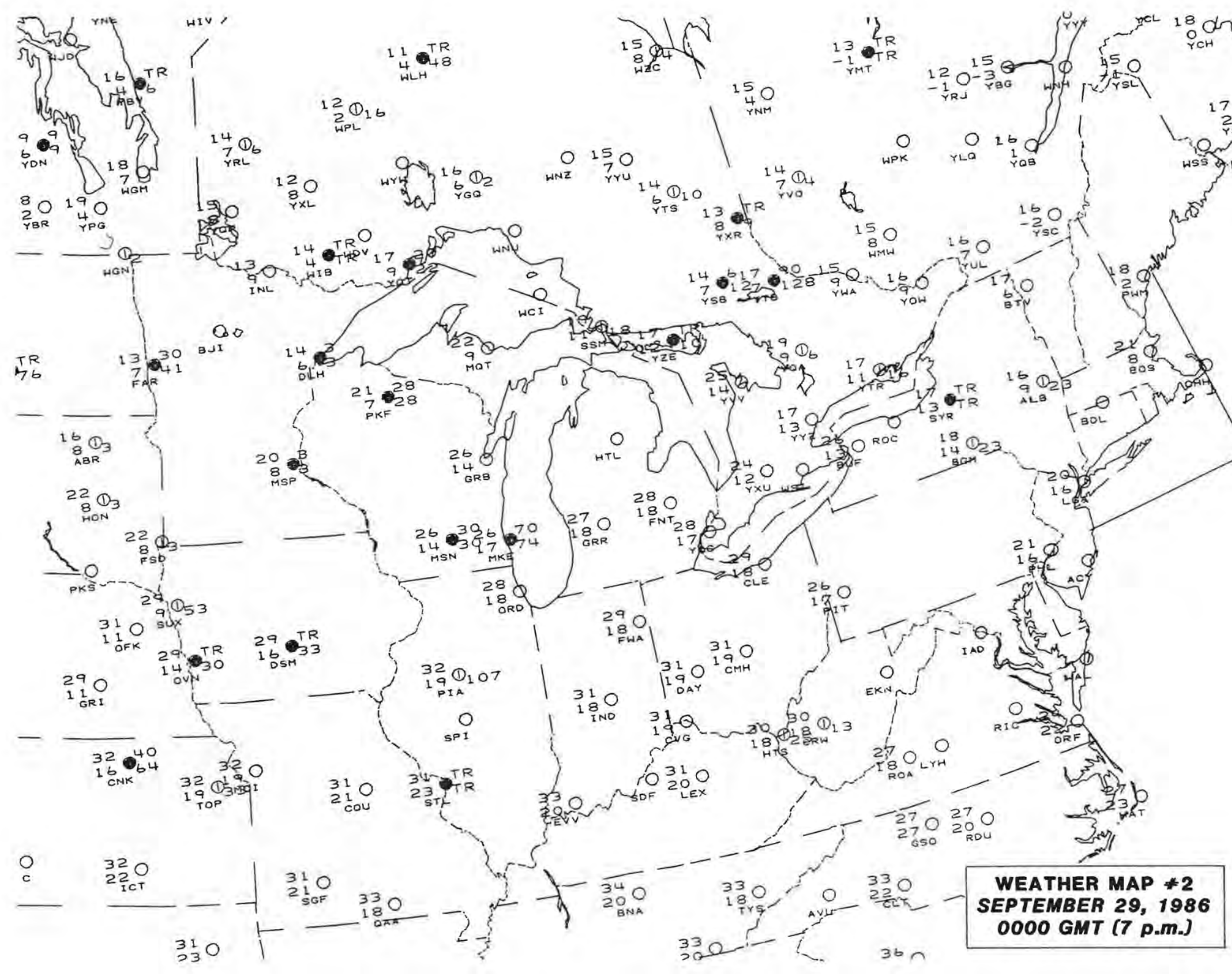
Table 1 Decode of observed data for Lester B. Pearson International Airport (YYZ) Toronto, Ontario

Observation at 1200 GMT (7 a.m.), September 29, 1986	
Max. Temp. (preceding 24 hours)	17°C
Min. Temp. (preceding 12 hours)	15°C
Decode of Station Circle	Precipitation in the past 6 hours
6-hour precipitation amount	4.0 mm
24-hour precipitation amount	4.0 mm
Snow depth on the ground	nil
Observation at 0000 GMT (7 p.m.), September 30, 1986	
Max. Temp. (preceding 12 hours)	24°C
Min. Temp. (preceding 18 hours)	15°C
Decode of Station Circle	Precipitation in the past 6 hours
6-hour precipitation amount	18.0 mm
24-hour precipitation amount	46.2 mm
Snow depth on the ground	nil

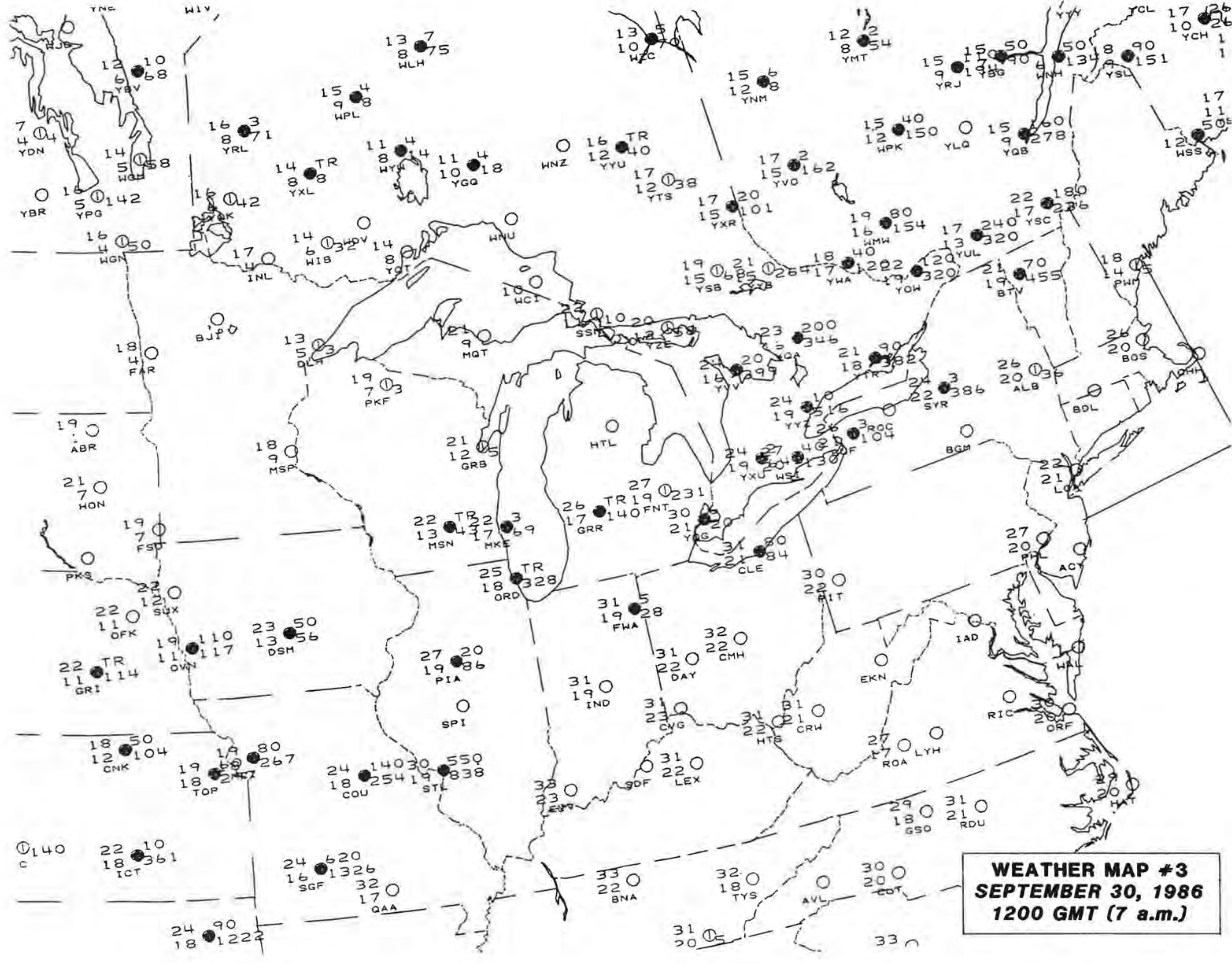
There are likely many activities that can be developed around the data set on the maps. In order to avoid a messy



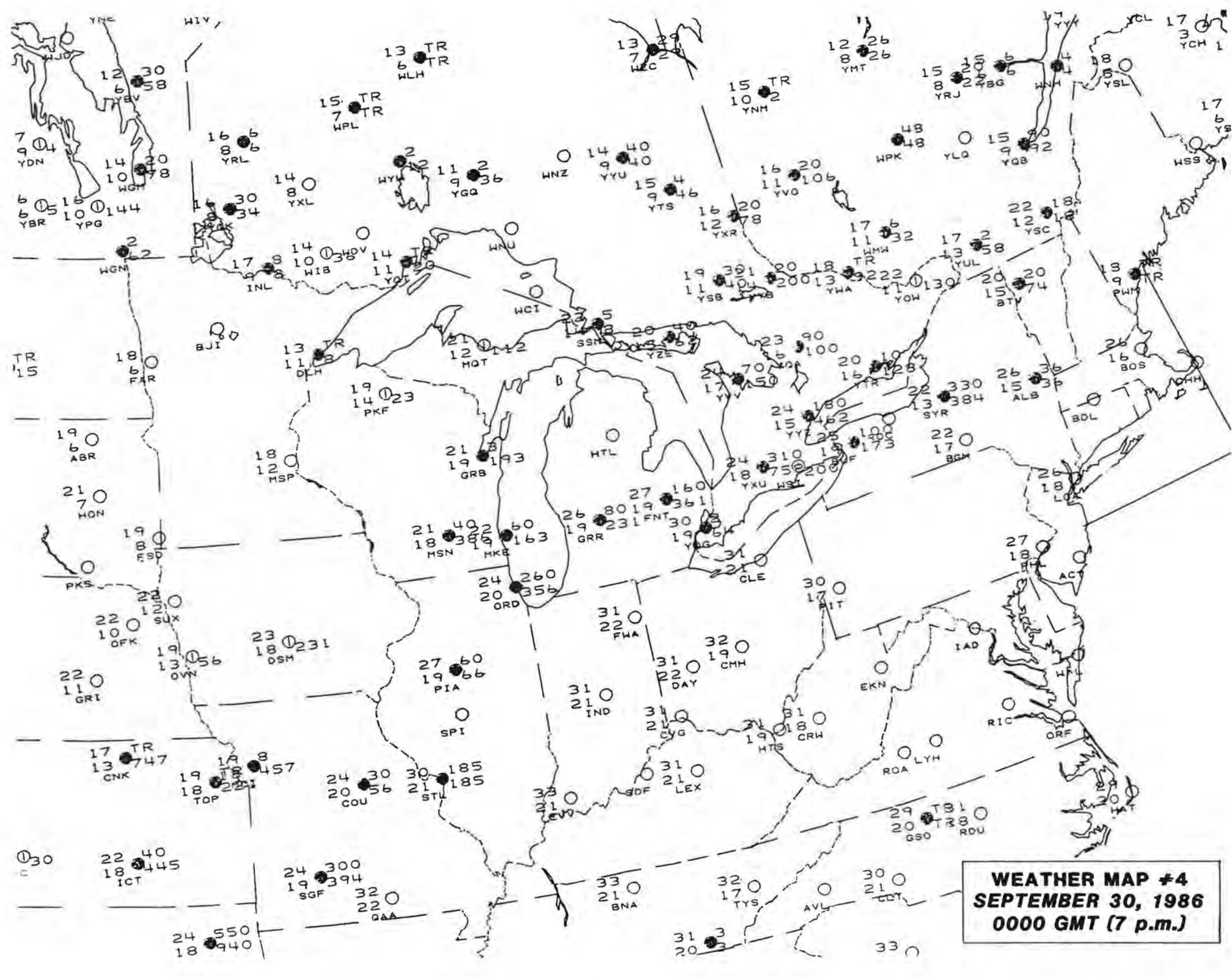
WEATHER MAP #1
SEPTEMBER 29, 1986
1200 GMT (7 a.m.)



WEATHER MAP #2
SEPTEMBER 29, 1986
0000 GMT (7 p.m.)



WEATHER MAP #3
SEPTEMBER 30, 1986
1200 GMT (7 a.m.)



WEATHER MAP #4
SEPTEMBER 30, 1986
0000 GMT (7 p.m.)

analysis it is strongly recommended that additional photocopies be made of the maps. For analysis purposes we suggest the following ideas:

- Observe the contrast in maximum temperatures between the colder and very warm air masses. Use a line through Kenora, Ont. (YQK), Duluth, Minn. (DLH), Milwaukee, Wis. (MKE), Fort Wayne, Ind. (FWA) to Nashville, Tenn. (BNA). A similar line from Kapuskasing, Ont. (YYU) through Lake Ontario to Pittsburgh, Pa. (PIT) and Greensboro, N.C. (GSO) can be studied. Note the changes and contrasts on all four charts and observe where the maximum precipitation amounts are recorded.
- How much rain fell in some localities over a 6- or 24-hour period? What are the implications for farming, and flood control? Calculate the volume of water that fell on one particular basin or county. How much is likely to run off? These are good sets of data to illustrate the basic elements of the hydrologic cycle. What happens to all the water?
- For those who are inclined to analyse the data, remember the "real" analyst uses a green pencil to delineate precipitation amounts and a red one to analyse temperatures. By analysing the maximum and minimum temperatures one may notice some interesting features; similarly, if one compares the four observing times. Precipitation amounts, of course, also indicate some interesting patterns that are likely to be tied in with the position of the cold front.
- Notice the large difference between the maximum and minimum temperatures that are observed at sites under clear skies in the cold air (northern Ontario and the Plain States) and the warm air (southeastern States) on either side of the cold front. What are the processes that are responsible for this? Why is this less likely to happen when the observing site reports a lengthy period of precipitation?

FURTHER READING

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A Bird's-Eye View

Continued from page 9

plant as well as the relatively warm, river drainage water.

Further, note the presence of patchy but reflective fog and mist on the NIR image over central Lake Ontario. The temperature of the fog is very near that of the water and land surfaces. Thus it cannot be seen on the 11-μm image. In the area of fog, as determined from the NIR image, the 11-μm image depicts the temperature of the top of the fog and not the water surface. Careful use of both the 11-μm and NIR images is mandatory to deduce the correct interpretation in this area.

Undoubtedly, the reader will identify many more features of interest in the accompanying images. Careful application of the interpretation techniques suggested will yield consistently accurate results. Information beyond the grasp of the birds is at your fingertips. Quite frankly, I doubt if the owls really give a hoot!

Philip Chadwick is an instructor in the Professional Training Section at the the Atmospheric Environment Service Headquarters in Downsview, Ontario.

BOOK REVIEW

Continued from page 7

compromising the scientific content". In this, Thomson has succeeded admirably, putting together a richly illustrated introduction to a fascinating marine region.

The book starts with the big picture, setting the B.C. Coast in the geological context of plate tectonics, with its seismic and volcanic consequences. A broad overview of "The Coast Today" entices the reader with beach cusps, tombolos and sandspits. The following chapters focus on waves and tides, phenomena of prime concern to the yachtsman. A solid qualitative account of tide-producing forces and the response of coastal waters to oceanic tides leaves the reader with a good modern background on the subject. Wind-driven currents, including upwelling, are also treated briefly.

The properties of wind waves are described in succinct detail, the mechanisms of their generation reviewed and their effect on the shoreline illustrated. There are also sections on tsunamis (seismic sea waves) and internal waves.

The first part of the book uses numerous local examples to explain and document basic physical oceanographic phenomena; the second half focuses even more closely on specific areas of the B.C. Coast. The circulation, wave climate and local features of most interest in the Strait of Georgia, the Strait of Juan de Fuca and Johnstone Strait as well as the more open areas west and north of Vancouver Island are described and illustrated.

Thomson has summarized and brought to the general public the results of decades of scientific work by government and industry researchers. He has done this in a conversational style through which shines his own contagious enthusiasm for the sea and its shores. The illustrations (line drawings and photographs, some in colour) are numerous and captivating. The result is a delight: a book that grabs your attention and invites you to learn more, a source of wonder and discovery for naturalists of all ages.

To cap it all, *Oceanography of the British Columbia Coast* is relatively inexpensive (courtesy the Department of Fisheries and Oceans and the author, who collects no royalties) and is also available in a French edition.

Paul H. LeBlond
The University of British Columbia

DEFINING WINTER'S MISERY

by David W. Phillips

Canada is much more than a cold, snowy forest. It is a vast territory stretching across 5½ time zones and covering more than a quarter of the Western Hemisphere. Vancouver is closer to Mexico City than it is to Halifax, and St. John's nearer to Moscow than to the Beaufort Sea. Not surprisingly, Canada has a wide range of climates, including polar ice-cap, semi-desert, maritime, Mediterranean, and dry and humid continental. Each climate is characterized by four seasons with varying lengths. In the settled south, some places never experience cold winds, slush and blowing snow during the year, while others endure winter as the longest season, even in the mildest year.

For most Canadians, the frequency, duration and severity of winter's unpleasantness may justifiably be used as the criteria for answering: What is winter? Each winter, Canadians are resigned to a five-month "indoor living" ordeal. The alternative, it appears, is to deny the very existence of winter. Apparently, this is just what Winnipegers do! According to Lawrence Vopnfjord (1982):

> Winnipegers secretly revel in the denial of the excesses of winter. We pride ourselves a superior and hardy breed with a depth of character built on our perennial success at survival.

The character of winter varies greatly from place to place and from year to year. Along the Pacific Coast, winter arrives with persistently cool, wet and foggy weather. Poleward, winter is cold and dark, with little precipitation. Mid-latitude, continental areas are subject to more frequent and more intense storm systems and fluctuating spells of long-lasting cold, and abbreviated mild spells. In cities winter misery is associated with shin-high soakers, salt-covered roads, icy "black" sidewalks, wind-blasted street corners, dirty snowpiles and bleak cityscapes.

Locally and globally some winters and years are colder, warmer or stormier than others. In 1969, Edmontonians received certificates for surviving a record cold winter – 26 consecutive days with below zero (°F) and that was only their fourth coldest since 1881 (103 years of record). In 1984 these same people had the balmiest January-to-March period on record, more than 7°C above normal and milder than Toronto that year. Variability is a normal characteristic of climate.

There is strong evidence to suggest that residents in most climates become adjusted to the weather norms in their own regions. Large deviations from normal occur from time to time. It is then that conditions become uncomfortable and stressful. For example, if the weather was −10°C with light snow and a wind speed of 8 km/h at Vancouver on a particular winter day, this would represent a most uncomfortable and dangerous situation and Vancouverites would be suffering accordingly. However, a similar situation in Edmonton or Winnipeg would be relatively common to most denizens, who are accustomed to such weather and are prepared for it. Laurence Kalkstein (1982) uses this notion of human discomfort being dependent upon variations from the mean or normal conditions to describe the weather severity of a place.

Exposure to extreme cold claims more lives in Canada than all weather hazards combined, including lightning,

Credit: Keith McNichol, The Edmonton Journal

storms, floods, heat waves, and tornadoes. Mortality statistics, compiled by Statistics Canada over a recent 15-year period, show a total of 1,621 deaths attributed to "excessive cold" for an average of 108 deaths per year or about 0.5 per 100,000 persons. Cataclysms – a composite category including deaths caused by storms, floods, earthquakes, tidal waves and other natural events – claim only 17 Canadians a year.

Lawrence Truppi of NOAA's Environmental Protection Agency suggested (1980) that during the 1966 U.S. cold wave there was a large increase in indirect casualties of cold weather in normally mild-wintered areas. "On a day that would be balmy by Rocky Mountain standards – high temperatures in the sixties (°F), lows in the forties (°F) – there was nearly a doubling of the normal death rate in southern Florida". In Edmonton, however, two remarkably different Januarys, 1981 and 1982, resulted in identical mortality rates for the month, 355 deaths, even though more than 22 winter misery days occurred in January 1982 and none in 1981. A winter misery day is defined below.

CLASSIFYING CANADIAN WINTER

Climatologists are fond of classifying the climates of different areas using such basic elements as temperature, precipitation, humidity and insolation. Most classification schemes relate climate to agriculture and vegetation and place special emphasis on defining the boundaries between climate types. Another approach is to calculate a climate index in which all the elements are individually weighted and then aggregated into a single discrete value.

In 1984, the author along with Ronald Crowe (1984) developed the *climate severity index*, a human climate classification that describes in a single number many of the unfavourable (uncomfortable, depressing, hazardous and confining) aspects of climate. The extreme values of 18 climate parameters, including wind chill, humidex and length of winter/summer are combined into an index that ranges from 0 to 100. The index has proven quite popular as a guide for those selecting the more amenable climates for recreational and retirement living, for employers concerned about the timing of outdoor activities and performance, and for workers seeking fair and equitable remuneration for working outdoors.

The same approach was used to develop a *winter severity index* using the same four factors, namely: discomfort, psychological state, hazardousness (danger), and immobility (difficulty of travel). Each factor was defined by the aggregation of several subfactors (represented by climate elements). The weighting assigned to a subfactor depended on its assumed relative importance.

For each main meteorological station in Canada, points were assigned to each subfactor, depending on extreme values, intensity or duration. For example, a station with winter (number of months with a mean daily temperature less than 0°C) lasting ten or more months was assigned full points for the length-of winter subfactor, whereas one with no month meeting the criterion was assigned zero points.

A percentage breakdown of the relative importance of the factors and subfactors defining winter severity is shown in Figure 1 for the specific weighting scheme chosen. Table 1 defines the elements and gives the maximum points (weight) for each subfactor.

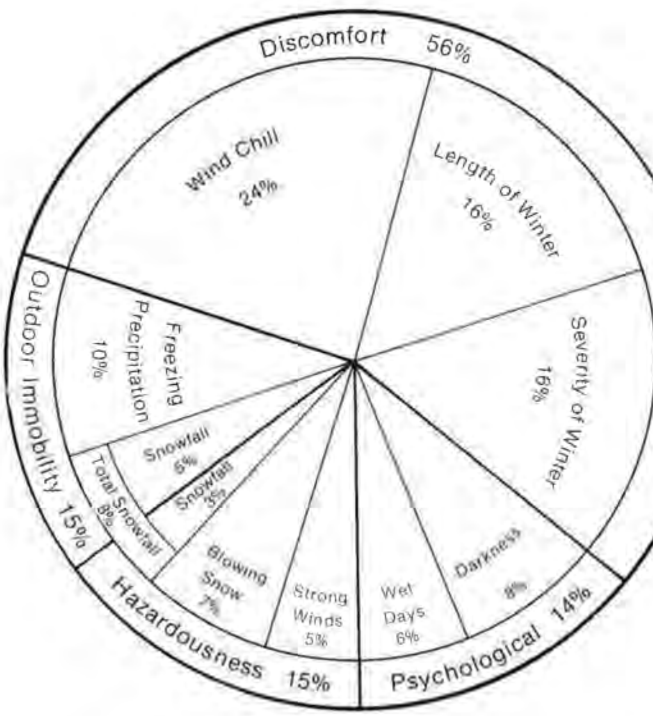

Figure 1 Percentage contribution of each of the four factors and nine subfactors defining winter severity.

Table 1 Weighting assigned to the factors and subfactors composing the winter severity index

Factor/Subfactors	Maximum Points	Factor/Subfactors	Maximum Points
Discomfort (400 points)		Hazardousness (100 points)	
Wind Chill Mean percentage of time in January that the wind chill exceeds 1400 watts/square metre	170	*Strong Winds* Mean percentage frequency of January wind speed equal to or greater than 30 km/h	34
Length of Winter Number of months with a mean daily temperature less than 0°C	115	*Blowing Snow* Absolute frequency of the number of hours with blowing snow (over a 10-year period)	44
Severity of Winter Mean daily temperature of the coldest month	115	*Snowfall* Mean winter snowfall (cm)	22
Psychological State (100 points)		Outdoor Immobility (100 points)	
Darkness Increasing darkness factor with increasing latitude	55	*Freezing Precipitation* Absolute frequency of the number of hours with freezing precipitation (over a 10-year period)	67
Wet Days Average number of days with measurable precipitation (rain and/or snow) in December, January and February	45	*Snowfall* Mean winter snowfall (cm)	33

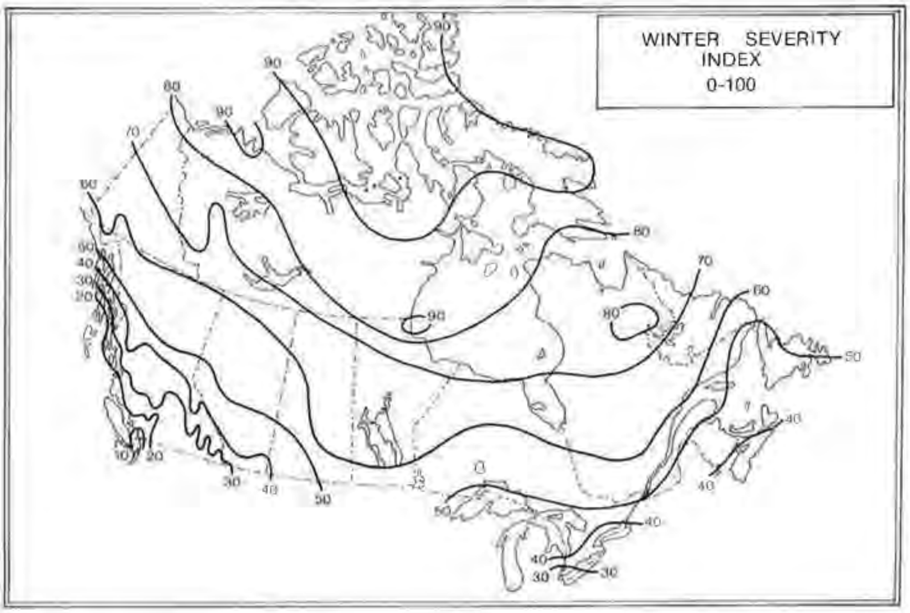

Figure 2 Winter severity index for Canada. Index values range from 0 to 100 for minimum to maximum severity.

Table 2 Winter severity index and the subfactors for Canadian metropolitan areas arranged in decreasing order of population (1981 Census) (maximum points in brackets)

Pop. Rank	Metropolitan Area	Discomfort (55)	Psychological State (15)	Danger (15)	Immobility (15)	Winter Severity Index* (100)
1	Toronto	19	4	4	7	34
2	Montréal	25	6	6	10	47
3	Vancouver	1	7	1	1	10
4	Ottawa-Hull	26	5	4	11	46
5	Edmonton	37	3	2	7	49
6	Calgary	32	2	5	5	44
7	Winnipeg	47	3	5	7	62
8	Québec	29	6	9	12	56
9	Hamilton	19	4	4	7	34
10	St. Catharines-Niagara	19	4	5	8	36
11	Kitchener	20	4	5	8	37
12	London	19	6	6	7	38
13	Halifax	18	6	5	9	38
14	Windsor	15	4	5	5	29
15	Victoria	0	6	1	1	8
16	Regina	44	3	7	7	61
17	St. John's	16	8	10	16	50
18	Oshawa	20	4	5	7	36
19	Saskatoon	44	3	4	6	57
20	Sudbury	34	6	7	6	53
21	Chicoutimi-Jonquière	37	6	8	9	60
22	Thunder Bay	35	4	4	6	49
23	Saint John	23	5	7	9	44
24	Trois-Rivières	27	6	8	11	52

*Note: These values are estimates for central city locations. Some cases are significantly different from the values calculated for airport locations outside the city.

Considering the importance of comfort in our daily lives, the discomfort factor was treated as the most important one, accounting for more than half of the winter severity index. The other three factors were each given equal weight and judged to be of lesser importance than discomfort because they are generally associated with ephemeral and less frequent conditions.

The winter severity index (Figure 2) is designed so that values approaching 100 indicate the highest severity in Canada. The pattern of winter severity is similar to the pattern of year-round climate severity. The highest index is found over the northern Queen Elizabeth Islands, the Beaufort Sea coast and the Hudson Bay coast near Churchill. Over the settled south, severity values are much lower. The lowest values occur at Victoria and Vancouver. Low values below 30 also occur over the southern interior British Columbia valleys and the extreme southwestern portion of Ontario. High values occur over the Yukon Territory, Saskatchewan and Manitoba, northern Ontario, and most of Quebec and Newfoundland. In-between values are found in southern Alberta, central Ontario and the Maritimes.

Table 2 shows winter severity index values for Canada's 24 largest cities. For instance Toronto with 34 points and Halifax with 38 have only moderately stressful winter climates, whereas St. John's (50) and Montréal (47) are more uncomfortable. Winnipeg has the highest index value (62). Victoria with 8 is the city with the lowest index. It is noteworthy that Edmonton's three airports (International, well south of the urban area; Namao, north of the city; Municipal, in the north-central part of the city) have winter climate severity values 54, 52 and 49, respectively – an indication of the degree of moderation provided in an urban setting.

EXAGGERATING WINTER SEVERITY

Most people's perception of the Canadian winter is based on the occasional newsfilm and front-page story about city residents struggling against winter's latest storm. There is no question that winter, especially in Western Canada, can be long and difficult. But how frequently do these paralysing storms occur? Do the few that occur each year present an erroneous picture of what Canadian winter is really like? To find out, an analysis was undertaken of 10 years of extreme winter weather data for three airports: Edmonton International, Edmonton Municipal and Winnipeg International. Four extreme weather

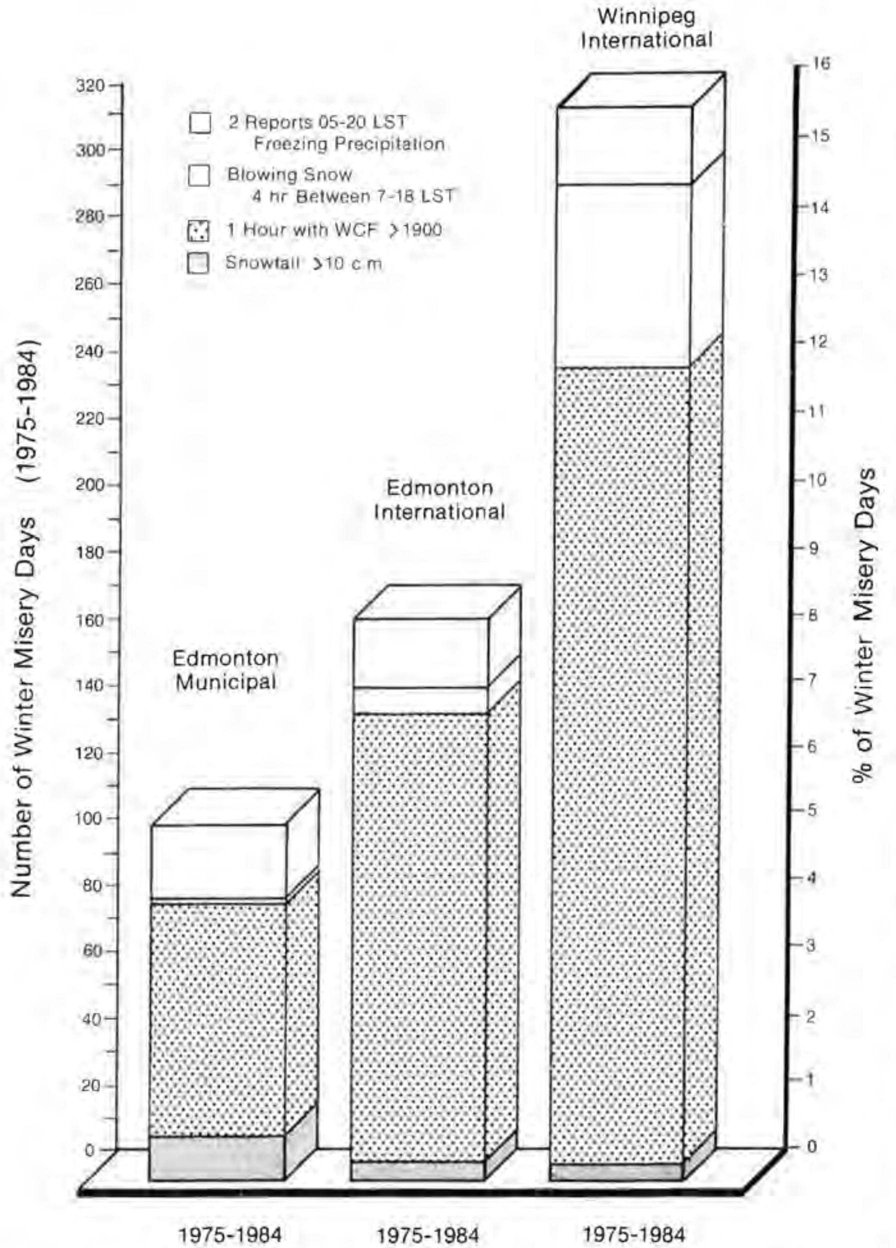

Figure 3 Winter misery days (October to April, 1975–1984) for Winnipeg International and Edmonton Municipal Airports (urban) and Edmonton International Airport (rural).

situations were identified and the frequency of a winter misery day was abstracted. A *winter misery day* is a day with at least one of the following weather conditions:

- A single-day snowfall accumulation of 10 cm or more
- At least four hours of blowing snow between 07 and 18 LST
- Two or more reports of freezing precipitation between 05 and 20 LST
- One report of a wind chill factor exceeding 1900 (conditions for outdoor travel become dangerous; exposed areas of flesh freeze in less than two minutes for the average person)

The analysis reveals surprisingly few days per winter with "stay-home" weather (Figure 3). At Edmonton Municipal Airport only 5% of all days between October and April are winter misery days, compared with 8% at Edmonton International Airport outside the city (a difference of about 6.2 days per year). The major Canadian city with the most severe winter climate is Winnipeg, yet only 15% of the days between October and April are winter misery days at the International Airport. In January, winter misery days account for 10% of all days at Edmonton Municipal (December has more of these days), 20% at Edmonton International and 40% at Winnipeg. The average annual number of winter misery days and the range of annual values in 10 years of data are as follows:

	Average	Range
Edmonton Mun.	11	4–19
Edmonton Int.	17	4–35
Winnipeg Int.	32	17–44

Other observations are:

- The wind chill factor at each location is the prime reason for winter weather misery, accounting for 70 to 80% of these days.
- Major snowfalls in Edmonton are more frequent in October, November, March or April than in December, January or February.
- The number of misery days significantly increases between November and December at all three locations.
- A day with at least four hours of blowing snow occurs rarely at Edmonton, only once a year at Edmonton International, and 5.5 days a year at Winnipeg.

Winter days with two or more of the misery conditions described above, numbered 4 at Edmonton, 6 at the International Airport and 51 at Winnipeg International (based on 10 years of data from 1975 to 1984).

One assumes that an analysis of data for other Canadian cities, but using different misery day criteria that typify conditions at those cities, would produce similar results.

CONCLUSION

Variety is the norm in Canadian climate. This feature is especially true in winter. South of the Arctic Circle, the January mean climate map shows temperatures ranging from −33° to 3°C, precipitation totals from 10 to 400 mm and sunshine durations from 0 to 110 hours. Differences across Canada are not nearly as large in July. For an individual season, month or day, the differences can be much more pronounced, with particular periods in one year being quite unlike those of the preceding year. Then again, some places are regularly struck by disastrous events such as cyclones, droughts or floods while others rarely if ever suffer these hazards.

The great diversity of climate necessitates some corresponding diversity in the decisions that are made in planning or designing with climate in mind. Recognition and acceptance of the assets and liabilities of the diverse climate and its variability at any place from day to day or year to year is essential if human comfort, safety and efficiency is to be optimized in our everyday activities.

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David Phillips is Superintendent of the Developmental Climate Section of the Canadian Climate Centre in Downsview, Ontario. Mr. Phillips has participated in a wide variety of climate applications activities. He has authored numerous publications and articles. During the past several years he has directed the publication of the *Canadian Weather Trivia Calendar*.

RÉSUMÉ *Pour la majeure partie du Canada, l'hiver commence bien avant le début du solstice d'hiver et continue au-delà de l'équinoxe de printemps. La durée et les rigueurs de l'hiver varient beaucoup d'un endroit à un autre et d'année en année. On a créé l'indice des rigueurs de l'hiver aux fins de comparaison dans tout le Canada. L'indice comprend neuf des éléments les plus désagréables du temps hivernal, dont la froideur du vent, les vents forts, les rafales de neige et les précipitations verglaçantes. Il va sans dire que l'hiver est le plus rigoureux dans le Nord et le plus clément dans la région du sud-ouest de la Colombie-Britannique. Des villes principales, Winnipeg et Regina possèdent, en tête de liste, l'indice des rigueurs de l'hiver le plus fort, tandis que Victoria et Vancouver enregistrent les valeurs les plus faibles.*

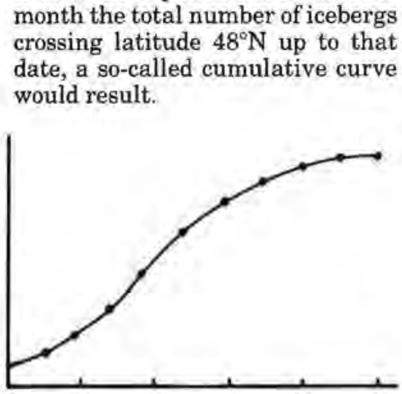
La plupart des Canadiens se rendent coupables d'amplifier le côté déplaisant de l'hiver. On donne la définition d'un jour d'hiver abominable. Contrairement à l'avis général, de tels jours se présentent bien moins souvent. On enregistre à Winnipeg 15 p. 100 de jours d'hiver abominables entre octobre et avril et seulement 5 p. 100 à Edmonton.

QUESTIONS RELATED TO ICEBERG STUDY

by Jerry E. Salloum

The set of questions presented below is related to the article on icebergs published in a previous issue of *Chinook* (Volume 8, Number 4, pages 64–70). Thorough reading of the article and an understanding of the basic concepts is required in order to arrive at reasonable answers to the questions. Answers and solutions will be published in a subsequent issue of *Chinook*. Any correspondence should be directed to the CMOS Ottawa address. Attention: Editor, *Chinook* (Iceberg Study). Please include a stamped, self-addressed envelope with your correspondence.

1. The estimated volume of the world's glacial ice is 2.7×10^7 km^3. The surface area covered by the world's oceans is 3.6×10^8 km^2. The volume of water in the world's oceans is 1.4×10^9 km^3. By how many metres would ocean levels rise if all glacial ice melted? What piece of information given above is not essential in calculating the answer? What two important facts have been ignored in this question?
2. Compare sea ice with iceberg ice.
3. Name 5 types of icebergs.
4. Compare the ice-caps of Greenland and Antarctica.
5. Imagine a cube of pure water 100 m $\times$ 100 m $\times$ 100 m that freezes to become a cube of ice floating in a lake of pure water. Assuming the specific gravity of ice to be 0.9, answer the following:
   - What is the volume occupied by the cube of water?
   - What is the mass of the cube of water?
   - What is the volume occupied by the cube of ice?
   - What is the mass of the cube of ice?
   - What mass of lake water is displaced by the floating ice cube?
   - What volume of ice remains above the water-line?
   - At what depth is the base of the ice cube?
6. If one were to plot at the end of each month the total number of icebergs crossing latitude 48°N up to that date, a so-called cumulative curve would result.



   - What is the above cumulative curve "saying"?
   - What is the significance of the last point plotted on any cumulative curve?
   - What is the significance of a zero slope on such a curve?
   - Convert the above curve into a rough graph that shows monthly totals rather than accumulated totals.
7. How many positions of stability would you expect to find in
   a) A floating flat fence board?
   b) A floating rectangular fence post?
   c) A floating basketball?

   Of what value is such a question to this study?
8. Knowing that one nautical mile is equivalent to one minute of latitude, calculate the distance to the North Pole from the northern tip of Greenland (84°N). If the southern tip at Cape Farewell is at latitude 60°N, how long would an aircraft take to traverse the north-to-south distance at a speed of 200 knots?
9. Look up the longitude of the coast of Greenland at the 70th parallel. Since the distance between consecutive meridians decreases in accordance with the cosine of the latitude at which it is measured, calculate the distance across Greenland from coast to coast at latitude 70°N.
10. What factors determine
    a) The crushing strength of ice?
    b) The iceberg's residency period in ocean water?
    c) The iceberg's rate of drift?
    d) The iceberg's rate of melt?
    e) The iceberg's drift path?

SUMMER OF '86 IN REVIEW

Amir Shabbar

The season was dismally cool and wet in eastern Canada but provided good vacation weather on the west Coast.

In western Canada, timely rains ended two years of drought on the Prairies. The rain and cool weather also kept the outbreak of forest fires to a minimum. Late summer warmth and dry weather provided ideal conditions for thousands of tourists to visit EXPO 86.

TEMPERATURE

A vast area of the nation from the Rockies through the Great Lakes Basin to the East Coast and including the Arctic experienced a cooler than normal summer. The temperatures were near normal in southern British Columbia. Temperature departures were not large – less than 2°C at the majority of the climate stations. Cool weather – about 1°C below normal – persisted from the lower Great Lakes to the Maritimes. Southern Ontario sweltered during a brief two-day heat wave, July 6–7, when maximum temperatures reached a record 34°C and the humidex registered an uncomfortable 41°C. The highest temperature was 38°C in August at Lytton, B.C., while the lowest reading was −7°C at Resolute, N.W.T. in the same month.

PRECIPITATION

Much of Canada experienced a wetter than normal year. Precipitation was as much as 130 to 160 per cent of normal over the Great Lakes Basin and the Maritimes and up to 150 per cent of normal in southeastern British Columbia. Southern portions of the Mackenzie Valley and northern Manitoba received more precipitation than usual. Alberta sustained record-high July precipitation amounts, which were as much as 300 mm in west-central forest regions. Higher elevations of the Alberta foothills received about 25 cm of snow between July 16 and 19. The West Coast, the southwestern Prairies and northwestern Ontario experienced drier than normal weather. Both Victoria and Vancouver recorded no measurable precipitation during August setting new monthly records.

SIGNIFICANT CLIMATIC IMPACTS

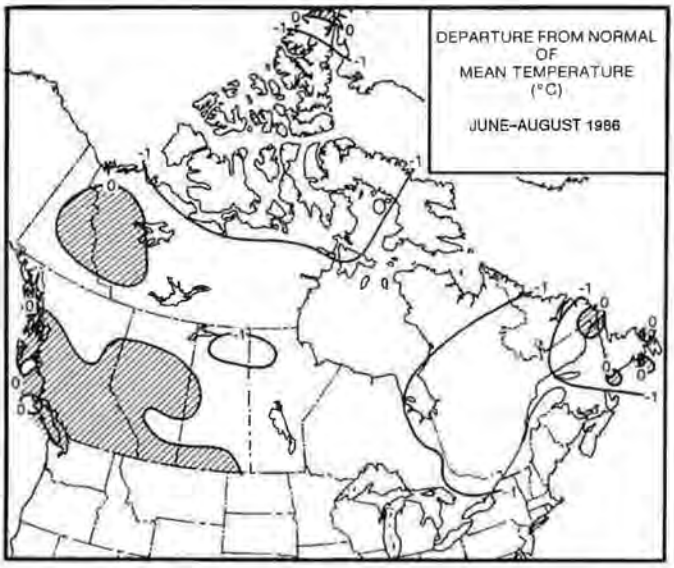
Summer's cool and damp weather disappointed most Canadians this year. From the Great Lakes to Newfoundland, heavy rains caused local flooding and kept some farmlands waterlogged. The Atlantic Provinces endured one of the most dismal summers this year; month after month record-low temperatures were set as the mercury fell several degrees below normal. Sydney, Nova Scotia, had its coldest July ever (15°C). Late frost damaged some sensitive crops in new Brunswick and Prince Edward Island. In June, frost destroyed a blueberry crop worth $3 million at Lake St-Jean, Quebec.

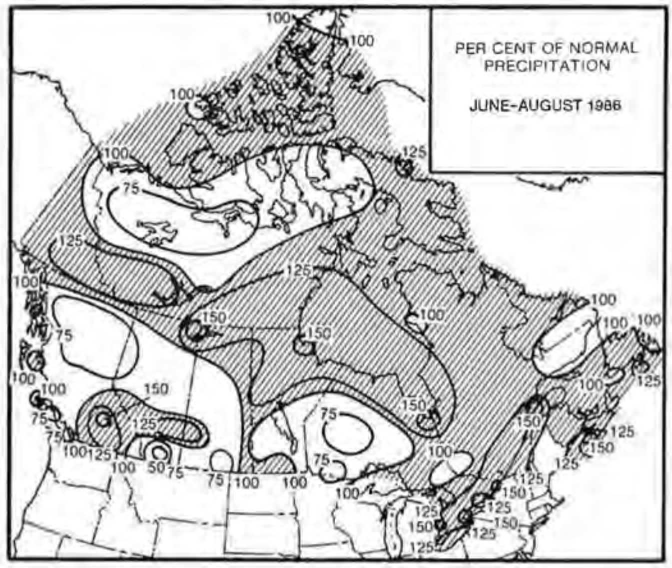
Heavy rains inundated southern Ontario during late summer, including major roadways in Toronto where it was the wettest summer since 1928 – 356 mm. Moosonee on Hudson Bay received a record July rainfall of 189 mm.

Southern Ontario had numerous outbreaks of severe weather. On June 16, a violent tornado touched down just north of Minden. Along its 80-km track, 50 to 100 cottages were damaged or destroyed. On August 1, golfball-size hailstones destroyed tender fruit and vegetables in the Holland Marsh and the Niagara Peninsula; crop damage was estimated at $20 million.

Heavy rains inundated farmlands in southern Ontario causing an estimated $100 million of crop damage.

Crops rotting in the lush Holland Marsh just north of Toronto.





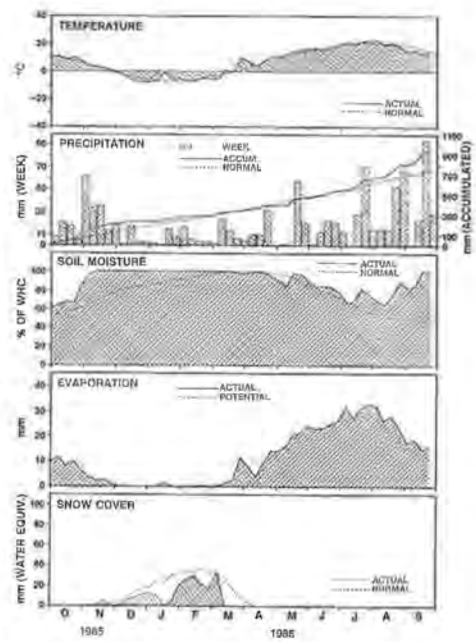
Damaging winds, destructive hailstorms and violent tornadoes caused widespread crop and property damage in the southeastern Prairies in July and August. July was excessively wet on the Prairies and one of the wettest on record in Saskatchewan. Central Alberta received more than 300 mm of rain, better than half of which fell between July 16 and 19. Torrential downpours caused the North Saskatchewan River to rise to near record flood stages, and damaged at least 300 homes in the river valley communities of Edmonton. Huge tracts of farmland along the Pembina River were waterlogged. Two deaths were attributed to the floods. The same storm that deluged central Alberta, brought a touch of winter in midsummer to higher elevations in the foothills; nearly 25 cm of snow fell in Banff, Jasper and Yoho National Parks.

The timely rains proved beneficial to Prairie agriculture, ending two years of drought in southern Saskatchewan and southern Alberta. Summer started out wet on the West Coast, and several communities in the Interior valleys of British Columbia received twice the normal amount of rainfall in June. On June 15, heavy rains washed out two bridges and part of the Canadian National Railway tracks at Terrace. After mid-July, the weather turned warm and dry. Daytime temperatures soared well above 30°C making it an ideal time for thousands of tourists to visit EXPO 86. August was very dry on the West Coast. Victoria and Nanaimo had the longest dry spell on record, 45 days – while at Vancouver the same 45-day stretch was the second longest.

Overall, the summer of 1986 was a quiet season for forest fires across Canada. However, lightning strikes in the hot and dry weather helped ignite major forest fires in the central Yukon. Over 100 fires destroyed more than 41,000 hectares of timber in the Territory.

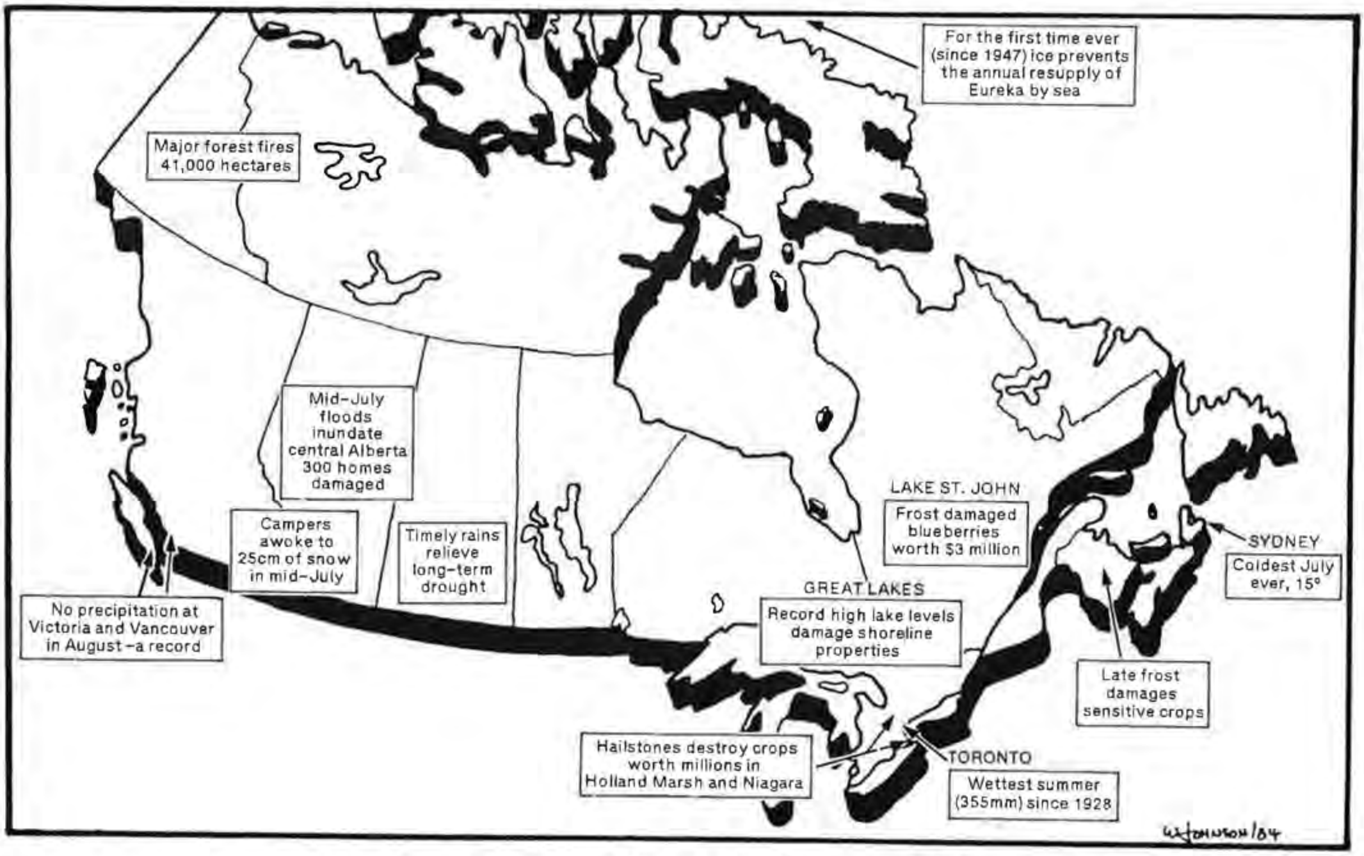
As a result of cooler than normal temperatures, ice conditions were more severe than usual in the High Arctic. For the first time since 1947, heavy ice floes blocked shipping lanes in Norwegian Bay and prevented the annual resupply of Eureka by sea.

A typical saturated cornfield north of Toronto on September 30.



Time series of water budget components at Toronto from October 1985. Values are based on a 7-day mean. WHC is the water-holding capacity of the soil.

Amir Shabbar is a climate prediction meteorologist in the Canadian Climate Centre engaged in research, with a special interest in long-range prediction problems.



Major climatic impacts across Canada during the summer of 1986.

GUIDELINES FOR CONTRIBUTORS OF ARTICLES TO *CHINOOK*

1. Content, Language and Readership
Articles on topics of general interest in meteorology and oceanography, written in either English or French and suitable for a high school readership, are invited.

2. Length and Format
The suggested article length is in the range of 1500 to 3000 words with two to four figures (and captions). Clear illustrations and photographs are particularly encouraged. Contributors are also asked to provide a 100-200 word summary, preferably but not necessarily in the other language. Summaries will be translated (if necessary) and published in the other language only.

3. References
Literature citations within the text are discouraged. Instead, it is suggested that credit for results and ideas be given by naming the authors or their institutions in the text, and including references at the end of the text in the form of a short "Suggested Reading" list. A reference to a journal article should include the authors' names and initials, year of publication, full title of article, and journal name, volume number and page numbers. A reference to a book should include the authors' names and initials, year of publication, title of book, and the publisher's name and address. All references should be listed in the alphabetical order of the first authors' surnames.

4. Procedure for Submission
Two double-spaced typewritten copies of the manuscript should be sent to: *Chinook* Editor, c/o Canadian Meteorological and Oceanographic Society, 151 Slater Street, Suite 903, Ottawa, Ontario, Canada K1P 5H3. Finished line drawings and good quality black-and-white photographs (one original and two photocopies of each) should be included. Colour illustrations or photographs are welcome as candidates for the front cover of each issue. Contributors are also asked to provide a short description (about 50 words) of their professional affiliation (if any) and their meteorological and oceanographic interests, and to indicate whether their contribution has been or will be published elsewhere.

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