Chinook

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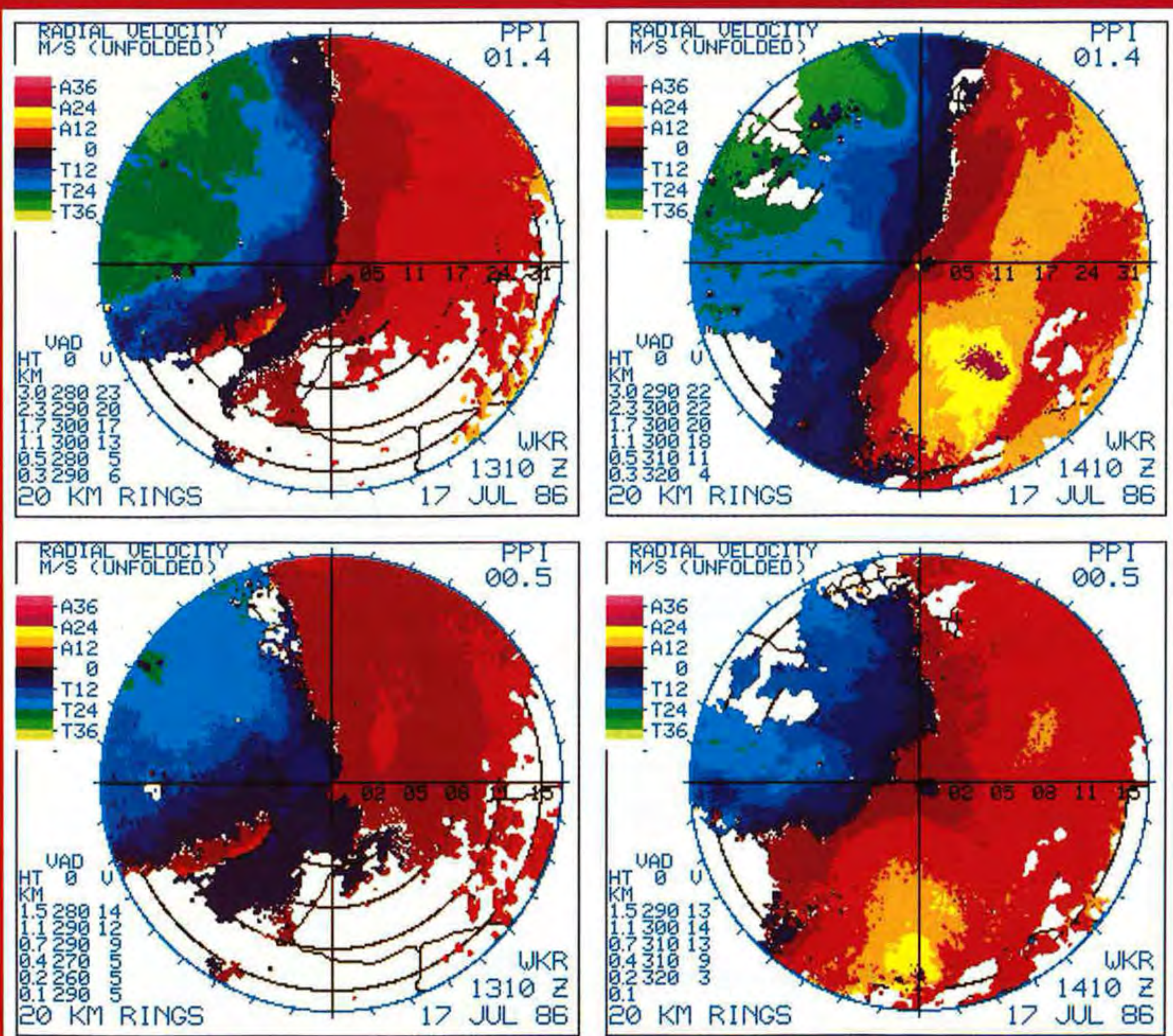

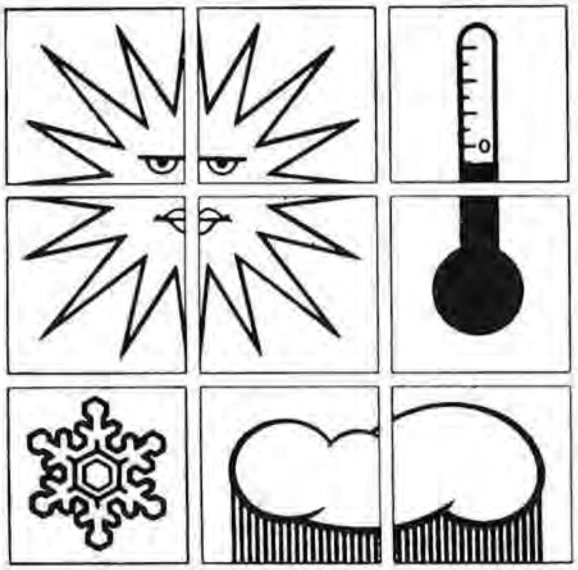

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FROM THE EDITOR'S DESK

Tom Nichols and Cliff Crozier take us on an exciting journey into the high-tech world of Doppler radar. This is complex stuff, but really one of the state-of-the-art tools of a modern front-line meteorologist. Not only will Doppler radar offer us a better understanding of what goes on in the more severe thunderstorms, but it is becoming an indispensable weather instrument for the severe weather forecaster.

Hans Martin gives an inside view of the complex and controversial problem of acid rain. We read about this environmental blight almost weekly and it is very prominent in the political arena on both sides of the Canada-U.S. border. How does it affect our environment and what is the magnitude of the problem?

Our Weather Map Series is a longer one in this issue: six maps. This time we take you to Atlantic Canada. The winter of 1988–89 was not the rambunctious stormy season that would normally be expected. We look at a most unwelcome Easter snowstorm, which brought havoc to all the Atlantic Provinces.

The next issue, Volume 11, No. 3, will be a biggie, with special features from "The Changing Atmosphere" Conference, which was held in Toronto in June 1988 and which has become a reference point for Canada in terms of leadership on environmental issues. That issue will – in part – be supported through generous financial assistance from the Atmospheric Environment Service. The features will be provided by such notables as the Honourable Dr. Gro Harlem Brundtland, the Prime Minister of Norway, Dr. F. Kenneth Hare, Canada's foremost climate expert, Sister Aida Velasquez, a leader in the ecological struggle in the Philippines, and Dr. Jag Maini, the Assistant Deputy Minister of the Canadian Forestry Service.

Hans VanLeeuwen

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COVER

The cover pictures are computer processed displays of precipitation velocities measured with the AES Doppler weather radar at King City. This latest addition to the weather observation tool chest is an enormous advance towards viewing storm details that were previously unobservable. On 17 July 1986 an organized area of thunderstorms or a mesoscale convective system (MCS) was crossing southeastward over southern Ontario. Two pictures at different elevation viewing angles are shown for 1310 UTC on the left; and two for the time one hour later on the right.

These Doppler observations show the increase in wind speed with height; the precise location and structure of a trough line with a sharp wind shift; the appearance of two wind jets interacting with the storm complex that will bear on the future development of the weather; and the changes in the wind field with time. For further details see the article on page 33.

THE LAW OF THE ATMOSPHERE

by Hans Martin

This article is an excerpt from a speech presented at the Journalist's Breakfast, June 29, 1988 during the conference on The Changing Atmosphere. *Particular emphasis is given to chemical emissions in the atmosphere and acid rain and their impact on the total environment.*

I'd like to present my personal views on what the Law of the Atmosphere is, and my views on (1) why a law is not what we will get, (2) why we don't know what we will get and (3) why we will likely do the right thing following a correct approach over the next several decades.

WHAT KIND OF LAW IS LIKELY?

First of all, why will we not get a law? Perhaps it's a matter of interpretation. In physics, we have laws. Every force has an equal and opposite force, $E = mc^2$, and so on. We don't question these things. In jurisprudence, we have laws. Do not cross the street against a red light, do not do in your mother-in-law unless it's absolutely essential. And then, we go to courts and we have courts that subject our laws to interpretation. What do we mean by "absolutely essential." This approach, of course, contrasts significantly with the approach that is taken in science and physics.

What do we mean by a Law of the Atmosphere then? Do we mean rules? "SO_2 will no longer enter into the sky." No. This is not the type of law we're talking about. Do we mean principles that are subject to interpretation? "H_2O, entering the atmosphere, due to anthropogenic emissions within national boundaries, or the transboundary fluxes of H_2O or its secondary products, due to such emissions, shall be reduced by parties, when economically feasible, by 30%, by the year 1991, based on the reference year 1978." Alas, we're getting closer to what we're going to get with that approach. But let's explore this second class, this second group, which does resemble, perhaps, the jurisprudence laws, those that are subject to interpretation and some flexibility.

What do we need to make laws work? Well, normally, you have three elements. First, you have to define the victim as well as, in this case, the polluter. Who's doing what to whom? Second, you require a competence, a court or an administrative body that must be competent to deal with the case. Third, you need enforceability. The court, or administrative body, has to be able to provide an adequate and enforceable remedy.

If we expect the Law of the Atmosphere to have articles and to follow these rules, which will be dealt with in this fashion, I think we will be disappointed.

THE LAW AND UNCERTAINTY

Let me move on to "why we do not know what we are going to get". It's rather basic. Because we have not defined the problem adequately or the extent of damage to nature, nor do we have a clear concept of the rate of change, we are confronted with uncertainty. Uncertainty hinders rapid rational judgement. We are trying to manage ignorance.

In this conference, we have three issues that we're dealing with: climate change, stratospheric ozone and acid rain. We are conversant with acid rain. In fact, most of you prefer not to explore this issue. This is correct. It reflects our maturity and our understanding. We know what pollutes (nitrogenic sulphur); we know where it comes from (the transport sector, power plants, smelters ...); we know where it goes (source/receptor relationship we have developed in science); we know how long it stays in the atmosphere (three days, five days); we know what it endangers (lakes, streams; it contributes to forest damage, material corrosion and so on ...); we know about episodes and how devastating they are (spring snow melt or intensive rainfalls); we have moved on to remedies, we know which ones are availabe, we know what they cost, we know the time-scale for damage and recovery and, in fact, we've undertaken programs in some countries to bring about recovery.

Acid rain has been a training ground for us. It has been our kindergarden; for scientists, for policy-makers, for engineers, for economists, for legal experts, and for the public – wherein lies all our hope. We're not done yet. Not with acid rain. We have health to look at more closely. We have to sort out the issue of forest decline in Europe and northeastern North America. But we have graduated from kindergarden.

Now, we have the nervous anxiety of children entering primary school.

But nature has intervened, and we are not allowed the normal years to develop our skills, talents, methods and sensitivities. We're confronted with a curriculum that includes primary and secondary school, university courses and graduate studies, simultaneously. Yesterday, a journalist said four words to me: "I find this scary!", and I agree. Uncertainty is no source of comfort.

The uncertainties concerning pollution, which is causing chemical alterations in the atmosphere, are many: How to identify the culprits, their origins, their destinations, how long they remain in our atmosphere, how these compounds and products interact, what is their damage potential, what are their extremes in concentration (their episodicity), where lie the remedies, at what costs, and what is our time-scale?

Time is our enemy. Biological evolution and adaptation of advanced life forms do not work on our time-scale of years and decades. In the matter of man's plans to manage the environment, nature has rejected our agenda.

I mentioned a moment ago the training we experienced in dealing with acid rain and the training that has occurred within the general public wherein lies our hope. The latter task will continue to be *your* job. You have not tried such a project before, to educate people throughout the world about the consequences of our actions and the need for remedy and help, and this, for a grocery list of pollutants that grows with sulphur dioxide, nitrogen peroxide, hydrocarbons, CFCs in six or eight forms, methanes, CO_2, on and on ....

nations to correct a global problem. They are real, they are filed in various institutes, they are available to all of us.

Flexibility is essential. We must continue to be flexible, to allow for new pollutants, to allow for new legal instruments, to allow for economic considerations (debt, technology transfer), to direct scientific research, to answer policy questions and to create institutions. It is happening and that is the hope that we have.

The agreed framework is not in place, this Law of the Atmosphere. This framework will shepherd our legal instruments and our commitments as we put them together. It will evaluate our progress. It will moderate as we proceed and it will set schedules. We are getting close, I think we are at the beginning. This conference will push us along.

ARE WE DOING ANYTHING RIGHT?

The third thing I wanted to discuss is: Are we doing anything right? The answer is, I think, *yes*! We are probably taking the correct pathway. So what is it? Perhaps it's elusive. It is a step-by-step development of instruments to control and/or reverse the degree, or rate, of chemical alterations in the atmosphere. That is what has been happening over the last decade or so.

In 1979, we had, within the United Nations, a Convention on Transboundary Air Pollution. It was a framework. In 1982, in Stockholm, we set down general principles and reconfirmed the principles of the decade earlier, in 1972. In 1985, we had a protocol in Helsinki to reduce sulphur dioxide emissions by 30%. In 1987, the Brundtland Commission report on sustainable development was released and, in Montréal, we signed a protocol on CFCs, to address the matter of stratospheric ozone depletion.

THE LAW OF THE ATMOSPHERE

This year, in October, we will have a second protocol, out of the United Nations Convention, on nitrogen oxide emissions. Remember that in 1972, the world chuckled, perhaps discretely, when Scandinavian scientists proclaimed that the pollutants in Central Europe were damaging their northern countries. No one is chuckling anymore. That was only 15 years ago. We seem to have found the pace and it's a fast one! More important, I think we've demonstrated the capacity to skip grades.

These legal instruments, that have been produced in the last decade or so, and that we will continue to produce, *are* the Law of the Atmosphere, if you intend to use that term. The protocols, the conventions, the agreements, the principles, these are elements of a binding commitment between nations to correct a global problem.

THE FUTURE

We, students, you and I and all of us, find that our schools and university corridors are a shambles with students keeping lockers full of books for many grades and classes. The library desks are cluttered. The joint projects are incomplete in the work-rooms. Some want the class hours reduced, the work is heavy and some of the teachers are incompetent. Some cannot afford to continue without scholarships. Often we work alone, without guidance, in pairs or groups, in strange disciplines considering social disruption, laws, and economic inequality. We are surprised that these disciplines contain our daily problems. We are surprised that we are the cause of these complex interlinked issues. Our studies must become much more orderly, more regulated. This order will help our progress, and improve our reports, our essays and our research papers. We have to work in teams, faster. We have to learn, we have to produce better products.

We chose to be here; we fashioned this environment, the system. We are now facing the final exam. As for The Law of the Atmosphere, the framework – yes the school must be put in order by this framework, and it will, here during these days and over the next few years. We have to be more efficient and we have to pass our tests.

I hope you will be at the graduation.

I hope I will be there as well.

Hans Martin is acting director of the Air Quality Research Branch of the Atmospheric Environment Service, which is responsible for the federal research programs on stratospheric ozone depletion, air toxics, the atmospheric aspects of the acid rain issue, and environmental emergency response.

From 1980 to 1989 he was Senior Advisor in Environment Canada on the Federal Acid Rain Study Program, and director of the Acid Rain Liaison Office in Environment Canada, which was instrumental in the development and coordination of research programs within the federal government and with provincial counterparts.

Dr. Martin has been a member of the Canadian delegation to the ECE Convention on Transboundary Air Pollution.

RÉSUMÉ *Questions sur la « Loi sur l'atmosphère » telles que: Pourquoi ce ne sera pas une loi que nous obtiendrons? Pourquoi on ne sait pas ce que nous obtiendrons? Pourquoi, au Canada, nous ferons certainement le bon choix en suivant une approche correcte dans les prochaines décades.*

Plusieurs questions, souvent très complexes, se posent à savoir ce que signifie vraiment « Loi sur l'atmosphère ». En fait, ces lois, suivant la procédure juridique, pourraient certainement être flexibles et sujettes à interprétation. Elles demandent la définition de la victime et de la source de pollution, une cour ou une administration compétentes pour traiter des problèmes, et enfin, des remèdes adéquats et applicables.

Les changements climatiques, l'ozone stratosphérique et les pluies acides furent discutés lors de la Conférence de Toronto sur l'atmosphère en évolution. Les pluies acides et les problèmes scientifiques et environnementaux associés servent de banc d'essai aux activités jurdiques et techniques. Un fort degré d'incertitude accompagne les difficultés nombreuses et complexes. Plusieurs questions d'intérêt juridique ne sont même pas près de recevoir une réponse raisonable.

Quand même, on peut dire que la communauté internationale a fait des pas dans la bonne direction. Au cours des dix dernières années plusieurs protocoles importants on été établis; ils forment la base principale aux progrès futurs. On doit travailler en équipe, et améliorer notre niveau de connaissances et produits. Le temps presse!

WINTER 1988–89 IN REVIEW

by Aaron Gergye

UPPER ATMOSPHERIC CIRCULATION

The general pattern over North America in the winter of 1988–89 included an intense Arctic vortex over Davis Strait and higher than normal heights over the southeastern United States. The cold air associated with the unusually strong Arctic vortex extended as far south as the Gulf of St. Lawrence. Consequently, the northeastern part of Canada experienced a cold, fairly dry winter as storms took a more southerly track. Over the western part of Canada, an amplified ridge pushed the jet stream farther north, resulting in less precipitation than normal in the Yukon, the northern parts of British Columbia and the Prairie Provinces.

TEMPERATURE

Overall, the amplified ridge-trough couplet over western and eastern Canada, respectively, resulted in a generally mild winter over the northwest and a colder than normal winter in the northeast.

Temperature departures during December were above normal over the West and below normal over the East. The Yukon and the northeastern corner of the Northwest Territories recorded temperatures 6°C above normal after a number of weather systems pumped mild Pacific air into these regions. In the eastern half of the Northwest Territories, strong winds and cold temperatures created extreme wind chills on a number of December days. Most of Ontario experienced its coldest December since 1985.

Temperatures were above normal south of 60°N during January especially over the Prairies, and in southern Ontario, which experienced the mildest January since 1950: Windsor led the way with the warmest January since records began in 1940. It was bitterly cold over Baffin Island, and although the northern Yukon was only 2°C below normal for the month, numbing-cold weather made the news as temperatures plunged to −50°C. However, major Pacific storms did push some stations above the freezing mark. On the Prairies, the significant January feature was the blizzard-like conditions at the end of the month. An intense Arctic front dropped temperatures 10 to 15°C within an hour at many places, and an incredible 21°C at Lethbridge.

During February, the Yukon and the western half of the Northwest Territories recorded temperatures well above normal, with the extreme northwestern corner of the Territories ending the month 16°C above normal. Winter seemingly arrived elsewhere across Canada. Numerous B.C. stations recorded their coldest February ever, and the southern half of the Prairies were cold. Below normal temperatures made their first sustained impact in southern Ontario. The Maritimes had the coldest February since the late 1970s.

PRECIPITATION

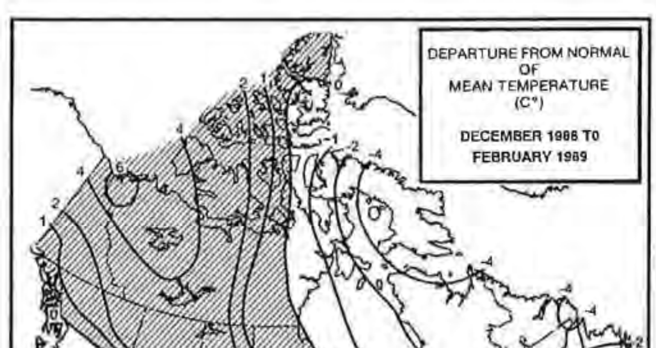
Precipitation was generally below normal the last 3 months except for a swath extending from the High Arctic through Keewatin District to northwestern Ontario. Newfoundland was slightly above normal.

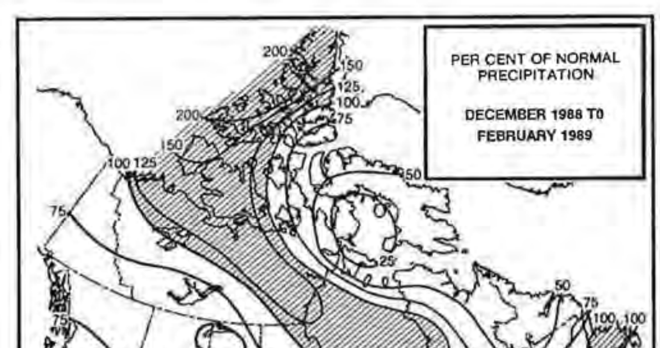
The highlight during December was the light precipitation especially over eastern Canada. Some concerns arose over the lack of precipitation in central and western Saskatchewan where the snowfall was well below normal, and in some areas of Alberta, where the seasonally accumulated precipitation amounts were 30 to 50% of normal. In Toronto, the first measurable snowfall occurred on December 9 – the second latest start of snow in 150 years. A number of stations in Quebec and the Maritimes also set records for the least amount of precipitation in December.

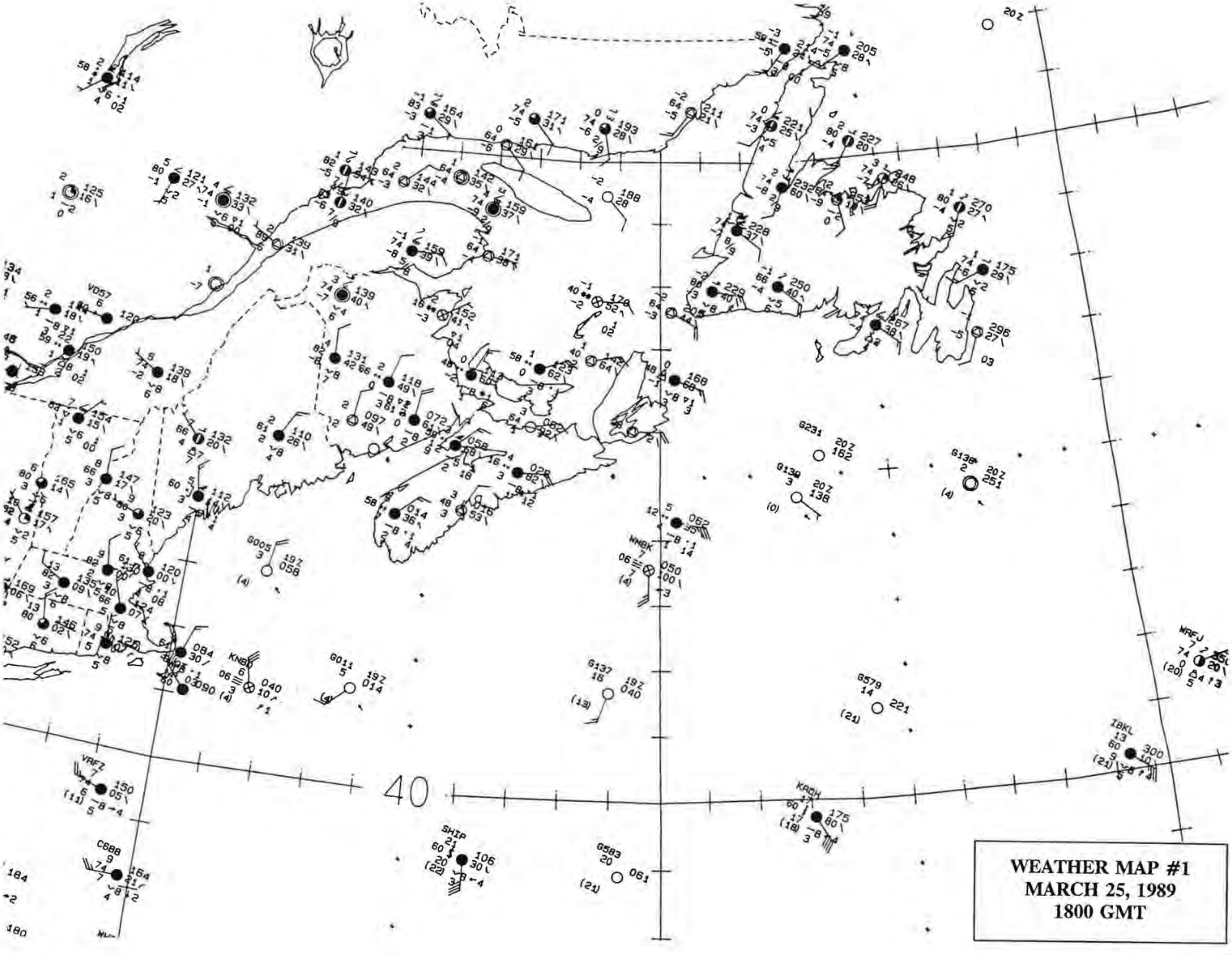
In January abundant precipitation was recorded in the mountain passes of the Yukon, along the B.C northern coast, in the southwestern foothills of the Rockies, and in Newfoundland. Light precipitation continued in the northern and central Prairies, where some areas recorded less than half their normal snowfalls. It was drier than normal in southern Ontario, – the Kingston area was the driest since 1933 – eastern Quebec, Labrador and the Maritimes.

February was bone dry in many sections of Canada.

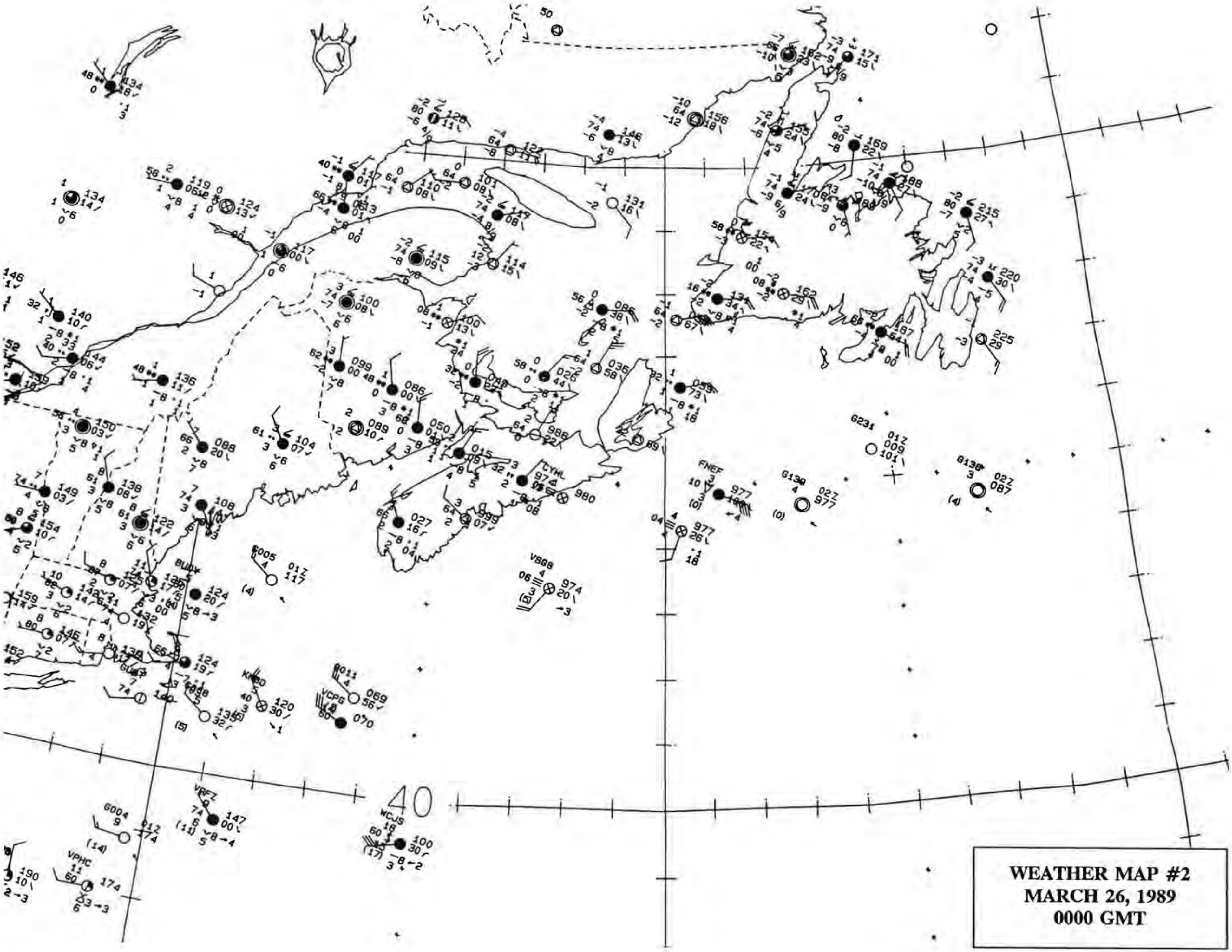
Continued on page 42



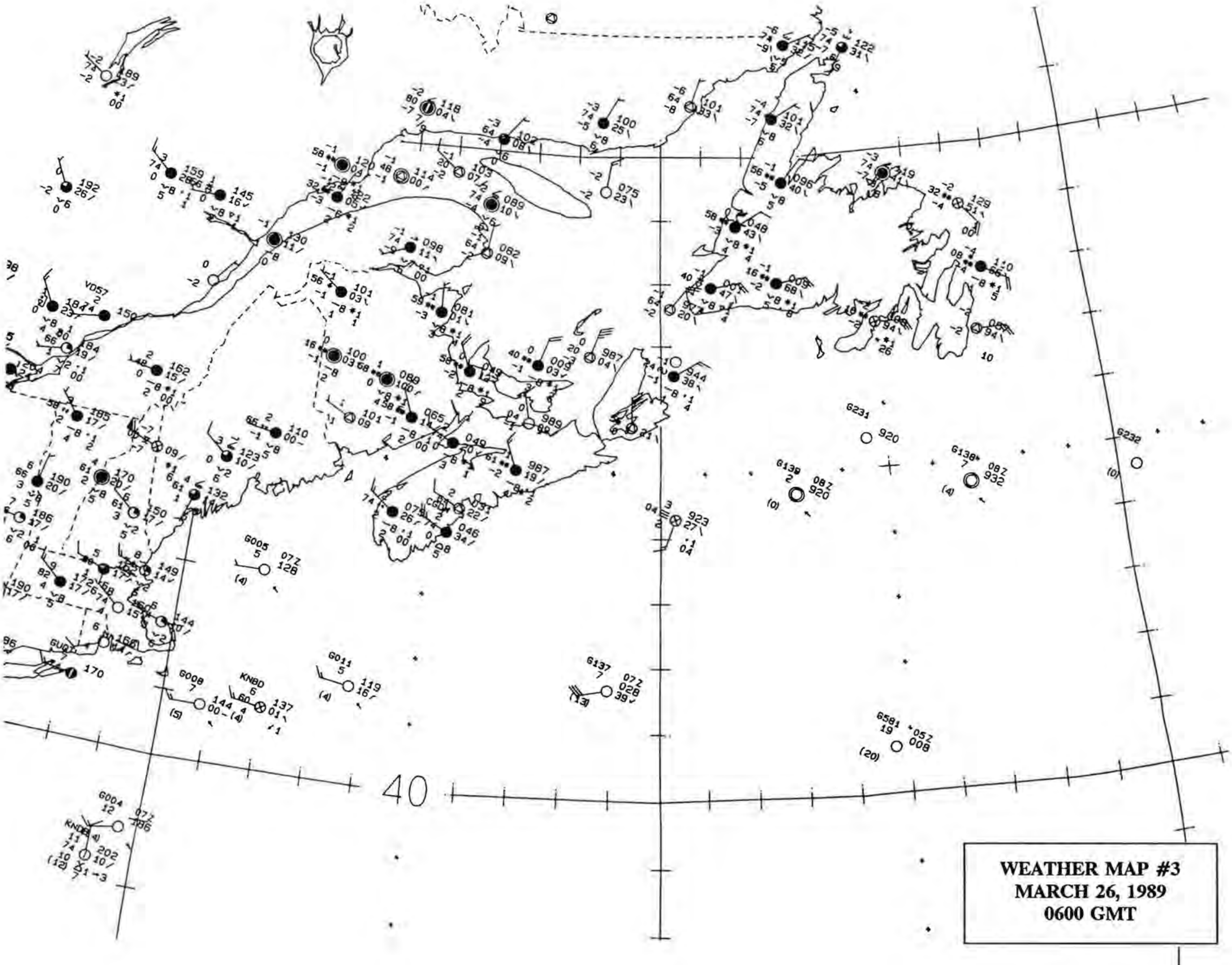




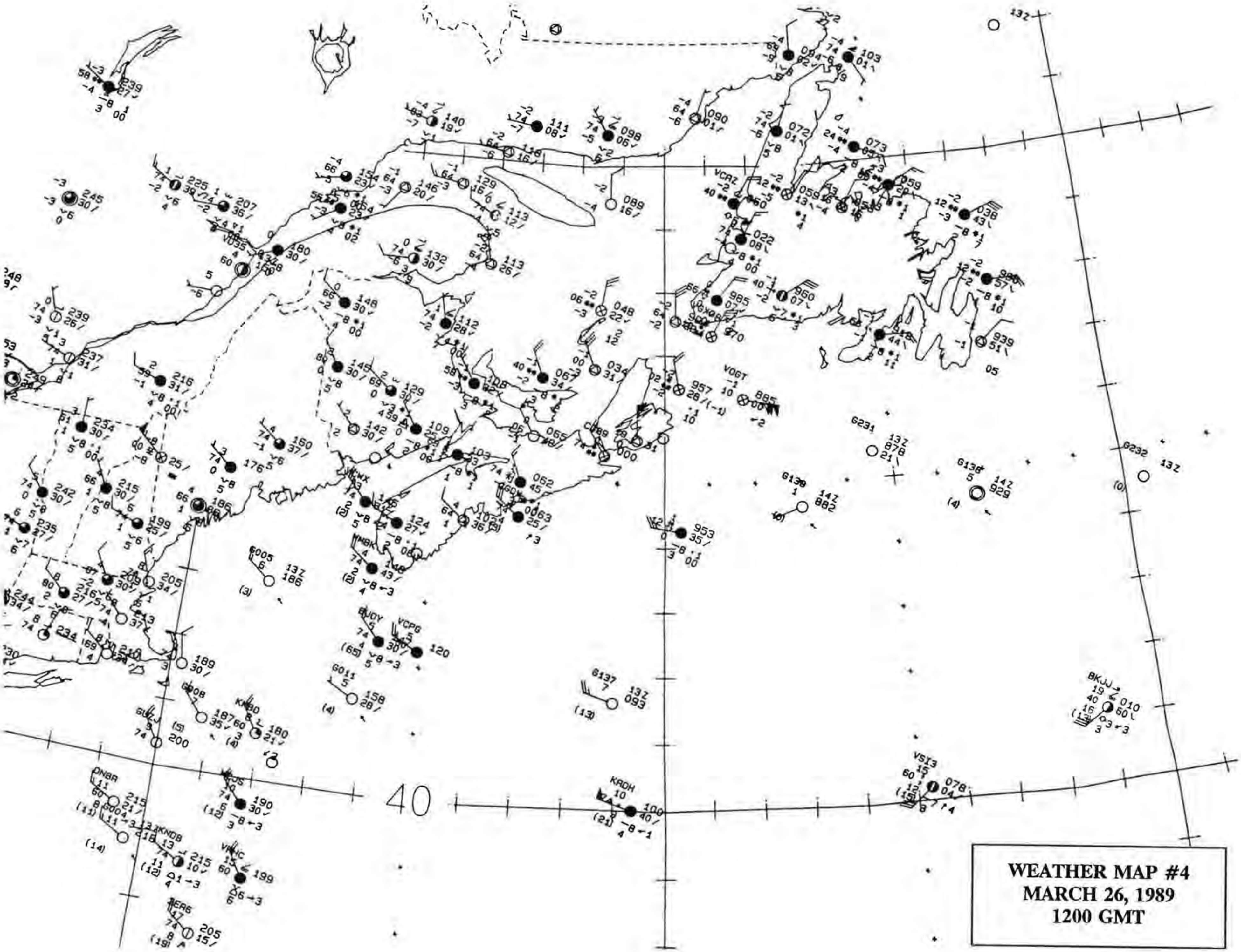
WEATHER MAP #1
MARCH 25, 1989
1800 GMT



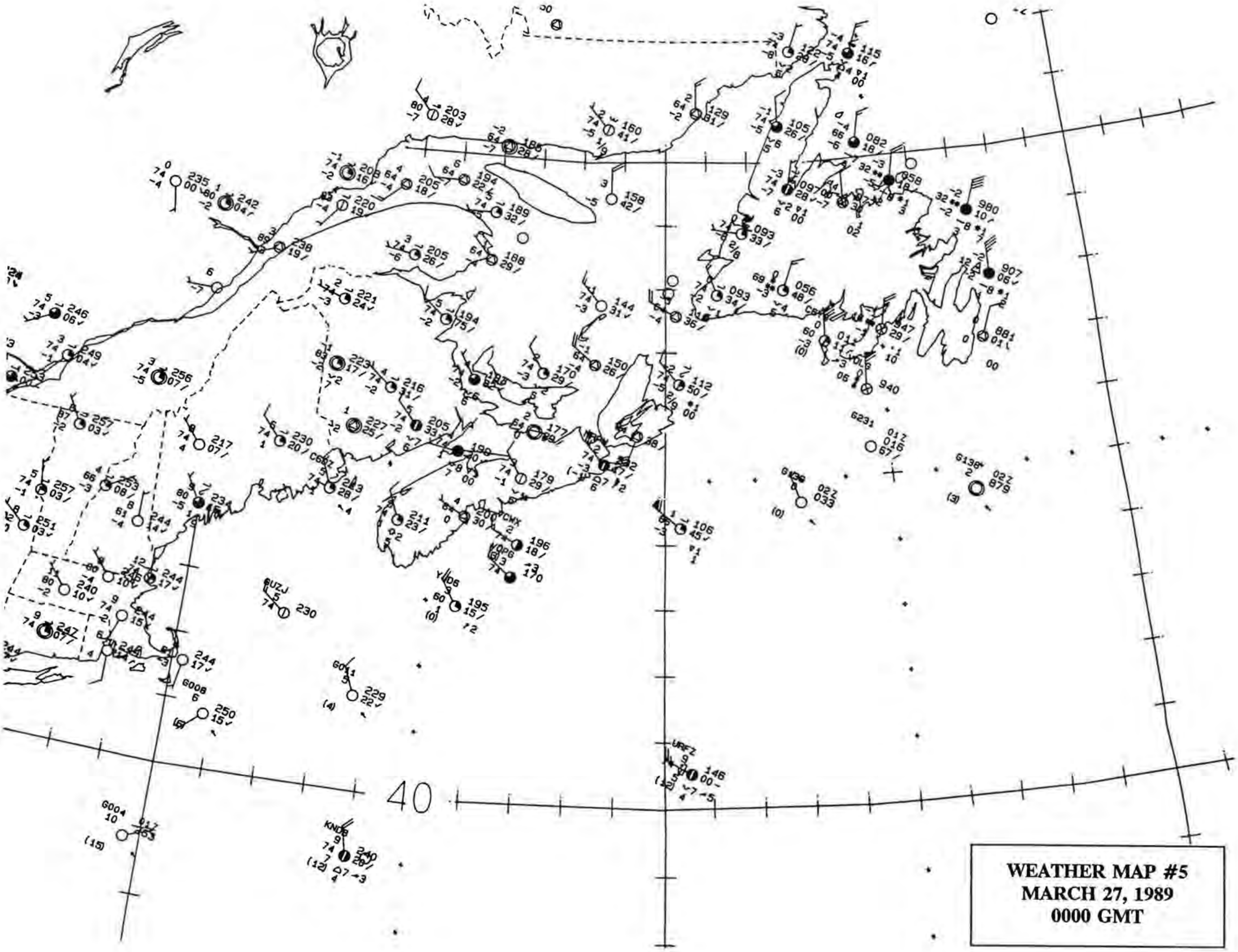
WEATHER MAP #2
MARCH 26, 1989
0000 GMT



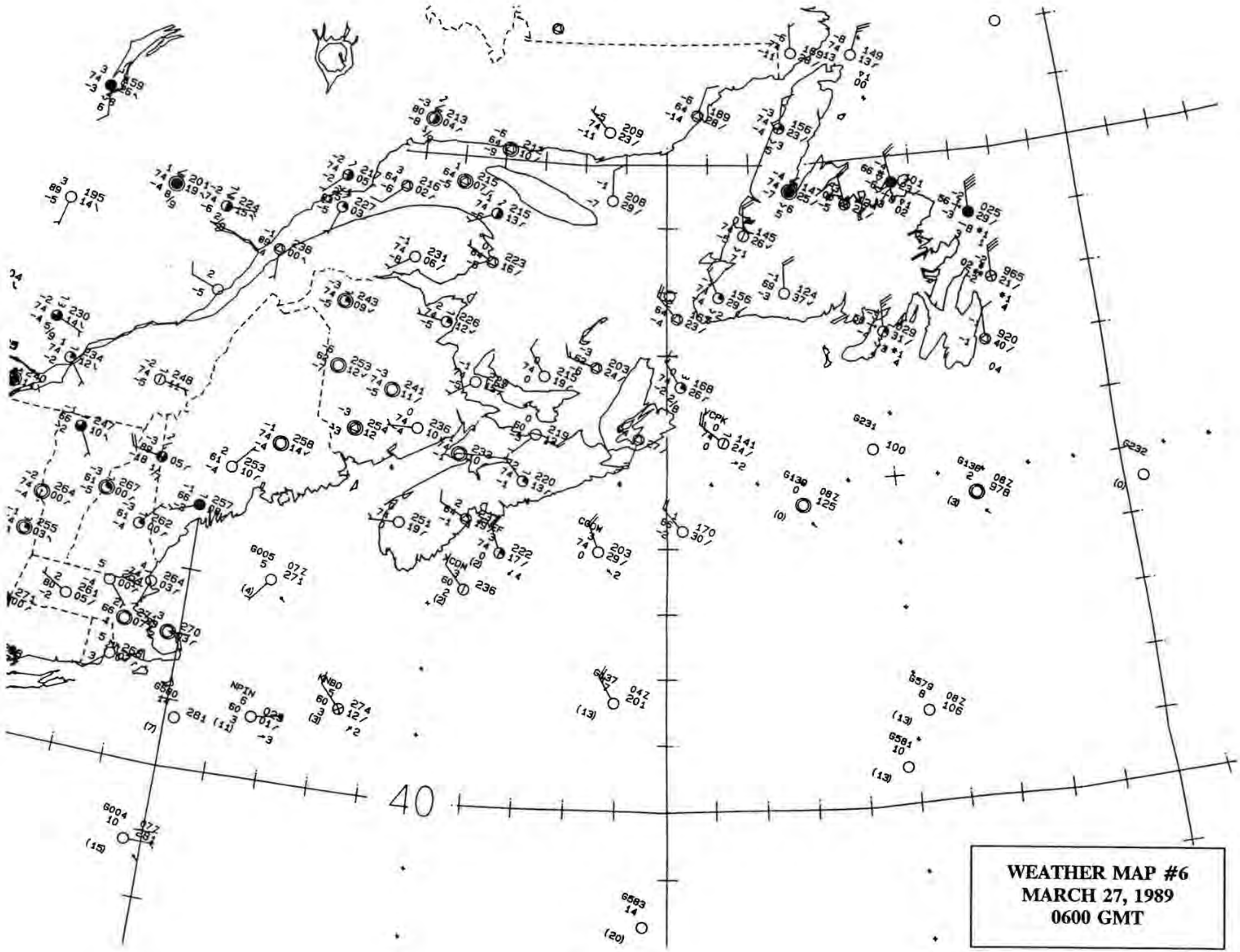
WEATHER MAP #3
MARCH 26, 1989
0600 GMT



WEATHER MAP #4
MARCH 26, 1989
1200 GMT



WEATHER MAP #5
MARCH 27, 1989
0000 GMT



WEATHER MAP #6
MARCH 27, 1989
0600 GMT

DOPPLER RADAR LOOKS FOR THE ILL WINDS

by Thomas Nichols and Clifford Crozier

RADAR – an acronym for RAdio Detection And Ranging is old hat. Its intense development took place some 50 years ago as a remote sensing device to detect and locate hostile aircraft at a long range. It was soon realized that storm clouds could also be detected by radar and over the past 30 years weather services around the world have steadily increased their acquisition of radar systems to help them observe, diagnose and predict the weather. Weather radars can locate and follow precipitating clouds within a nominal range of about 200 km and provide a measure of the rain or snow intensities. A most important application has been the ability to locate and warn of the more severe storms that can seriously impact on the daily life of the public. Improvements in technology and years of study have shown that it can also provide the weather forecasters and the research scientists the means of studying the less intense storms as well.

So what's a *Doppler Radar*? Doppler radar provides an additional dimension to weather observations – the means of measuring the velocities of weather targets. The motions of these targets made up of millions of small water drops or snowflakes are used to estimate the air motions that are an integral part of storm development. The observation and understanding of the movement patterns while they develop and change will ultimately lead to more timely and better weather forecasts. Although the principles of the Doppler phenomenon were first expounded by the Austrian physicist J.C. Doppler some 150 years ago, it has been the great advances in computer technology hand-in-hand with radar that have led to the recent excitement in applying Doppler radar techniques to weather analysis and forecasting.

RADAR AND THE CANADIAN WEATHER SERVICE

The Atmospheric Environment Service (AES), which is the national weather service of Canada, has had a weather radar network covering much of the densely populated areas of the country for many years. The Cloud Physics Research Division of the AES designed and developed a Doppler weather radar system as part of its research program in the physics of precipitation and severe weather, such as thunderstorms, tornadoes and strong winds. It was installed at the King Weather Radar Research Station, located near King City, Ontario (a short distance north of Toronto), in the spring of 1985 as a prototype system. The primary mandate for the facility is research, but the first results of the developments were so spectacular that an operational program was rapidly constructed to transmit the Doppler radar analyses of the observations immediately to the main regional forecast office for the area, the Ontario Weather Centre (OWC). Figure 1 shows the building and tower topped with the fiberglass radome that houses the rotating antenna at the Research Station.

Doppler radar provides a great deal of additional information on mesoscale meteorological phenomena – that is, weather features with horizontal dimensions of a few kilometres to a few hundred kilometres. For example, warm and cold fronts, and large convective complexes that often spawn the severe storms of summer are features that are often inadequately analysed because key features can slip through the standard meteorological observing networks.

Figure 1 The AES Weather Radar Research Facility at King City showing the laboratory and the antenna tower and radome.

Although Doppler radars are useful for observing weather in all seasons of the year in our northern climate, this article will concentrate on the strides made towards the early recognition of severe summer convection. A proper interpretation of the Doppler radar observations can provide a useful insight into the structure of these convective storms and the factors that may be used to better predict the severity of local summer storms, particularly those that too frequently cause significant damage to life and property.

RADAR OBSERVES THE WEATHER

Most weather radars operate as pulsed radars, i.e., a short burst of energy at radio frequencies is transmitted, then the system "listens" for the signal that returns if it has encountered a target. The most usual target of interest in meteorology is nominally a heavy cloud consisting of raindrop- or snowflake-size particles. Since the radio waves travel at the speed of light, a measure of the time interval between transmission and reception of the energy allows the distance to the target to be calculated, i.e., the range is determined.

An antenna with a parabolic dish or reflector is used to concentrate the transmitted pulses into a narrow beam similar to the beam from a searchlight. The same antenna is most often used to gather the energy returned from any target during the listening period. By sweeping the antenna through 360° of azimuth, and also elevating the antenna in an appropriate observing program a spatial plot of all the targets can be made, i.e., the pointing direction of the antenna defines the direction to the target.

Although the idea sounds simple the practical application of the technology is quite complex because of a number of factors, i.e.:

- The energy is transmitted for 2/1,000,000 second and the listening period is less than 4/1000 second – extremely short periods. The accuracy of measurement of these very short time periods is extremely important. For example, the energy wave travels at 300 million metres per second and an error of only 1/1000 second would result in an error in positioning of 150 km.

- The power of a transmitted pulse is 260 kilowatts (kW) whereas the returned power is less than 10^{-11} kW (i.e., less than 0.00000000001 kW) – very low levels for detection.
- The transmitted beam gradually spreads with increasing distance from the radar transmitter, as the light from a searchlight does – tending to diffuse the target and decrease small target detectability.
- The "target" is not a single large object, such as an aircraft, but rather a large collection of particles (rain, snow or hailstones). To obtain a meaningful signal value (called reflectivity) under these conditions, each target must be sampled or pulsed at least 25 times and the results averaged somehow.
- The radar beam is refracted or bent and absorbed while passing through the different temperature and moisture gradients and intervening precipitation in the atmosphere – tending to alter the target position slightly and decrease its detectability.
- The returned energy depends on the size and composition of the target, the portion of the transmitted beam that is actually intercepted by the target, and the distance of the target from the radar. Although liquid water reflects much more power than the same mass of ice does, a snowflake can partially melt or accrete many tiny drops from collisions and confound the measurements. Wet and dry hailstones present another complication. A meteorologist must interpret the results in the light of such conditions.

In spite of all these factors the radar is used quite successfully to detect, locate and track weather targets and to give an indication of the intensity of the precipitation – the reflectivity or precipitation rate.

DOPPLER RADAR ADDS THE WINDS

A Doppler radar not only observes and measures the precipitation, but also provides a measure of the velocity of the particles from which air motions can be estimated. The reflections of the pulsed bursts of energy still depend on the numbers and composition of the targets, but if the radar electronics can accurately keep track of the phase of the transmitted pulse frequency, then additional information can be calculated if there is any change in phase in the returned signal. This change in phase or Doppler frequency shift provides the information needed to determine that component of the target velocity that indicates motion directly towards or away from the radar. This is the well known "Doppler effect" and was first discovered during the study of sound waves.

To explain what is meant by a "Doppler frequency shift" think of the sensation perceived by an observer standing beside a railroad track when a train approaches and passes with its horn sounding. While the train approaches and passes, the stationary observer notes a drop in the pitch of the sound. The effect is more noticeable if the train is moving faster. Although the sound wave actually produced by the train doesn't change, the motion of the train first towards then away from the observer causes the shift in frequency for the observer.

A Doppler radar uses the same principle applied to the microwave frequencies of the radar. However, determining a "velocity" from all of the precipitation particles that are found within the radar beam is an even more complex task.

In the King City system the radar operates at a wavelength of 5 cm, which is equivalent to a frequency of 5,600,000,000 Hz (Hz or Hertz – a unit of frequency equal to 1 cycle per second). At speeds common in the atmosphere for everyday weather situations, say 35 km/h, the Doppler shift is only 400 Hz. This represents measuring a change in frequency of 0.000007%. This measurement is also being made for a new set of targets as often as every 0.0000016 second. Fortunately this small change in frequency (shift) can be determined if the change in phase can be measured, which is a slightly less difficult task. Nevertheless, the equipment to determine the change in phase must be of a high calibre and well maintained if the calculated target speeds are to be realistic.

As in measuring the precipitation intensity, there are several factors that further increase the complexity of measuring the velocities:

- The signal returned to the radar is from a conglomeration of particles of different sizes each moving somewhat independently of the others. Thus the returned signal contains a spectrum of velocities. Larger drops return more power than smaller drops do, so that the velocity estimates will be biased by that of the large drops to some extent.
- In normal circumstances and applications the best estimate of the velocity is obtained by some form of averaging. This requires a substantial amount of computer power to continuously keep up with the changing patterns during stormy weather. Velocity samples must be obtained almost instantaneously before the wind field changes like those that occur in a turbulent atmosphere, and before the scanning antenna has moved appreciably to view a different part of the storm. There are inherent limits, however, both in speed of velocity sampling and in antenna movement.
- The smallest mesoscale feature that can be measured is determined by the antenna beamwidth and the length of the pulse in space. The velocity estimate is made from an averaging of samples (i.e., pulses) in time and space, and the larger the volume the greater the spread of the particle velocities and the greater the smoothing of the velocities, to the point that small-scale features will be undetected. A narrow beam of short pulse length gives the greatest resolution.
- In the Doppler mode there are limits to the maximum range and the maximum velocity that can be determined without ambiguity. The limits depend on the wavelength of the radar and the pulsing or sampling rate. Unfortunately the dependency on the pulse repetition rate (PRF) works adversely in opposite directions. To optimize the Doppler radar performance it is usual to increase the PRF to maximize the measurable velocity range and to decrease the pulse length in order to increase the spatial resolution and to keep within the radar total power output limits. The King radar is pulsed for 0.5 millionth of a second, at a rate of up to 1200 times a second.

DOPPLER RADAR INFORMATION DISPLAYS

After the Doppler radial velocities have been acquired the information must be displayed in a form that can be readily interpreted. Many will be familiar with the very common display that has been used for years – the Plan Position Indicator, or PPI as it is known. In this display the targets are shown in a plan view, that is, they are located on a horizontal surface, usually a map, in their true geographic relation with respect to the radar. In the case of "conventional" radars the intensity of the target is usually displayed in colours or shades of grey. Although many other display

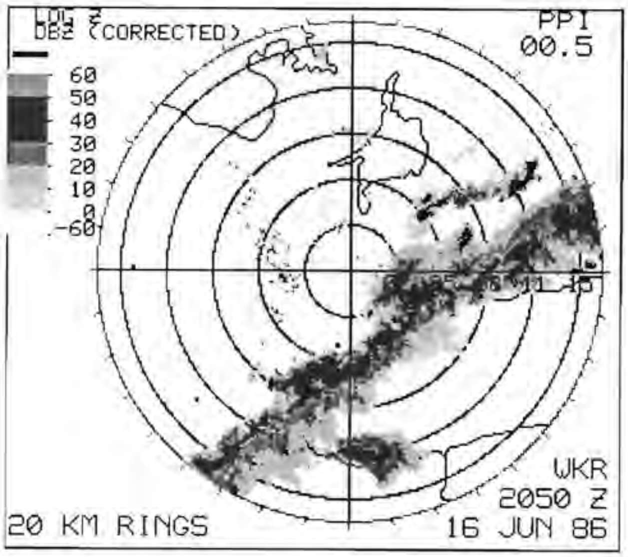


Figure 2 A PPI radar reflectivity image of a summer frontal storm. The radar is at the picture centre with range rings displayed at 20 km intervals. The precipitation is mapped in colours with increasing intensities according to the colour-intensity scale in the upper left.

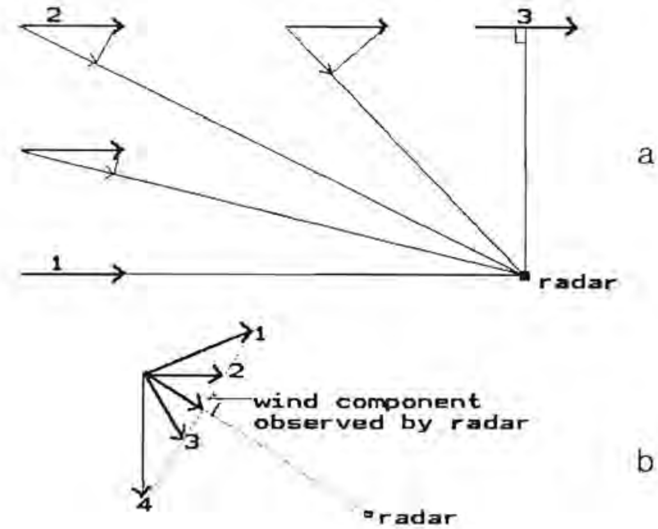


Figure 3 Doppler measurements of the wind.
a The radial velocity component of true winds. West wind vectors are displayed as heavy arrows. Lighter arrows represent the radar radial velocity components at 5 different azimuths. At arrow 1 the winds are equal.
b A family of wind velocities with the same radial velocity component. Many wind vectors can have the same radar radial velocity component.

formats have been used, this one has proved the most popular and most understandable from the average user's standpoint and packs a great deal of information in a concise form.

Figure 2 is a PPI illustration of the precipitation intensity display from the radar observations. Within the radar viewing area (within a range of 220 km, or 110 km for Doppler displays) the precipitation targets are displayed in colours representing varying intensities corresponding to the scale in the upper left-hand corner, overlaid on an outline of the geography (mainly lakes and a few key observing stations) in the southern Ontario area. It is readily apparent where the precipitation is occurring and where the intense areas are located. While new information continuously updates the picture every 10 minutes the movement and the development of the storm areas can easily be followed and their future progress predicted.

For a broad view of the velocity information the PPI format has proved to be equally useful for communicating a vast amount of technical information for a large area in a limited time. It should be emphasized that each measured velocity is a radial velocity, i.e., it is only the velocity component of motion directed towards or away from the radar. In the Doppler radial velocity displays, the targets are shown in their correct relative locations and the radial velocity magnitudes are indicated in up to 32 shades of colour representing 32 velocity class intervals. However, they can be recorded with much greater fidelity for more intensive analysis and research studies.

Other information that is a by-product of the velocity calculations are the velocity spectral width, which loosely can be interpreted in terms of turbulence or wind shear in the atmosphere; and the signal strength with regard to background noise, which is some measure of the reliability of the measurement. These have also been displayed in a PPI format.

Having obtained the Doppler velocity display the next step is to interpret the picture in terms of readily understandable meteorological structures and processes. The interpretation is more complex than for the usual precipitation intensity picture, but with experience and some readjustment in pattern conception the process becomes easier. A good grasp and firm understanding of what is being viewed in the picture is essential.

INTERPRETING A DOPPLER RADIAL VELOCITY PATTERN

It must be constantly kept in mind while attempting any interpretation of the velocity displays that the velocities are radial velocities with respect to the radar site, i.e., velocities directed away or towards the radar. Figure 3a illustrates the variation in the radial velocity that would be observed when measured at different viewing angles (radials) for a wind of constant speed and direction. At point 1 the wind is directly towards the radar along the radial and is therefore equivalent to the (whole) wind. At point 2 the radial component is only about 9/10 of the whole wind, and at point 3 there is no component towards or away from the radar.

Figure 3b portrays a few of the infinite number of possible winds that could produce the observed radial velocity. The trick in interpretation is to visualize in the mind the likely wind structure that would produce the radial velocity pattern observed and how this relates to the actual weather.

Several other points should be kept in mind when making an interpretation:

- The viewed surface in this type of display is not a completely horizontal surface, but is conical. While the straight beam that is pointed in a slightly elevated position moves away from the radar site it increases in altitude above the earth's surface (see Figure 4). The height of the radar beam (in hundreds of metres) under standard atmospheric conditions of refraction is marked at several ranges along the line running east from the radar (e.g., see Figure 5a). This corresponds to the eleva-

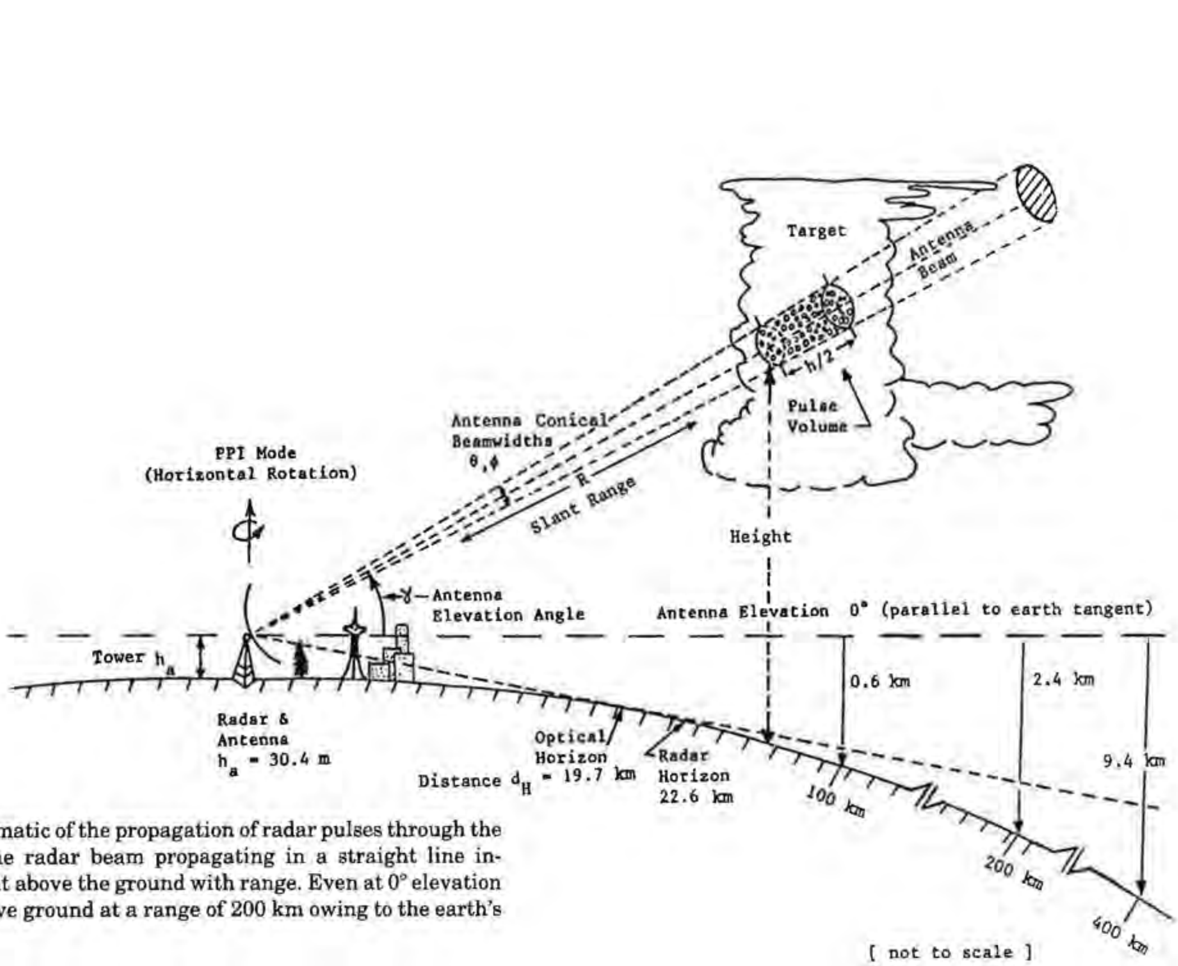


Figure 4 Schematic of the propagation of radar pulses through the atmosphere. The radar beam propagating in a straight line increases in height above the ground with range. Even at 0° elevation it is 2.4 km above ground at a range of 200 km owing to the earth's curvature.

tion angle of the antenna provided in the upper right-hand corner of the display.

- As a corollary, in a PPI velocity display each annular range ring represents a wind at a different altitude that is dependent on the elevation angle. The range on the display is therefore very much related to altitude and this fact is used to determine vertical wind profiles. Characteristic patterns in the PPI display will be indicative of characteristic wind patterns in the vertical.
- The colour scheme adopted for the display uses the warm colours (reds) for velocities directed away from the radar and cold colours (blues) for those directed towards. As a memory aid remember: RABT (or rabbit), for Red Away, Blue Towards.

There are an infinite number of radial wind patterns that may be observed. Even the simplest of wind fields can show a complex pattern at first sight, but the pattern is clearly conveying a significant message about the winds in the radar viewing area. Figure 5a is the theoretical pattern that would result if the winds were west (270°) and of constant speed (20 m/s) with height, assuming the targets filled the full display area. Figure 5b shows the pattern that would result if the winds were westerly at about 1 m/s at ground level (the radar site), southwesterly about 25 m/s at an altitude of 2 km, and southerly about 20 m/s at 3 km. The reverse "S"-shaped pattern in the contours is characteristic of a wind that backs with altitude. The closed contours around a high wind zone (green and purple areas) indicate the wind speed increases with altitude to a maximum, then decreases, and a confined core of high winds or a jet exists. The alignment of the high-wind couplet (the away and towards radial-wind maxima) determines the direction of the jet. Winds in the real atmosphere most frequently vary a great deal with height and within the viewing area of the radar; therefore interpreting the observed patterns is a challenge.

Figure 6a is a PPI velocity image produced when an area of light snow crossed the radar viewing area. The pattern is fairly symmetrical about the radar, i.e., about the centre of the image. The symmetry implies that the wind field is reasonably uniform over the observation area at any one height, and only small changes in direction and speed occur with height (i.e., range from the radar). The characteristic "S" pattern is indicative of a wind veering with height (and the greater the curvature the greater the veering).

This image can be used to illustrate the technique for determining and visualizing wind profiles. The "S"-shaped boundary between the red and blue shades represents a line of zero radial velocity, i.e., the wind is blowing neither away from nor towards the radar but is tangential to the radar site. An altitude scale (in hundreds of metres) for the radar beam (PPI elevation 0.6°) is placed on the image along a line to the right of the radar location. To determine the wind at an altitude of 1 km, the scale is used to obtain the range where the beam is at this altitude. The beam is at 1-km altitude at a range of about 70 km. As illustrated graphically in Figure 6b, a circle of radius 70 km intersects the zero radial velocity contour at azimuth angles of about 160 and 340° where the wind direction is tangential to the radar site or is normal to the beam azimuth. The wind direction is therefore from 250°, since the 180° ambiguity is resolved by noting the general towards-away flow of air in the pattern.

The wind speed is determined by noting the radial velocity on the 70-km circle (Figure 6b) at the azimuth normal to the radar beam (i.e., 250°). The speed at this point would theoretically be a maximum for this altitude. In Figure 6a it will be noted that this area is devoid of radar echo, but it can be estimated by interpolating or by referring to the velocities at the mirror image azimuth that the speed is between 12 and 18 m/s.

Figure 7 is a real image from a synoptic-scale winter storm. Precipitation is occurring over a broad area. Winds at

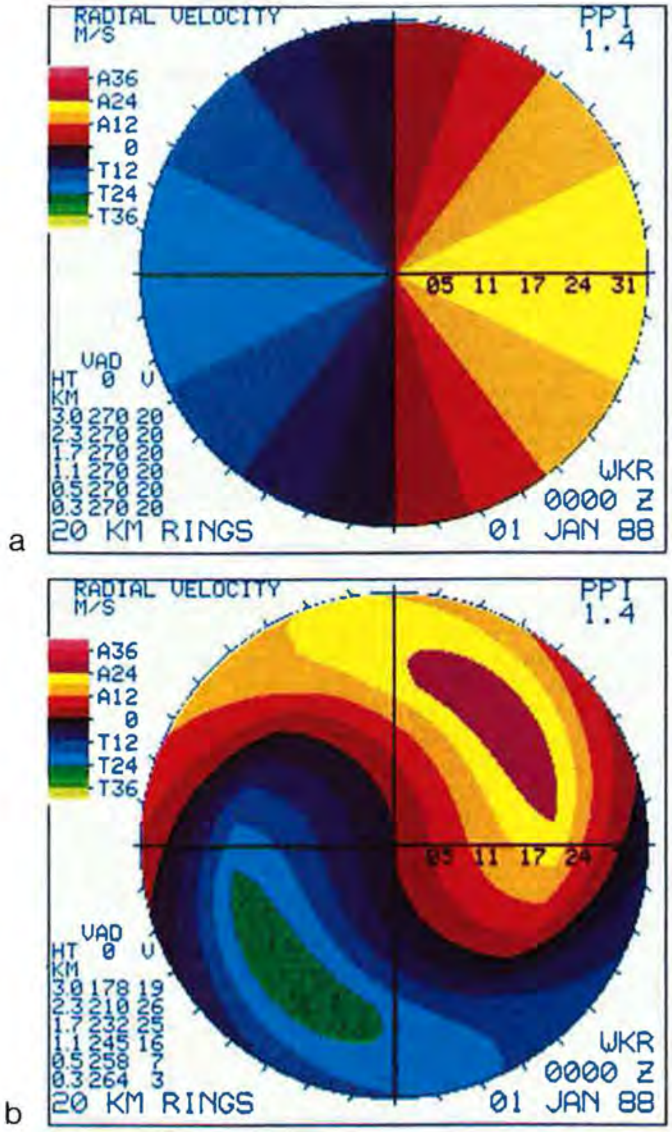


Figure 5 Theoretical patterns of radial velocities in PPI format assuming the display is filled with precipitation echo. The VAD (Velocity Azimuth Display) table in the lower left gives the wind direction and velocity with height that has been automatically calculated by the computer for the pattern.
a West wind having a speed constant with height.
b West wind backing and increasing in speed with height, then decreasing.

the surface (near the cross-hairs at the radar site) are easterly and quickly increase with height to more than 12 m/s. Above 1.5 km, the wind shifts abruptly to southwesterly and the speeds increase to 30 m/s at 3 km. The apparent "holes" in the pattern, located on the wind shift at the (diagnosed) frontal surface, occur because the data processor producing the display has determined an average velocity near zero. Thus the top half of the radar beam is in the warm air above the frontal surface while the bottom half of the beam is in the cold air viewing winds that are almost diametrically opposed in direction and speed. The Doppler observations reveal a mesoscale pattern of the storm structure that is not obtainable by other means; furthermore any changes can be monitored on an almost instantaneous

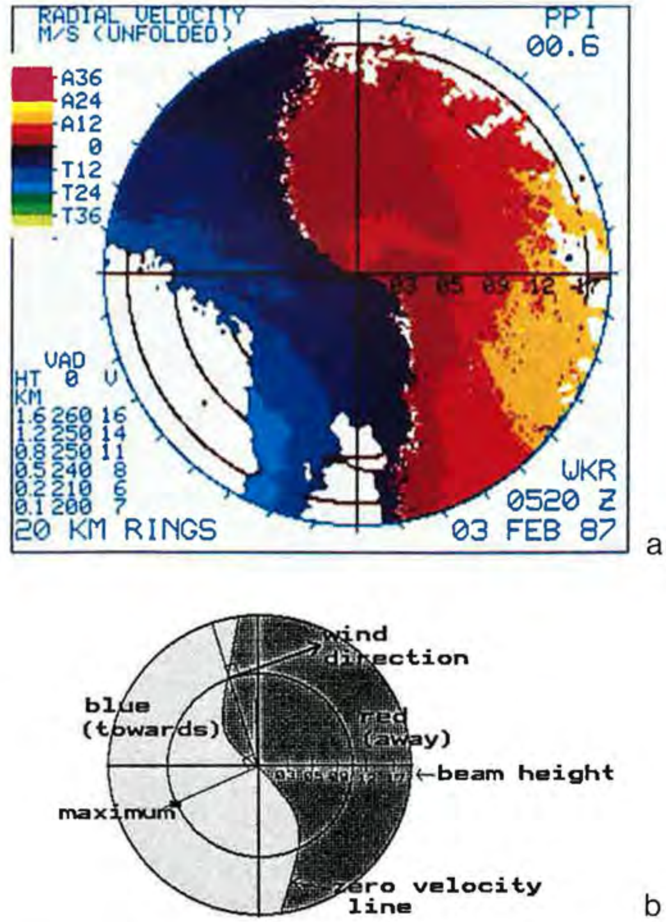


Figure 6 Interpreting the PPI radial velocity radar images.
a Radial velocity image of a winter storm.
b Determining true winds graphically. See text for a description of the technique.

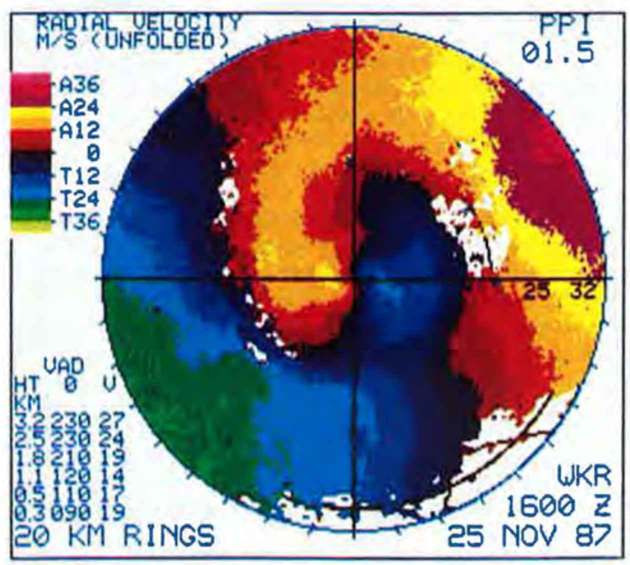


Figure 7 The complex PPI radar radial velocity image of mesoscale patterns in a synoptic-scale winter storm with widespread precipitation.

basis. The pattern identifies the altitude where an abrupt change in wind is occurring that might pose a threat to flying aircraft and that in other circumstances could identify a freezing rain situation.

DOPPLER RADAR AND SEVERE SUMMER STORMS

Figures 5, 6 and 7 are illustrations when the wind field is fairly uniform over the range of the radar. However, summer convection that leads to some of the severest and most damaging storms in the region is usually quite isolated. These storms are capable of generating their own wind fields. The winds around these storms can therefore be much different from the broad-scale synoptic circulation. Although the Doppler images are much more difficult to interpret they provide clues on the development that are not available from any other observation system. Recognition of these clues or "signatures", as they are called, is particularly important in the early detection of potential tornadic thunderstorms. These are referred to as TVSs – "Tornado Vortex Signatures". The dangerous part of the life cycle of these storms is often only 30 minutes to an hour long, but may be much longer on occasion. Under certain circumstances rotational wind patterns begin to form 20 to 30 minutes before tornadoes develop and are a tip-off that hazardous weather is imminent. This allows severe weather warnings to be more precise and localized. The developments occur rapidly and any warnings must be communicated quickly to the area concerned, so that even advance detection and recognition by 20 to 30 minutes is of value.

Not all tornadoes are detectable by radar; in fact, many are of such a small size that unless they are very close to the radar their tight circular powerful wind vortex will not be resolved by the radar – a TVS by itself is rarely observed. But very often a precursory mesoscale circulation pattern can be observed. This (so-called) "mesocyclone" has a pattern similar to that of a tornado but has a diameter 10 to 50 times greater and much lower average wind speeds. Recognition of the mesocyclone provides advance warning of the high potential for development of very severe storms, possibly leading to tornadoes. The forecaster uses other meteorological observations, such as rawinsonde temperature soundings, to further refine the estimate of likely storm severity. The spatial resolving power of the radar is critical for detecting small-scale severe weather features. The radar beam gradually spreads as its range from the transmitter increases until at a range of 100 km it is about 1 km in width and height. Thunderstorms are of the order of 1 to 10 km in diameter and tornadoes only about 0.5 km. Features smaller than the beamwidth can only be inferred.

Not all winds causing severe damage are due to tornadoes. A tornado is one of the most severe and damaging wind storms, usually covering a longer swath along the ground, and often persisting for longer periods than other severe wind storm events. They can occur either singly, touching the ground for short periods, regenerate again, or occur with others to cover an extended narrow path over the ground. Other sudden wind storms may be due to such phenomena known as microbursts, macrobursts or gust fronts. Each has its own characteristics and life cycle, which can often be observed by radar. Doppler radar is one way of distinguishing the features that are characteristic of the different types of wind storms.

SUMMER STORM EVENTS

The Doppler radar facility has been able to detect, locate, identify and track many severe summer storms that have hitherto been undetectable or that could not be identified unambiguously by conventional radars.

Study of the medium-scale structure of convective storms led to the discovery of a rotating region in the cloud developing in the mid-altitudes of the storm. These have been called "mesocyclones". The regions nominally average about 5 km in diameter, have rotational velocities of about 20 m/s and gradually extend towards the ground. The mesocyclones are identifiable by the Doppler radar since they appear as velocity peaks of opposite sign adjacent to one another when the storm motion is removed.

Mesocyclones are often the forerunner of tornadic storms although not all tornadoes have been positively associated with mesocyclones or vice versa. However, there is ample evidence that the detection of a mesocyclone is cause for paying special attention to possible severe storm occurrences particularly if the state of atmospheric conditions determined from other information points in the same direction. A number of these events have been documented by the Doppler radar at King.

Figure 8a is the reflectivity image of a complex of thunderstorms that had exhibited the potential for development to damaging proportions. Southwest of the radar there are at least three well developed thunderstorms stretched along in a line. In two of the cells identified by dark pink circles (and annotated with the heavy black arrows), a substantial mesocyclonic circulation has been detected in the velocity field. Figure 8b is a graphic illustration of the velocity pattern that is detected in a mesocyclone by the Doppler radar. Figure 8c is the radial velocity image observed and the arrow points to the area with the most obvious rotational signature. The circulation also indicates convergence at this altitude by virtue of the orientation of the away-toward demarcation line with respect to the radar radial. This thunderstorm spawned a fairly weak tornado that touched down in Mississauga and Etobicoke with some resulting damage. It is to be noted that the extent of these patterns is very small and the mesocyclone is difficult to discern by visual inspection without careful and time-consuming study. To assist the forecaster, computers that control and process the radar data are programmed to find appropriate model patterns and highlight the positions on the display images using circles as shown in Figure 8a.

The downburst is a strong downdraft that induces an outburst of damaging winds at or near the ground. It can vary in size from less than one kilometre to tens of kilometres and may last from a few minutes to half an hour. Wind speeds of better than 200 km/h have been observed. Downburst, microburst or macroburst damage has often been erroneously attributed to tornadoes. A downburst or macroburst can also be observed with a Doppler radar.

The "gust front" is one type of downburst, i.e., a macroburst, that is commonly diagnosed from Doppler radar observations. While precipitation falls from a storm and evaporates, the air is cooled by evaporation, becomes denser (heavier) than the surrounding air and sinks towards the ground. When it reaches the ground it can only spread out horizontally in all directions to form the well known gust front – a rush of gusty cool air from a nearby thunderstorm that most people will remember experiencing on a hot summer afternoon. Figure 9a is a schematic drawing of the wind flow with the developing downburst showing how the radar can observe an area of towards-velocities with an area of away-velocities immediately to the rear.

Figure 9b is a reflectivity image of a well developed thunderstorm immediately to the west of the radar site. In the corresponding radial velocity image of Figure 9c the downburst signature is quite evident (arrow 1). Arrow 2 is directed towards a band of higher velocities associated with the gust front of an earlier downburst. These phenomena would not likely have been detected and diagnosed from radar reflectivity images alone.

Summer convective storms can be very isolated and often are not situated within observing distance of a regularly reporting weather station where they would be detected. Although often of small size and affecting only small areas they can cause extreme damage. In these circumstances a familiar forecast calls for scattered thunderstorms. Although the storms may not materialize for all areas, for some they can become very real and personally disastrous. At the present time their precise locations cannot be predicted with any degree of confidence for advance periods greater than 2 to 4 hours. For shorter periods the radar is invaluable in pin-pointing the storm locations down to the size of a county and for times within a few hours. Figure 10a portrays just such a case.

A thunderstorm less than 20 km in diameter formed in the early afternoon on the south shore of Georgian Bay (northwest of the radar). During the afternoon the storm was tracked southeastward and by early evening (0000 UTC) was approaching the area near the mouth of the Niagara River at Lake Ontario. High reflectivity values (55+ dBZ) observed (near the arrow) are the sign of a very intense storm. The high reflectivities are due to a mass of large raindrops in the "target" as well as hailstones that return a strong signal owing to their large size particularly if they are wet or covered with a thin skin of water. This hailstorm caused several million dollars damage to the peach crop in the Niagara Peninsula even though it affected only a very limited area. Figure 10b is the corresponding radial velocity image for the storm. The radial velocity and the reflectivity patterns are consistent with the thermodynamic and dynamic models that have been developed for this type of storm over many years of observation and study. A simplified graphic description of the storm model is shown in Figure 10c. The unique contribution of the Doppler facility to the observations is the strong outflow or gust front generated by the thunderstorm in the classic position with respect to the high reflectivity area and storm core. This "signature" definitely labels the storm as being locally severe.

The pictures on the front cover show the mesoscale activity associated with a large storm that tracked southeastward across southern Ontario on 17 July 1986. The images provide insight into the small-scale complexities of the wind field associated with this organized area of thunderstorms or mesoscale convective system (MCS) as it is called. The two images on the left-hand side are for the time 1310 UTC at elevation angles of 0.5 and 1.4°; the two on the right-hand side are for one hour later. Note how the winds in the northwest quadrant generally increase with an increase in height (i.e., higher elevation viewing angle).

At 1310 UTC the leading line of convection associated with the MCS is just passing over the radar site. In the area to the west-southwest of the radar note the sharp shift from blue colours (winds towards the radar) to the narrow band of red colours (winds directed away from the radar). The very sharp shift in winds defines a trough line.

One hour later, at 1410 UTC, the leading convective line is just on the southeastern edge of the display and rainshowers are occurring over most of the radar observation area. The wind maximum behind the line shows up to the southeast of the radar at 24 to 30 m/s (elevation 1.4°), while slightly lower in the atmosphere (elevation 0.5°) the maximum is directly south of the radar with a speed between 18 and 24 m/s. These images indicate there are still some missing parts to the full story. A large area with wind speeds of more than 30 m/s has entered the radar viewing area from the northwest and can be seen in the higher elevation picture (upper right-hand figure); there are likely two high-speed cores or jets in this area with a general west-northwest direction, i.e., the entry of the jets on the surface being viewed. To the southeast there is only one small area with a wind maximum of 24 to 30 m/s, i.e., the exit of the jet on the surface being viewed. There is also a small high-speed core visible on the lower elevation picture (lower right-hand figure) directly south of the radar. It is speculated that one branch of the incoming wind jet or jets begins to ascend (above the surface depicted in the picture) while the other branch is descending and curving to the right as the two interact with the storm complex.

The presentation of these few storm examples is an illustration of the types of storm analyses that can now be made by applying Doppler techniques to weather observation and forecasting. A new dimension has been added to the mesoscale observation of storms that each year cause much severe local damage. Continued scrutiny and study of these storms will unravel some of the mysteries of storm genesis and development and lead to better predicitons and local severe storm warnings.

ABOUT THE RADAR FACILITY

The first Doppler weather radar in Canada was established by the Atmospheric Environment Service of Environment Canada is 1985 at a site north of Toronto, Ontario, near King City. The primary purpose was to provide a radar facility for the continuing program of atmospheric research into phenomena associated with clouds and precipitation. The research program quickly proved that the technology could immediately be transferred with great advantage to the operational sector. A strong component of the program is devoted to understanding the characteristics and nature of precipitating and severe storms and to developing techniques to provide better forecasts and more effective weather warnings. The research team works closely with the Ontario Weather Centre at Pearson International Airport and continually provides radar observations and analysis displays to the Centre through dedicated communication lines.

A new set of radar observations and analyses are sent to the weather centre every ten minutes to keep the forecasters fully informed of the progress of storm developments. The information is viewed as a hard-copy print or as an image on a colour video screen. The video terminal gives great flexibility for rapidly recalling the information and viewing the different displays.

A network of modestly sized computers and associated peripheral equipment controls and monitors the radar equipment, processes and records the data for an archive, produces 14 different displays every 10 minutes, and transmits the information to a variety of users. In addition to the AES research branches and the Ontario Weather Centre, other full-time users include electric power utilities, conservation authorities, cable TV, private meteorological companies, highway snow clearing operators, public information agencies and other government services.

Computers are an indispensable component of the radar facility and have made it possible to capitalize on the great potential of radar observations. People instruct and run the computers, but the computers then reliably and tirelessly take over the routine operations and carry out computations and instructions at superhuman speeds. Computer software

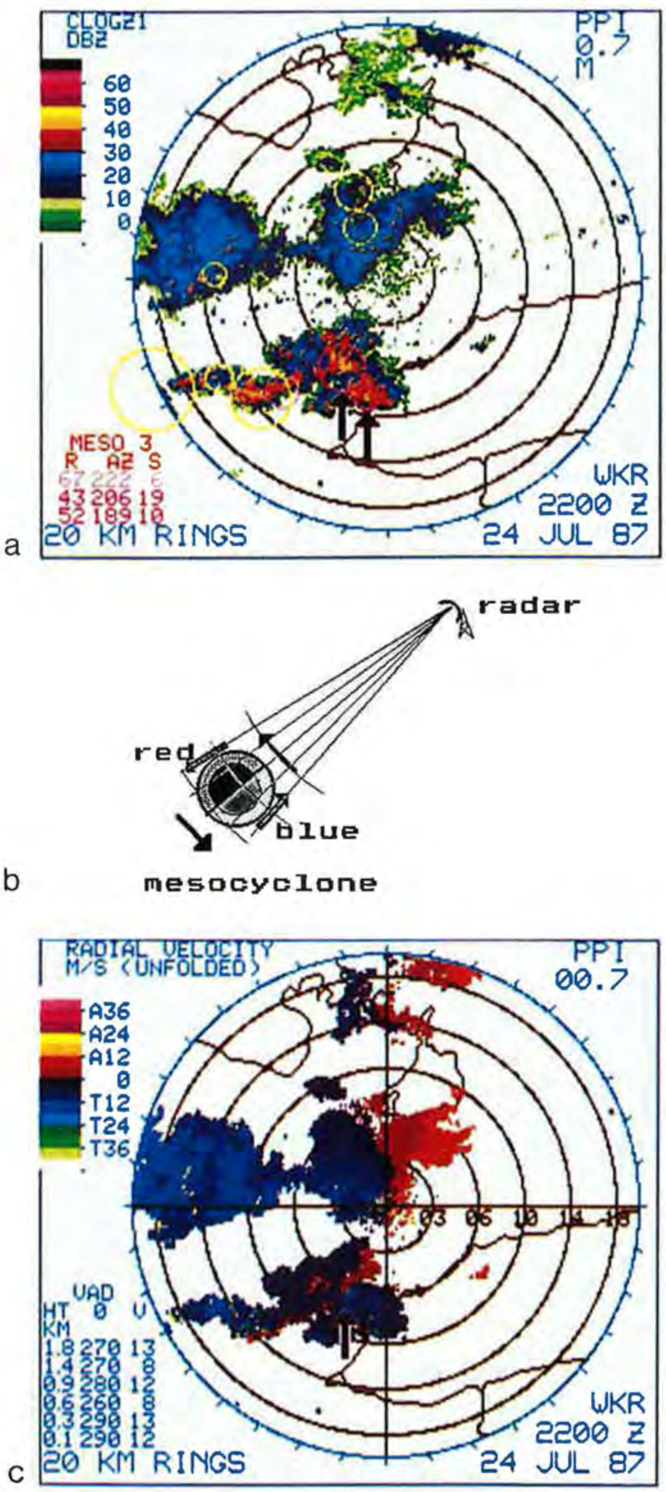


Figure 8 Doppler radar observations of a mesocyclone.

a Reflectivity image of a thunderstorm complex. The colour-coded circles identify areas where mesocyclones of varying size and intensity have been detected. Arrows point to two of the most intense mesocyclones.

b Graphic illustration of the velocity pattern in a cyclonic mesocylone. Velocities of opposite signs occur in close proximity. The solid arrows are tangential winds not measured by the radar.

c Radial velocity image of storms. The arrow points to the mesoscyclonic circulation that is most obvious.

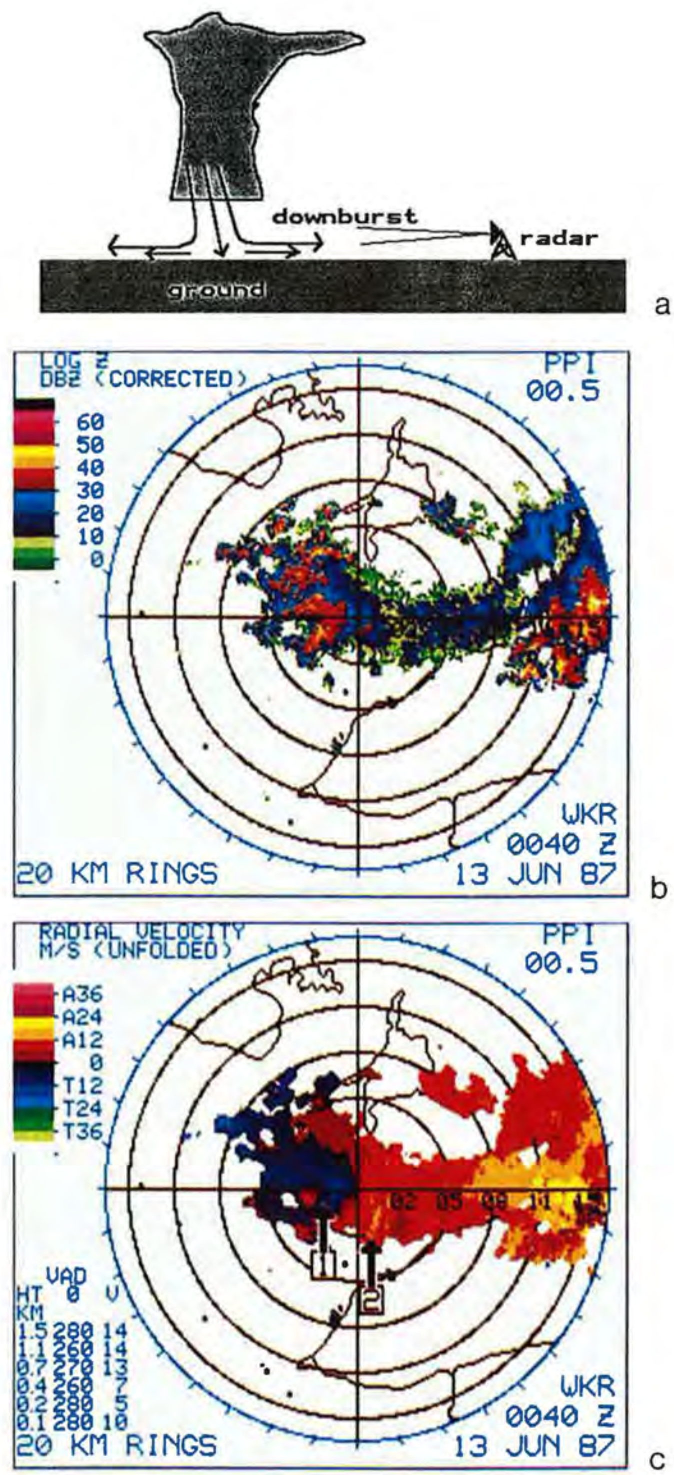


Figure 9 Doppler observations of a downburst and gust front (macroburst).

a Schematic of wind flow developing a downburst and gust front in a thunderstorm. The core of strong descending air in the thunderstorm fans out in all directions when it reaches the ground.

b Reflectivity image of a mature thunderstorm. The core of strongest activity (red and yellow) is located 10–20 km west of the radar.

c Radial velocity image showing a downburst located near the core of heaviest precipitation (arrow 1). Arrow 2 points to a gust front that occurred with an earlier downburst and has since moved away from the storm.

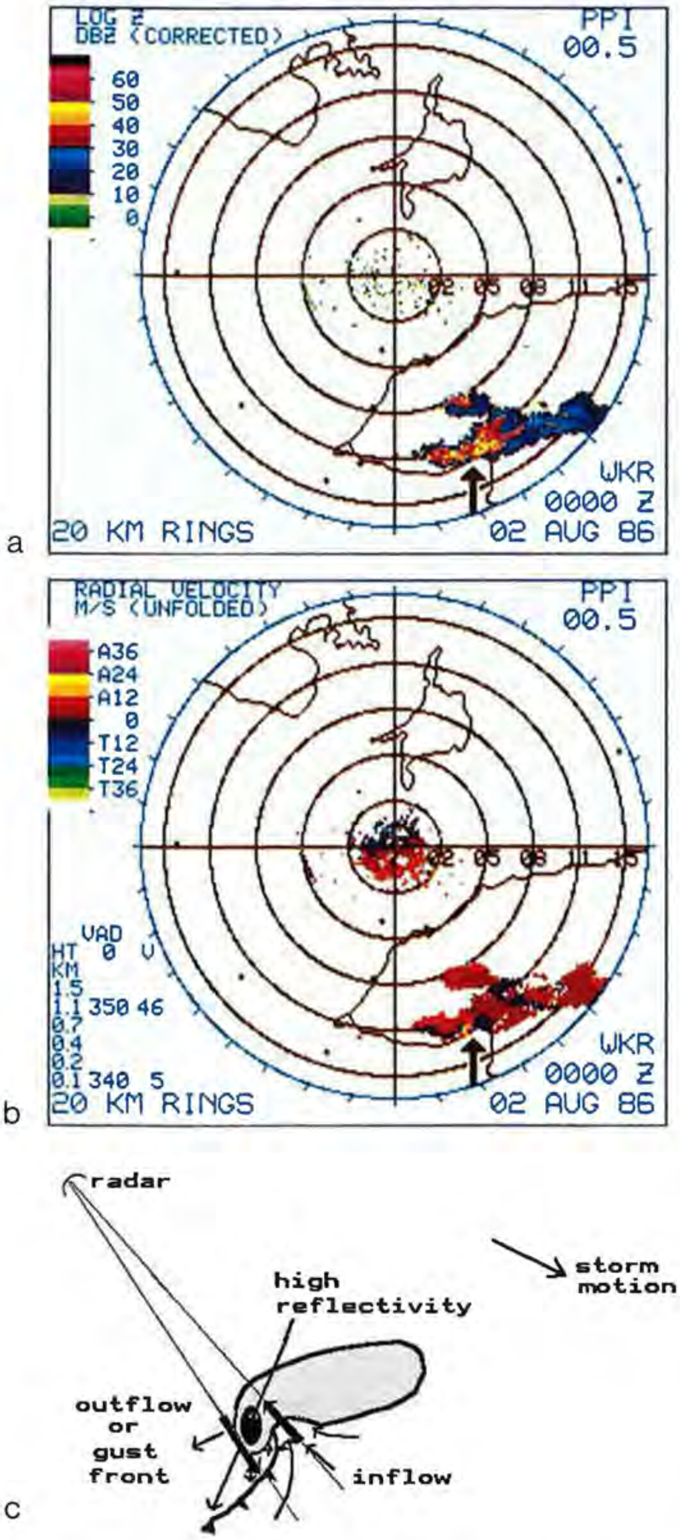


Figure 10 Isolated summer severe convective storm – "The Niagara Peach Storm". The arrow points to the main centre of activity of the damaging storm.

a PPI reflective image of the severe hailstorm.

b Radial velocity image showing the velocity couplet (away-towards).

c Graphic illustration of one model of a severe convective storm having characteristics similar to the observed storm's.

has been developed to produce the displays and manipulate them for viewing to the best advantage. For example, in day-to-day usage, areas can be enlarged for better viewing and analysis, old pictures can be recalled for comparisons, and a time sequence of pictures animates the echo motions. Objective analysis techniques using algorithms have been developed to identify mesocyclones, downbursts and gust fronts and to highlight severe storm areas.

The radar observes precipitation targets in all directions and heights of the atmosphere out to a range of 256 km from the radar site and measures Doppler factors to a range of 113 km. In the normal operating mode, the target resolution is of the order of about 1 km. The resolving power of the radar is determined by the width of the directed antenna beam (a cone 0.65° in diameter) and the duration (in time) of the radar pulse. The short bursts of energy lasting for one half or 2 microseconds are pulsed at rates of 250 to 1200 pulses a second. The radar operates in the C-band of microwave frequencies at 5600 MHz or at a wavelength of about 5 cm – a good weather observing wavelength, but a compromise that balances performance against equipment costs.

A radio direction finding station at the radar site is part of a network that provides the location of lightning strikes to ground within the radar viewing area. These observations are combined with the radar information to locate the storms that become electrically active. The information helps to further define storm severity.

The facility operates around the clock throughout the year and is automated to operate without attention outside normal daytime working hours. The personnel team who provide the expertise for research and development of the system and the operational support consists of research scientists, research meteorologists, programmers, engineers and technicians. The capital investment in equipment is significant and will be a factor in any plan for future deployment of the technology.

SUMMARY

The establishment of the Doppler weather radar facility in Canada has been an exciting new development for meteorologists and atmospheric scientists. The technology is rapidly emerging from the research laboratories to serve practical everyday meteorological needs. Doppler radar applied to a broad spectrum of meteorological phenomena in all seasons has already proven itself to be an exceptional observation and forecasting tool. There is a potential for much wider application and for growth in the technology that will materialize from continued research and experience. Progress in realizing the potential can be expected as scientists and engineers in government, universities and industry combine their collective and innovative skills.

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Clifford Crozier is a research scientist in the Cloud Physics Research Division of AES where he has conducted research in weather modification, lightning and severe storms and radar meteorology. As Program Manager and Senior Radar Research Scientist he established the AES Doppler Radar Facility at King City in 1985. He received the CMOS 1988 Dr. Andrew Thomson Award in Applied Meteorology in recognition of his pioneering work in the application of Doppler radar to meteorological analysis and forecasting. Mr. Crozier retired in 1987 after 38 years with the AES, but continues part-time with his research and in an advisory capacity at the King Research Station.

Thomas Nichols is a meteorologist with AES. In 1985, following positions as an operational forecaster and meteorology instructor, he was granted education leave for studies using the King weather radar data. Now with Training Branch, Mr. Nichols works closely with scientists in the Cloud Physics Research Division and meteorologists at the Ontario Weather Centre on the development of radar applications and the transfer of new technology to the operational sector.

RÉSUMÉ *Ce n'est que récemment que les météorologistes ont commencé à appliquer la technologie du radar doppler, comme outil d'observation et d'analyse, à leurs opérations régulières. L'intégration des systèmes et logiciels informatiques au radar progresse et s'étend rapidement. Parmi ces progrès citons : la capacité du radar doppler de déterminer la vitesse des particules cibles, d'en déduire la circulation interne et externe à mésoéchelle et, de ce fait, de faire une meilleure analyse des caractéristiques des systèmes météorologiques et de prévoir leur comportement futur. Les observations à distance, presque instantannées, sont continuelles et couvrent une région définie autour de l'emplacement du radar. La recherche de moyens de détection et de poursuite des orages violents producteurs de tornades a mené aux premiers développements des techniques doppler et fut, en général, poursuivie dans le Midwest américain.*

Au Canada, dans le sud de l'Ontario, les premières expériences ont démontré son utilité dans l'observation et la prévision du temps violent. Notre connaissance du comportement des tempêtes, en toute saison, sera aussi grandement améliorée. Pendant la saison de temps violent, il serait inhabituel d'isoler la signature type d'une tornade, mais on peut reconnaître et identifier la circulation mésocyclonique souvent associée aux tornades et qui apparaît de 30 à 60 minutes avant celle-ci. Par elle-même, l'occurrence d'un mésocyclone est un signe précurseur de potentiel de temps violent dans les environs et pointe la région que les prévisionnistes doivent spécialement surveiller avec grande attention. La caractérisation de cette circulation permet aussi d'identifier d'autres perturbations dangereuses par les vents quelles produisent, telles que les orages violents, les rafales et les microrafales descendantes, et les fronts de rafales, qui peuvent causer la mort et des pertes matérielles. Le système doppler permet de « voir » l'organisation de la circulation en air clair; dans le futur on pourra ainsi identifier les régions propices à la naissance de tempêtes convectives, et au déclenchement et à la progression des brises de lac.

Les observations de la circulation de tempêtes à plus grande échelle, à d'autres moments de l'année, fournit une multitude de renseignements sur les activités à plus petite échelle à l'intérieur de ces tempêtes, ce qui explique souvent des comportements autrefois et le progrès d'une surface frontale. On pourra identifier la phase du changement de la pluie à la neige. Cette nouvelle source de renseignements apportera des prévisions plus opportunes et précises.

Le radar doppler a déjà prouvé qu'il est un excellent outil d'observation et de prévision des phénomènes météorologiques. Il est encore possible d'en faire une plus grande utilisation et d'en améliorer la technologie par la recherche et l'experience. Son emploi se répend rapidement à travers le monde. Pour les météorologistes et les scientifiques de l'atmosphère il s'agit d'un progrès des plus intéressants.

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Winter 1988–89 in Review

Northern areas of the Northwest Territories, however, received above normal precipitation. Many southern Yukon localities and numerous B.C. stations recorded their driest February ever, whereas several stations in southwestern Manitoba recorded only 13 to 18% of normal precipitation. In northern Ontario, Earlton had the lowest winter snowfall since 1940, Sudbury was the driest in 35 years and Pickle Lake, the driest since records began in 1940. Except for 2 stations, Quebec recorded below normal precipitation amounts – the Fermont-Wabush area was the driest since 1962.

IMPACTS

December

Dec. 1–5: The Klondike Highway south of Whitehorse to Skagway was closed for 3 days because of avalanches of heavy snow.

Strong winds caused power outages in the Peace River District. Logging was at a standstill owing to a lack of frost.

A fatal accident was attributed to snow on the Laviolette Bridge in Trois-Rivières. Poor weather caused a light plane crash at Wasaganish, Quebec.

In Victoria, B.C., Bonsai cherry trees were blooming 2 months earlier than usual.

Dec. 13–19: Heavy snow and 100 km/h winds caused whiteouts and road closures in the Yukon coastal mountain passes.

Heavy snow buried parts of the central B.C. interior. Power outages lasted as long as 2 days.

Rowan Gorilla 1, a jack-up oil rig, encountered a hurricane-force Maritime storm. The crew of 27 abandoned the rig before it capsized and sank.

January

Copious precipitation caused slides and road closures in the Yukon.

Heavy snow closed highways in northern B.C. coastal mountains.

Plunging temperatures, plentiful snow, and severe wind chills wreaked havoc across southern Alberta. Edmonton received 32.6 cm of snow in 24 hours.

Lack of snow harmed the Maritime ski industry.

Hurricane-force winds and storm surges forced evacuation of several Newfoundland communities.

February

Television and newspapers showed the effects of record-breaking cold in the Yukon – frozen gas pumps, gelled motor oil.

Feb. 21–23: In the Maritimes, a mixed bag of precipitation caused a number of highway fatalities, and heavy rain and heavy snow resulted in serious flooding in some areas.

Aaron Gergye is a climate meteorologist with the Canadian Climate Centre who is a member of the editorial staff of *Climatic Perspectives* and who works on the development and production of long-range weather forecasts.

ARCTIC EASTER BUNNY VISITS ATLANTIC CANADA

Weather Map Series, March 25 to 27, 1989

by Hans VanLeeuwen

Easter 1989 will likely be remembered by many in the Atlantic Provinces. The weather somehow did not cooperate with the annual display of Easter finery. In fact, what occurred was a rather unusual severe event for what had been a less severe than usual winter and spring. The region had experienced fewer major storms and generally below normal precipitation compared with similar periods in other years.

Aaron Gergye, of the Canadian Climate Centre in Downsview, Ontario, noted that the weeks prior to the severe spring storm saw a "resumption of [storm] activity along the traditional east-coast winter storm track." The storm "formed on the 23rd [of March] over the warm waters of the Gulf of Mexico, a favourite area for storm development. The storm crossed Florida, and then headed northeastward to arrive off the [southeast] coast of Nova Scotia on March the 25th."

Frank Amirault, from AES Halifax, reported that "the storm caused strong winds, freezing rain and snow". He also noted that the "precipitation began on [Easter] Saturday, the 25th, as snow, then changed to rain, freezing rain and back to snow again on the 26th." Local transportation people described the weather situation as "the 'worst' that plow crews had to contend with for some time." Holiday travel, on land and in the air, was almost completely disrupted.

In Newfoundland, the situation was as bad, if not worse. George MacMillan, from the AES office in Gander, reported that "20–40 cm of snow fell during this storm when it hit southeastern Newfoundland" and that "the snow was whipped by winds in excess of 100 km/h, with Bonavista reporting gusts to 102 km/h late Saturday."

This issue's map series has six maps, rather than the four that we normally present. You will also notice more of the Atlantic Ocean area, to the south of the region to be analysed. Ship reports are not that much different from land station reports except for data on sea temperatures (information in parentheses below the dew-point temperature), and ship direction and speed (lower right-hand part of the plot, e.g., → 4).

The series starts with map 1 showing the conditions on Easter Saturday, March 25, at 2 p.m. AST (2:30 NST). The storm track and some of the positions of the centre of the storm are plotted on Figure 1. Map 2 indicates the situation that evening (8 p.m. AST); Easter Sunday's weather is depicted on the maps for 2 a.m., 8 a.m. and 8 p.m. AST, respectively. Map 6 shows the final stages of the storm at 2:30 NST.

My suggestions are that you take pencil and eraser (remember, a weather analyst's best friend!) and begin carefully drawing some isobars, starting with the 1,000 mb (100 kPa) line and then lines at 4- (0.4 kPa) or 2-mb (0.2 kPa) intervals upwards or downwards. This is not going to be easy since over the ocean you will not have that many reports. So this is where your eraser will be needed.

Try and draw some isotherms, let's say every 4°C and notice the changes in temperature over the period. Also very useful here would be to identify and outline the regions of

precipitation, including the area of each type of precipitation.

Take a good look at the differences between the air temperatures and the water temperatures and note the following: where the air is much colder than the water; what cloud types are reported in such a situation; and how rapidly the water temperatures decrease as you move northward. That sharp temperature gradient to be noted in the sea temperatures, south of Nova Scotia and Newfoundland, is called the ???? Stream. Yes, you knew the answer, the *Gulf Stream*!

This particular map series lends itself very well to a "streamline" analysis, that is, drawing lines that give a sense of the airflow at a particular time. Take a look at the wind direction, and get a sense of that flow. For instance, at 8:30 a.m. NST the airflow over Newfoundland is generally from the east-northeast over the St. John's area, and a bit more northeasterly over the western part of the island; the airflow over Nova Scotia could easily be drawn as streamlines for a north-northwesterly flow. Try it; it can be very illustrative of the instantaneous flow over a particular area.

A final suggestion for activities would be to simply describe the total weather in "plain words", in a certain region, at a particular time, or over a time period, let's say six or twelve hours. Finally, looking at the first three maps, try and predict what the weather would likely be at the time for map 6. However, this means you should not take a peek at what really happened! This could be a good class activity.

REFERENCES

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Chinook, Vol. 8, No. 2 (Reference for weather plots decoding information.) If you need a copy, please send a stamped self-addressed envelope to the CMOS office in Ottawa: Attention: *Editor Chinook* (Weather Map Series: Vol. 11, No. 2).