Chinook

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VOL. 8 NO. 2

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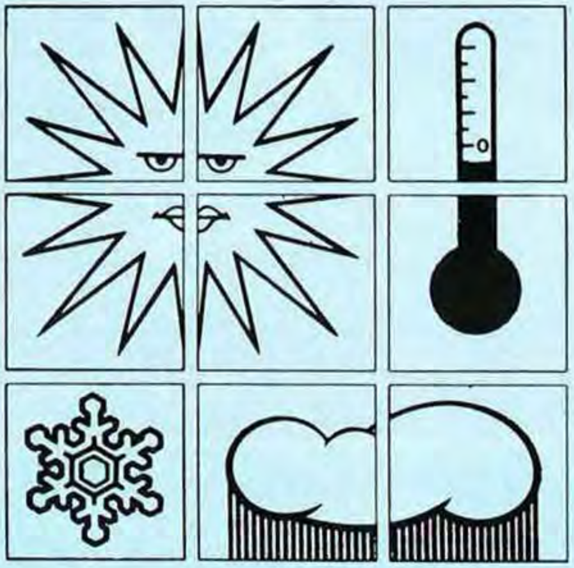

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A new feature is introduced in this issue, which is primarily directed at school audiences. The four weather maps (centrefold) describe in coded format the weather across central North America on March 19th, 1986. A basic decoding guide is provided (page 35) while some practical activities are suggested along with a few questions (page 33). Although the exercise is mainly aimed at secondary school students as part of their science or geography curriculum, weather enthusiasts are encouraged to participate. The centre pages can easily be removed, and can of course be duplicated for classroom use. We look forward to your comments and suggestions. It is our intention to repeat this feature and to introduce Atlantic, Prairie and Pacific sets. Under the heading of Further Reading (see page 34), you will find many basic texts which each discuss some of the basics of the atmospheric processes and phenomena. Several of these books also provide more detailed coding guides for the international weather symbols.

We also intend to introduce more exercises and experiments related to the oceans and the atmosphere. We hope that these will help liven up the science class.

Hans VanLeeuwen

COVER

The false-colour satellite image on the cover shows a low-water situation in Chignecto Bay (upper) and the Minas Basin (lower) of the Bay of Fundy area. A more detailed description can be found on page 38. Also see the article on tides on pages 24–28.

COUVERTURE

On voit en page couverture une image satellitaire en fausses couleurs qui montre en marée basse, la baie de Chignecto (en haut) et le bassin de Minas (en bas) de la région de la baie de Fundy. On peut trouver en page 38 une description plus en détails. Voir aussi l'article sur les marées en pages 24 à 28.

Chinook

Spring/Printemps 1986 Vol. 8 No. 2

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THE TIDES OF THE BAY OF FUNDY AND GULF OF MAINE
I. Why They are so Large

by John W. Loder

Have you ever driven by the Avon River causeway near Windsor, Nova Scotia or the Shur-Grain dock in Port Williams, Nova Scotia (Figure 1) and returned six hours later to find that the sea has largely disappeared from one side of the causeway or from the dock-side? Or, have you ever watched and listened to the churning waters in the harbour of Saint John, New Brunswick, or the river-like flow streaming past Cape Split, Nova Scotia (Figure 2) towards or from Minas Basin? (See cover picture and description on page 38.) If so, you have witnessed the tides of the ocean in near-peak form: The upper Bay of Fundy has the highest tides in the world, and the Bay and the Gulf of Maine together form one of our planet's most energetic tidal systems.

TIDES AND THEIR DISTRIBUTION

The ocean tides are simply a superimposed set of long-*period* and long-*wavelength* waves on the ocean's surface, somewhat like the much shorter-period and shorter-wavelength waves that may have bobbed your dory or sloop up and down, and pushed it to and fro on a windy day. The regular oscillations in surface *elevation* and horizontal current associated with both of these types of wave result from the restoring force of the earth's gravity on a vertically-displaced parcel of ocean water. Unlike wind-generated waves, the ocean tides are, in general (but see the next section for further discussion), forced by the gravitational attraction of distant but massive bodies – the moon and sun – and have set periods determined by the astronomical movements of these bodies relative to the earth. The principal tidal waves have periods of about a half day (the *semidiurnal tides* with two high waters daily) and a full day (the *diurnal tides* with one high water daily). Their relative strength varies greatly with location: In the Bay of Fundy and Gulf of Maine, the semidiurnal tides are dominant while along the British Columbia coast, the diurnal and semidiurnal tides are mixed with significant contributions from both.

Tidal elevations have been measured at numerous ports around the Fundy/Maine system for many decades and, in combination with recent elevations measured at some offshore sites, have been used to calibrate a computer model of the tides in the system, developed by David Greenberg of the Bedford Institute of Oceanography. The model solves theoretical equations that are a mathematical representation of Newton's Second Law of Motion. Its prediction of the elevation pattern associated with the semidiurnal *M_2 tide* (the principal lunar tide) is shown in Figure 3. This tide is by far the largest in the Fundy/Maine system and its amplification accounts in large part for the region's extraordinary tides. The elevation pattern is presented in terms of lines along which the *elevation amplitude* is the same, and lines along which the *elevation phase* is the same. It can be seen that the amplitude increases continuously from the edge of the continental shelf, where it has a value of about 0.4 m corresponding to the M_2 tide in the adjacent deep North Atlantic Ocean, through amplitudes of a few metres in the lower Bay of Fundy, to maximum amplitudes of more than 6 m in the upper Bay. Indeed, at some places in Minas Basin, the *range in elevation* between low and high water is more that 15 m when the contributions from the other tides are included. Figure 3 also shows that high or low water occurs progressively later while proceeding into the Gulf and Bay, with Minas Basin lagging the outer Gulf by several hours (one hour corresponds to a phase change of 29°in Figure 3).

As discussed, the rise and fall of the sea surface is only one of the two primary features of ocean tides; an oscillatory *ebb* and *flood* of a large volume of water must also be associated with the changing surface elevation. The distri-

Figure 1 (Left) High and (Right) low water at Port Williams, Nova Scotia, on the same day.

bution of M_2 tidal currents in the Fundy/Maine system at one instant in the tidal cycle, as predicted by Greenberg's model, is shown in Figure 4. At that instant, about three hours before low water in Minas Basin or two hours before that at Saint John, the tide is ebbing at speeds of 4–8 knots (2–4 m/s) in Minas Channel (Figure 4a) where there is a channelling effect (Figure 2) of the flow to and from Minas Basin, and at speeds of about 2 knots (1 m/s) over much of the lower Bay (Figure 4b). The tidal currents are also strong in the outer Gulf (Figure 4c) where a large volume of water is forced to flow at speeds of up to 2 knots over Nantucket Shoals, Georges and Browns Banks, and the shallow area off southwestern Nova Scotia. In fact, the total volume transport into and out of the system associated with this twice-daily tidal flow has a peak value of about 25×10^6 m^3/s, over 2000 times the yearly-averaged freshwater discharge of the St. Lawrence River. This voluminous horizontal movement of water across the edge of the continental shelf is another manifestation of the vast energy of the Fundy/Maine tidal system.

A NEAR-RESONANT SYSTEM

The main reason for the large M_2 tide in the Bay of Fundy and Gulf of Maine is that the 12.4-hour period of this tide is close to the period at which the waters of the Bay and Gulf combined slosh to and fro most easily. This so-called *"natural" period* depends on the system's horizontal extent, shape and depth; it has been estimated by Christopher Garrett of Dalhousie University to be about 13.3 hours for the Bay and Gulf together. It is similar to the preferred period for the oscillation of a guitar string (dependent on the string's length, diameter, tension and other properties) and for a sound wave in an organ pipe (dependent on the pipe's length and end conditions, and on the speed of sound in air). When the period of the forcing of these systems is

Figure 2 The strong tidal current at the tip of Cape Split, Nova Scotia, associated with the flood tide through Minas Channel.

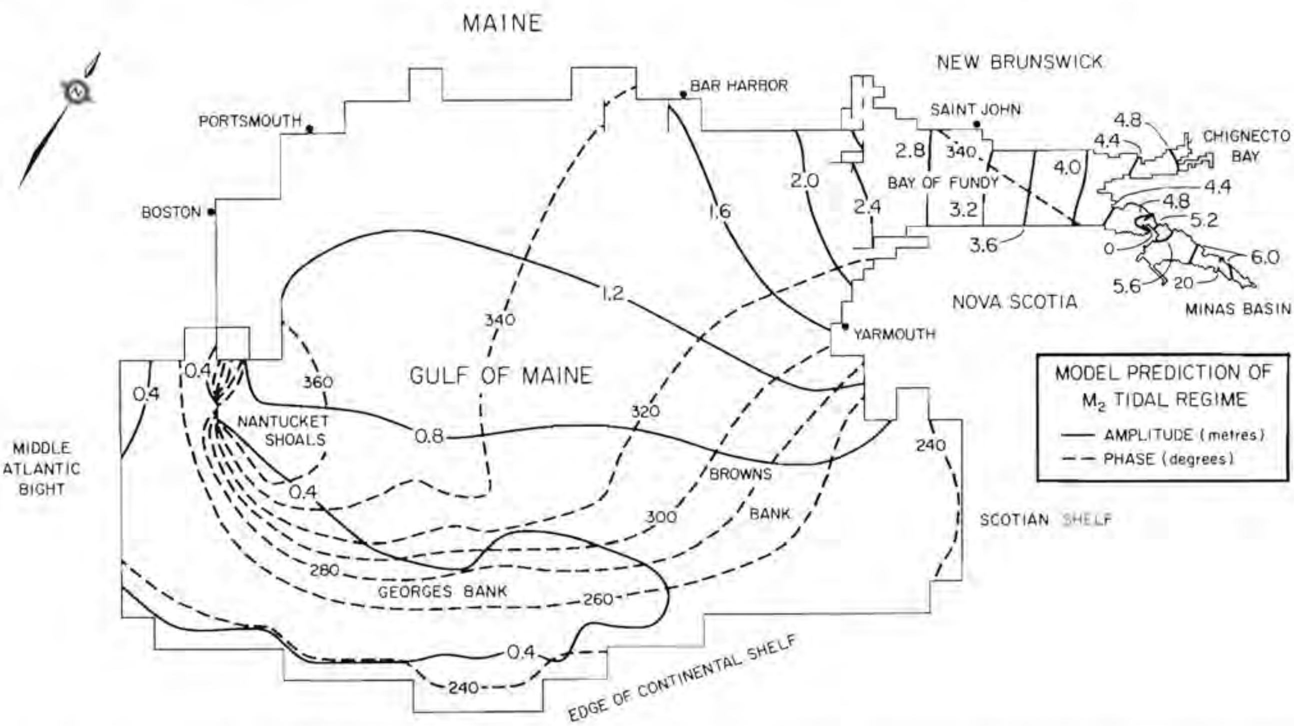


Figure 3 Lines along which the M_2 tidal elevation in the Bay of Fundy and Gulf of Maine is predicted by Greenberg's computer model to have the same values of amplitude (m) and phase (degrees). The boundaries of the model domain lie along the bordering coastlines of Canada and the United States, across the Scotian Shelf and Middle Atlantic Bight, and along the edge of the continental shelf.

near their natural period, there is an enhanced response – a phenomenon called *resonance*. Since the primary forcing of the M_2 tide in the Fundy/Maine system (and on the ocean's continental shelves in general) is the deep ocean tide at the shelf edge (which is itself forced by the moon's gravitational attraction), the system's response to M_2 forcing is quite akin to that of an organ pipe closed at one end and nearly in *quarterwave resonance* (Figure 5), with the large volume transport across the shelf edge being analogous to the sound wave's velocity *antinode* at the pipe's open end, and the closed ends of the Bay and pipe reflecting the incoming waves. The near-quarterwave resonance of the M_2 tide in the Fundy/Maine system is also evident in the elevation amplitudes in Figure 3, which show an elevation *node* near the shelf edge and an *antinode* at the system's closed end, although the phase propagation apparent in that same figure indicates that the M_2 tide is not a pure *standing wave* in the system.

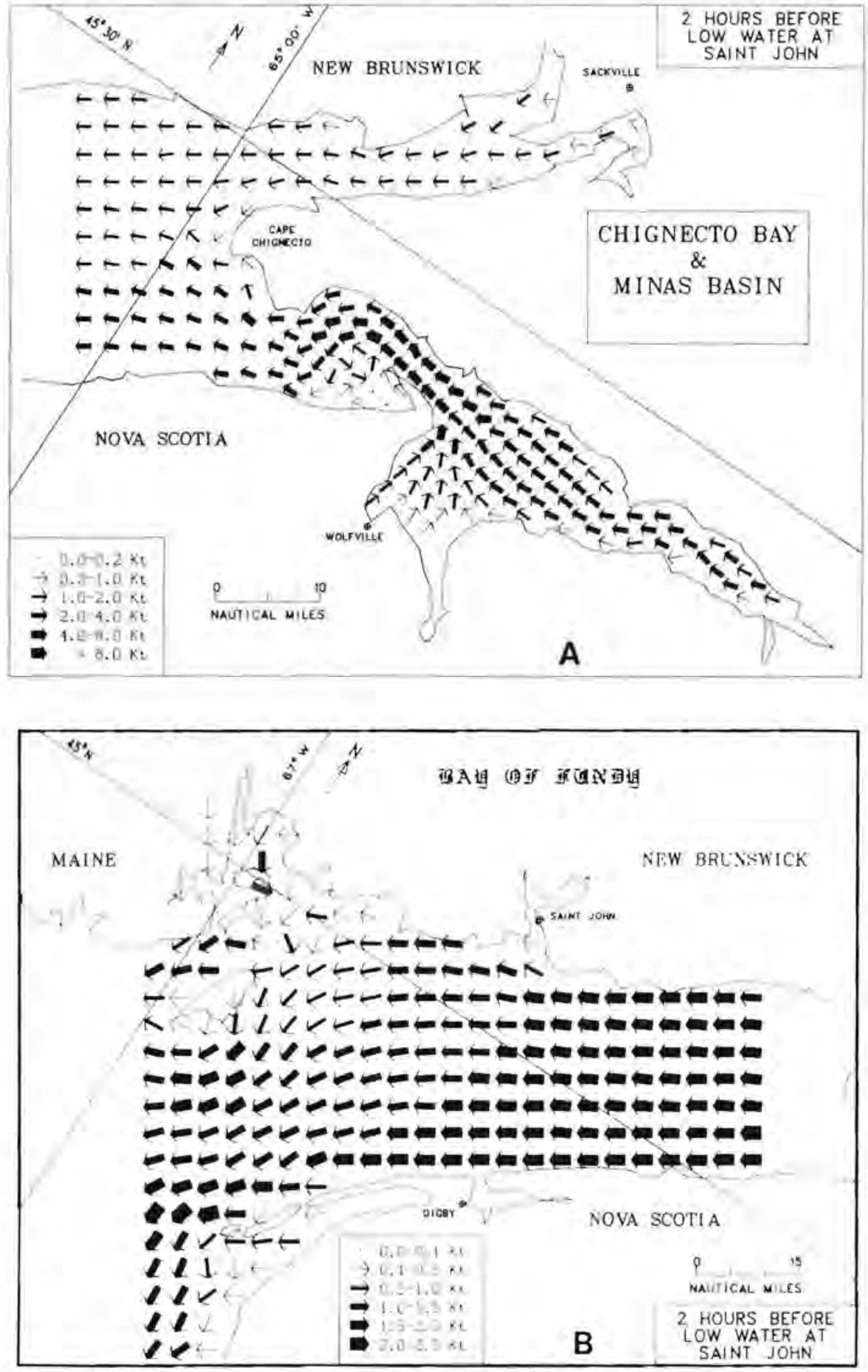


Figure 4 M_2 tidal currents in (a) the upper Bay of Fundy, (b) the lower Bay of Fundy and (c) the Gulf of Maine, predicted by Greenberg's computer model. (From the Canadian Hydrographic Service's Atlas of Tidal Currents – Bay of Fundy and Gulf of Maine.)

SIGNIFICANCE OF THE REGION'S LARGE TIDES

It can be seen from Figure 1 that the large range in tidal elevation in the Bay of Fundy, and to a lesser extent along the coasts of Maine and southwestern Nova Scotia, dictates that marine vessels entering and leaving port consider the *stage* of the tide, and that those at dockside allow for the tide in their mooring arrangement. Even away from the coastline, the stage of the tide can influence the navigability of waters containing submarine reefs, banks and other obstructions. Perhaps an even more important factor in determining the navigability of such waters, as well as of such relatively confined channels as Saint John Harbour, is the strength of the tidal currents. Fortunately, tidal elevations and currents are largely predictable, and with sufficient experience or the use of the Tide Tables available from the Governments of Canada and the United States, the dangers to safe navigation can be minimized.

Indeed, with ingenuity, man can turn large tidal elevations and currents to his advantage. Fishermen can, at low tide, harvest on foot the catch from their weirs (fish traps) suspended on wooden poles mounted in the seabed, and commercial vessels can time their passage through areas such as Minas Channel to ride the current. In addition, the tremendous energy in near-resonant tides can be partially harnessed and used to generate electricity as evidenced by the 240-megawatt tidal power plant on La Rance River in France and the much smaller (20 megawatt) pilot plant now operating at Annapolis Royal in Nova Scotia.

The large tides in the Bay of Fundy and Gulf of Maine have many other important effects on the regional environment, one example being the huge mud-flats exposed at low tide in Minas and Cumberland Basins, which are an important feeding ground for migratory shore birds. I will discuss this and other secondary influences of the tides in a follow-up article.

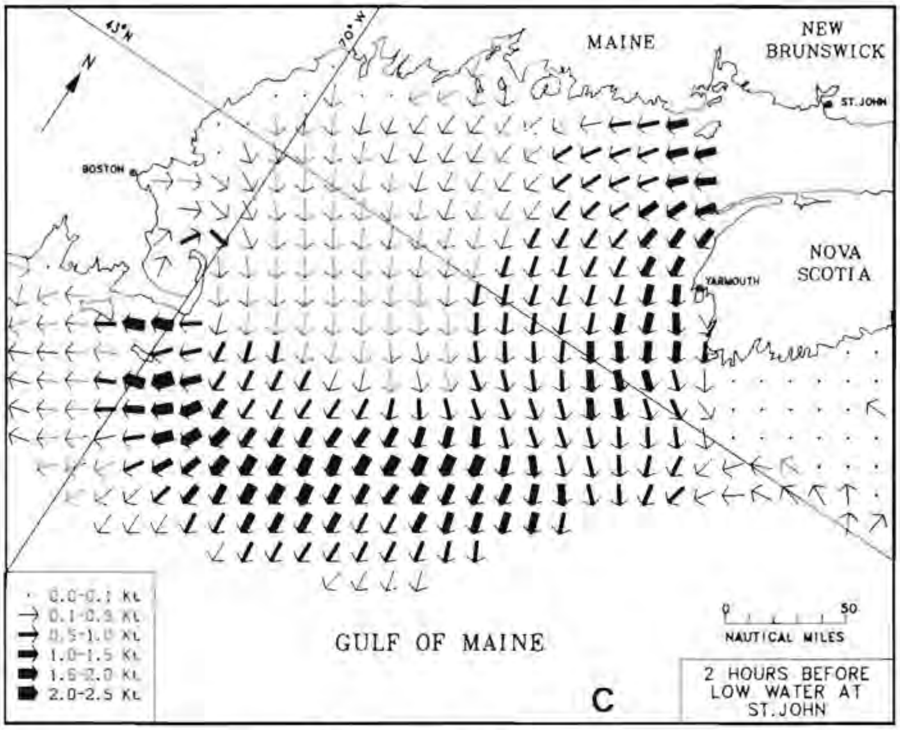


Figure 4 (Concluded).

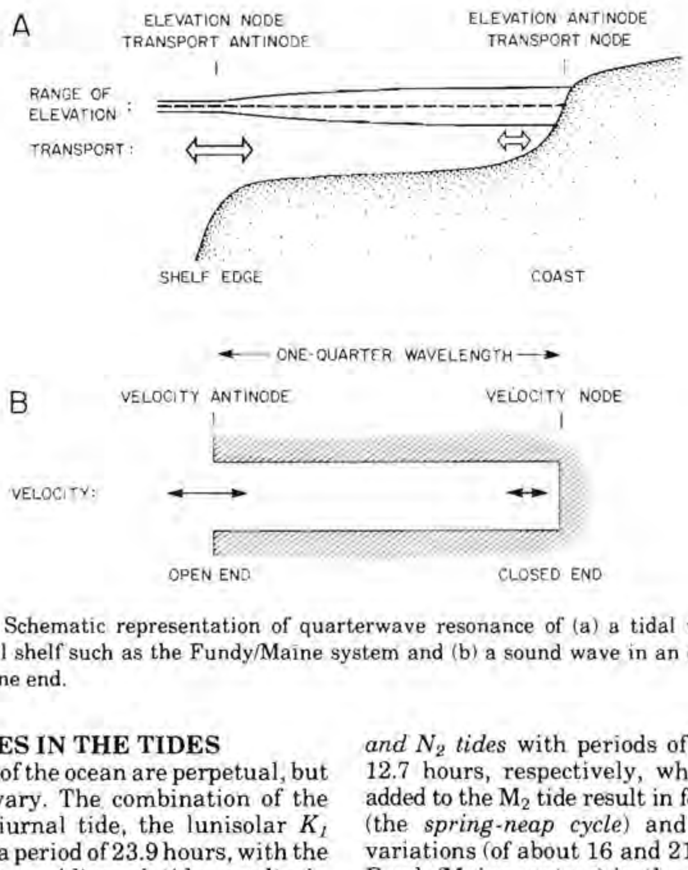


Figure 5 Schematic representation of quarterwave resonance of (a) a tidal wave on a continental shelf such as the Fundy/Maine system and (b) a sound wave in an organ pipe closed at one end.

CHANGES IN THE TIDES

The tides of the ocean are perpetual, but they do vary. The combination of the largest diurnal tide, the lunisolar *K_1 tide* with a period of 23.9 hours, with the dominant semidiurnal tide results in every second high water in the Fundy/Maine system being higher than the previous one. In addition, there are other semidiurnal tides such as the *S_2 and N_2 tides* with periods of 12.0 and 12.7 hours, respectively, which when added to the M_2 tide result in fortnightly (the *spring-neap cycle*) and monthly variations (of about 16 and 21% for the Fundy/Maine system) in the semidiurnal tidal range. The tides also vary periodically on many other time-scales ranging from hours to centuries and millenia: Perhaps the longest-period variation that may be detectable during our lifetimes is the 18.6-year *nodal modulation of the M_2 tide*, which causes a few per cent change in the elevation amplitudes shown in Figure 3.

The tides in near-resonant systems like the Bay of Fundy and Gulf of Maine can also undergo non-periodic changes due to alterations in their natural period associated with changes in average sea-level or in the system's geometry. For example, David Scott of Dalhousie University and David Greenberg have shown that, associated with the global rise in sea-level since the last ice-age (about 15,000 years ago), an increase in the M_2 tide in the Fundy/Maine system has occurred. In addition, man himself may alter the system's natural period, and hence its tides, through large engineering projects such as the proposed construction of a larger tidal power plant in the upper Bay. This possibility has also been investigated by Garrett and Greenberg, the latter using the computer model from which the elevations and currents in Figures 3 and 4 are derived. They have predicted that, although a reduction in a system's "length" upon construction of a power plant should result in a natural period that is closer to the M_2 period and hence lead to (slightly) larger tides in much of the system, there should also be a change in the spatial pattern of the tidal wave leading to smaller tides in the upper Bay. Fortunately, it appears that neither of these changes would be drastic. But their possible occurrence underlines the importance of understanding why the tides of the Bay of Fundy and Gulf of Maine are so large.

STUDENT EXERCISES

i) *Tidal Elevation at Saint John*

The oscillations in sea surface elevation associated with each tidal wave can be represented by $E = A \sin(2\pi t/T)$ where E is the elevation at time t, A is the elevation amplitude and T is the tidal period. The amplitudes of the M_2, K_1, S_2 and N_2 tides at Saint John, New Brunswick, are 3.0, 0.2, 0.5 and 0.6 m, respectively. Using your programmable calculator or home computer, obtain and plot hourly values of tidal elevation at Saint John for the following cases:

a) The M_2 tide alone for 25 hours
b) The M_2 tide plus the K_1 tide for 50 hours (note that alternate high waters are higher)
c) The M_2 tide plus the S_2 tide for 30 days (720 hours) (note the spring-neap cycle: higher high waters and lower low waters occur every two weeks)

d) The M_2 tide plus the N_2 tide for 60 days (1440 hours) (note the monthly cycle: higher high waters and lower low waters occur approximately once a month)

e) The sum of the M_2, K_1, S_2 and N_2 tides (a good approximation to the actual variation)

ii) *Effective Length of the Fundy/Maine System*

The natural period of a tidal system closed at only one end is approximately 4 times its effective length divided by the speed of the tidal wave. The latter is given by $(gH)^{1/2}$ where $g = 9.8$ m/s^2 is the gravitational acceleration and H is the water depth (m). Assuming the Fundy/Maine system has an average depth of 150 m, calculate its effective length, and using Figure 3 and a map of the region compare this length with the distance from the head of Minas Basin to the edge of the continental shelf. Also, estimate the wavelength of the M_2 tide in the region.

iii) *Natural Period of Water in Your Bathtub*

Partially fill your bathtub with water and repeatedly push the water towards one end of the tub at various regular intervals. For the same magnitude of push, the pushing interval that results in the largest sloshing in the tub is the system's natural period. When you push at this interval, resonance occurs: Be careful not to overdo it!

Now, measure the depth of water and length of the bathtub and compare the system's observed natural period with that suggested by the formula outlined in the previous exercise. Explain why this formula incorrectly estimates the present system's natural period by a factor of two.

DEFINITIONS

Antinode: See standing wave.
Diurnal tides: Tides that generally have one high and one low water daily.
Ebb: Outward movement of tide.
Elevation: Vertical displacement of the sea surface from its position in the absence of tides.
Elevation amplitude: Magnitude of the elevation's maximum value.
Elevation phase: The time or fraction of a tidal period before a particular stage of the tide will occur at each position; expressed in hours or degrees where 360° correspond to one tidal period; high waters occur simultaneously on lines of constant elevation phase.
Flood: Inward movement of tide.
K_1 tide: The largest diurnal (denoted by subscript 1) tide, which is associated with the gravitational attraction of both the moon and sun.
M_2 tide: The principal tide associated with the moon's gravitational attraction (the subscript 2 denotes semidiurnal).
Natural period: Period of the external forcing of constant magnitude that results in a system's maximum response.
Nodal modulation of the M_2 tide: The occurrence of larger M_2 tides every 18.6 years, caused by the 18.6-year variation of the plane of the moon's orbit relative to the earth's ecliptic. The fractional variation is about ±3.7%.
Period of the tide: The time between successive like stages of the tide; e.g., between successive high waters, low waters, ebb currents or flood currents.
Quarterwave resonance: Resonance having only one quarter of a wavelength of a standing wave.
Range in elevation: The elevation change between low and high water. For a single tide, it is twice the elevation amplitude.
Resonance: Enhanced response of a system that is being forced at its natural period.
S_2 and N_2 tides: The solar and larger lunar elliptic semidiurnal tides, respectively.
Semidiurnal tides: Tides that generally have two high and two low waters daily.
Spring-neap cycle: Higher high and lower low waters followed by lower high and higher low waters about one week later; caused by superposition of the S_2 and M_2 tides.
Stage of the tide: See period of the tide.
Standing wave: The waveform that occurs in a resonant system. The elevation phases at all positions are the same or differ by 180°. The elevation and velocity amplitudes are maxima at fixed positions referred to as antinodes and minima at fixed positions called nodes.
Wavelength of the tide: The horizontal distance between simultaneous like, but separated, stages of the tide; e.g., between simultaneous high waters that are separated by a region of low water.

SUGGESTED READING

Canadian Hydrographic Service, 1981: Atlas of Tidal Currents – Bay of Fundy and Gulf of Maine. Department of Fisheries and Oceans, Ottawa, 36 pp.

Canadian Hydrographic Service, 1982: Sailing Directions – Nova Scotia (SE Coast) and Bay of Fundy. Department of Fisheries and Oceans, Ottawa, 303 pp.

Canadian Hydrographic Service, 1984: Canadian Tide and Current Tables 1985, Vol. 1, Atlantic Coast and Bay of Fundy. Department of Fisheries and Oceans, Ottawa, 53 pp.

Forrester, W.D., 1983: Canadian Tidal Manual. Canadian Hydrographic Service, Department of Fisheries and Oceans, Ottawa, 138 pp.

Garrett, C., 1974: Ocean Tides. *Geoscience Canada*, Vol. 1(4), 8–14.

Garrett, C., 1984: Tides and Tidal Power in the Bay of Fundy. *Endeavour*, New Series, Vol. 8, 58–64.

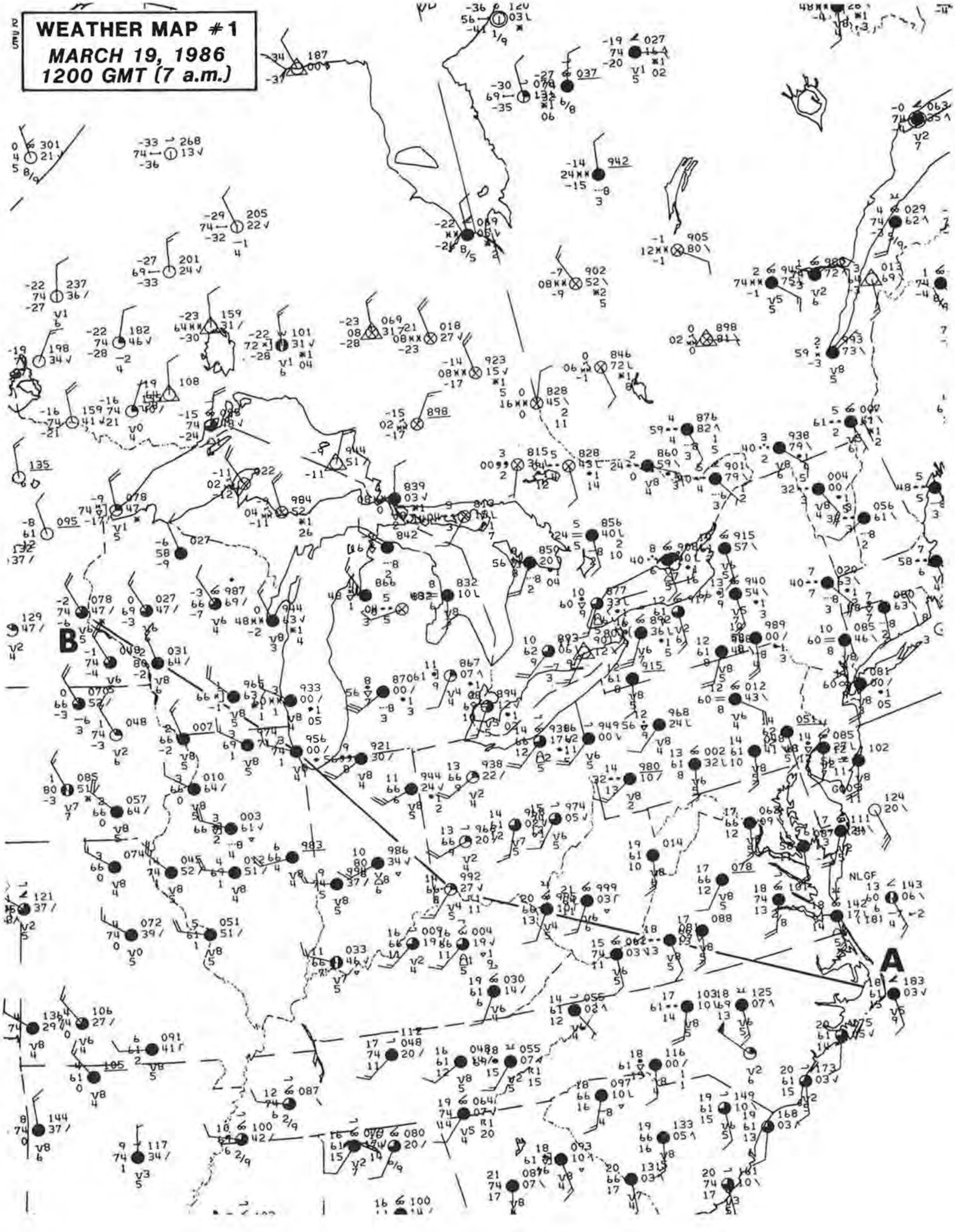
Greenberg, D.A., 1985: Tidal Modeling and Tidal Power in the Bay of Fundy (to appear in *Scientific American*).

John Loder is a physical oceanographer and research scientist with the Department of Fisheries and Oceans, in the Ocean Circulation Division of the Bedford Institute of Oceanography, at Dartmouth, Nova Scotia. His research specialty is the study of circulation and mixing on continental shelves, and he has been involved in developing theoretical models of the circulation and mixing associated with the strong tidal currents in the Gulf of Maine.

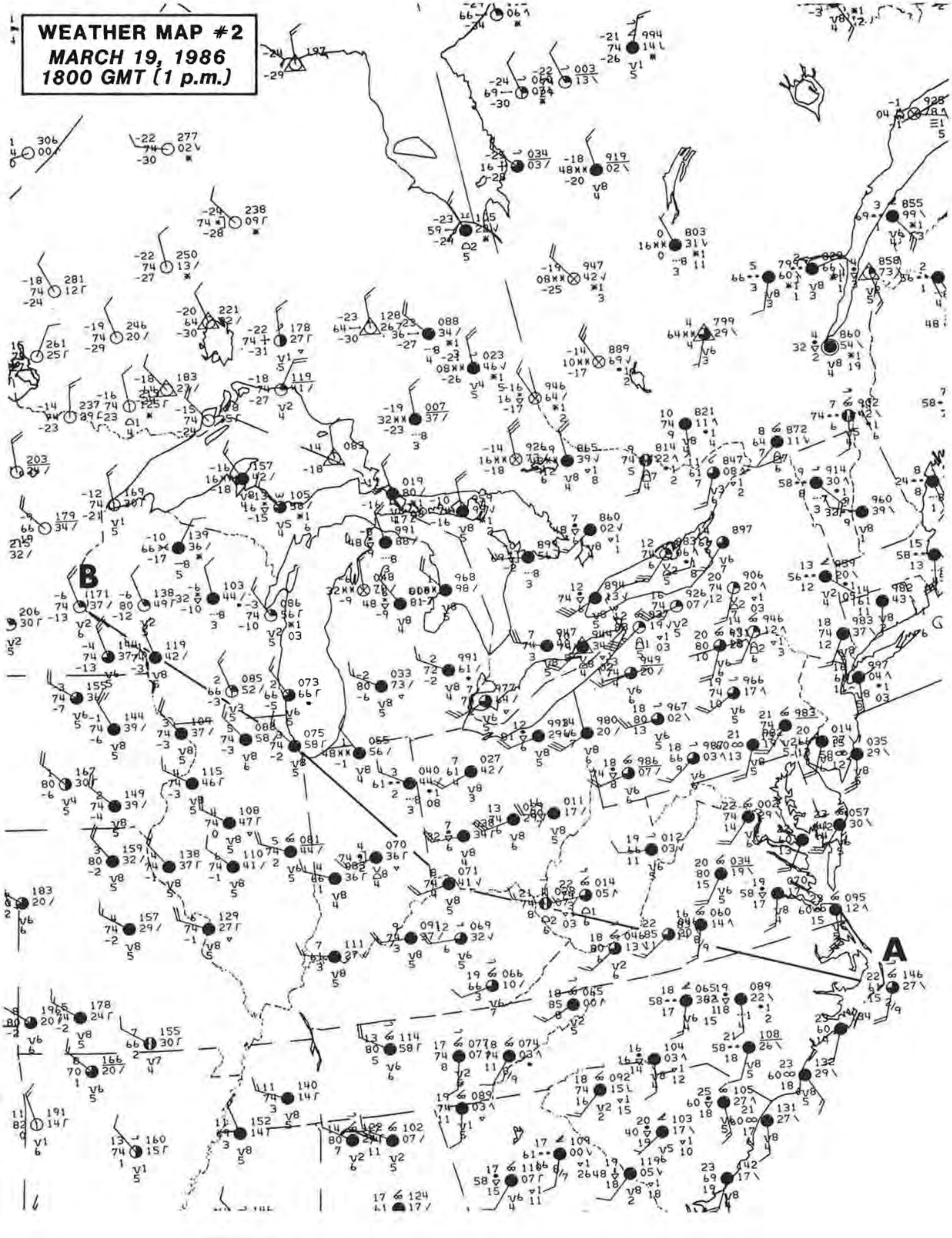
RÉSUMÉ *Les marées les plus hautes au monde ont lieu dans le bassin de Minas situé dans le haut de la baie de Fundy. C'est que la baie et le golfe du Maine forment un système de marées quasi-résonant : la période naturelle de 13,3 heures de ce système se rapproche de la période de 12,4 heures de la marée principale semi-diurne (deux fois par jour), soit la marée lunaire M_2. Dans cette région, on observe donc une très forte marée M_2 avec des changements considérables du niveau de la mer dans la baie de Fundy et de forts courants de marée dans les bancs peu profonds de l'extérieur du golfe du Maine ainsi que dans la baie. Des marées de telle envergure doivent être considérées lors de la navigation dans la région. La province de la Nouvelle-Écosse exploite maintenant une certaine quantité de cette énergie marémotrice en la transformant en électricité.*

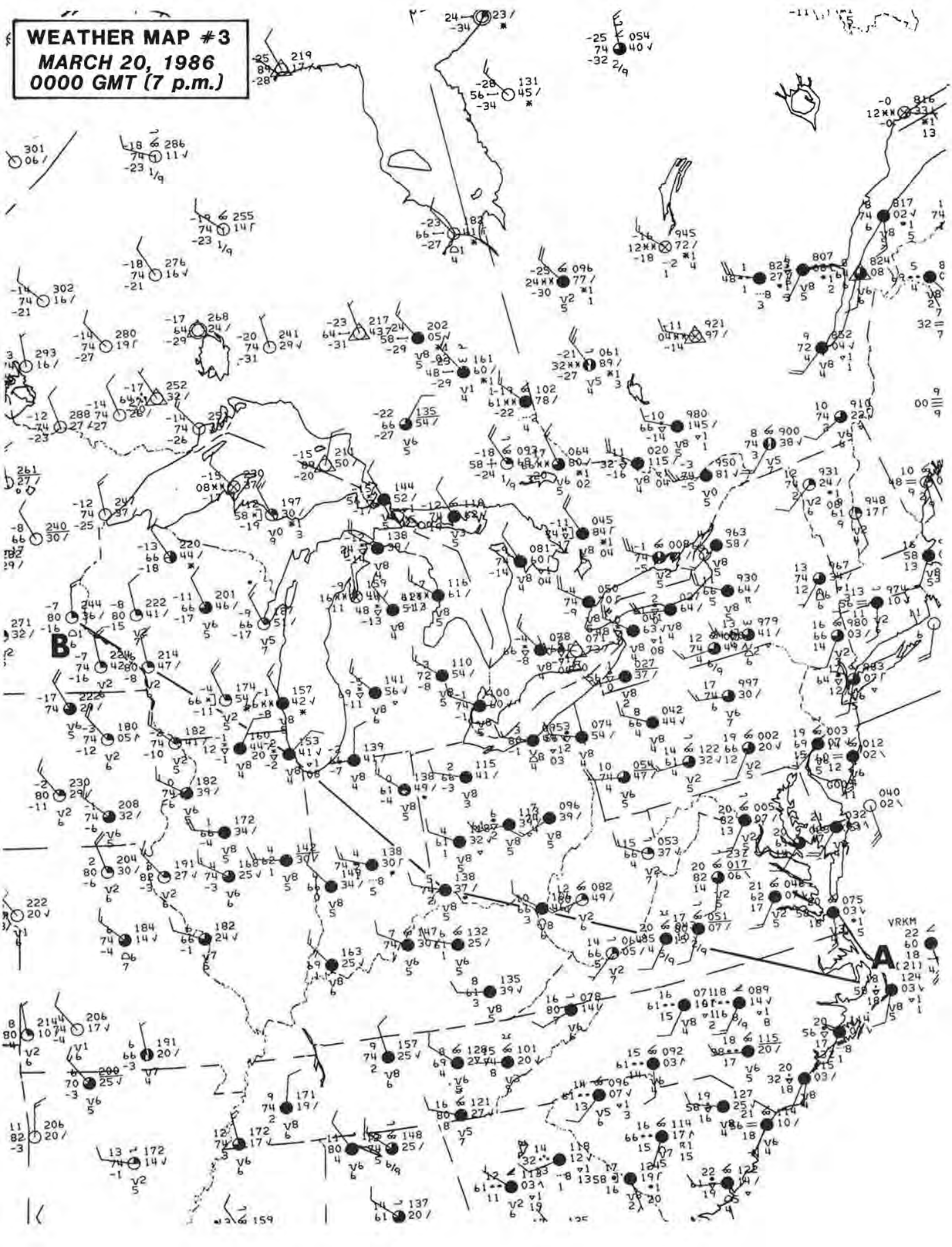
WEATHER MAP #1

MARCH 19, 1986
1200 GMT (7 a.m.)



WEATHER MAP #2
MARCH 19, 1986
1800 GMT (1 p.m.)




WEATHER MAP #3
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WEATHER MAP #4
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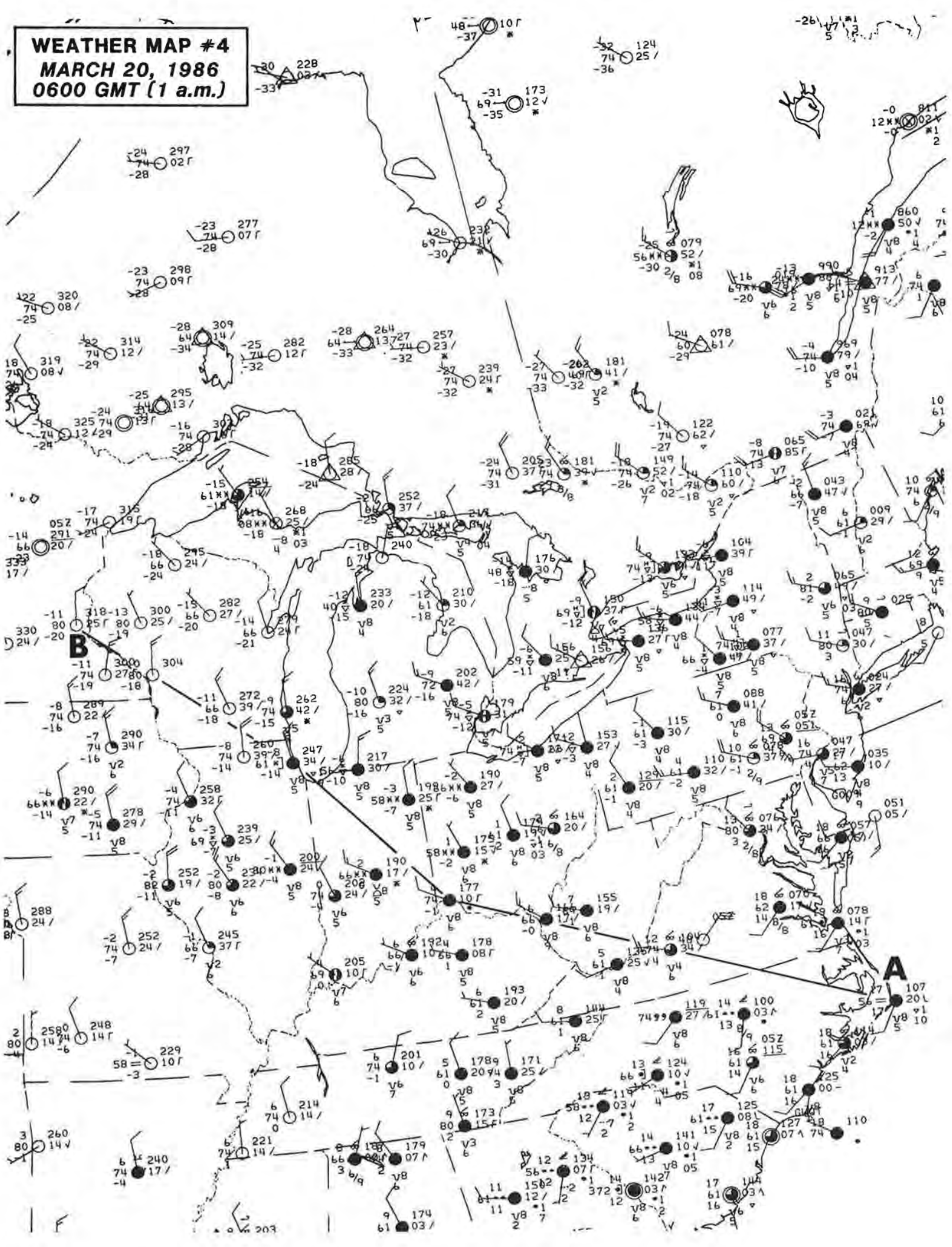
0600 GMT (1 a.m.)



WINTER'S LAST ARCTIC BLAST!

Weather Map Series, March 19 and 20, 1986



The weather map series consists of four charts with plotted, but unanalysed data for March 19th and 20th, 1986. The observational times of the data are: Map 1, 1200 Greenwich Mean Time (GMT) or 7 a.m. Eastern Standard time (EST); Map 2, 1800 GMT or 1 p.m. EST; Map 3, 0000 GMT or 7 p.m. EST; Map 4, 0600 GMT or 1 a.m. EST on March 20th. The charts thus reflect the weather conditions over the east central part of the United States and Canada centred on the Great Lakes, and also reflect the changes that occurred from the early morning hours to just after midnight. A closer look at the maps and the data will reveal a great deal about what was happening with the weather, how each specific weather element changed and what relationships exist between these seemingly independent bits of information.

The first thing one should attempt is to try and put some order to the data. An important step is to understand what each piece of plotted data means. On page 35, you will find a decoding guide, which will explain in some detail the plotting model; some examples are provided. More detailed information and guides are mentioned under Further Reading.

The next important step is to relate the observations and the weather phenomena to the geographical locations. This is thus a great oportunity to refresh our geographical knowledge!

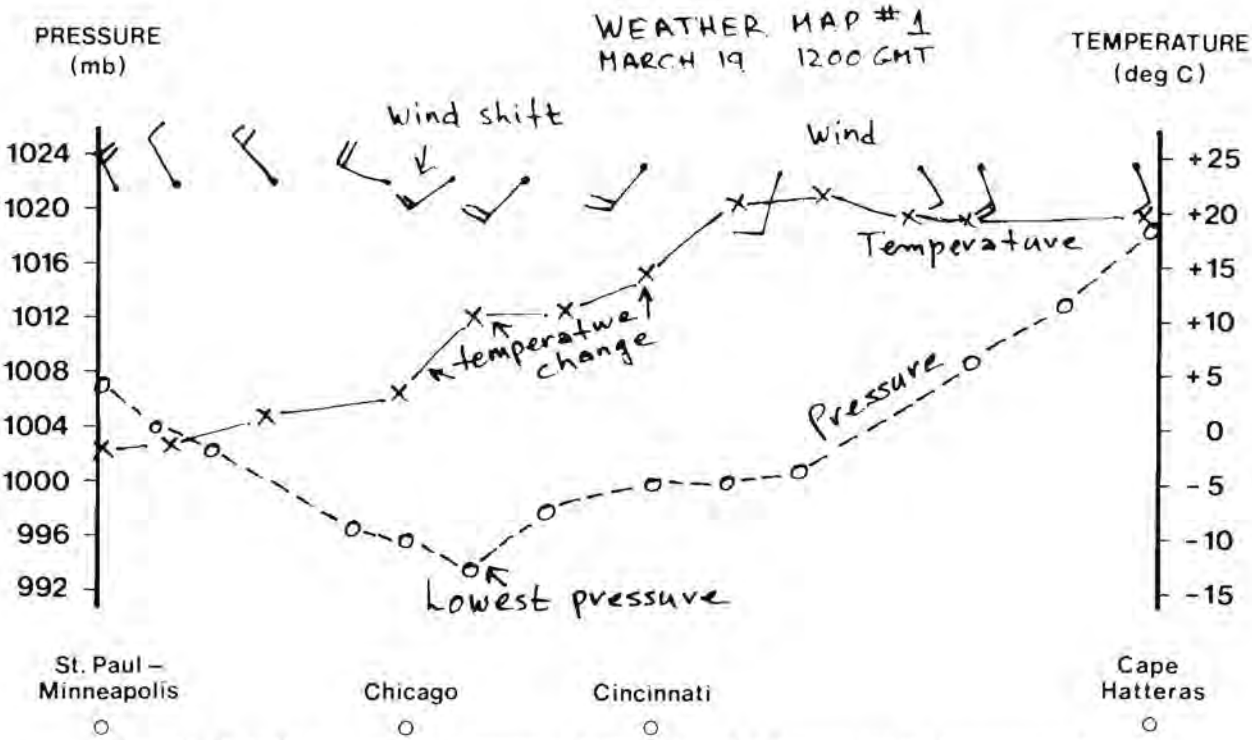
Before setting our hand at analysing the data, it might be helpful to look at one observing site and decode the data plotted for it.

On the western end of Lake Ontario we will find the data that were observed at the Toronto synoptic site – L.B. Pearson International Airport – which is located west of Metropolitan Toronto. At 7 a.m. (Map 1) the reported temperature was 10°C, the dew point was 9°C, the wind was from the southwest at 23–31 km/h, and the sky condition showed 6/8 cloud cover consisting of low cloud (swelling cumulus). The pressure at that time was 987.7 mb or 98.77 kPa, while during the past three hours the pressure had fallen steadily and then remained constant, the total fall being 3.3 mb or 0.33 kPa. Rain showers were occurring at the time of the observation and the visibility was 10 km (code 60). Please note the "Toronto" weather on maps 2, 3 and 4 and note the changes in each of the weather elements. Note that the temperature at 7 p.m. is down to −4°C (falling from a maximum of 12°C at 1 p.m.), the wind has shifted to a northwesterly direction and increased in strength (32–41 km/h) and the pressure has risen since 7 a.m. from 987.7 mb to 1005.0 mb, a rise of 17.3 mb! Visualize this change on a home barometer or barograph. You will further notice, that the skies remained cloudy most of the day and snow showers were reported around midnight in most of southwestern Ontario.

It is important before doing any of the suggested activities, to be able to decode the various bits of data and to get some idea about the weather in different parts of the area delineated.

The following activities are designed to assist the amateur analyst and student in getting a "feel for the weather" and for the changes in the elements from 7 a.m. on March 19th to just after midnight (March 20th), an 18-hour period. I suggest you use a sharp pencil in all the line-drawing activities. Also draw your initial lines lightly. Mistakes are common; remember, an eraser is often an analyst's best friend.

1) Using a red pencil, draw isotherms (lines of equal temperature) on each map, starting with the 0°C isotherm (solid line) and then at 5°C intervals (dashed lines). Notice the changes in temperature during the day. Why did these changes occur? This question may be easier to answer after some of the other elements have been analysed.
2) Using a black pencil, draw isobars (lines of equal pressure) on each map, starting with the 1000.0 mb (100.00 kPa) isobar and then every 4 mb (0.4 kPa). Draw them as solid lines. Mark the centres of highest and lowest pressure (example: **L** 979 mb). By the way, the proper drawing of isobars is not an easy exercise. Some hints may prove helpful. You will notice that the winds blow almost parallel to the isobars but with a tendency to blow across them towards lower pressure. Just by looking at the maps and concentrating on the "windflow" you should get a feeling for the general direction of the isobars. Try and draw a couple of isobars to get the general pattern; for instance, the 1000-mb, 1008-mb and 1016-mb isobars.
3) The next exercise is to draw isallobars (lines of equal pressure change: rises and falls). Draw the rises in blue and the falls in red, at intervals of 1 mb (0.1 kPa). Draw the line that separates rises from falls in purple. Again it takes a little while to get used to spotting the specific information. Looking at the analysed "three-hourly pressure tendencies" on the four maps, you will notice some interesting changes in the general pressure field. See if you can visualize any relationships with your isobar analysis.



Example Note the zone where the pressure is lowest, the wind shift occurs and the temperature changes.

4) The final basic activity on the series of maps is to identify the areas of precipitation and to note the types, such as snow, rain, drizzle, and showers. Notice that snow in general is associated with air temperatures at or below the freezing point. Do you notice movement and change in the precipitation areas during the 18-hour period?
5) The following are some general topics for consideration and discussion: Note at the observing sites where fog is being reported (≡) or the sky is obscured (⊗) that the difference between the temperature and the dew point is either zero or very small. This means the air is nearly saturated. Also notice the same condition at weather stations that report precipitation. Where would the air be the driest? Do you see a relationship between the air being close to saturation and the horizontal visibility reported at the station?
6) Could you describe the major changes in the "weather" in such locations as Montréal (Québec), New York City (New York), Chicago (Illinois), Sault Ste. Marie (Ontario), Thunder Bay (Ontario), Cape Hatteras (North Carolina) and Louisville (Kentucky)? Use all the reported elements in your discussion. Also make reference to your analyses of temperature, pressure and precipitation.
7) Along the line A-B, which is marked on each map, notice the changes in the weather elements as you move from Cape Hatteras (North Carolina) through Cincinnati (Ohio), and Chicago (Illinois) to St. Paul-Minneapolis (Minnesota). Take a separate blank sheet of paper and draw a horizontal line A-B on it and plot the weather elements on this line (see example). Where do the significant changes take place in such elements as wind, temperature and pressure? Do this for each map and notice the movement of the zone of significant change. You will notice the changes identified with the movement of a cold front, that is, the leading edge of the advancing cold air (mass), pushing southeastward across the Great Lakes area that day.

There are many other interesting activities that can be performed on these maps and undoubtedly a great deal that can be discussed to explain why the "weather" occurred. In future series, an attempt will be made to address these. Also different parts of North America will be used for analysis purposes.

For further study, the following publication is recommended:
Learning Weather / Découvrons la météo. Available from the Canadian Government Publishing Centre (see advertisement on the inside front cover of this issue).

FURTHER READING

Anthes, R.A.; H.A. Panofsky and J.J. Cahir, 1978: *The Atmosphere* 2nd Edit., Merrill Publ. Co., Columbus, Ohio, 442 pp.

Barry, R.G. and R.J. Chorley, 1968: *Atmosphere, Weather and Climate*. Methuen & Co., London, 319 pp.

Battan, L.J., 1979: *Fundamentals of Meteorology*. Prentice-Hall, Englewood Cliffs, N.J., 321 pp.

Devuyst, P., 1979: *Météorologie et prévision du temps*. Eyrolles, Éditeur-Paris, 96 pp.

Eagleman, J.R., 1980: *Meteorology: The Atmosphere in Action*. D. VanNostrand Co., 384 pp.

Flohn, H., 1969: *Climate and Weather*. McGraw-Hill, 253 pp.

Leduc, R. and R. Gervais, 1985: *Connaître la météorologie*. Presses de l'Université du Québec, Qué., 229 pp.

Miller, A., 1971: *Meteorology*. 2nd Edit., Merrill Publ. Co., Columbus, Ohio, 154 pp.

Miller, A.; J.C. Thompson, R.E. Peterson and D.R. Hagan, 1983: *Elements of Meteorology*. 4th Edit., Merrill Publ. Co., Columbus, Ohio, 417 pp.

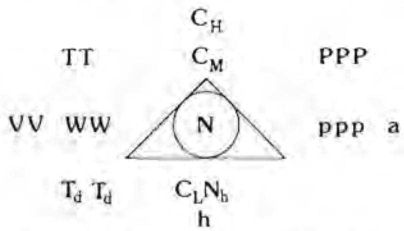
Ouellet, A., 1971: *La météo*. Les éditions de l'homme, Montréal, Bruxelles, 175 pp.

Schaefer, V.J. and J.A. Day, 1981: *A Field Guide to the Atmosphere*. Houghton Mifflin Co., Boston, 355 pp.

Weisberg, J.S., 1976: *Meteorology: The Earth and Its Weather*. Houghton Mifflin Co., Boston, 241 pp.

SYNOPTIC MAP PLOT

The information on the weather maps on the four centrefold pages is quite varied and in part is in a coded format. The data can be identified and decoded using the synoptic map plot below and the explanations that follow.



EXPLANATION OF THE SYMBOLS AND CODES

PPP Mean sea-level pressure in millibars or kilopascals (example: 249 is 1024.9 mb or 102.49 kPa; 993 is 999.3 mb or 99.93 kPa)

TT Air temperature in degrees Celsius (example: 13 is +13°C; −19 is −19°C)

T_dT_d Dew-point temperature in degrees Celsius (examples are similar to those for air temperature)

VV Visibility (in kilometres) in coded format, for example:

Code	km	Code	km	Code	km
02	0.2	32	3.2	61	11
08	0.8	48	4.8	66	16
16	1.6	58	8	74	24

WW Present weather: A full table of present weather symbols contains 100 different entries – impossible to include in this brief article. Precipitation, for example, is typed according to intensity (light, moderate or heavy) and character (intermittent, showery or continuous). At least 10 different types of fog are recognized. The most frequently used symbols are listed below.

N.B. A bracket to the right of the symbol means: occurred during last hour, but not at time of observation.

,	intermittent light drizzle	*	intermittent moderate snow	(≡)	fog in sight
,,	steady light drizzle	**	steady light snow	≡	fog
•	intermittent light rain	* ▽	light snow shower		heavy thunderstorm
	steady heavy rain	=	mist		light or moderate thunderstorm with rain
• ▽	light rain shower	<	lightning		smoke

ppp Pressure change in the three hours preceding map time (example: 26 is 2.6 mb or 0.26 kPa)

a Character of the pressure change associated with ppp. The characteristic plotted represents the barometer trace and is self-explanatory. for example, the symbol ┌ means that the pressure rose steadily during the first part of the 3-hour period, then remained constant; the symbol ^ means that the pressure rose slightly at first, then fell during the remainder of the 3-hour period, the total pressure change being a decrease.

△ Symbol for an automatic reporting station.

WIND PLOT

The shaft of the arrow represents the direction from which the wind blows. The wind speed is given by the number of barbs and/or flags on the shaft (see table below):

- Full barb is 14–22 km/h (8–12 knots)
- Half barb is 5–13 km/h (3–7 knots)
- Solid flag or pennant is 88–96 km/h (47–52 knots)

SPEED	SYMBOL	SPEED	SYMBOL
(2–4 km/h)		(70–78 km/h)	
(5–13 km/h)		(79–87 km/h)	
(14–22 km/h)		(88–96 km/h)	
(23–31 km/h)		(97–105 km/h)	
(32–41 km/h)		(106–115 km/h)*	

NOTE: A circle around the station location indicates calm wind.

CLOUD PLOT

$C_HC_MC_L$ High, middle and low cloud symbols, respectively. The table below contains the major cloud types.

HIGH CLOUDS base above 6,000m	Thin Cirrus	Thick Cirrus	Tufted Cirrus	Cirro-stratus	Cirro-cumulus	
MIDDLE CLOUDS base between 2,000-6,000m	Thin Alto-stratus	Thick Alto-stratus or Nimbo-stratus	Alto-cumulus	Alto-cumulus in small patches	Alto-cumulus in bands	Alto-cumulus with Alto-stratus
LOW CLOUDS base below 2000m	Fair weather Cumulus	Swelling Cumulus	Cumulo-nimbus	Strato-cumulus	Cumulus flat-tened to Strato-cumulus	Stratus Fractus and/or Cumulus Fractus

N Total amount of cloud that covers the sky. The following symbols indicate the sky cover.

0	○	Absolutely no clouds	5		5/8
1	⦶	1/8 or less	6		6/8
2	◔	2/8	7		7/8
3		3/8	8	●	8/8 (overcast)
4	◑	4/8	9	⊗	sky obscured

N_h Total amount of low or middle cloud amount expressed in eighths

h Height (in metres) of the lowest cloud, in coded form, for example:

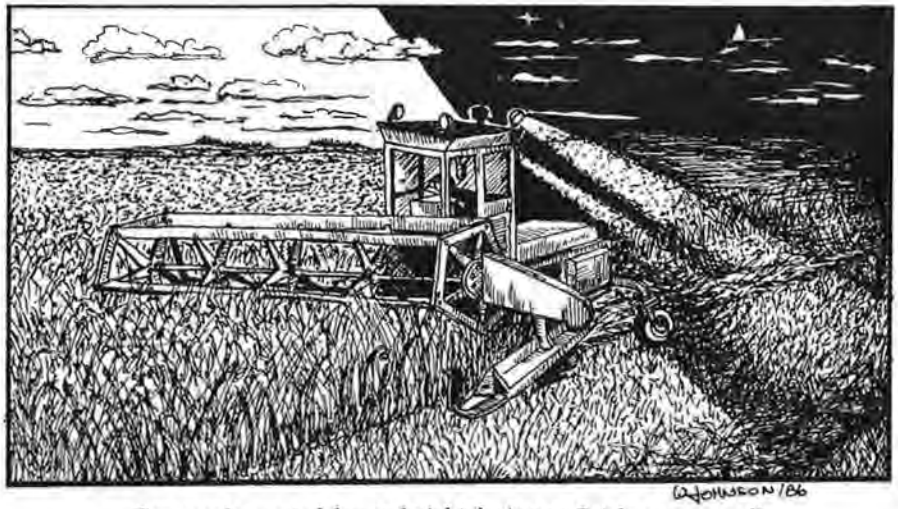
Code	Height	Code	Height
0	0 to <50	8	2000 to <2500
2	100 to <200	9	>2500 or no cloud
4	300 to <600	X	Sky completely obscured, no cloud visible
6	1000 to <1500		

THE FALL AND HIGHLIGHTS OF 1985

by Michael J. Newark

The temperature and precipitation patterns across Canada during the 1985 fall season (September to November, inclusive) was remarkably similar to those in 1984. The west was very cool, with well above normal precipitation, while the east was a little warmer and drier than normal (except for cool temperatures in Atlantic Canada). For the second year in a row the mean atmospheric circulation pattern for the season displayed an anomalous cold trough over western North America and an abnormal ridge over the east – a pattern just the reverse of that expected for the normal season.

Most of the above normal precipitation in the west fell during September, much of it as snow due to record cool temperatures. High monthly precipitation records were set at many Alberta and B.C. locations. During October record precipitation fell in British Columbia and frequent snowfalls blanketed the Prairies, while abnormally cold temperatures persisted. Fortunately, farmers were able to take advantage of a brief spell of very warm weather during late October. By working night and day they were able to combine their fields and save the harvest.



Farmers harvested day and night during an October warm spell.

RECORD COLD IN THE WEST

During the latter half of November, bitterly cold Arctic air spilled southwards, encompassing the southern Yukon, British Columbia and the Prairie Provinces. This resulted in the coldest November on record in some parts of British Columbia, and the coldest November since the turn of the century in some Prairie regions. Mean November temperatures were as much as 12°C below normal in the west. At the onset of the cold wave, the Arctic winds sweeping across the Yukon and the Prairies created blizzard conditions. However, during the cold period, skies were often clear, resulting in record amounts of sunshine, and very light precipitation except for the southeast shore of Vancouver Island, where snow squalls produced accumulations as great as 38 cm.

HEAT WAVE IN THE EAST

Regions from Ontario and eastwards experienced a very pleasant start to the fall. A heat wave occurred during September in the Great Lakes-St. Lawrence Valley region, and the month was very dry. In parts of New Brunswick, farmers were forced to haul water for their livestock because wells and streams dried up owing to the lack of rainfall. A smaller than usual potato harvest was also attributed to the prevailing dryness. Deficient rainfall in parts of the Atlantic Provinces continued throughout October; precipitation only returned to normal with the onset of east coast storms in November.

RECORD NOVEMBER RAINFALL IN SOUTHERN ONTARIO

November in southern Ontario was the wettest and dullest ever at many locations, and followed on the heels of a very wet October. Toronto, with 186.2 mm of rain had the wettest November since 1840, and the wettest of any month in seventy years. Some places even received more than twice their normal monthly precipitation. From the end of October into the first week of November several days of rain, heavy at times, fell in southern and central Ontario owing to the very slowly moving remnants of hurricane *Juan*. Many 24-hour precipitation records were broken.

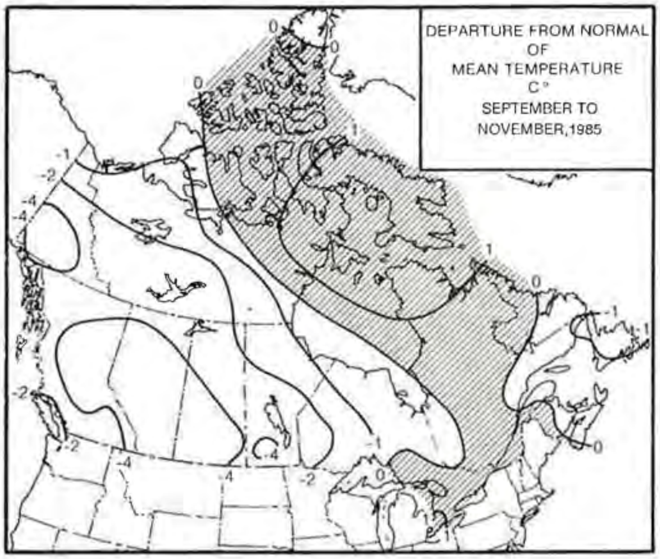
SEVERE STORMS

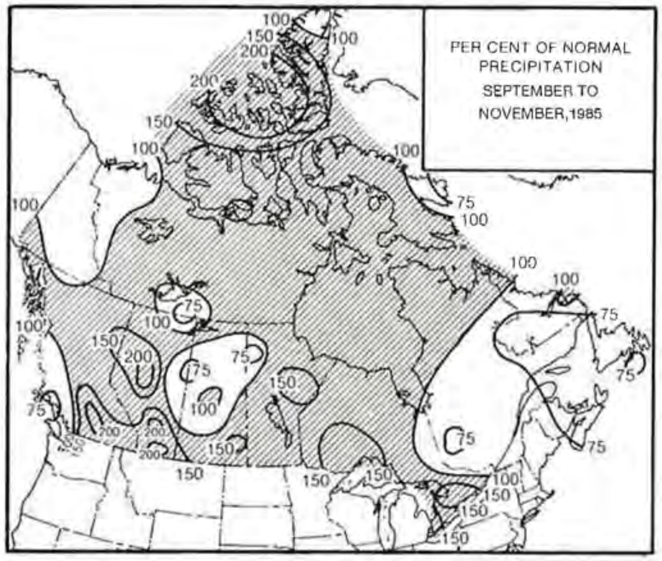
On September 7, a tornado crossed Big Rideau Lake, Ontario and caused one fatality. Then on September 19, severe thunderstorms north of Lake Superior produced golfball-size hail at Nakina, and a 125-mm deluge at Geraldton. The severe local storm season apparently ended on October 4, with a small tornado at Wheatley, Ontario.

Large-scale storms, on the other hand, began to increase in number and intensity. Several major windstorms and blizzards swept across the eastern Arctic, most notably on September 24, October 25 and November 6. Wind gusts as high as 120 km/h were reported, and buildings experienced structural damage at Resolute Bay and Grise Fiord. On October 16, a storm near the Queen Charlotte Islands with 120 km/h gusts generated 3-metre waves in which two fishing boats foundered and sank. Freezing rain fell in southern Ontario on November 12 and in southern Québec on November 16, causing thousands of minor traffic accidents. A particularly severe storm in southern Manitoba crossed northern Ontario and central Québec into northern Labrador between November 19 and 21, and resulted in blizzard conditions, up to 40 cm of snow accumulation, and damaging winds.

FREEZE-UP IN THE NORTH

In the Beaufort Sea, the polar pack of old ice was held close to the oil drilling sites by prevailing westerly winds. Consequently water temperatures were colder than normal, leading to a freeze-up earlier than usual. However, the annual resupply of outposts in the area was completed by the first week of October, with the help of the *John A. MacDonald*, a powerful Canadian Coast Guard ice-





breaker sent from the east coast. Freeze-up of Hudson Bay began a bit later than normal, but ice formation accelerated throughout November because of colder than normal temperatures. By November 4, the last ship traffic cleared Hudson Strait past Cape Chidley. In the Yukon and western Northwest Territories, lakes and rivers began to freeze over in early November, and by the third week of the month ice bridges were established across most major rivers.

As fall closed, the atmospheric circulation pattern completely reversed, bringing the cold wave to an abrupt end in the west, and returning the Canadian weather regime to normal.

NOTABLE 1985 MONTHLY EXTREMES

Period	Place	Record
RAINFALL – Driest		
April	Moncton, N.B.	28.7 mm
April	Natashquan, Qué.	23.2 mm
June	Lethbridge, Alta.	3.2 mm
August	Port Hardy, B.C.	11.8 mm
September	Moncton, N.B.	14.8 mm
September	Truro, N.S.	18.0 mm
Year	Victoria Airport, B.C.	508.8 mm
RAINFALL – Wettest		
April	Hope, B.C.	370.6 mm
April	Revelstoke, B.C.	114.3 mm
June	Halifax, N.S.	307 mm
August	Winnipeg	218.0 mm
November	Southern Ontario locations	up to 230 mm*
RAINFALL – Greatest One-Day		
August 3	Near Parkman and Wawota, Sask.	380 mm
SNOWFALL – Heaviest		
January	Goose Bay, Nfld.	235 cm
April	Fort McMurray, Alta.	45 cm
May	Atlantic Provinces	up to 33 cm
November	Geraldton, Ont.	101 cm
November	Victoria Gonzales, B.C.	50.2 cm
TEMPERATURE – Coldest		
October	Castlegar, B.C.	−16°C
SUNSHINE – Most		
July	Several B.C. Locations	≥ 400 hours
SUNSHINE – Least		
October	Cranbrook, B.C.	109 hours
November	London, Ont.	16.8 hours
WIND – Highest Hourly Speed		
January 28	Goose Bay, Nfld.	143 km/hour

*Total Precipitation

CLIMATE FOR THE YEAR

Extreme variability characterized the climate of 1985. The spring and summer drought in western Canada was the event with the greatest impact. It caused one of the worst forest fire seasons in British Columbia and, for the second year in a row, it reduced crop production in the southwestern Prairies. Economic losses were estimated to be over a billion dollars, through depleted harvests of timber, grain and hay, and the extra expenditures on fighting fires, reseeding, insect spray, etc.

The weather turned extremely cold during November, which was the coldest on record at many B.C. locations and nearly the coldest, in neighbouring regions of the Yukon and the Prairies. Southern Ontario experienced the wettest November ever, receiving more than twice the normal precipitation.

Hailstorms and tornadoes were abundant, particularly in eastern Canada, where the third worst tornado disaster in the country's history struck southern Ontario and adjoining Québec at the end of May. Torrential thunderstorms hit southeastern Saskatchewan with about 380 mm of rain during one 6–8 hour period in August – probably the greatest one-day rainfall in Canada east of the Rockies.

At least 30 winter storm events caused wide-ranging disruptions to transportation, power transmission, schooling and business. Excluding fatalities due to lightning, hypothermia or weather-induced heart attacks, 38 people are known to have died as a result of the weather, while hundreds were injured.

Michael Newark is the Founder-Editor of *Chinook* (1978–1984) and Managing Editor of the AES publication *Climatic Perspectives*.

SATELLITE VIEW OF THE UPPER BAY OF FUNDY AT LOW TIDE

The image on the cover is a false-colour composite of spectral bands 4 (0.5–0.6 μm), 5 (0.6–0.7 μm) and 7 (0.8–1.1 μm) from the multi-spectral scanner on the LANDSAT satellite. Two of these bands (4 and 5) are in the visible region of the electromagnetic radiation spectrum, and the third (7) is in the near-infrared region. The false colours indicate the different intensities of the radiation in these combined bands, and hence, depict the various reflective properties of the land and water surfaces.

The image was taken during low water on June 30, 1975. The various shades of red and orange in land areas indicate the different textures (e.g., rocks, trees, grasslands) of the reflective surface below. Similarly, the various shades of blue and green in water areas depict the water's different reflective characteristics associated with different concentrations of suspended sediment. The deep blues in the outer Bay of Fundy, Northumberland Strait and the inland lakes correspond to the clearest (lowest concentrations of suspended sediment) waters, while the greenish-blue shades in Chignecto Bay (upper) and Minas Basin (lower) show the water's increased sediment content in these areas of strong tidal currents. The light brown areas bordering the coastline in the upper part of Chignecto Bay and throughout most of Minas Basin are mud-flats exposed only during low water. The daily appearance and disappearance from view of these mud-flats, which are several kilometres wide in many areas, are dramatic reminders of the large tides in the Bay of Fundy and Gulf of Maine (see article on pages 24–28). (Photograph courtesy of the Canada Centre for Remote Sensing, and Dr. Carl Amos of the Bedford Institute of Oceanography.)

NEWS AND NOTES

Acid Rain: Effects and Neutralization

Over a two-year time period we performed a series of tests on acid rain. In these experiments we tried to determine:

1) The pH levels of Espanola's precipitation and tapwater
2) The effects of acid rain on garden plants
3) The damage caused by acid rain to plant roots or foliage
4) The effects of acid rain on aquatic life
5) The ability of lime to neutralize/reverse the effects

In the first experiment we hoped to discover what the pH levels of Espanola's rainfall and tapwater were. We did this by regularly collecting snow samples from around Espanola, allowing them to melt down, and then measuring their pH levels and taking an average. Espanola's rainfall turned out to have a pH of 4.0, and its tapwater a pH of 6.1.

In this experiment, we watered two typical garden plants (tomatoes and marigolds) using different strengths of acid, with pHs of 6.1 (tapwater), 5.6 (clean rain) and 4.0 (the average pH of Espanola's precipitation). We also hoped to determine which part of the plants was being harmed the most by the acid. From the results of this experiment, we concluded that tomatoes and marigolds grow best when watered with tapwater and that acid rain does significant damage to them. It also appeared that the plant foliage was being damaged more than the roots.

This part of the study was a replication of the previous experiment, using a different plant (the radish plant). Our conclusions were similar to those of the other experiment in that pH 6.1 proved to be the most conducive to plant growth and pH 4.0 the least.

In this part of the study, we hoped to discover what the effects of acid rain on aquatic plants are. We did this using two aquariums. One represented a lake receiving acid rain while the other served as a "normal" lake. We concluded that acid rain has devastating effects on lakes and the aquatic life within.

In the final part of the study, we experimented with the ability of lime to neutralize the acid. We wanted to see if life harmed by acid rain could recuperate after the acid was neutralized. This proved partially successful in that the lime diluted the acid but failed to "bring back" damaged life. This may have been because life in the aquarium was beyond the point of recuperation.

Christian Fielding and Keiri Tait

The authors are students at the A.B. Ellis Public School in Espanola, Ontario. Their article briefly describes their project, which received a CMOS award at the Canada-Wide Science Fair held in Cornwall during May 1985.

CRITIQUE

LA PRÉVISION DU TEMPS. Pour comprendre les phénomènes météorologiques en toute facilité. Par E. Neukamp. Miniguide Nathan Tout Terrain, 1985, 79 p., 60 photos couleurs, traduit de l'allemande, 5,65 $.

Ce livre de petit format retient l'attention par la grande beauté de ses photos. Nul doute que toute personne intéressée à la météorologie trouvera qu'il est un heureux complément, et à peu de frais, à tout atlas ou guide de photos de nuages. D'ailleurs, l'auteur, qui est géologue mais aussi dessinateur, photographe, paysagiste et réalisateur, a déjà gagné un prix pour ses photos de nuages. Les quelques illustrations, très schématisées, sont aussi bien exécutées quoique l'on y retrouve certaines imprécisions.

L'auteur donne de bons conseils aux météorologistes amateurs. C'est un des rares ouvrages destinés au grand public qui conseille aux météorologistes en herbe de reconnaître les nuages, d'observer le ciel, les variations de la pression, de la température et de l'humidité, et de suivre quotidiennement le bulletin météo afin de préciser les prévisions en fonction des paramètres propres à leurs régions.

Ce livre est avant tout construit en fonction des photos que l'auteur y a mises. Le texte est donc limité et le tout n'est pas véritablement organisé en chapitres et sections. Les notions que l'on y présente sont donc très sommaires. De plus, la traduction de l'allemand est probablement à l'origine de plusieurs imprécisions, ce qui aura pour effet de créer une certaine confusion chez le lecteur.

Malgré ces quelques défauts, ce petit livre demeure attrayant et assez original. Néanmoins, le lecteur aura avantage à approfondir les notions de météorologie en consultant d'autres ouvrages.

Richard Leduc

PROFESSIONAL AND BUSINESS DIRECTORY

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 805, 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.

5. Editorial Policy
The suitability of articles for publication will be decided by the Editor upon consultation with at least one other member of the Editorial Board. Particular attention will be given to the readability of articles by a lay readership.

6. Reprints
Reprints of articles will not be made available. Four copies of the issue in which an article appears will be provided to the principal author. Additional copies will be supplied at the author's cost, provided the request is received before printing.

Chinook

THE CANADIAN MAGAZINE OF WEATHER AND OCEANS

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

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

WHY? The aims of *Chinook* are

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

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

- secondary school and community college students
- farmers, fishermen and foresters
- márine-recreation, sports and tourism operators and enthusiasts
- aviators
- amateur observers of natural phenomena
- specialists in other sciences
- environmentalists

HOW? Subscriptions to *Chinook* may be ordered using the handy form above.

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Please enter my subscription to *Chinook* for one year (1986, 4 issues) at the following rate (please check one):

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