A Review of the Physical Oceanography of the Bay of Fundy

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ABSTRACT

The physical oceanography of the Bay of Fundy is examined. The large tides and tidal currents, attributable to a resonance effect, are a dominant force in the system. Variations in water levels and currents are caused by the predictable variability in the tidal generating forces, and by the less predictable meteorological forcing and fresh water input. The large tides give rise to unusual effects such as tidal bores and reversing falls. The potential and kinetic energy and dissipation levels associated with the tides are all very large. Examinations of hydrographic data and modelling results have indicated strong vertical mixing caused by the tides, but horizontal exchange in the system is low compared to low-tide, open-sea situations. The mean currents in the upper Bay are largely tidally-driven, but in the lower Bay, fresh water runoff plays a major role. The ice characteristics are also greatly influenced by the tidal range and tidal currents. Wave information in the Bay is sparce, but wave energy typically is not large.

Key words: physical oceanography, Bay of Fundy, tidal dynamics, numeric model studies

RÉSUMÉ

L'océanographie physique de la baie de Fundy fait l'objet du présent rapport. De fortes marées et d'énormes courants tidaux attribuables à un effet de résonance, constituent une force dominante dans le système. Certaines variations du niveau de l'eau et des courants sont causées par la variabilité prévisible des forces génératrices de la marée astronomique, ainsi que par le forçage météorologique direct et l'apport en eaux douces. Les grandes marées donnent lieu à des phénomènes particuliers comme le mascaret et les chutes réversibles. L'énergie potentielle et cinétique de même que les niveaux de dissipation associés aux marées sont tous très élevés. L'examen des données hydrographiques et des résultats de modélisation ont révélé l'existence d'un mélange vertical très fort, lequel est dû aux marées, tandis que l'échange horizontal est faible dans le système comparativement à ce qui existe dans les zones littorales de faible marée et de mer libre. Dans la baie du Nord, les courants moyens sont généralement mus par les marées, mais dans la baie du Sud, l'écoulement des eaux douces joue un rôle de premier plan. Les caractéristiques glacielles sont aussi dominées par le marnage et les courants tidaux. On ne sait pas grand chose de la houle qui règne dans la Baie, mas l'énergie des vagues est singulièrement faible.

INTRODUCTION

There are many processes important in the physical oceanography of the Bay of Fundy. One picture is obtained by thinking in terms of the dominant M_2 tidal signal of 12.42 hrs, the annual signal and the annual means of current and hydrographic parameters. Although this would cover most of the dynamics of the system, much of interest is attributable to the variability in these signals. The very predictable variations in tides and the less predictable annual and short time scale variations in meteorology are of great importance to the synoptic picture of the Bay and significant to many non-physical aspects of the environment. This paper attempts to briefly describe what is known about the dominant processes in the Bay of Fundy and indicate some important areas of variability in these processes.

THE SEA LEVEL TIDAL REGIME

Prior to the late 1960's the large tidal oscillations in the Bay of Fundy were thought to be caused by the near resonance between the M_2 tide (period 12.42 hours) and the natural period of the Bay. Defant (1961), for example, referring to the Bay, stated "the resonance condition is almost completely fulfulled". However, when a detailed calculation was made (Rao 1968), the free period of the Bay of Fundy alone was found to be about 9 hours which could amplify the tides, but is far from resonance. Later, Garrett (1972, 1974) showed that the entire Gulf of Maine and Bay of Fundy (Fig. 1) combined to form one resonant system with a period of close to 13 hours. Duff (1981) has suggested that "frequency entrainment" - a process by which a system forced near to natural period will convert energy to this natural period from the forced period, - may also play a part in the large Fundy tides.

Figure 2 shows the amplification of the tide incident on the shelf edge. The tidal range increases from the shelf edge by a factor of 2 1/2 to Boston, 3 to Yarmouth, 6 to Saint John, 10 to Upper Chignecto and 12 in upper Minas. Greenberg (1979) demonstrated that most of the energy enters via the Northeast channel and the northern shelf, with some entering through Great South Channel.

The above describes the M_2 component of the tide - the largest single constituent with a period of 12.42 hours and representing 90% of the tidal energy. It can reasonably be considered by itself to represent the "mean tide". The amplitude of the next two largest constituents, N_2 (period 12.66 hrs) and S_2 (period 12.00 hrs) are a factor of 4.7 and 6 smaller than M_2 respectively. The ratio of these terms is fairly constant throughout the Bay of Fundy and Gulf of Maine (Garrett 1972). It is principally the beating of these three frequencies that provides the spring-neaps variation over the course of 15 and 29 days. Beating results from the superimposing of two waves of different frequencies, which leads to a maximum combined range when the waves are in phase, and to a minimum when the waves are out of phase. The diurnal variation in this system is caused by two main constituents: K_1 (period 23.94 hrs) and O_1 (period 25.82 hrs). These are far enough from the natural period that they lead to no resonant

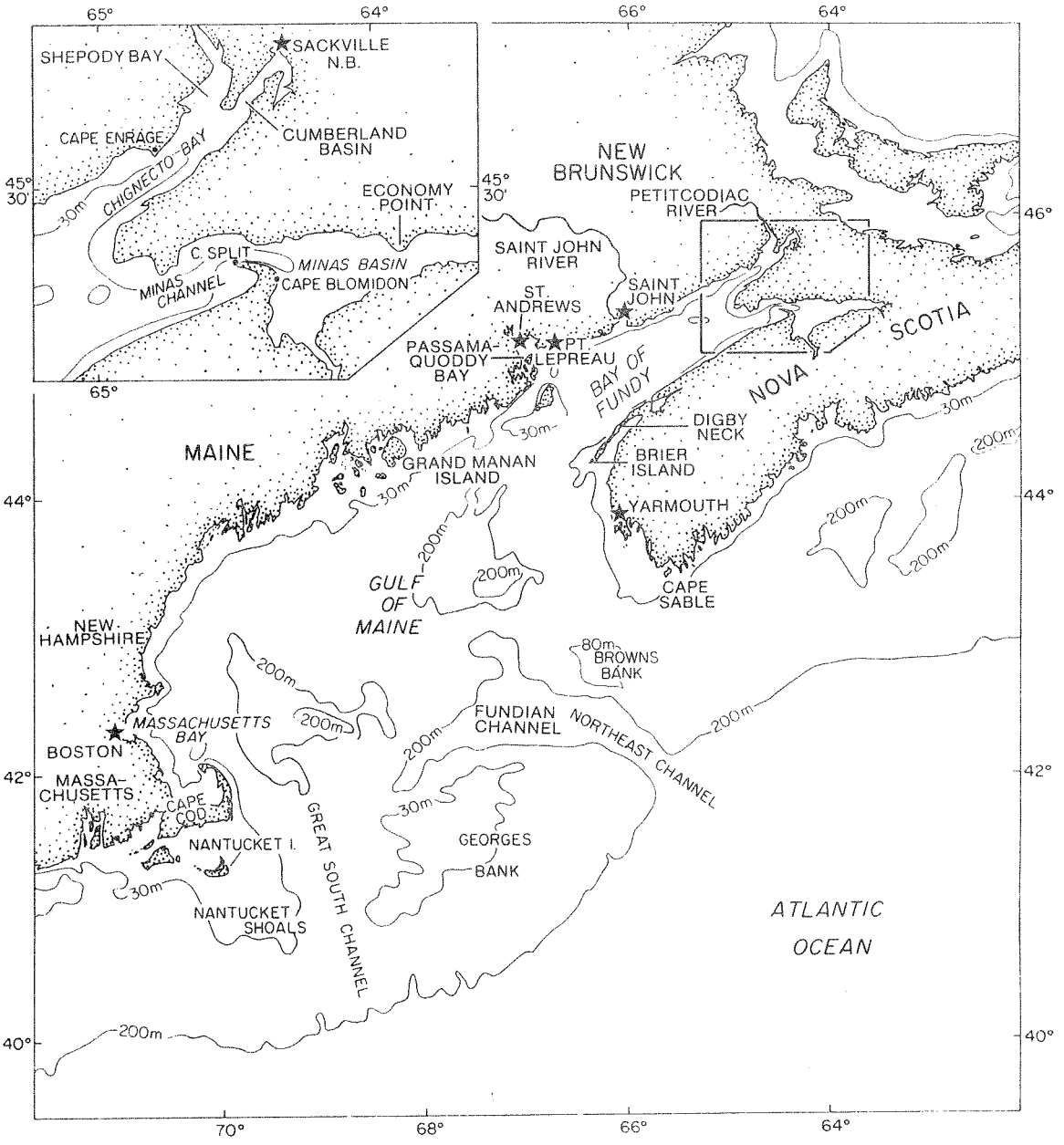


Fig. 1. Location Map for the Bay of Fundy and Gulf of Maine.

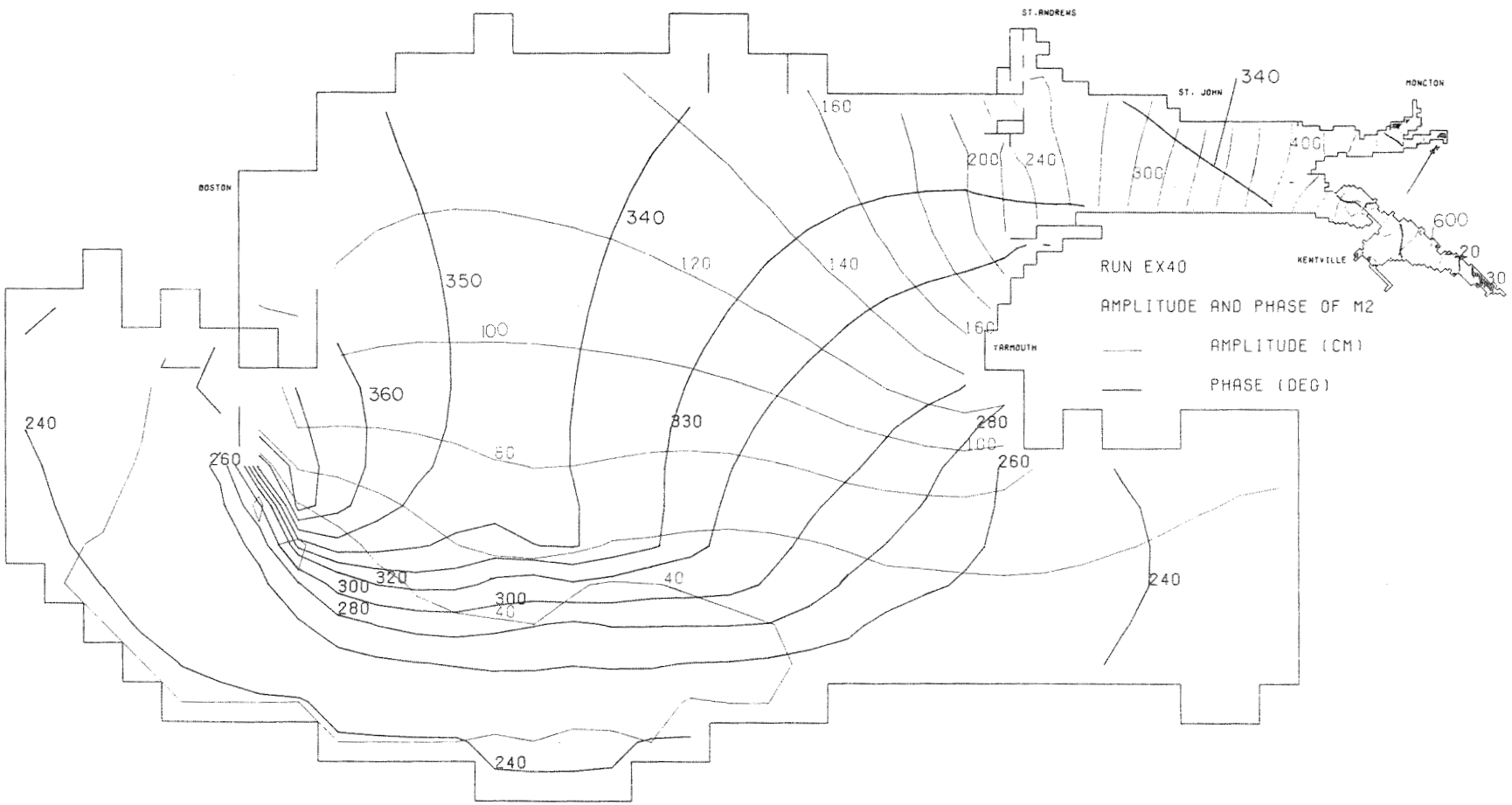


Fig. 2. The M_2 tidal regime from Greenberg (1979). Phases are relative to time zone +4. The M_2 tide can be considered the mean tide in the Bay of Fundy and Gulf of Maine.

amplification. The amplitude of these constituents is fairly constant throughout the Bay and Gulf at 10-15 cm. The beating of these two signals also leads to a spring-neaps cycle. The beat frequencies of the semi-diurnal and diurnal tides themselves beat, creating a third beat frequency that leads to two times a year when higher than normal tides are experienced. In the Bay of Fundy and Gulf of Maine the ratio of the highest tide range of the year to lowest is about 2:1. This is small compared to some areas, such as near the French tidal power plant at La Rance where the ratio is about 6:1. The largest and smallest tides are typically seen twice yearly, but the major part of the variability occurs over the 15 day and 29 day cycle (see Fig. 3 below).

Over the longer period the tides are amplified by an 18.6 year nodal variation. The effect is to change the different constituents by different percentages. The largest effect in the Fundy-Maine system is from the ±3.7% variation in M_2 amplitude. It is thought that frictional effects and the competing effect from diurnals which have a nodal variation out of phase with the semi-diurnals, would reduce this to ±2.6% (Garrett 1977).

TIDAL CURRENTS

Much of what has been said about variability in tidal elevation applies to tidal currents. It is harder to get accurate tidal constituents from current observations for three reasons. Simple continuity tells us that the tidal current will be closely related to tidal elevation, but vary with basin configuration and topography. A general hourly picture of mean tidal currents is given in the Atlas of Tidal Currents (CHS 1981), based on the numerical model described in Greenberg (1979). Some general observations, can be made. The currents are of the order 1 $m.s^{-1}$ around Southwest Nova Scotia and over Georges Bank. The rest of the Gulf of Maine has lower tidal currents - about 0.5 $m.s^{-1}$ and even lower in the western corner of the Gulf. The tidal currents increase from 0.75 to 1. $m.s^{-1}$ from the mouth of the Bay to Cape Chignecto and continue fairly uniformly at that level in Chignecto Bay. On the Nova Scotia side, the entrance to Minas Channel has tidal currents of 1 to 1.5 $m.s^{-1}$ increasing to as high as 4 $m.s^{-1}$ in the narrows by Cape Split then decreasing to a typical strength of 1.5 $m.s^{-1}$ in the Minas Basin.

TIDAL BORES AND REVERSING FALLS

Tidal bores are found in some shallow rivers that flow into the head of Chignecto Bay and Minas Basin such as the Petitcodiac River. They occur when a large amplitude tidal wave travels over shallow water. The speed at which a tidal wave moves is proportional to the depth of water over which it travels. In very shallow water, the amplitude of the tidal wave is significant with respect to the depth of the water. Thus the leading and trailing edges of the wave are retarded as they move. The typical shallow water tide rises quickly on the flood and receeds slowly on the ebb. In a tidal bore situation, the wave steepens to the extent that it

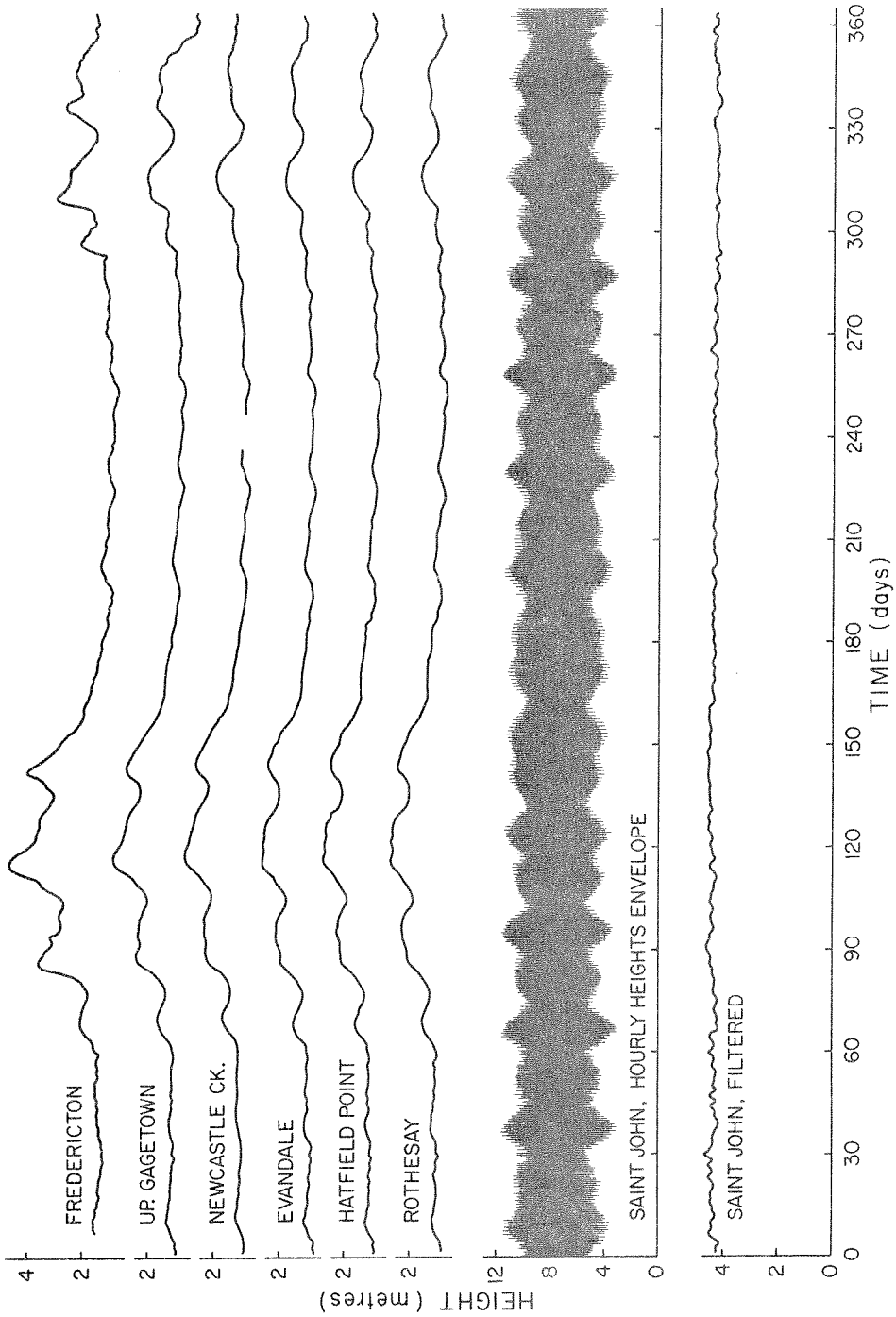


Fig. 3. Filtered hourly water levels of the lower St. John River upstream of Reversing Falls and the unfiltered and filtered water levels in St. John Harbour. The unfiltered harbour data show spring-neaps variations typical of the Bay of Fundy and Gulf of Maine. The river levels reflect variations in high tide levels in the harbour. There is no obvious correlation between the mean harbour level and the mean river level.

breaks. Much energy is dissipated in a tidal bore so it cannot continue indefinitely over the shallow water. Thus the Petitcodiac bore does not penetrate as far upstream following the siltation resulting from the completion of Moncton Causeway.

Reversing Falls, found at the mouth of the Saint John River, is driven by the combinations of high tides and river runoff over a shallow, narrow, restriction. At times of normal river flow, high water in the harbour causes an inflow past the Falls and low water causes an outflow. The mean level of the river behind the Falls is more variable and always higher than the mean level of the harbour. During times of high runoff, the level of the river is so high the falls do not reverse. The outflow at the falls at low water is "critical", meaning that it is flowing at its maximum rate, and lowering low tide would not increase the flow. At high water the inflow is not as restricted for normal river levels. Although there is no inflow during high runoff, the outflow at this time is retarded. A consequence of this regime is that the mean level in the reservoir tends to reflect the high tide levels in the harbour (Fig. 3). At times of high runoff, (inferred from the Fredericton record) the effects are more pronounced downstream at spring tides. At low runoff times, river levels seem to peak during the higher spring tides. Flooding situations caused by high runoff could be more severe when the peak runoff occurs at times of higher than normal tides.

ENERGY CHARACTERISTICS

The partitioning of tidal energy is described in Greenberg (1979) from which the following is excerpted.

Values of mean energy and mean work rates are given in Table 1. The distribution of kinetic energy and frictional work is shown in Fig. 4, and 5. The potential energy is, predictably, highest in the upper reaches of the Bay of Fundy, where the tidal range is greatest. In these areas, in particular, and generally in the Bay of Fundy, the mean potential energy is higher than the mean kinetic energy. In the Gulf of Maine the kinetic energy is greater than the potential energy, and is concentrated in a wide band from around the Nantucket area, through Georges Bank, across the Fundian Channel, and into the Bay of Fundy. There are local maxima through Great South Channel, Northeast Channel and at the entrance to the Bay of Fundy. The mean kinetic energy of the New Hampshire corner of the Gulf of Maine is very low. The kinetic energy per unit area reaches a maximum in the narrows by Cape Split, where there are strong currents through the deep channel. The mean kinetic energy in Chignecto is in comparison, very low. The frictional dissipation in the Gulf of Maine is concentrated in a band similar to that of the mean kinetic energy, but with maxima over the shallow areas. There is very little dissipation in the New Hampshire corner of the Gulf. The frictional dissipation increases gradually from the body of the bay into Chignecto Bay. There is a dramatic increase from Cape Chignecto into Cape Split, then a reduction in dissipation in the Minas Basin, although values are still relatively high.

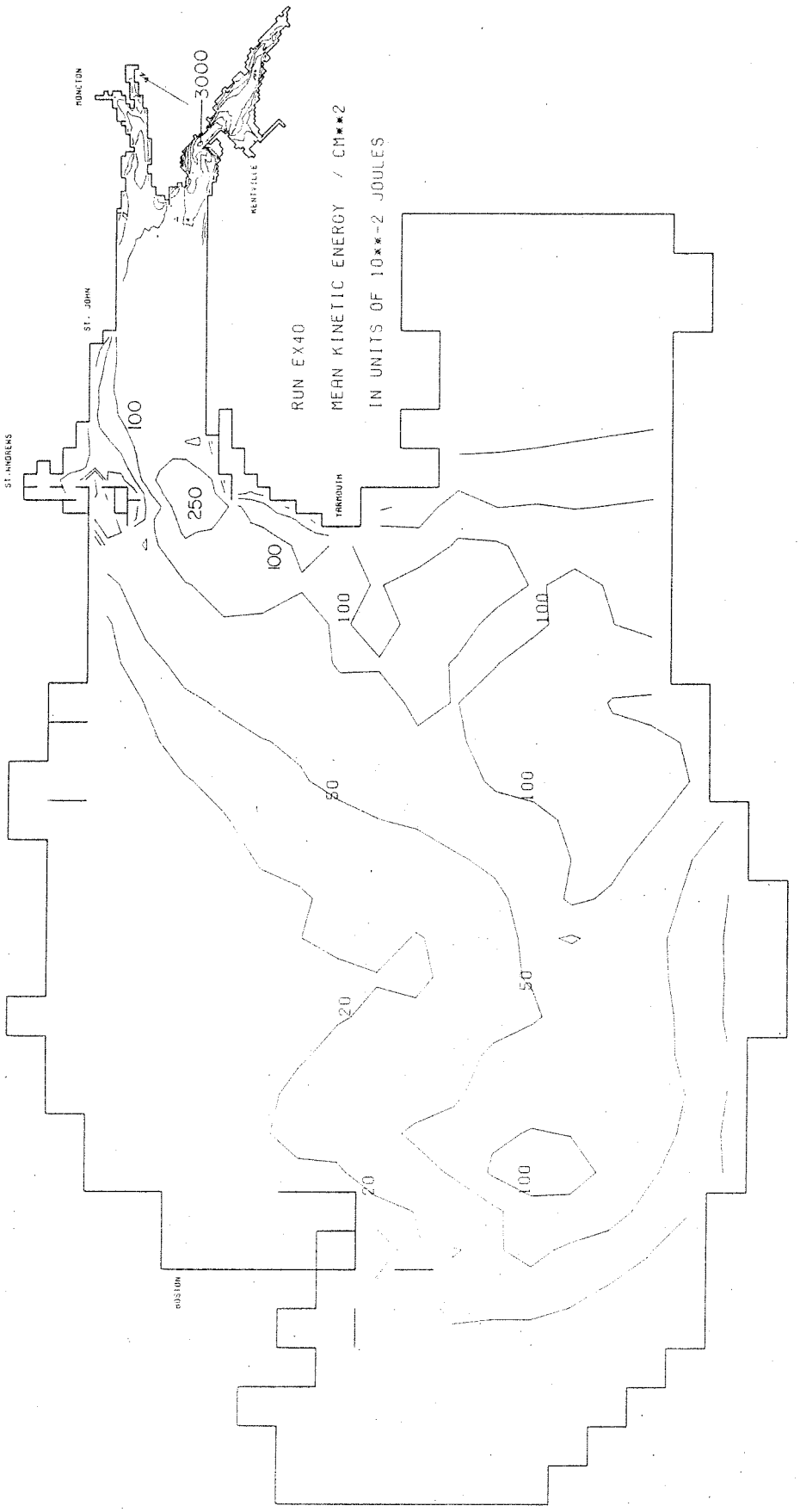


Fig. 4. The mean kinetic energy of the Bay of Fundy and Gulf of Maine from a numerical model simulation of the M_2 tide (Greenberg 1979).

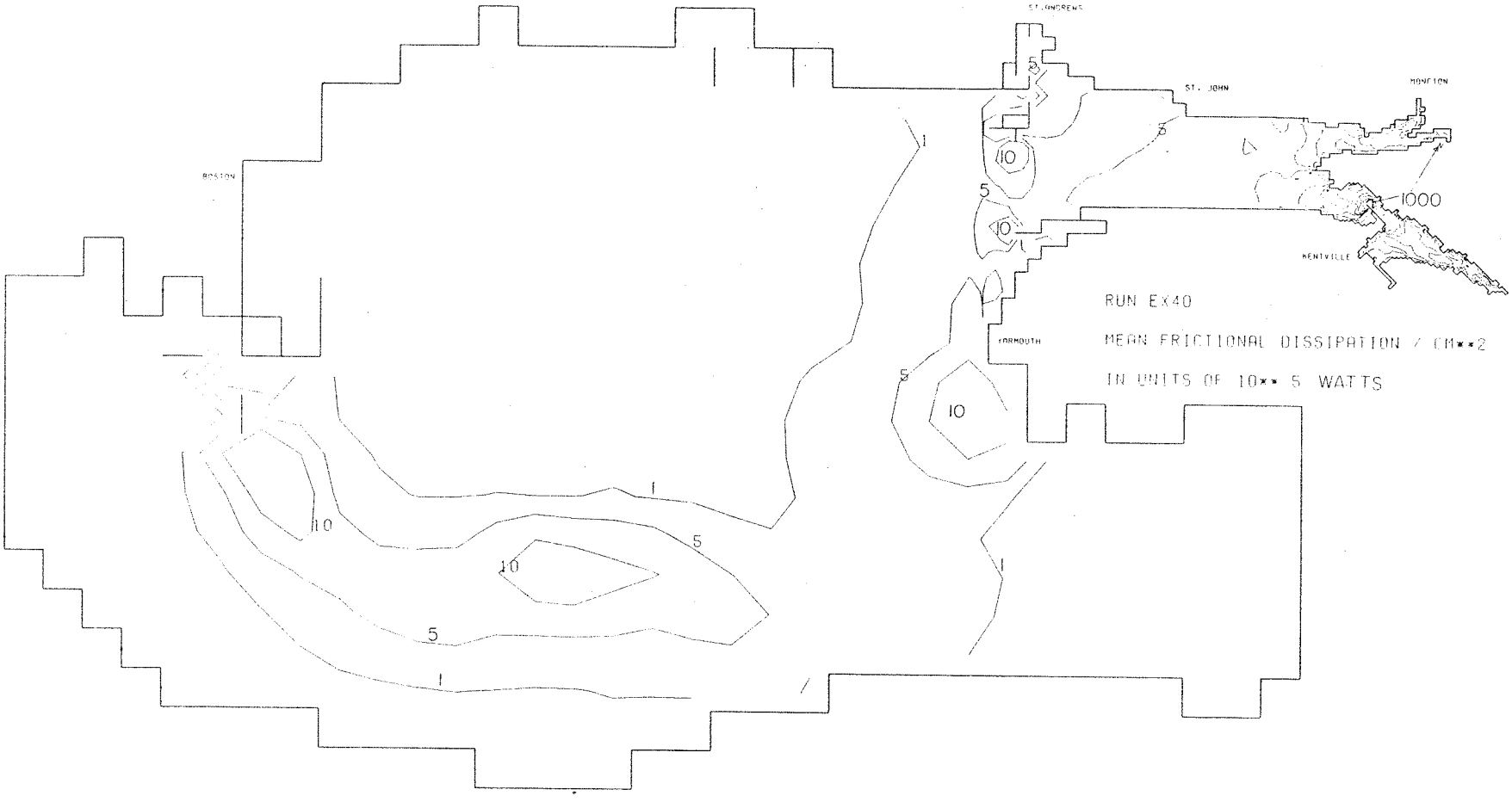


Fig. 5. The mean frictional dissipation in the Bay of Fundy and Gulf of Maine, from a numerical model simulation of the M_2 tide (Greenberg 1979).

Using the values in Table 1, the dissipative Q, where $Q = \frac{\text{Frequency x energy}}{\text{Dissipation rate}}$, was found to be 5.0 for the entire system and for the Gulf and Bay considered separately. Q is a measure of the damping of the system.

TEMPERATURE AND SALINITY CHARACTERISTICS

An integrated study of the temperature and salinity characteristics for the entire Bay of Fundy remains to be done. We can, however, put together a picture that gives us some idea of the hydrography of the region from different studies, recognizing year to year variability most noteably from variations in fresh water runoff in the St. John River (Bumpus 1960) and to some extent from meteorological effects. The data used for this outline comes from Hachey (1952), Bailey (1954), Bailey et al. (1954) who looked in detail at aspects at the mouth of the Bay; Amos and Joice (1977) who examined the Minas area; Amos and Asprey (1981) who looked at Chignecto Bay; and Kate Kranck (personal communication) and Don Gordon (personal communication) who surveyed the main body of the Bay.

Bailey (1954) studied long term measurements across a transect from St. Andrews to Digby Neck. He found data from the years 1950-1952 to be very similar, but quite different from the 1917 data in which similar salinities were observed, but temperatures were 2.0° C colder. He identified tidal mixing, vernal warming, runoff, and autumn and winter cooling to be important processes in the seasonal hydrographic picture. The analysis of data from a station north of Grand Manan Island (Bailey et al. 1954) from three depths showed sinusoidal variations over the year. Salinity reached a maximum near bottom (about 33 °/₀₀) with little seasonal variation and a minimum at the surface in the spring (about 30 °/₀₀) where the seasonal variation was greater. The temperature minimum of near 0°C was noted at the surface in the winter and the maximum at this station was 13°C in the late summer, found at all depths.

The spatial variation of salinity and temperature in the Bay can be pieced together from several sources of data. At the mouth of the Bay where there is extensive stratification the salinity in summer is about 33 °/₀₀, but fresher at the surface. The surface salinity falls regularly from the mouth to near 31°/₀₀ by Cape Chignecto. In Chignecto Bay values of 30 °/₀₀ have been found and in upper Minas Basin 28 °/₀₀ has been observed. In the fall and winter, when there is less fresh water runoff, the salinities tend to be higher and more spatially uniform. Surface temperatures in the late summer show a pattern of colder 11°C water at the mouth of the Bay warming to 14°C at Cape Chignecto and rising further to 17°C in Chignecto and 21°C in upper Minas Basin. In the fall, the temperatures are spatially more uniform and cooler than in summer. In the winter, the gradient is reversed, with the coldest (0°C) water at the head of the Bay and 3°-4°C water at the mouth.

TABLE 1. Mean energy and work for an M_2 tidal cycle for different areas.

(1) From the head of Minas to Cape D'Or.

(2) From the head of Chignecto to a line midway between Cape Enrage and Cape Chignecto.

(3) Covering the head of the bay before it divides into Chignecto and Minas.

(4) The Bay of Fundy area covered by the medium mesh.

(5) The Gulf of Maine and continental shelf area covered by the coarse mesh.

The dissipative Q of each region is also given.

(from Greenberg 1979)

Area	Mean Potential Energy 10^{14} Joules	Mean Kinetic Energy 10^{14} Joules	Mean Total Energy 10^{10} Joules	Mean Rate of Friction Dissipation 10^{10} Watts	Q
1. Minas	1.15	.38	1.53	1.02	2.1
2. Chignecto	.38	.03	.41	.06	9.6
3. Upper Fundy	.65	.21	.86	.22	5.5
4. Lower Fundy	2.39	1.59	3.97	.60	9.3
Total Fundy	4.57	2.20	6.77	1.90	5.0
5. Gulf of Maine	4.34	8.45	12.79	3.60	5.0
Total Fundy-Maine	8.91	10.65	19.65	5.50	5.0

HORIZONTAL AND VERTICAL MIXING

Although some studies of horizontal mixing have been made, there is much scope for identification of the important processes in, and quantifying of, the water exchange in the Bay. Ketchum and Keen (1953) analyzed hydrographic data for the Bay of Fundy and concluded that during times of heavy runoff in the St. John River the flushing time was about 76 days. When runoff is less important the flushing time would be much longer. Holloway (1981) analyzed salinity and runoff data and found the eddy diffusivity in the Minas Basin to be related to the tidal friction along the axis of the Basin. The estimated values were of the order 200 $m^2.s^{-1}$. This is a value similar to what one would expect in a typical open coastal area.

Tidal currents cause much of the vertical mixing in the Bay of Fundy and Gulf of Maine. Garrett et al. (1978) found that for the summer months below a critical value of the ratio of depth to tidal dissipation the water was vertically well mixed; while above that value, water could be stratified (Fig. 6a, b). Most of the Bay northeast of Saint John is well mixed as are areas around Grand Manan Island, Brier Island and southwest Nova Scotia. When summer heating is reduced and meteorological forcing increased, in the late fall, winter and early spring, the stratification is reduced throughout the Bay (Bailey 1954).

From the above and to some extent from the data in the previous section, we can see that the tides are very effective at vertically mixing the Bay, but that horizontal exchanges are comparatively low, even with the existing large tidal excursions.

MEAN CURRENTS

Numerical model studies (Tee 1976, Greenberg 1983) have indicated that the barotropic residual circulation at the head of the Bay is largely driven by the tides. This is also supported by observations (Godin 1968, Tee 1977). Strong residuals and four gyres have been identified around Cape Split and Cape Blomidon (Fig. 7). Around Cape Chignecto, Cap D'Or and in Chignecto Bay, model results show distinct mean current patterns but there are not sufficient observations to verify them. Some observations suggest that in parts of Chignecto Bay, the mean current varies in magnitude and direction with depth. In the main body of the Bay of Fundy some of the mean currents seem to be tidally generated while others, such as the principal counterclockwise gyre in the lower Bay seem to be driven baroclinically, principally from the fresh water input from the Saint John River. The computer model agrees with observations of a tidally driven gyre off St. John and strong seaward flow northeast of Grand Manan (Fig. 8). The model does not adequately resolve the rapid changes in topography at the mouth of the Bay, so the irregular pattern should only be thought of as evidence that tides do generate strong mean currents there. The seasonal wind stress does not seem to play a major role in determining the mean circulation pattern.

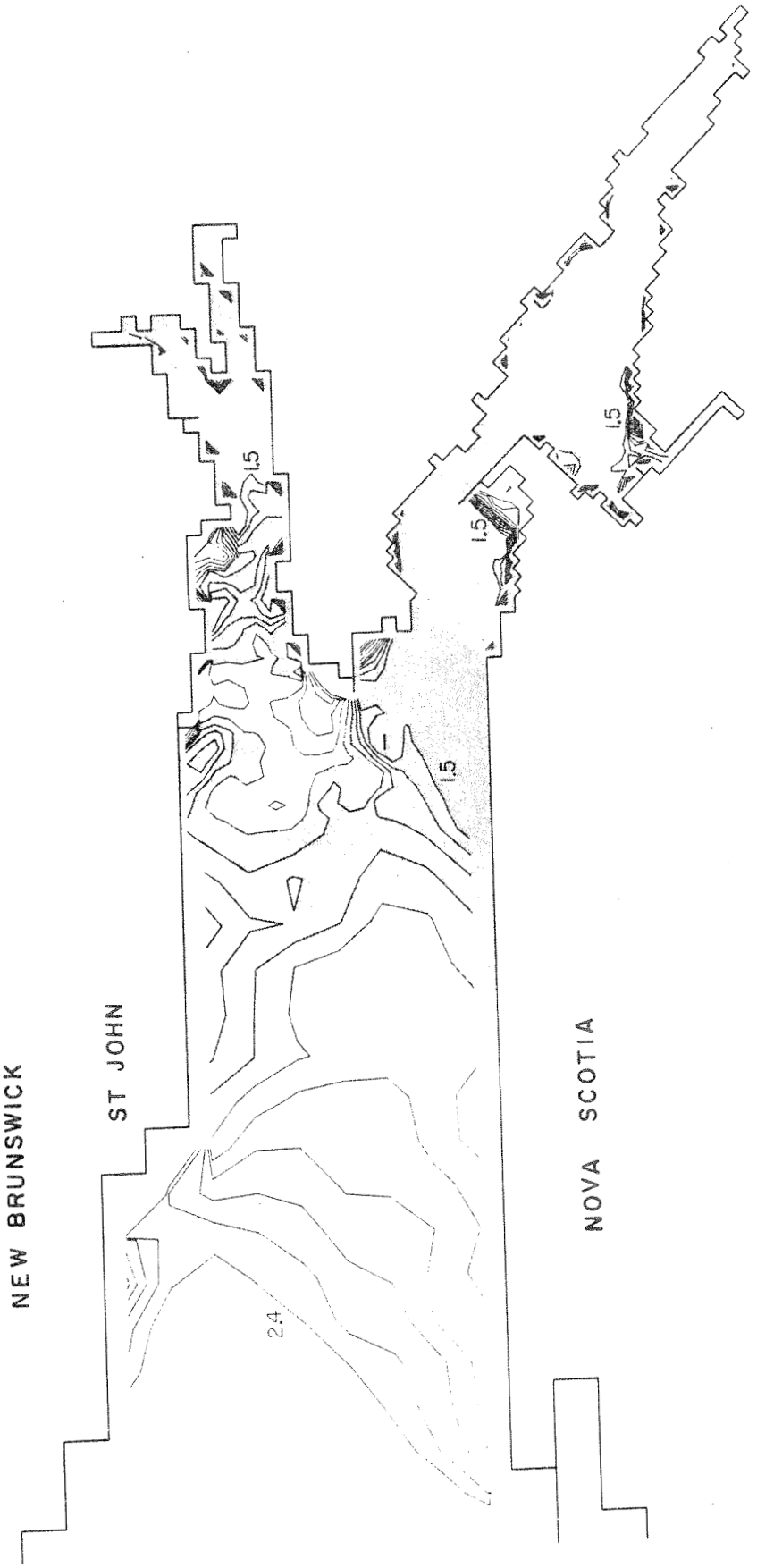


Fig. 6a. Contours of the mixing parameter $\log_{10}$ (depth/dissipation) for the Bay of Fundy. Observations from the Bay of Fundy indicated that when the parameter was less than 1.9 (shaded area), the water was well-mixed (Garrett et al. 1978).

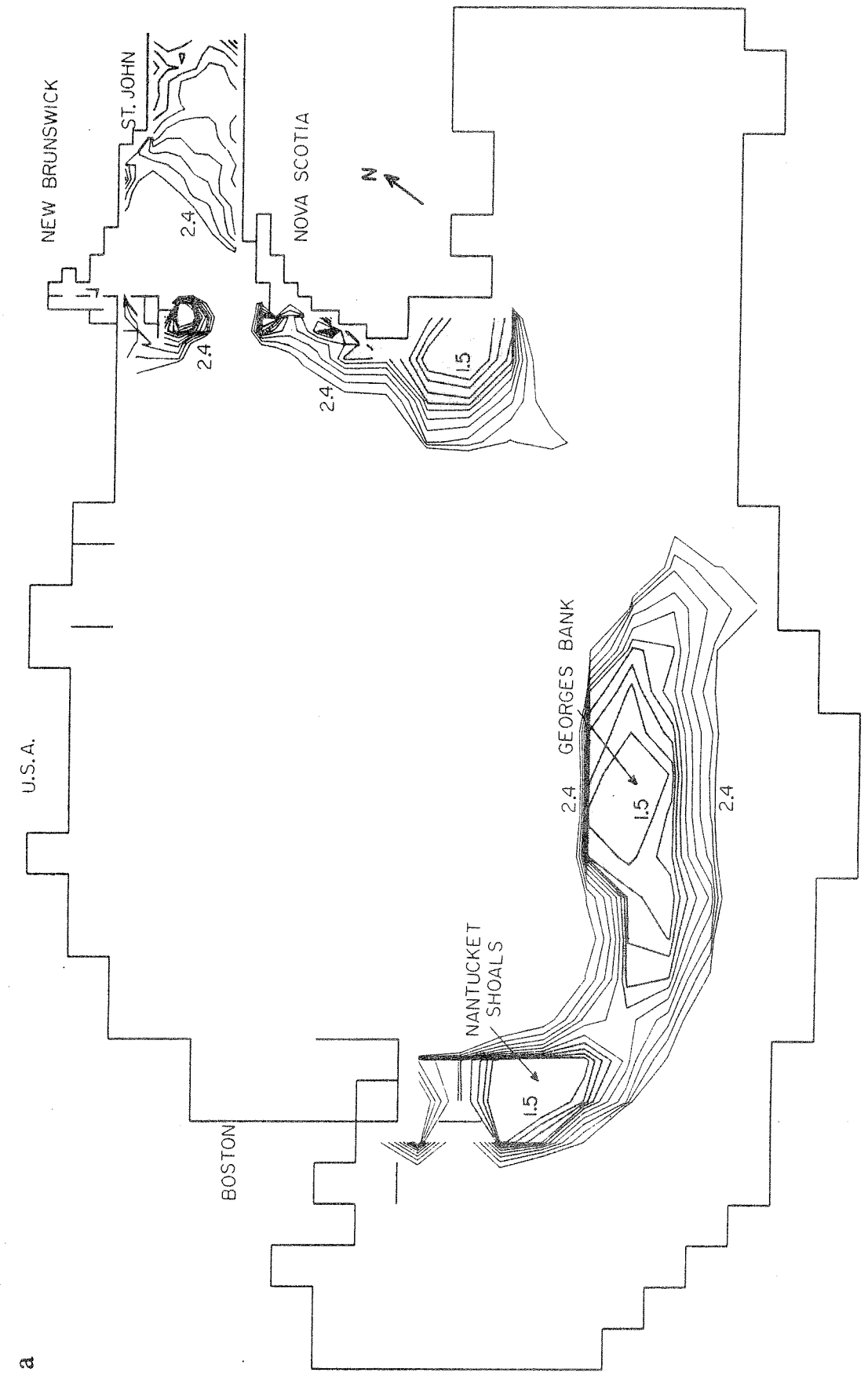


Fig. 6b. Contours of the mixing parameter $\log_{10}$ (depth/dissipation) for the outer Bay of Fundy and Gulf of Maine. Water is well-mixed when the parameter is less than 1.9 (shaded area) (Garrett et al. 1978).

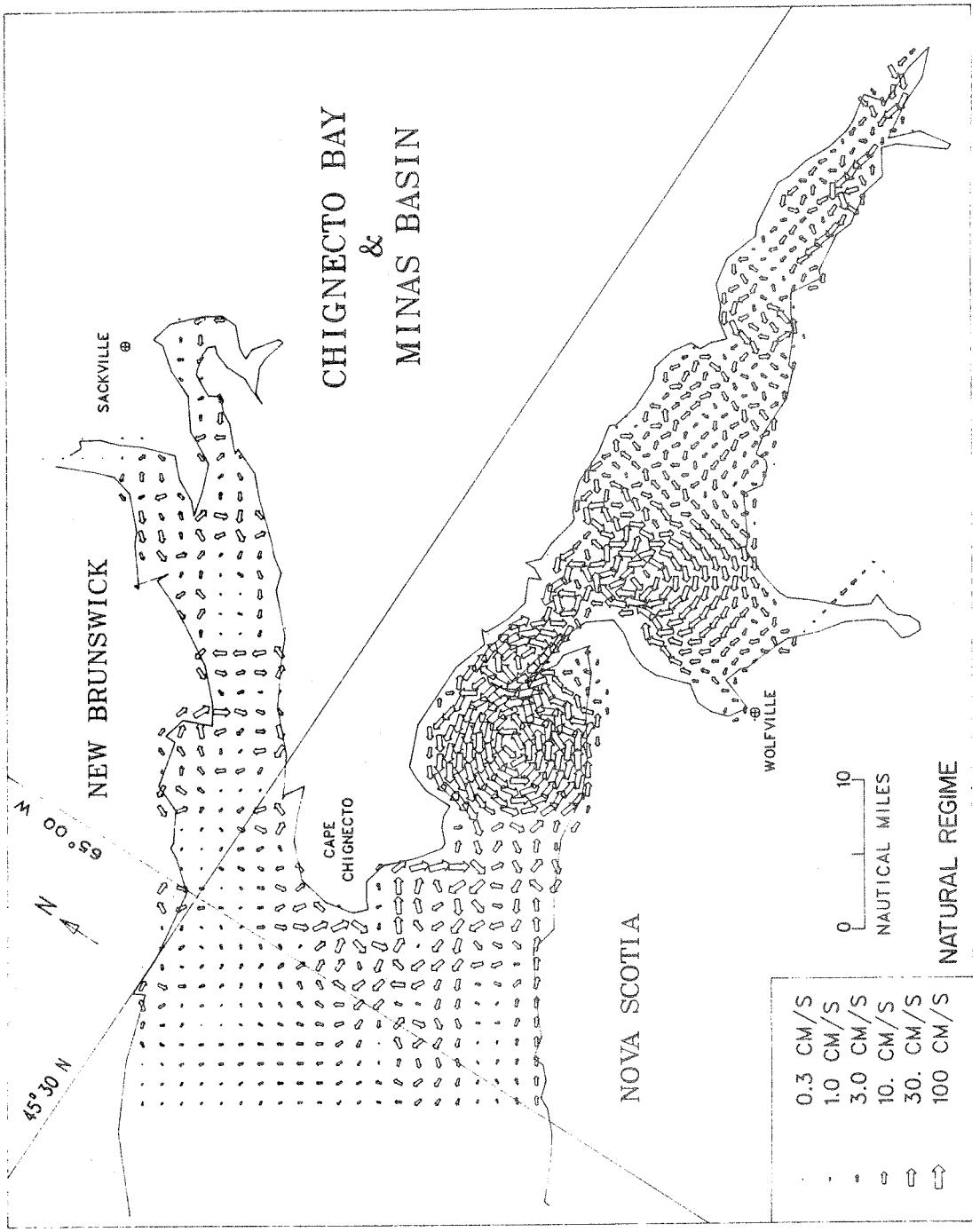


Fig. 7. Model predicted mean currents in the upper Bay of Fundy (Greenberg 1983).

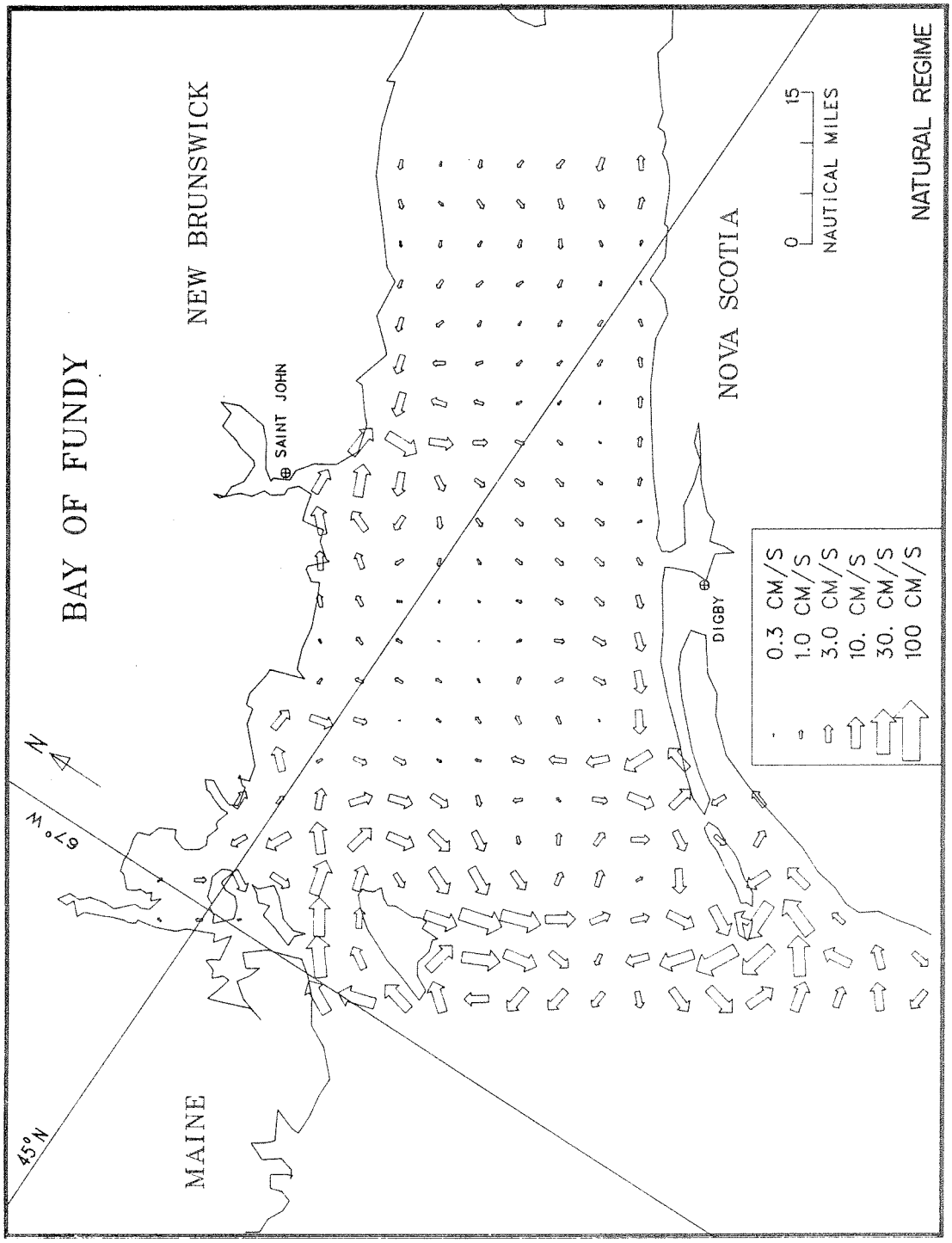


Fig. 8a. Model predicted mean currents in the lower Bay of Fundy (Greenberg 1983).

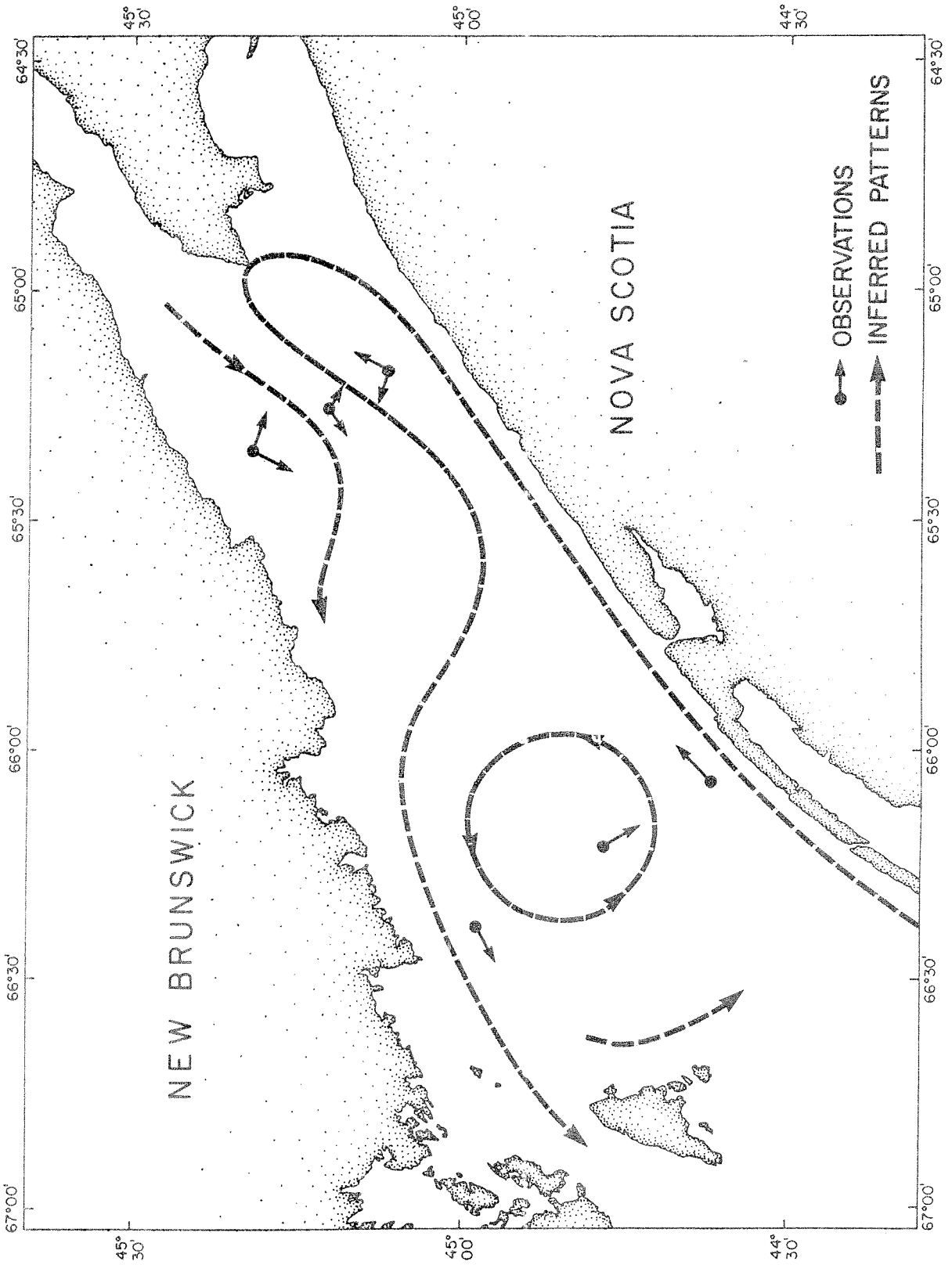


Fig. 8b. Mean current patterns from Godin (1968).

ICE, WAVES AND STORM SURGES

Ice observations are not routinely made in the Bay of Fundy. References to ice in the Bay of Fundy Sailing Directions (Anon 1982) deal as much with the Gulf of St. Lawrence as with the upper Bay. From the Sailing Directions and from ATPPB (1969), Greenberg (1977) concluded that at times, Cumberland Basin and Sheopody Bay are covered with fast ice. The only recent systematic ice study (Gordon and Desplanque 1983) contradicts this. They found that the breaking effects of the tidal range and movement by the tidal currents kept the ice in pieces and in motion most of the time. The reader is referred to Gordon and Desplanque (1983) for a detailed study including ice effects on sediment and on biology.

There have been some wave measurements in the upper Bay, but winter observations are difficult because of ice conditions. Observations in the lower Bay reported in Neu and Vandall (1976) at Tyner Pt. (near Pt. Lepreau) indicate that the significant wave height from November to April exceeds 1 m 25% of the time and exceeds 2 m 4% of the time. From May to October wave energy is reduced, reaching minimum values - approximately half the winter heights - during the late summer. There were two distinct wave periods noted: - a 9 second period attributed to sea swell generated outside the area, and a 5 second period from local generation. Longer period waves have been observed during bad storms (e.g. 16 sec during the "Groundhog Day" storm of 1976). Observations from Minas Basin (Amos and Joice 1977) show lower energy levels than observed in the lower Bay, with the significant wave height exceeding 0.6 m only 10% of the time. The observations suggest that larger waves group around a 4-5 second period. Observations from Chignecto Bay (Amos and Asprey 1981) are similar except that they do indicate some longer period, higher waves in central Chignecto.

Wave amplitude and wave period are known to increase with the duration, fetch and strength of the wind (Hasselmann et al. 1973). Wave development is also influenced by the strength of tidal streams (Phillips 1977). Wave amplitude is amplified when winds oppose currents and is decreased when wind and currents run in the same direction. There is also an apparent frequency shift from the Doppler effect of the waves moving in the current. Wind data compiled by Environment Canada (Anon 1982b) at Moncton Airport and Debert Airport for March and August are shown in Fig. 9. They represent periods of strong and weak winds respectively. It can be seen where some dominant wind directions align with the axes of the basins which would lead to increased wave energy and might interact with tidal streams. (More recent data from Sackville, N.B., which would be more relevant to Cumberland Basin, have yet to be compiled. An initial comparison of some simultaneous data, indicates that there are differences between these and the Moncton and Debert data).

Storms can cause deviations from predicted tide heights, with surges of 2 m or more observed in this area. The duration and height depends on the characteristics of the generating storm (wind, pressure, storm track, etc.). The elevation anomolies can last a few hours and might set up an oscillation that would not die down until well after the storm

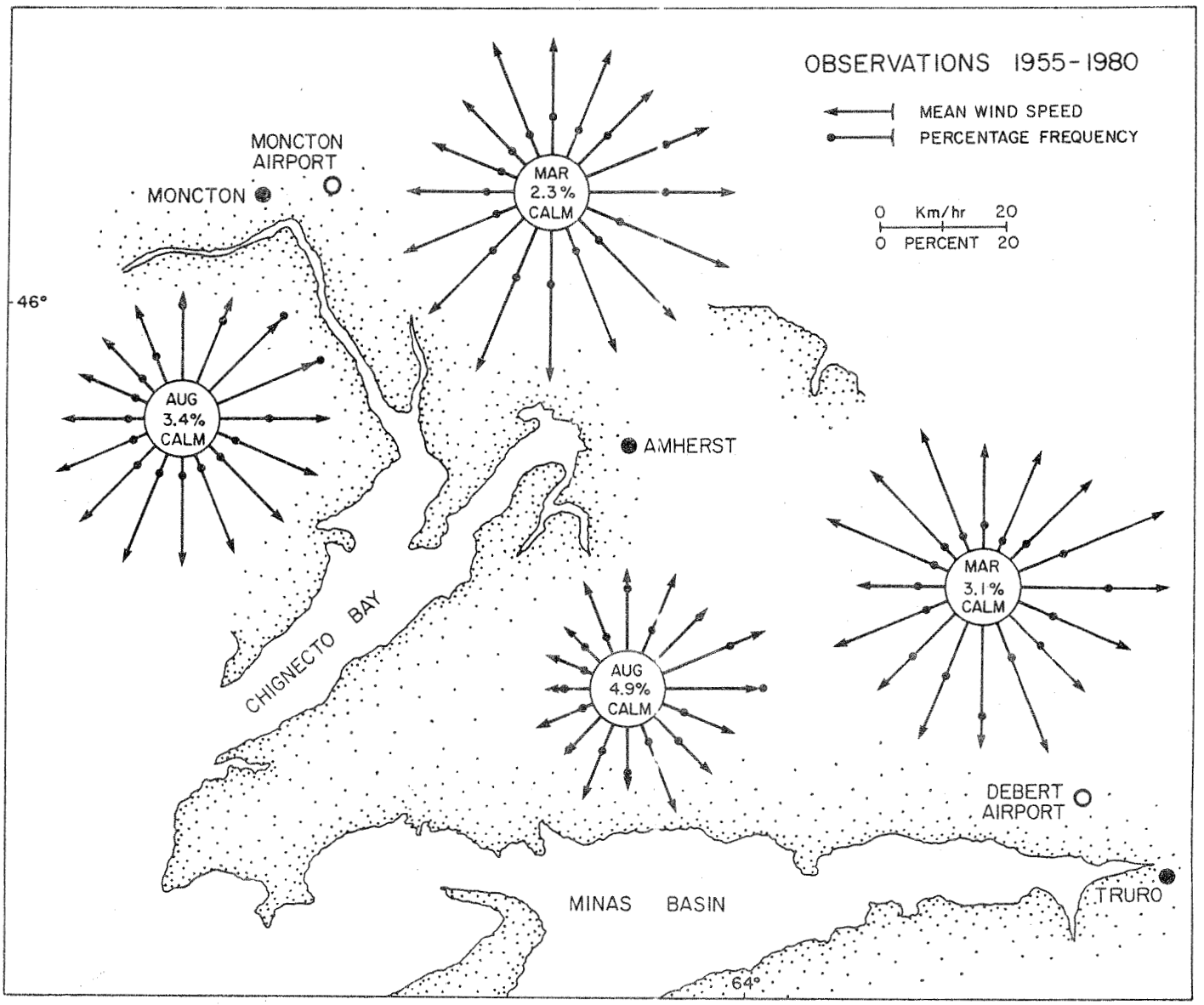


Fig. 9. Mean wind strengths and frequencies for different wind directions for a high wind month (March) and a low wind month (August). Averages are from 6 years data at Debert Airport and 26 years data at Moncton Airport.

had passed. In the Bay of Fundy, such surges are most significant if they arrive at a time of high water when areas outside the normal tidal range would be at risk. Although rare, such flooding has been reported, causing damage to some of the dyked lands around the upper Bay.

CONCLUDING REMARKS

In the above, tides have been emphasized due to their dominance in the system and perhaps also due to the author's perspective. In this brief description of the physical oceanography, the predictable (mean, seasonal and tidal) processes have been exposed and the importance of the variability in these processes has been emphasized. Some of the areas where work needs to be done have been indicated.

REFERENCES

Amos, C.L. and G.H.E. Joice. 1977. The sediment budget of the Minas Basin, Bay of Fundy, N.S., Bedford Institute of Oceanography Data Series, BI-D-77-3, 411 p.

Amos, C.L. and K.W. Asprey. 1981. An interpretation of oceanographic and sediment data from the upper Bay of Fundy. Bedford Institute of Oceanography Report Series, BI-R-81-15, 143 p.

Anon 1982. Sailing directions, Nova Scotia (SE coast) and Bay of Fundy. Canadian Hydrographic Service, Fisheries and Oceans, Ottawa. 303 p.

Anon 1982a. Canadian climate normals. Vol. 5 Wind. 1951-1980. Canadian Climate Program Atmospheric Environment Service, Environment Canada 283 p.

ATPPB (Atlantic Tidal Power Programming Board) 1969. Feasibility of tidal power development in the Bay of Fundy. Board Report and Committee Report Halifax, Nova Scotia.

Bailey, W.B. 1954. Seasonal variations in the hydrographic conditions of the Bay of Fundy. Manuscript report (Biological series), Fish. Res. Bd. Can. No. 2, 56 p.

Bailey, W.B., D.G. McGregor and H.B. Hachey. 1954. Annual variations of temperature and salinity in the Bay of Fundy. J. Fish. Res. Bd. Can. 11: 32-47.

Bumpus, D.F. 1960. Sources of water contributed to the Bay of Fundy by surface circulation. J. Fish. Res. Bd. Canada. 17: 181-197.

CHS (Canadian Hydrographic Service) 1981. Atlas of tidal currents, Bay of Fundy and Gulf of Maine. Department of Fisheries and Oceans, Ottawa. 36 p.

Defant, A. 1961. Physical oceanography. Volume 2. Pergamon Press, London, 598 p.

Duff, G.F.D. 1981. A gulf and ocean model of the Bay of Fundy tides, and their response to barrier construction and operation. Utilitas Math. 19: 3-80.

Garrett, C.J.R. 1972. Tidal resonance in the Bay of Fundy and Gulf of Maine. Nature 238: 441-443.

Garrett, C.J.R. 1974. Normal modes of the Bay of Fundy and Gulf of Maine. Can. J. Earth Sci. 11: 549-556.

Garrett, C.J.R. 1977. Tidal influences on the physical oceanography of the Bay of Fundy and Gulf of Maine. In: Daborn, G. R. ed. Fundy tidal power and the environment. Acadia University Institute Publication No. 28, pp. 101-115.

Garrett, C.J.R., J.R. Keeley and D.A. Greenberg. 1978. Tidal mixing versus thermal stratification in the Bay of Fundy and Gulf of Maine. Atmosphere-Ocean 16: 403-423.

Godin, G. 1968. The 1965 current survey of the Bay of Fundy - a new analysis of the data and an interpretation of results. Manuscript Rept. Ser. No. 8, Marine Sciences Branch, Dept. of Energy Mines and Resources, Ottawa.

Gordon, D.C. Jr., and C. Desplanque. 1983. Dynamics and environmental effects of ice in the Cumberland Basin of the Bay of Fundy. Can. J. Fish. Aquat. Sci. 40: 1331-1342.

Greenberg, D.A. 1977. Effects of tidal power development on the physical oceanography of the Bay of Fundy and Gulf of Maine. In: Daborn, G.R. ed. Fundy tidal power and the environment. Acadia University Institute Publication No. 28, pp. 200-232.

Greenberg, D.A. 1979. A numerical model investigation of tidal phenomena in the Bay of Fundy and Gulf of Maine. Marine Geodesy 2: 161-187.

Greenberg, D.A. 1983. Modelling the mean barotropic circulation in the Bay of Fundy and Gulf of Maine. J. Phy. Oceanog. (in press).

Hachey, H.B. 1952. The general hydrography of the waters of the Bay of Fundy. Manuscript report (Biological series), Fish. Res. Bd. Can., No. 455, 100 p.

Hasselman, K., T.P. Barnett, E. Bouws, H. Carlson, D.E. Cartwright, K. Enke, J.A. Ewing, H. Gienapp, D.E. Hasselmann, P. Kruseman, A. Meerburg, P. Müller, D.J. Olbers, K. Richter, W. Sell, H. Walden. 1973. Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP) DHI Zeitschrift (Special Issue), 95 p.

Holloway, P.E. 1981. Longitudinal mixing in the upper reaches of the Bay of Fundy. Est. Coast. Shelf Sci. 13: 495-515.

Ketchum, B.H. and D.J. Keen. 1953. The exchange of fresh and salt waters in the Bay of Fundy and in Passamaquoddy Bay. J. Fish. Res. Bd. Can. 10: 97-124.

Neu, H.J.A. and P.E. Vandall Jr. 1976. Review of the environmental forces for the design of the Tyner Point oil terminal. Bedford Institute of Oceanography Report Series BI-R-76-7, 19 p.

Phillips, O.M. 1977. The dynamics of the upper ocean, second edition. Cambridge University Press, 309 p.

Rao, D.B. 1968. Natural oscillations of the Bay of Fundy. J. Fish. Res. Bd. Can. 25: 1097-1114.

Tee, K.T. 1976. Tide induced residual current, a 2-D nonlinear numerical tidal model. J. Mar. Res. 34: 603-628.

Tee, K.T. 1977. Tide induced residual current-verification of a numerical model. J. Phy. Oceanog. 7: 396-402.

QUESTIONS AND COMMENTS

M. Dadswell: Are you aware of the weather station set up several years ago at Fort Beausejour (head of Cumberland Basin) by AES? The winds are quite different than those recorded at Moncton Airport.

N. Greenberg: NO