ATLANTIC COASTAL METEOROLOGY AND ITS EFFECTS ON AIR POLLUTION

by

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Introduction

The purpose of this talk is to provide some insight into the influence of east coast meteorology on the dispersion of air pollutants. The approach taken is to outline the major factors and processes which control or influence the weather and climate of our coastal region, to relate these processes and their effects to the air pollution dispersion problem and, finally, to present some results obtained from several regional air pollution meteorology field studies.

The Physical - Climatological Setting

First, some basic climatology. Canada's Atlantic Provinces are, obviously, situated in mid-latitudes (43° - 60°N approximately), located on the east side of the North American Continent and are adjacent to two major ocean current systems - the Gulf Stream and the Labrador Current. The region lies squarely in the mid-latitudes westerly wind zone whose weather is dominated by travelling synoptic scale disturbances. The east coast location and ocean current régime place their stamp on the climate of the region by introducing both maritime and continental influences and by favouring the initiation and development of major depressions in and adjacent to the area.

As Figure 1 illustrates, the Atlantic Provinces lie to the east of the mean position of a major (long wave) trough in the mid-tropospheric westerlies - a dynamically favourable region for cyclogenesis. The sea surface temperature régime with its strong horizontal gradient along the western edge of the Gulf Stream reinforces this cyclogenetic tendency. As a result, the area off Cape Hatteras is watched carefully by weather forecasters for signs of the, at times explosive, development or intensification of low pressure systems which produce many of the major storms affecting our area during fall and winter.

The Atlantic region is, on occasion, also affected during summer and fall by tropical storms and hurricanes which initially travel westward in low latitudes then may recurve northward and eastward under the influence of mid-tropospheric flow. Figure 2 illustrates the frequency of occurrence of tropical storms and hurricanes, by 1 degree sectors, during the period 1970-1979.

The dynamic nature of mid-latitude weather systems causes frequent changes in the airmasses which cover the region. These changes are often on a time scale of two or three days though, as we all know, longer stagnant periods do occur when the same airmass may remain over the area for a week or more. Airmass types, their source areas and trajectories have important effects on local and regional air pollution transport and dispersion as will become clearer shortly.

An airmass may be defined as an extensive body of atmospheric air which exhibits more or less uniform temperature and moisture (density) conditions in the horizontal. An air mass is formed when a body of air remains over a uniform

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surface for a sufficiently long period of time to come into quasi-equilibrium (thermodynamically) with the surface. The important airmasses affecting our region are either of tropical or arctic origin and reflect varying degrees of modification depending on their trajectories and travel times. Warm, humid tropical airmasses originating in the Gulf of Mexico frequently move northward in summer to cover the Maritime Provinces and, occasionally, Newfoundland bringing with them a pollutant load picked up during their passage over the industrial eastern U.S.A. Welcome relief in summer is provided by the passage of cold fronts and subsequent arrival of fresh, relatively clean, arctic or polar airmasses. In winter, tropical air rarely, if ever, reaches the Atlantic Provinces. Similar airmass transitions frequently occur, however, when fresh arctic outbreaks from the pole sweep out milder, substantially modified and less pristine air from our region.

A final element of the physical climatological setting of the Atlantic Provinces which is important from an air pollution perspective is the seasonal cover of snow and ice. Figures 3 to 5 illustrate aspects of the snow cover and ice climatology of the region. Snow and ice cover are relevant to air pollution through their influence on atmospheric stability and turbulence, factors of major importance in air pollution dispersion.

Air Pollution - Meteorological Aspects

The key meteorological factors in dispersion of air pollution from point and area sources are the local wind speed and direction and the vertical temperature structure of the atmosphere. Wind speed determines the rate of removal of pollutants emitted by a source from its immediate vicinity and wind direction determines the horizontal direction of travel of the pollution. The vertical temperature structure of the atmosphere exerts a control on the degree and scale of atmospheric turbulence (and, consequently, on the rate of lateral and vertical spreading of the plume) and on the depth through which pollutants may readily mix. These rather simple concepts will be dealt with more fully later in this presentation and are mentioned here only because they are essential to the understanding of the effects of our regional meteorological setting on air pollution dispersion.

As is the case in any region of Canada, the pollutant transport and dispersion capacity of the atmosphere varies seasonally in the Atlantic Provinces. This generalization is, however, complicated by the influence of the ocean which has an effect on mixing height climatology. It is instructive to examine, for example, the seasonal climatology of mixing heights, mixing layer wind speeds and ventilation coefficients at "maritime" and "continental" sites. Figures 6 and 7 illustrate the seasonal march of these variables at Argentia, Newfoundland and Caribou, Maine. The reversal of seasonal changes in monthly mean afternoon mixing heights and ventilation coefficients between the two stations is striking. At the coastal site, the modification of relatively warm airmasses by the underlying (cold) ocean in summer combined with the summer reduction in wind velocity produce a marked decrease in afternoon ventilation coefficient. Inland, diurnal heating in summer increases the afternoon mixing height very dramatically, resulting in improved ventilation at that season. Obviously, the Atlantic Provinces are a complex area from a pollution ventilation viewpoint since they encompass regions dominated by continental, maritime and intermediate influences.

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In addition to seasonal and diurnal influences, air pollution dispersion in the Atlantic coastal region is influenced by a number of other processes and phenomena which are worthy of mention. Attention has already been drawn to the modification of warm airmasses by passage over colder water. Situations where such modification is significant occur frequently particularly in spring and summer when relatively warm and moist air moves from Gulf Stream waters across colder inshore water. The creation of a surface based stable layer or inversion, "the marine stratum", is a result of this advection process and its occurrence is reflected in the extensive and persistent sea and coastal fog which we experience (Figure 8). As the marine stratum moves inland during the daytime, it is often gradually broken down by surface heating, the surface base of the stable layer being gradually pushed aloft. A reverse situation occurs in fall and winter when cold arctic air passing over relatively warm open water becomes unstable due to heating from below, resulting in significant convective activity showers and snow flurries along exposed coasts (Figure 9). This unstable air may be cooled again from below as it moves inland over cold snow covered ground, with consequent reduction or elimination of instability and development of a surface based stable layer or inversion.

Land and sea breeze phenomena are well known to coastal dwellers, occurring when differential heating over land and sea produces an onshore sea-breeze during daytime and, in conditions of weak regional pressure gradient, an offshore wind at night. As Figure 10 illustrates, these coastal phenomena are closed local circulations in the vertical which can, at times, produce striking reversals of plume direction. Residents of the Halifax-Dartmouth area will probably have observed such behaviour on the part of the plume from the Tufts Cove thermal plant.

Less commonly known, but also significant to air pollution dispersion, are coastal convergences and divergences of airflow resulting from sea to land changes in surface roughness and temperature régime. Such phenomena may produce localized concentration, or locally enhanced dispersion, of pollution.

Snow and ice cover, as implied earlier, may be significant modifiers of overlying airmasses, thereby influencing their dispersion characteristics. Development of near complete ice cover, for example, may be sufficient to "shut down" or at least limit the rapid thermal modification of the lower levels of cold arctic outbreaks passing over large water bodies such as the Gulf of St. Lawrence. Expansion of the ice pack may push coastal atmospheric phenomena to seaward while generating new local effects at the land - ice boundary. Along ice-free coasts, the presence of snow cover on land may increase the land - sea temperature gradient thereby enhancing the cooling from below of mild airmasses following water to land trajectories.

The preceding coastal effects combine with broad scale seasonal and diurnal changes in solar heating and atmospheric circulation and the influence of passing depressions and anticyclones to provide a highly transient atmospheric backdrop for air pollution control in the Atlantic region. The unique topography and atmospheric boundary layer climate of the areas surrounding a number of the major point sources in the region have necessitated special meteorological field studies in support of air pollution control at these sites. Results from some of these investigations will be discussed later in the presentation.

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Prior to examination of the regional application of dispersion models and of results from site specific case studies, it may be appropriate to say a few - very few - words on a broader scale air pollution question - the Acid Rain or Long Range Transport of Air Pollution (LRTAP) problem. Due to the absence of large industrial conurbations in the Atlantic Provinces, our home-produced air pollution tends to be largely of local or regional concern and makes only marginal contribution to the continental atmospheric loading. In effect, where LRTAP is concerned, if not completely virgin, we are certainly more sinned against than sinner. The meteorological reasons partly responsible for this state of affairs are simply stated - we lie downwind, on average, of the major industrial areas of the lower Great Lakes, Ohio Valley and eastern seaboard and we are located in a zone of moderate precipitation much of which is associated with airmasses which have fed upon the industrial and other urban emissions of those areas. We are, thus, subjected to both dry and wet deposition of pollutants transported in air masses which approach from the south and west. The solution to the LRTAP problem is clearly not a meteorological one. It, therefore, suffices to say that meteorological knowledge may, at best, contribute to a solution through development of atmospheric pollution transport and deposition models which may be applied to the problem of selecting an optimum (international) emission control strategy from a series of possible alternatives. Very active work on the development and refinement of suitable models is at present underway both in the U.S.A. and in Canada.

Sufficient emphasis has now been laid on the broader aspects of the meteorology and climate of the Atlantic Provinces and of the atmospheric processes relevant to air pollution dispersion in this largely coastal region. The remainder of the presentation will, as promised, touch upon dispersion modelling in a coastal environment and will highlight some results from local field studies. Because of its widespread use, all too frequently in inappropriate circumstances, it is of interest to examine the Gaussian model (or models) and its limitations.

The Gaussian Dispersion Model

Populations tend to be centered near water, for fairly obvious reasons. This results in the occurrence of industrial pollution in a coastal setting. The special nature of dispersion characteristics is not too well understood in such a setting. Furthermore no large scale diffusion studies have been conducted over the open water.

Pollutant concentrations are frequently calculated assuming a Gaussian Model such as

$$\chi(xyz) = \frac{Q \cdot \exp(-y^2/2\sigma_y^2)}{2\pi\sigma_y\sigma_z\bar{u}} \left(\exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right) + \exp\left(\frac{-(z+H)^2}{2\sigma_z^2}\right)\right) \qquad (1)$$

Where:

χ is the concentration at point (x,y,z) from a point source located at point (o,o,H)

H is the effective stack height

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x,y,z is the conventional right handed Cartesian coordinate system

$\sigma_y \sigma_z$ are the standard deviations of the plume spread in the horizontal and in the vertical

$\bar{u}$ is the mean wind speed

The main difficulty lies in the estimation of σ_y and σ_z. The values of these parameters are dependent upon the turbulent structure of the atmosphere at the time of measurement, surface roughness, height above ground level, wind speed, distance from source and sampling time of the concentrations. The familiar Pasquill-Gifford curves, examples of which are shown in Figures 11a and 11b, taken from Turner (1), apply only to very limited conditions, namely:

a) near ground releases
b) passive tracer with no ground absorption
c) flat homogeneous terrain and homogeneous wind flow
d) measurements not beyond 1 kilometre

There are several methods of estimating σ_y and σ_z. If a visible plume presents itself, Munn (2) suggests that its dimensions are close to $4\sigma_y$ and $4\sigma_z$. Even though σ_y and σ_z may be known with sufficient accuracy the model contains some very restricting assumptions:

a) the pollutant is assumed chemically inert with no deposition at the ground and no precipitation scavenging;
b) a non-zero wind speed is assumed;
c) steady state conditions are implied, that is, the wind and turbulence structure do not change with time. It must be noted that winds change more rapidly both time-wise and space-wise in coastal areas than they do inland. In any case, the steady state assumption built into the model limits its application to a few hours at most;
d) a homogeneous wind flow is assumed, that is, no lateral or vertical variation. This assumption is generally invalid, especially in coastal régimes. Coastal winds show marked variability and even over uniform terrain inland vertical changes in stability frequently develop.

The Estimation of Stability

The stability of the lower atmosphere is usually classified in one of possibly seven categories: A, B, C, D, E, F, and G, A being the most unstable class; D neutral and G the most stable class. Frequently class G is omitted, F then corresponds to the most stable class and will include cases formerly included in class G. The U.S. Nuclear Regulatory Commission (NRC Regulatory Guide No. 1.23, 1972) related these stability classes to temperature lapse rates as shown in Table 1.

Turner related stability classifications to net radiation and wind speed, which can be accomplished operationally through the use of:

1) wind speeds
2) cloud amounts and ceiling heights
3) solar altitude

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The first two of these can be obtained from local weather records, the third from the Smithsonian tables. Unfortunately, Turner's procedure has severe limitations and does not apply in a coastal or marine setting, or in other than flat, homogeneous terrain unaffected by the influences of large water bodies. It will be noted that Turner's method does not take wind shear into account, nor does Table 1.

When lapse rate and wind shear data are available the bulk Richardson number can be calculated, following Fülle (3):

$$R_i = g(\gamma_d - \gamma)/T_s(\bar{u}^2/z^2)$$

where:

g = acceleration of gravity

γ_d = dry adiabatic lapse rate of temperature (approximately 1°C/100m)

γ = lapse rate of temperature in lower atmosphere, $\Delta T/\Delta Z$ (°C/m)

z = height of wind speed measurement (m)

T_s = surface temperature (°K)

$\bar{u}$ = mean wind velocity

Tables 2a, 2b, 2c and 2d display minisonde data frequencies sorted by time of day versus Pasquill-Gifford stability class or bulk Richardson number. Both methods of classification show the expected diurnal variation. The ranges selected for classification by bulk Richardson number do not show the same central tendency as do those for the Pasquill-Gifford stability classification. In any case, since the bulk Richardson number is more closely related to the energetics of the atmosphere than is the temperature lapse rate taken by itself, it is evident that, in general, the bulk Richardson number is the more accurate indicator of stability.

Local Studies

AES Atlantic has conducted a number of field trips in coastal areas in order to collect vertical wind and temperature data in the lower two kilometres of the atmosphere, using regional minisonde equipment. Data has been acquired near the site of the generating plant at Lingan for all seasons of the year. Data was collected about 4 miles from the Point Lepreau nuclear generator site during 10 days early in August, 1980. In addition, minisonde equipment has been deployed from time to time in the Halifax-Dartmouth area, near the Strait of Canso and near Saint John, New Brunswick. These data were processed on a desktop computer. Figure 12 shows an example of plotted wind and temperature profiles taken from a processed minisonde data set.

The wind data output by the minisonde process consists of average values taken over each successive pair of readings of the two theodolites with which the instrumented balloon is tracked. Mean wind values are usually associated with the mid-points between successive balloon fixes as was the case in calculating bulk Richarson numbers for tables 2b and 2d. With rapidly fluctuating wind speeds this procedure may introduce errors, the significance of which would depend upon the use being made of the data.

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The Point Lepreau Studies

Data was collected using the regional minisonde equipment in the Point Lepreau area during the period August 5-15, 1980. This work was sponsored by the Point Lepreau Environmental Working Group for the purpose of gathering dispersion related data in the lower atmosphere representative of the general area surrounding the nuclear generating plant. A previous Emergency Measures Organization-related study had indicated that early morning surface based inversions associated with a south-westerly wind flow should reach a peak frequency of occurrence in July. This conclusion was based upon a comparison between Bay of Fundy annual surface water temperature cycle and that of air temperatures in New Brunswick adjacent to the Bay of Fundy. Unfortunately, it has not, to date, proven feasible to mount a trip to this area in July.

On the five days on which early morning soundings were taken quite pronounced early morning ground based inversions occurred on 3 days and on one of the two remaining days there was an inversion based at 220 metres and topped at 320 metres. Evening soundings were taken on five days. On four of these evenings ground-based inversions developed before 2200 hours. No soundings were taken after 2200 hours.

The point of intersection of the dry adiabat through the surface temperature with the temperature profile denotes the mixing height as depicted in Figure 13. In the absence of saturation it defines the thickness of the convective layer through which mixing can take place and so relates to the dilution of a pollutant released into the atmosphere. Mixing heights undergo a diurnal variation and usually attain a maximum value in the afternoon. The product of the mixing height and the mean wind in the mixing layer is termed the "ventilation coefficient" and is related to the pollution potential and vice versa. Portelli (4), using data from the upper air network has calculated mixing heights, wind speeds in the mixing layer, and ventilation coefficients for Canada. Any study based upon such a sparse network will obviously lack the detailed structure necessary to distinguish coastal and marine environments from continental régimes.

Maximum (afternoon) mixing heights for the period August 6-14, 1980, derived from the Point Lepreau minisonde data are shown in Table 3. Ventilation coefficients are also shown in this table. Portelli states that, "although mixing height and wind speed are important in delineating areas which, in all probability, are most susceptible to poor air quality, it is their combined effect that essentially determines the degree of air pollution potential. Values of afternoon ventilation coefficients which do not exceed $6000 m^2/s$ are considered indicative of high air pollution potential by the U.S. Air Pollution Forecast Program". He states further that at least for southern Canada, the threshold ventilation coefficient would not differ substantially from the U.S. value.

In Table 3, those cases where the wind flow is onshore are marked with an asterisk. They show a pronounced lowering of mixing heights and ventilation coefficients when compared to the others. Thus the influence of wind direction upon pollution potential shows quite clearly.

One must conclude that maximum (afternoon) mixing heights and ventilation coefficients, as displayed in Table 3, tended to be extremely low during most

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days in the interval August 6-14, 1980. The weather during this period was not unusual, a fact which confirms the suspicion that, in respect of the diffusion of air borne pollutants, the mid-summer period is generally very poor in the Lepreau area.

The Lingan Studies

Field studies were conducted at, or in the vicinity of, the site of the thermal generating plant at Lingan in an attempt to determine the pollution potential of the area. The main purpose of the project for AES was to collect data on vertical temperatures and winds in the lower boundary layer. Seven trips were made, in all, to the site, each averaging about one week's duration. Five of these trips were sponsored by EPS, one by the Nova Scotia Power Commission and one by AES, Atlantic. Regional AES minisonde equipment and technical support were used in each case, with EPS providing parallel air quality monitoring during many of the studies. Maximum (afternoon) mixing heights and related ventilation coefficients calculated from the Lingan data are shown in Table 4. It was thought that sufficient data might be on hand to screen out the impact of the wind direction on mixing heights and ventilation coefficients. In Table 4, values are given for onshore and for offshore wind flows. It is observed that mixing heights and ventilation coefficients are generally lower with onshore than with offshore winds. This relationship seems to break down in the Fall. However, it will be noted that the Fall data sample is smaller than the other season-related samples. The low values of the ventilation coefficients derived from the data are indicative of a high pollution potential, especially in the case of an onshore flow. Although the prevailing wind directions are west to southwest, the risk of an onshore wind is not negligible and is, in fact, greatest during the spring season. According to the values given in Table 4, the fall season is least susceptible to a high pollution potential with an onshore flow.

For air quality modelling purposes one would like to have as much site specific information as possible. Frequently the only wind information available is that from a local ground based observing station where the wind equipment is deployed at about 10 metres above ground, as a rule. One can then apply a power law to obtain winds at higher levels. This procedure has been rather thoroughly researched over the past 20 years or so and has been shown to give satisfactory results. The power law is stated thus:

$$(V1/V2) = (H1/H2)^{p}, \text{ where}$$

V1, V2 are the wind velocities at levels H1 and H2 and p is a parameter which is a function of lapse rate and surface roughness or more accurately a function of Monin-Obukhov length, L, and surface roughness, Z_o, according to Panofosky et al (5). This relationship is shown in Figure 14.

Three levels were used to calculate p from the Lingan data, namely:

a) anemometer level atop minisonde van, 8.2 metres;

b) first level at which minisonde winds were calculated (mean height, 40 metres above ground);

c) second level at which minisonde winds were calculated (mean height, 120 metres above ground).

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Table 5 shows the relationship between p and atmospheric stability for the Lingan data. Stability was defined by temperature lapse rate only. A screening procedure was used to ensure the use of only suitably accurate winds. Unfortunately, this procedure admitted only 17 cases with onshore winds so that further subdivision into stability classes was not feasible for these cases. Applying a p value of .34 (the neutral value) to Figure 14 indicates a value of about 90 to 100 cm for roughness length, Z_o, for offshore cases. This value is assumed to be related to the terrain downwind of the plant site when winds are blowing offshore, that is, it is the average overland value of Z_o in the vicinity. Figure 14 also gives the following values for 1/L corresponding to offshore winds:

$1/L = .021m^{-1}$ for unstable temperature lapse rates

$1/L = -.002m^{-1}$ for stable temperature lapse rates.

These values for Z_o, p, and 1/L are annual averages, more or less, based upon the entire Lingan data set. Seasonal variations are ignored. In addition, the values given for 1/L are stability-averaged values and do not necessarily apply precisely to any particular case.

Assuming that, in the mean, the stability of the onshore cases is near neutral, then the p-values for these cases applied to Figure 14 yields an estimation of roughness length, Z_o, of .23 cm. In any case, it is quite obvious that the roughness length over the open water will never approach its value over the adjacent land mass.

It is in response to discontinuities in such parameters as roughness length, Z_o, and surface temperature that the atmosphere attempts an adjustment near the coastline which results in a noticeable variability in the wind and turbulence structure. This process of adjustment is often complicated by such features as topographical forcing of the wind such as channelling through valleys, or by the presence of sizable towns or cities which impact significantly on the atmosphere.

The Saint John Study

East Saint John has long been known to suffer from periodically high SO_2 levels. Several studies have taken place in the past and air quality monitoring by NBDOE has been ongoing in the area for a number of years.

A concerted study, involving the assistance of a number of agencies, was organized by NBDOE during 1981 in an attempt to resolve the problem of source identification. AES, Downsview, provided one minisonde unit and recently acquired plume tracking and monitoring equipment. AES, Atlantic, provided one minisonde unit. Personnel for manning AES equipment was also provided.

Final results are not yet available for the project as a whole[1]. However, preliminary analyses of the data collected by the regional equipment have been performed. Table 6 shows the daily maximum mixing heights and ventilation coefficients during the period July 23 - August 4, 1981, on those days on which data was collected. The AES regional minisonde equipment was deployed at Forest Hills. Cases where winds were onshore at this location are marked with an asterisk. The data show extremely low mixing heights and ventilation

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[1] Results became available in March 1982 (see reference (13))

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coefficients. As is the case with the Point Lepreau and Lingan data the pollution potential is generally greater with an onshore than with an offshore flow.

Conclusion

The coastal discontinuity creates a zone in which the atmosphere seeks to adjust to an abrupt change in roughness length, surface temperature, and topographical features such as wind channelling. Simple Gaussian air quality models are not designed for application to such scenarios.

Pollution potential, as indicated by ventilation coefficients, is very high in those coastal areas for which minisonde data is available. This statement can be extended to all coastal sites in the Maritime Provinces. The natural tendency for populations and industry to locate adjacent to the coast will in time create a situation where pollution controls will become imperative.

Acknowledgements

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References

(1) Turner, D.B., 1968: Workbook of Atmospheric Dispersion Estimates - U.S. Department of Health, Education and Welfare.

(2) Munn, R.E., 1972: Atmospheric Pollution Meteorology - W.M.O. Manual on Air Quality Management in Europe.

(3) Fülle, D., 1976: A comparison of Three Stability Classification Systems using Surface and Radiosonde Data for Four Cities in the Western United States - Third Symposium on Atmospheric Turbulence, Diffusion, and Air Quality, October 19-22, 1976, Raleigh, N.C.

(4) Portelli, R.V., 1976: Mixing Heights, Wind Speeds and Air Pollution Potential for Canada - AES internal publication.

(5) Panofsky, H.A., A.K. Blackadar and G.E. McVehil, 1960: The Diabatic Wind Profile - Quarterly Journal of the Royal Meteorological Society, Vol.86.

(6) Wallace, J.M. and P.V. Hobbs, 1977: Atmospheric Science - An Introductory Survey. Academic Press.

(7) Neumann, C.J., 1981: Some Characteristics of Atlantic Tropical Cyclone Forecast Errors. Mariners Weather Log, Vol.24, No.4.

(8) Gates, A.D., 1973: The Tourism and Outdoor Recreation Climate of the Maritime Provinces. Environment Canada, AES. Publications in Applied Meteorology. REC-3-73.

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(9) Peach, J.A., 1975: The Tourism and Outdoor Recreation Climate of Newfoundland and Labrador. Environment Canada, AES. Publications in Applied Meteorology REC-2-75.

(10) Markham, W.E., 1980: Ice Atlas Eastern Canadian Seaboard. Environment Canada, AES.

(11) Craig, R.A., 1946: Measurements of Temperature and Humidity in the lowest 1000 feet of the Atmosphere over Massachusetts Bay. Papers in Physical Oceanography and Meteorology, Vol.10, No.1.

(12) Munn, R.E., 1966: Descriptive Micrometeorology. Academic Press.

(13) Hoff, R.M., 1982: The East Saint John, N.B. Dispersion Study, 22 July to 5 August 1981. Environment Canada, AES. Internal Report AQRB-82-002-T. 2 volumes.

Table 1. Stability class vs. Lapse Rate as presented in U.S. Nuclear Regulatory Commission Guide 1.23 (1972)

Stability Class	$\Delta T/\Delta Z$ (^{o}C/100 Metres)
A	< -1.9
B	$-1.9 \leqslant$ to $\leqslant -1.7$
C	$-1.7 \leqslant$ to $\leqslant -1.5$
D	$-1.5 \leqslant$ to $\leqslant -0.5$
E	$-0.5 \leqslant$ to $\leqslant +1.5$
F	$1.5 \leqslant$ to $\leqslant +4.0$
G	$\geqslant +4.0$

Table 2a. Data collected in August near Point Lepreau tabulated according to temperature lapse rate using Table 1.

TIME (ADT)	STABILITY CLASS							TOTAL
	A	B	C	D	E	F	G	
-0700				1	3		4	8
0701-0900	2			3		1	1	7
0901-1500	4	2	2	10	5	1		24
1501-1700	3		2	9	1			15
1701-2000	1			3	1			5
2001-				2	4	2	2	10
TOTAL	10	2	4	28	14	4	7	69

Table 2b. Data collected in August near Point Lepreau tabulated according to bulk Richardson Number, R.

TIME (ADT)	BULK RICHARDSON NUMBER							TOTAL
	<-1.0	-1.0 to $<-.2$	$-.2$ to $<0.$	$0.$ to $<.2$	$.2$ to $<.8$	$.8$ to <2.0	≥ 2.0	
-0700					2	1	5	8
0701-0900	3				1		3	7
0901-1500	12	1	1		4	1	5	24
1501-1700	7	3	1		2	1	1	15
1701-2000	1		1	1	1		1	5
2001-					1		9	10
TOTAL	23	4	3	1	11	3	24	69

Table 2c. Data collected in April near Lingan, N.S., tabulated according to temperature lapse rate using Table 1.

TIME (ADT)	STABILITY CLASS							TOTAL
	A	B	C	D	E	F	G	
-0700				1	1			2
0701-0900	1			2				3
0901-1500	11	1		13	1	1		27
1501-1700	4			6	1			11
1701-2000	1	1	1	4	2			9
2001-	1			2	1		1	5
TOTAL	18	2	1	28	6	1	1	57

Table 2d. Data collected in April near Lingan, N.S., tabulated according to Bulk Richardson Number, R.

TIME (ADT)	BULK RICHARDSON NUMBER							TOTAL
	<-1.0	-1.0 to <-.2	-.2 to <0.	0. to<.2	.2 to<.8	.8 to < 2.0	≥ 2.0	
-0700		1				1		2
0701-0900	1	2						3
0901-1500	9	13	1	1		1	2	27
1501-1700	4	4	1				2	11
1701-2000	3	2		2			2	9
2001-			1		2		2	5
TOTAL	17	22	3	3	2	2	8	57

Table 3. Maximum mixing heights and ventilation coefficients in the vicinity of Point Lepreau, N.B., during period August 5 to 14, 1980, as calculated from minisonde data. Those data associated with onshore winds are marked with an asterisk.

DATE	MAXIMUM MIXING HEIGHT (m)	MAXIMUM VENTILATION COEFFICIENT (m^2/sec.)
5	150*	885*
6	160*	560*
7	120*	300*
8	120*	600*
9	100*	750*
10	1200	14040
11	250*	1750*
12	320	2528
13	700	5320
14	700	2100
MEAN	382	2883

Table 4. Mean maximum (afternoon) mixing heights and related ventilation coefficients calculated from Lingan, N.S., minisonde data.

ONSHORE FLOW	WINTER	SPRING	SUMMER	FALL	ANNUAL
Number of Cases	8	11	5	3	27
Mean Maximum Mixing Height (m)	256	306	440	260	315
Mean Max. Ventilation Coefficient (m^2/sec.)	1534	1683	3329	6786	3333
OFFSHORE FLOW					
Number of Cases	13	11	9	9	42
Mean Maximum Mixing Height (m)	546	780	739	550	654
Mean Max. Ventilation Coefficient (m^2/sec.)	4788	8190	5177	5516	5917
ALL WINDS					
Number of Cases	21	22	14	12	69
Mean Maximum Mixing Height (m)	426	543	632	477	522
Mean Max. Ventilation Coefficient (m^2/sec.)	3548	4936	4517	5833	4708

Table 5. Mean p values vs. stability and wind direction for minisonde data collected near Lingan, N.S.

Levels	Offshore Winds			Onshore Winds
	Unstable	Neutral	Stable	All
Sfc to 1st Level	.23	.34	.37	.12
No. of Cases	14	22	16	17
1st to 2nd Level	.20	.29	.39	.095
No. of Cases	18	18	27	17

Table 6. Maximum (afternoon) mixing heights and ventilation coefficients for Forest Hills (Saint John) during period July 23 - August 4, 1981, as calculated from minisonde data. Those data associated with onshore winds are marked with an asterisk.

DATE	MAXIMUM MIXING HEIGHT (m)	MAXIMUM VENTILATION COEFFICIENT (m^2/Sec.)
23	400*	480*
24	1400	5460
25	160*	800*
26	240*	1920*
28	440	1144
29	620*	3296*
30	700	3570
31	450	2295
01	110*	880*
02	200*	1560*
03	120*	672*
04	250*	525*
MEAN	424	1884

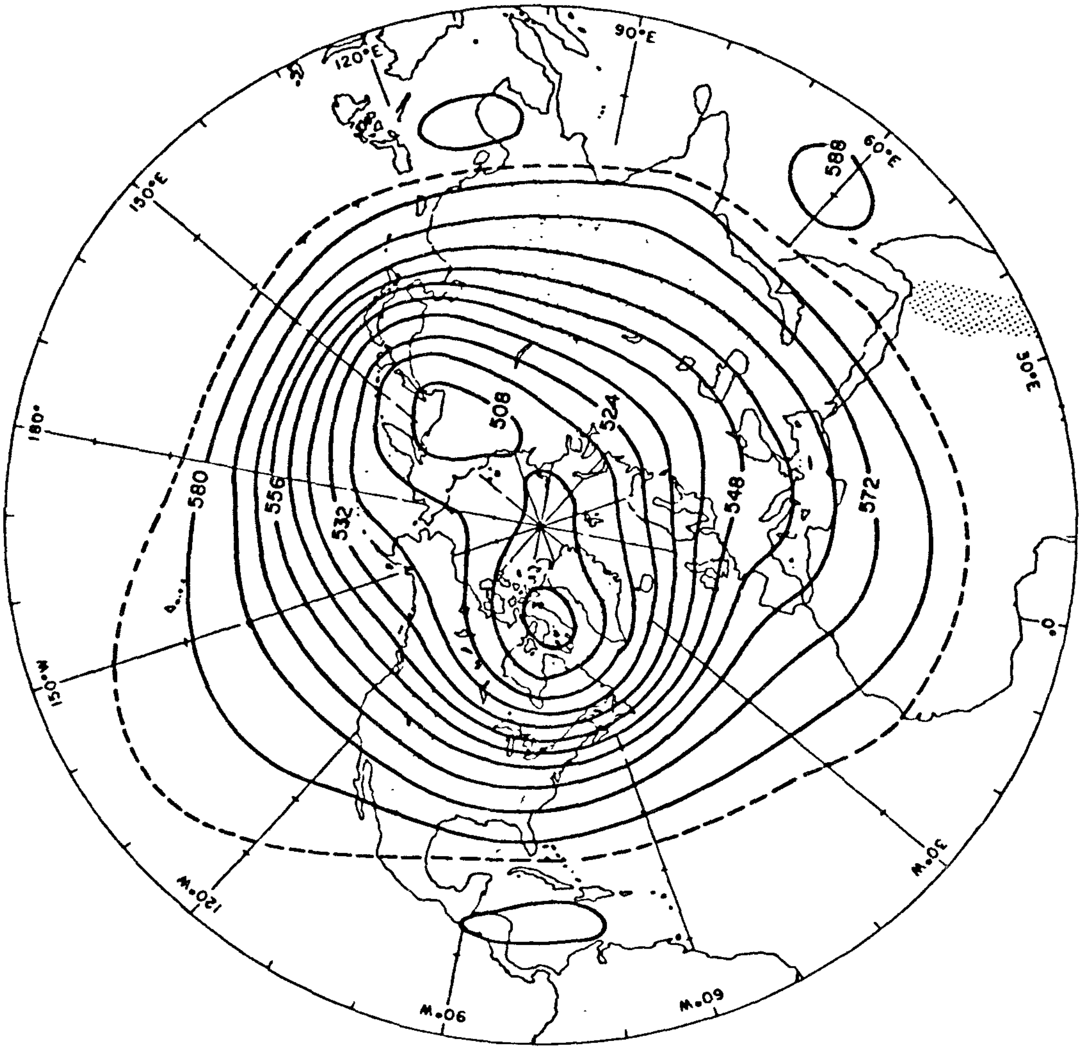

Fig. 1: Mean January 500 mb geopotential height (dekameters). (6)

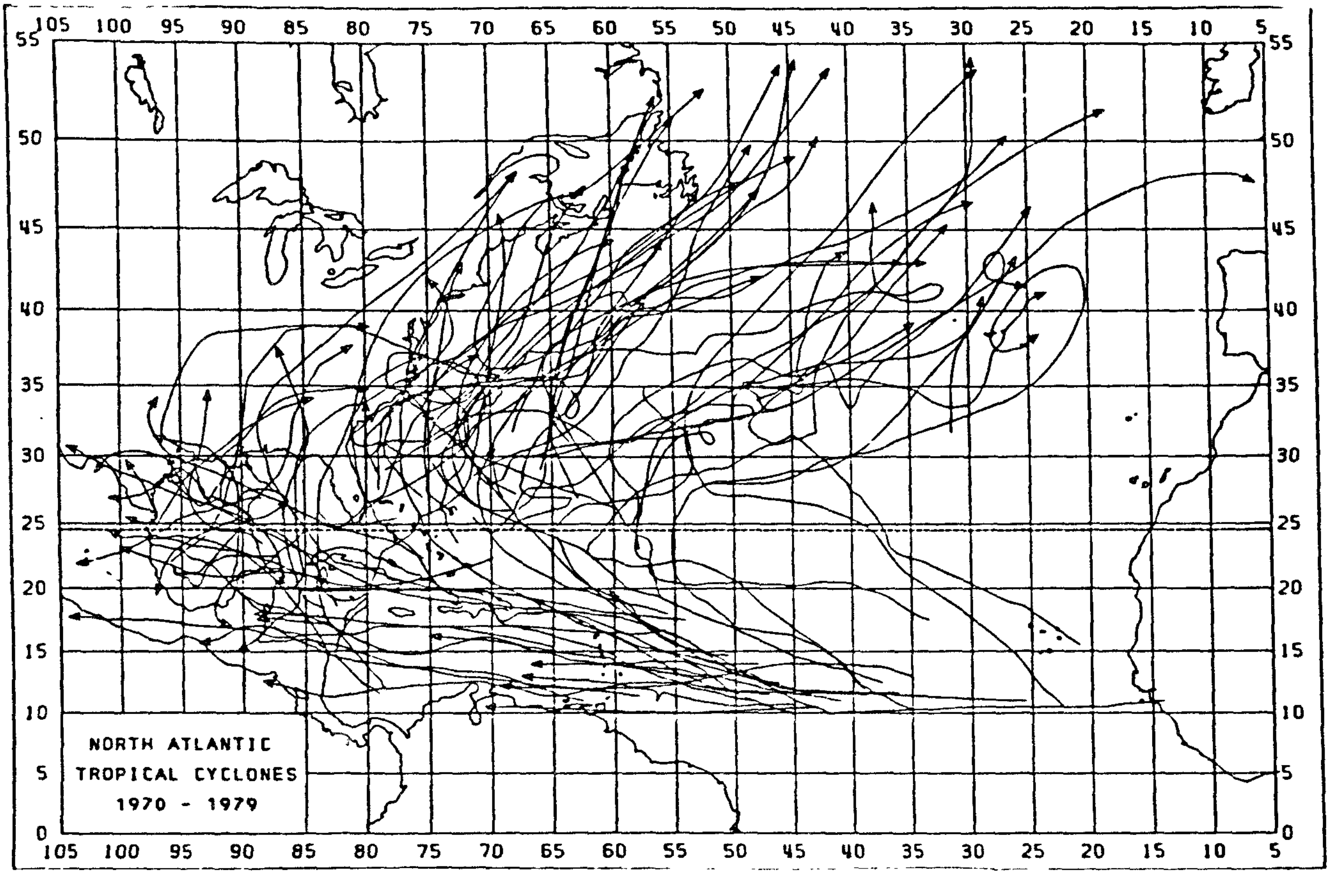

Fig. 2: Tracks of Atlantic Tropical Cyclones 1970-79. (7)

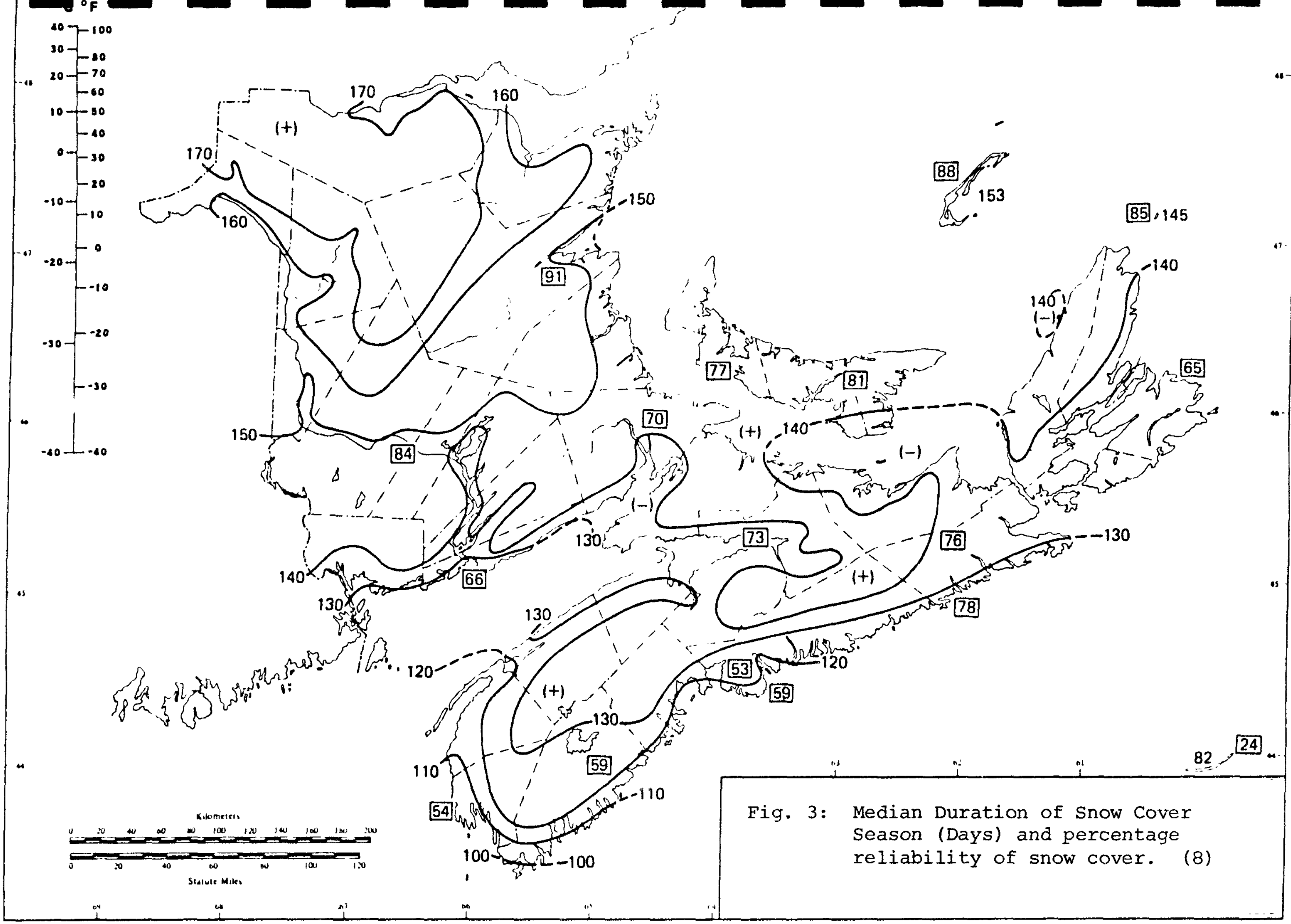

Fig. 3: Median Duration of Snow Cover Season (Days) and percentage reliability of snow cover. (8)

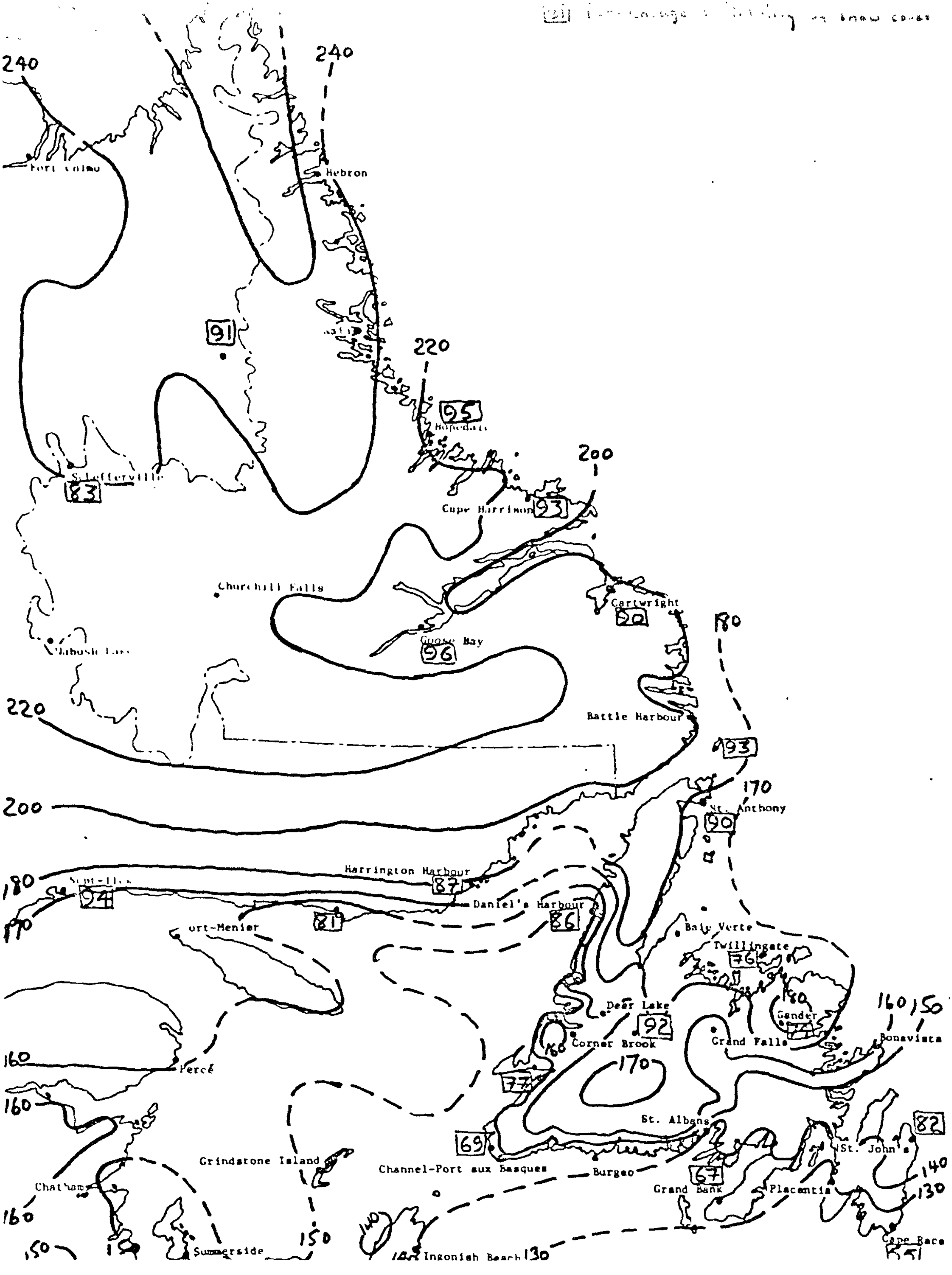

Fig. 4: Mean Duration of Snow Cover Season (Days) and percentage reliability of Snow Cover. (9)

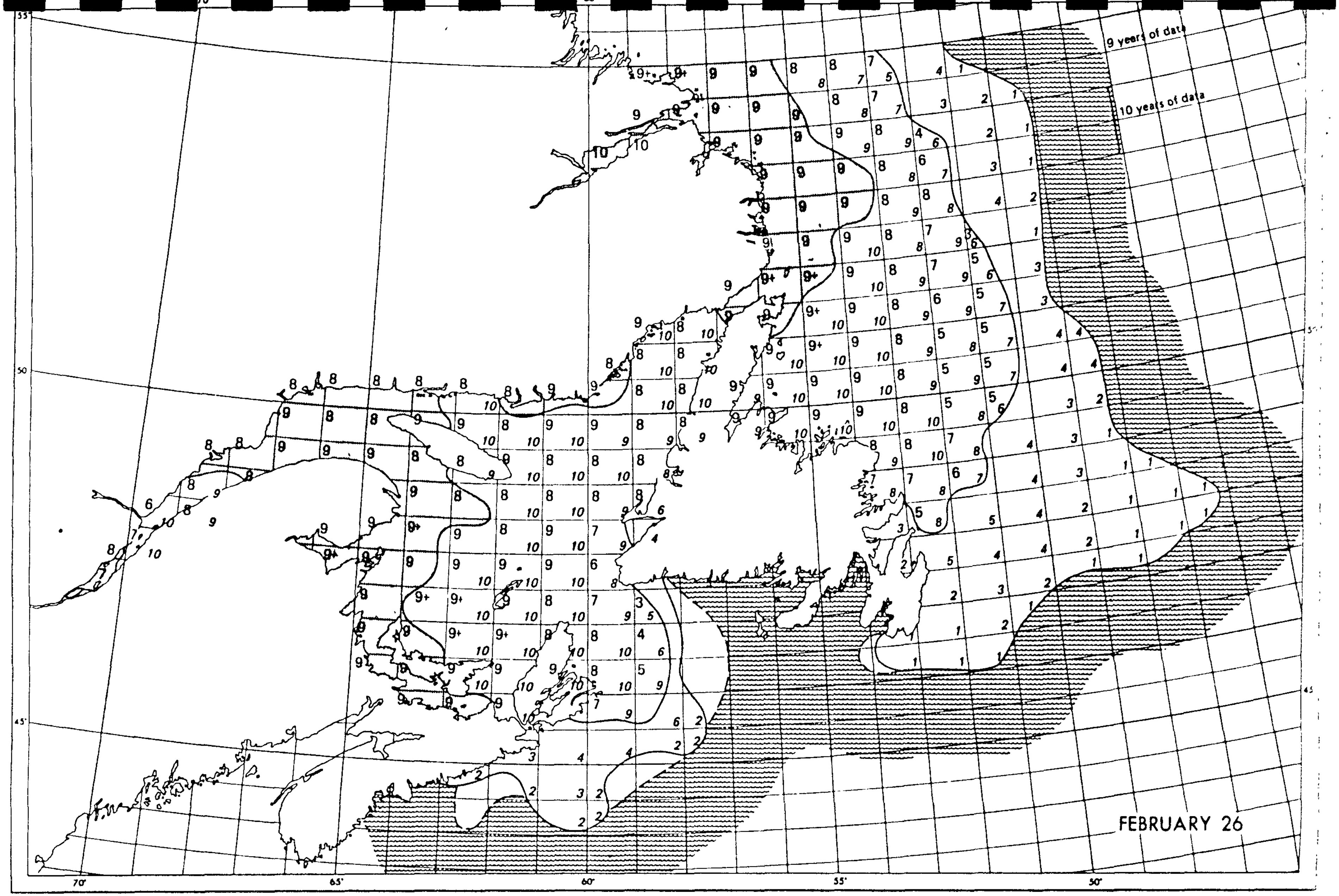

Fig. 5: February 26 ice conditions on the East Coast 1963-73. Maximum, median and minimum limits are shown. Figures in lower right of squares are number of years ice was present, those in upper left are median total ice concentration. (10)

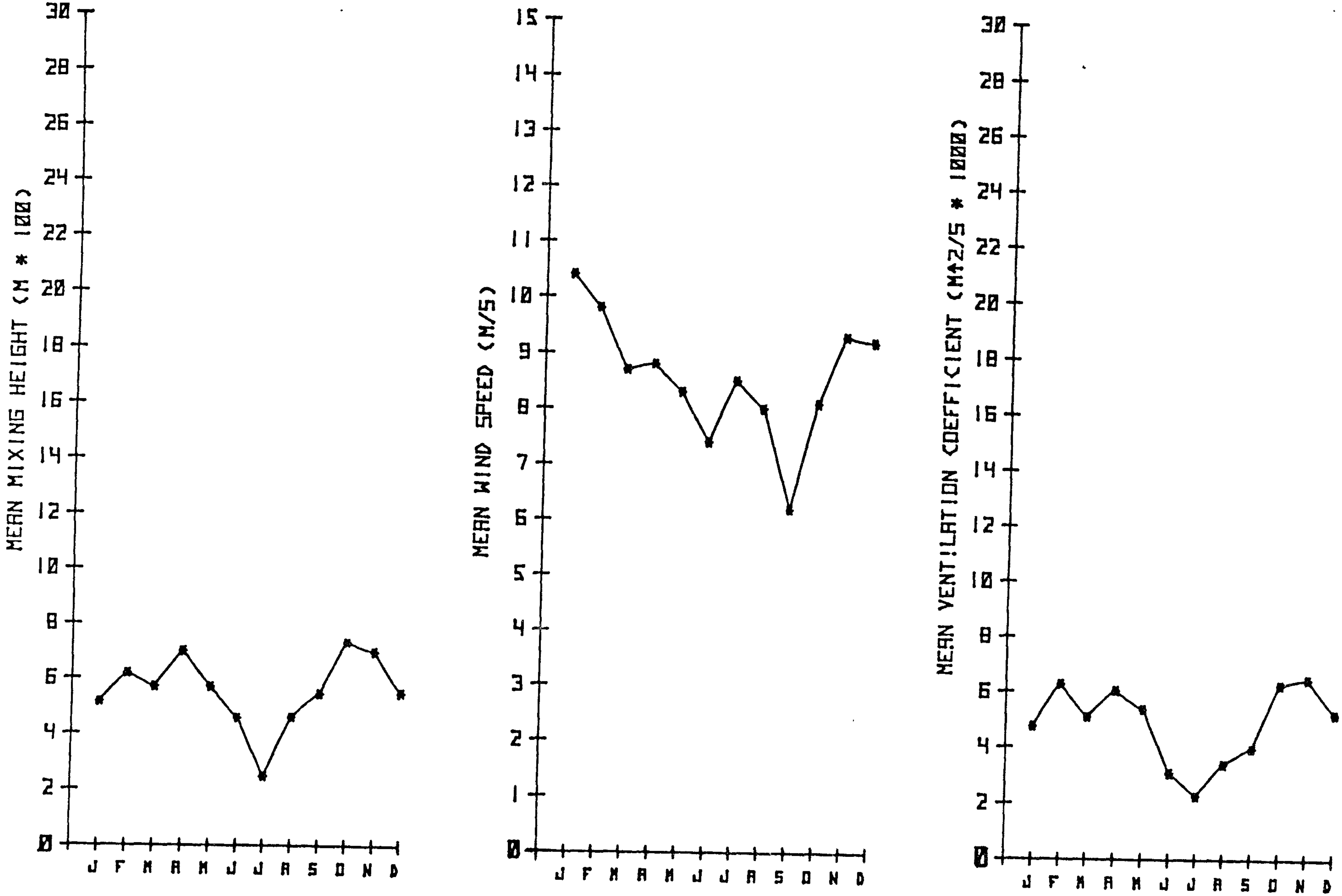

Fig. 6: Monthly mean afternoon mixing heights, mixed layer wind speeds and ventilation coefficients for Argentia, Newfoundland. 1965-69. (4)

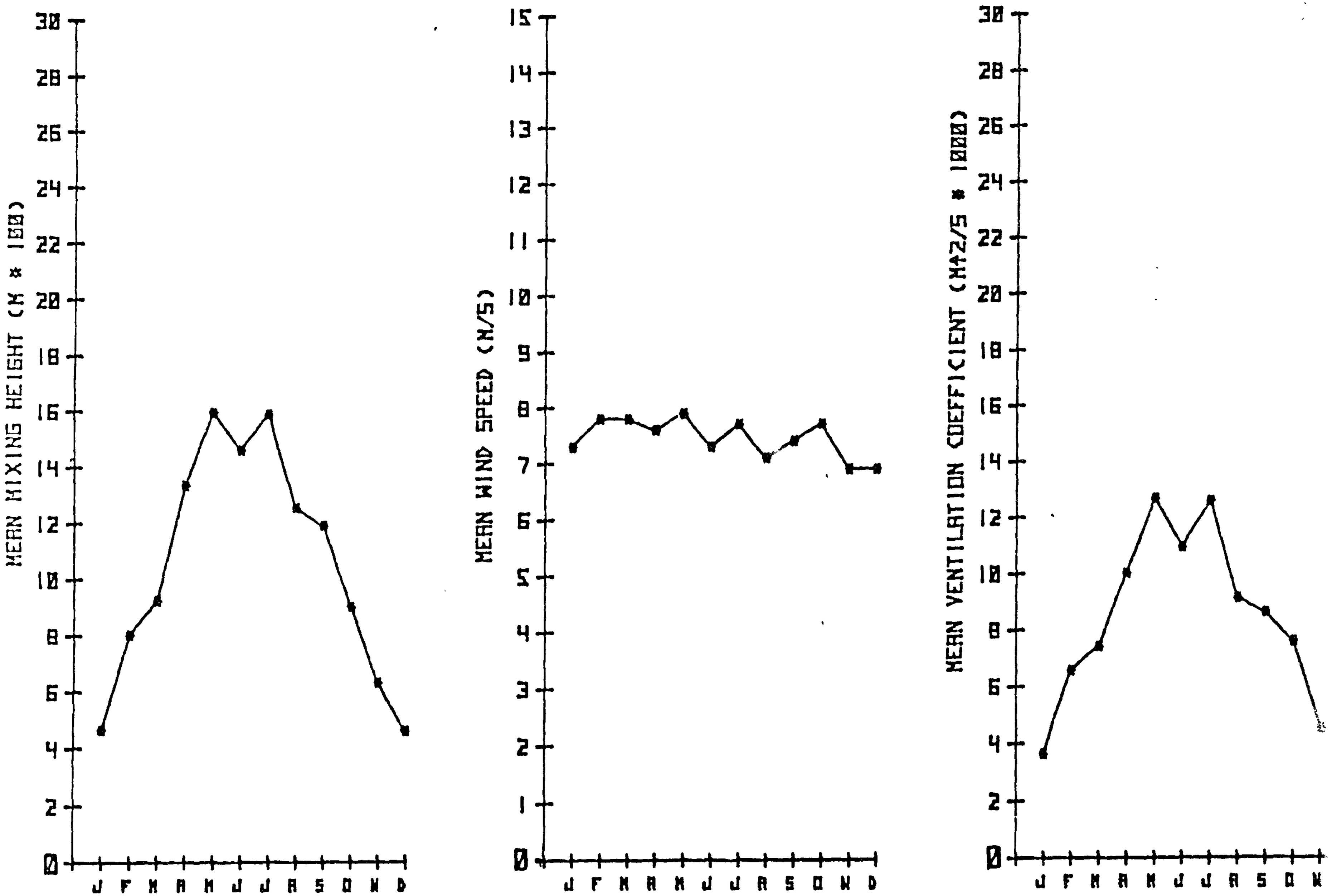

Fig. 7: Monthly mean afternoon mixing heights, mixed layer wind speeds and ventilation coefficients for Caribou, Me., 1965-69. (4)

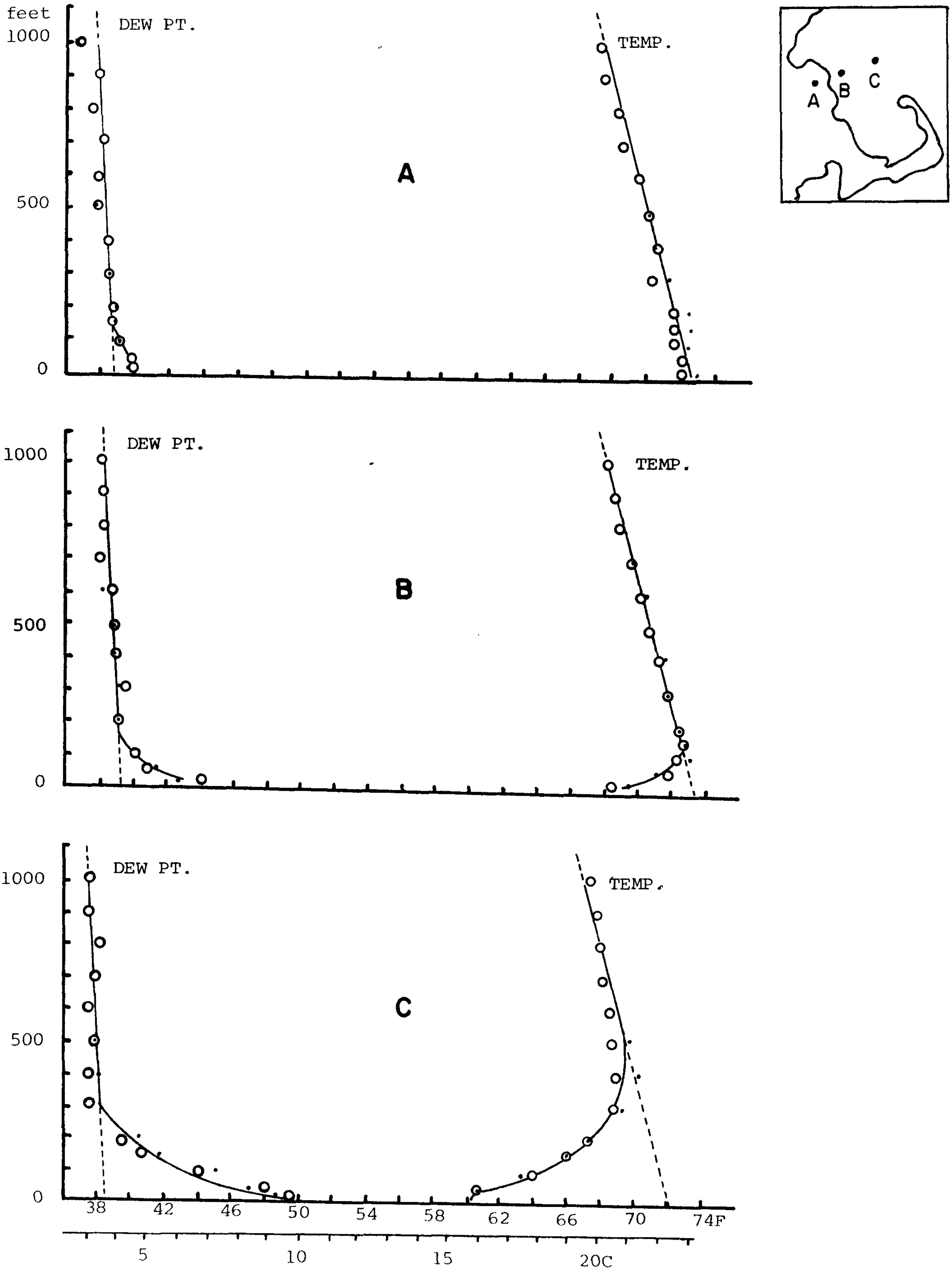

Fig. 8: Modification of warm air flowing out over a colder sea, Massachussets Bay. (11)

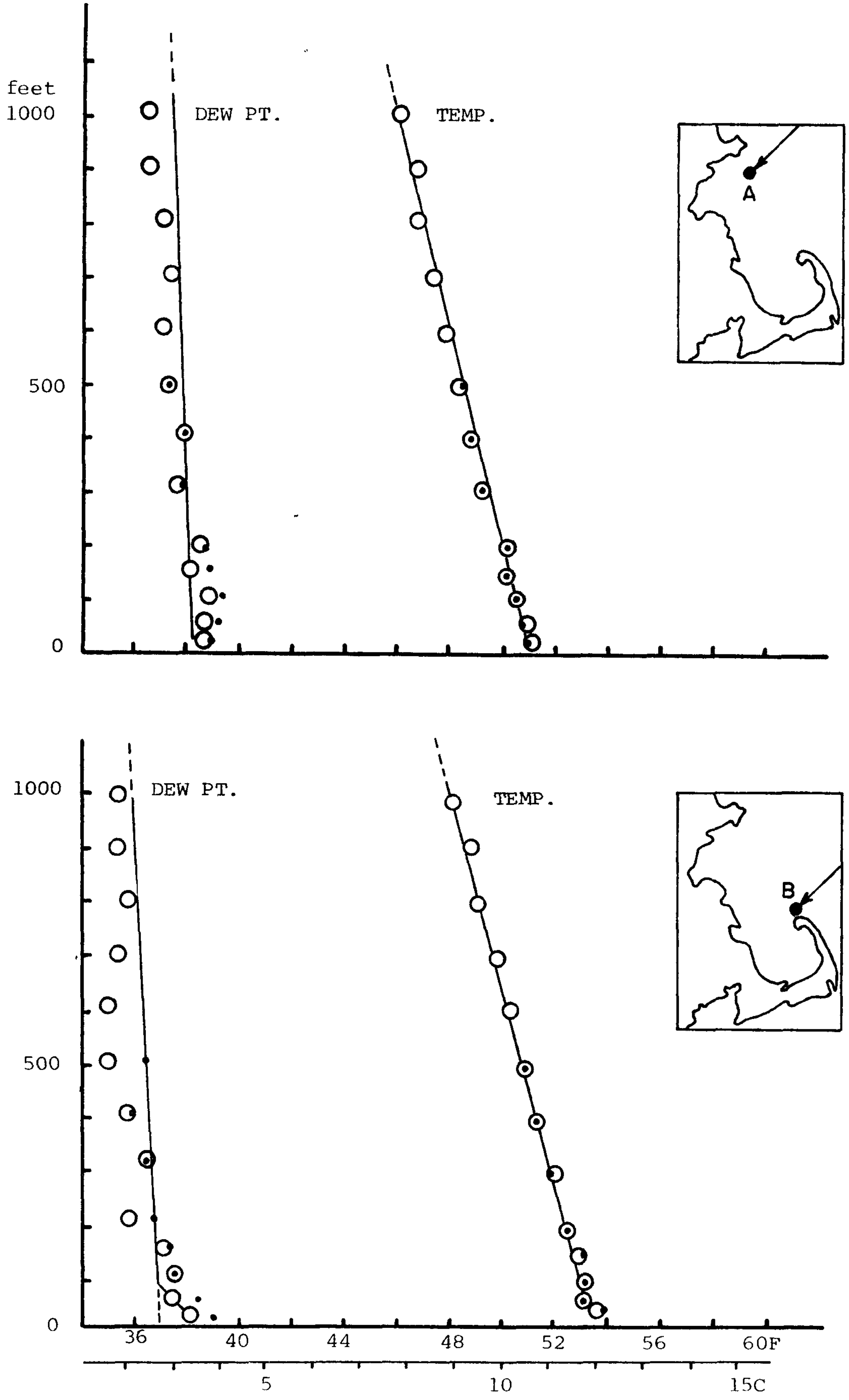

Fig. 9: Heating of cold air by a warmer sea surface. (11)

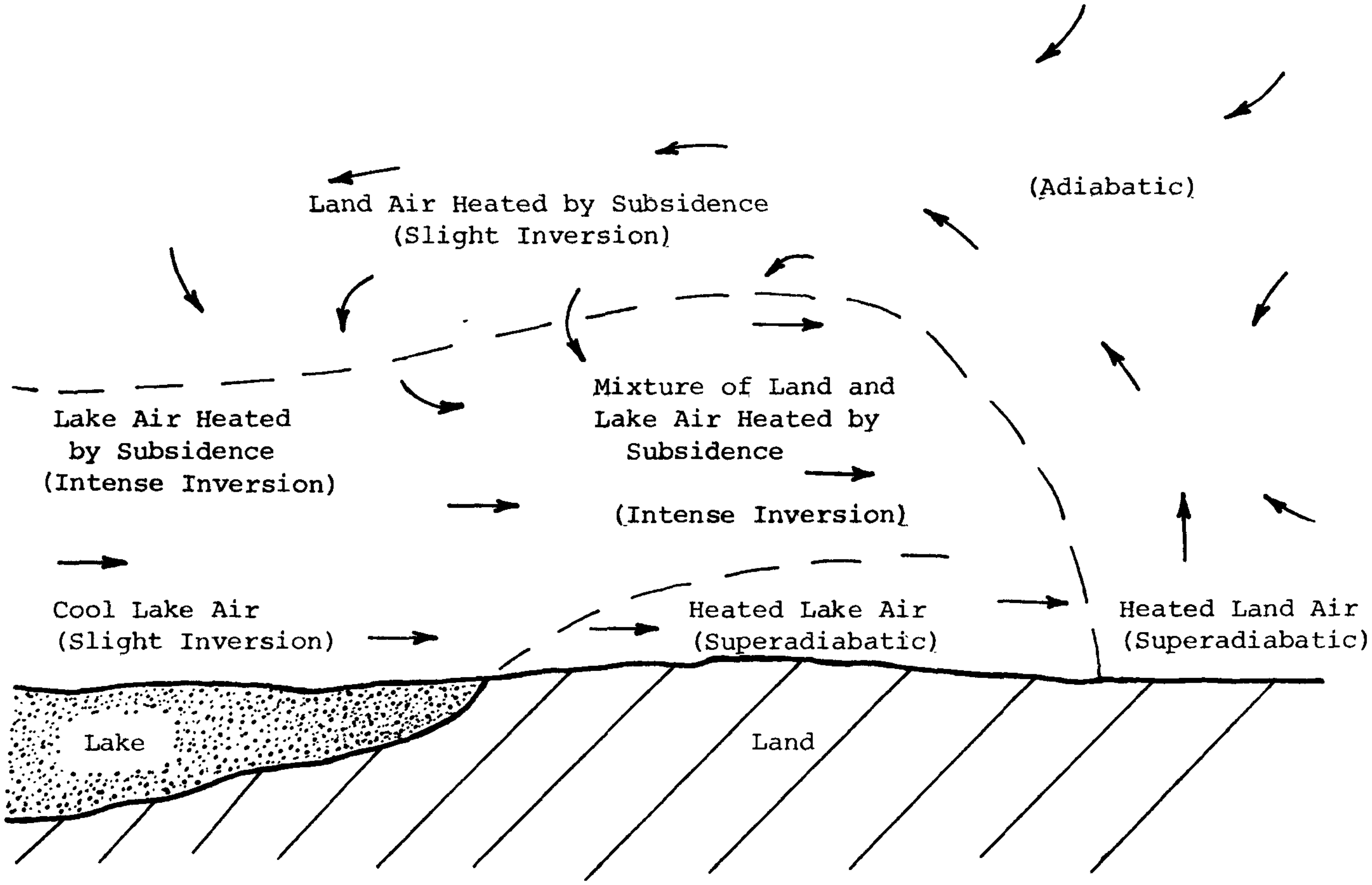

Fig. 10: Lake (sea) breeze phenomenon. (12)

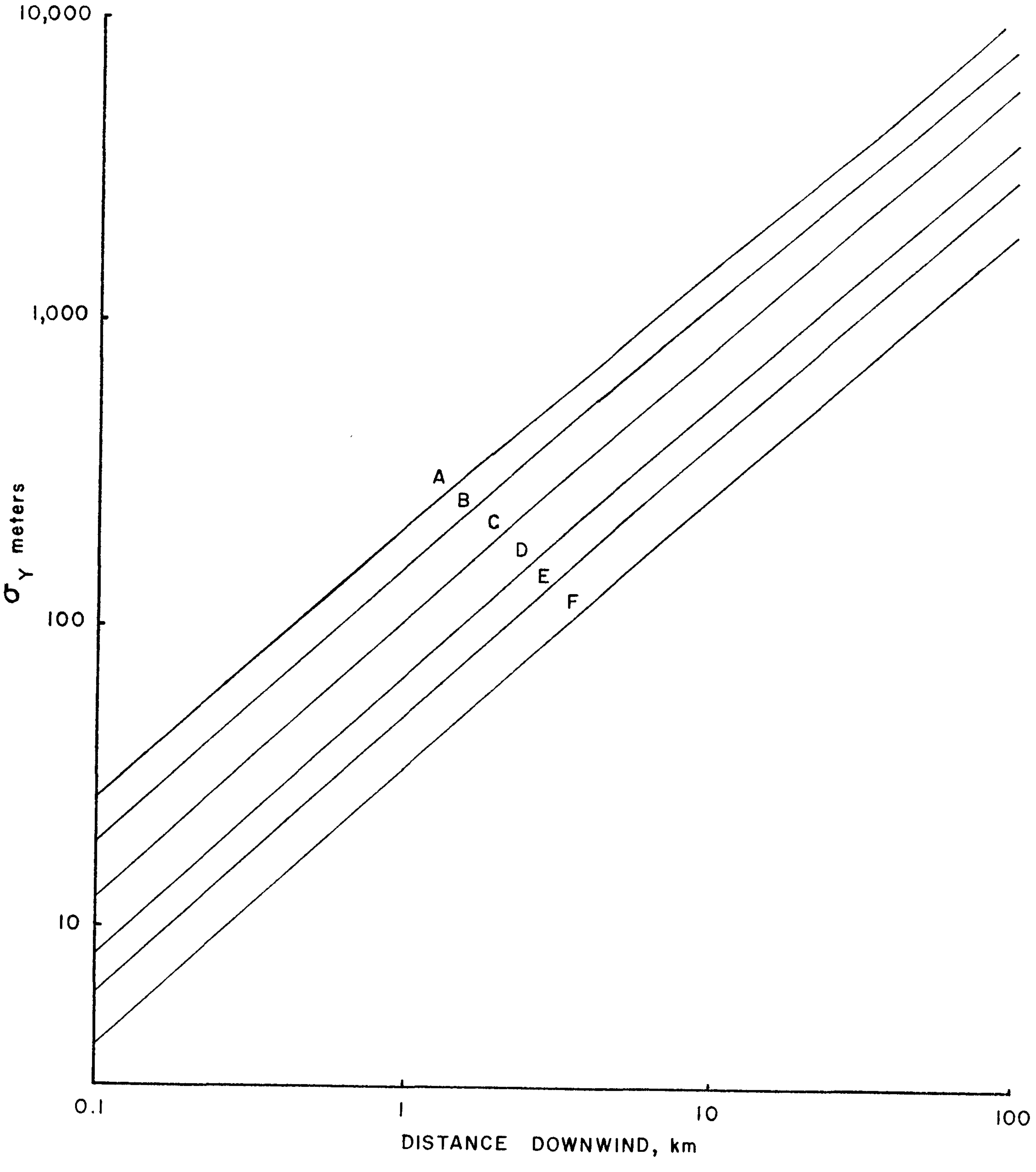

Fig. 11a Horizontal dispersion coefficient as a function of downwind distance from the source.

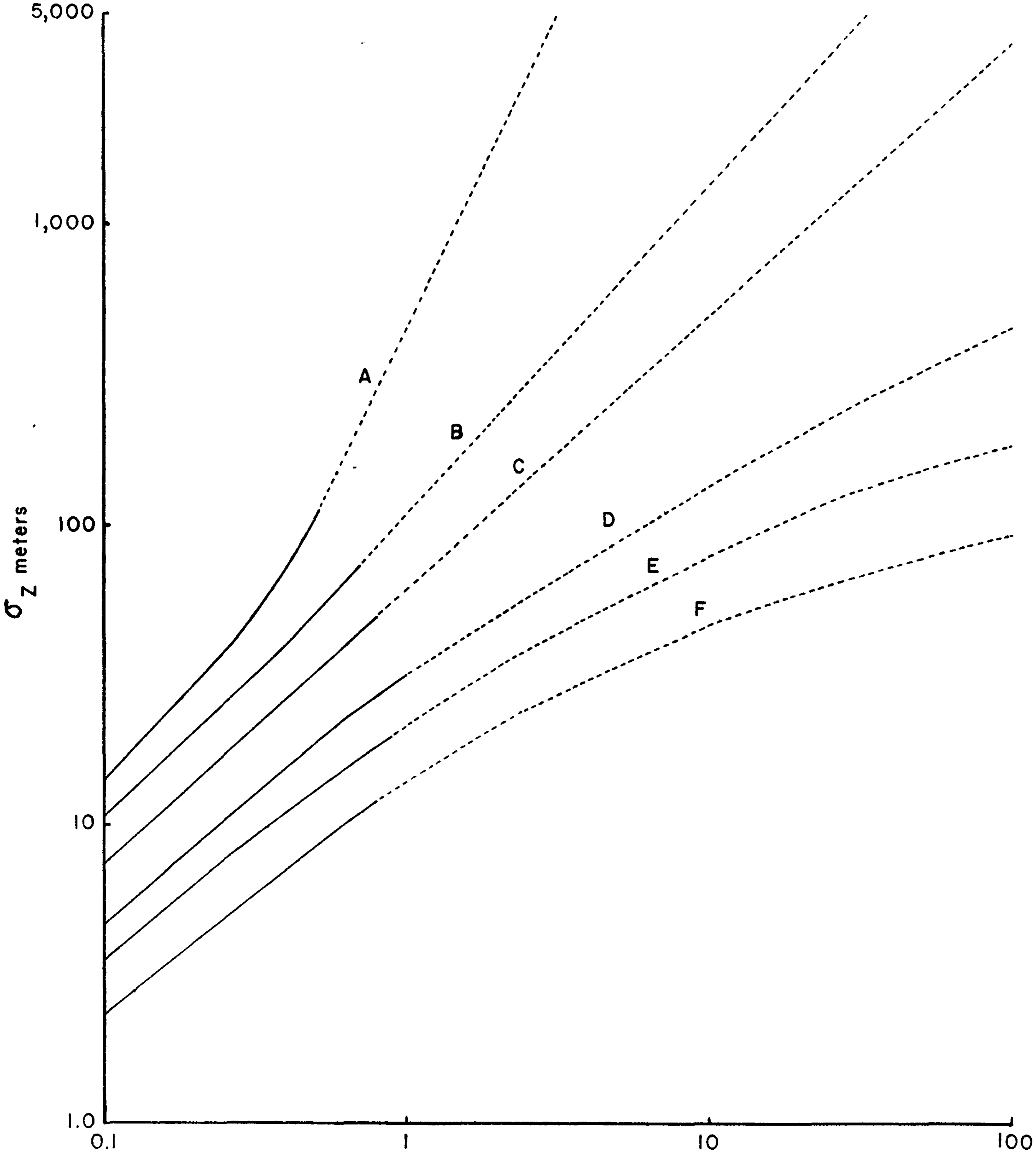

Fig.11b Vertical dispersion coefficient as a function of downwind distance from the source.

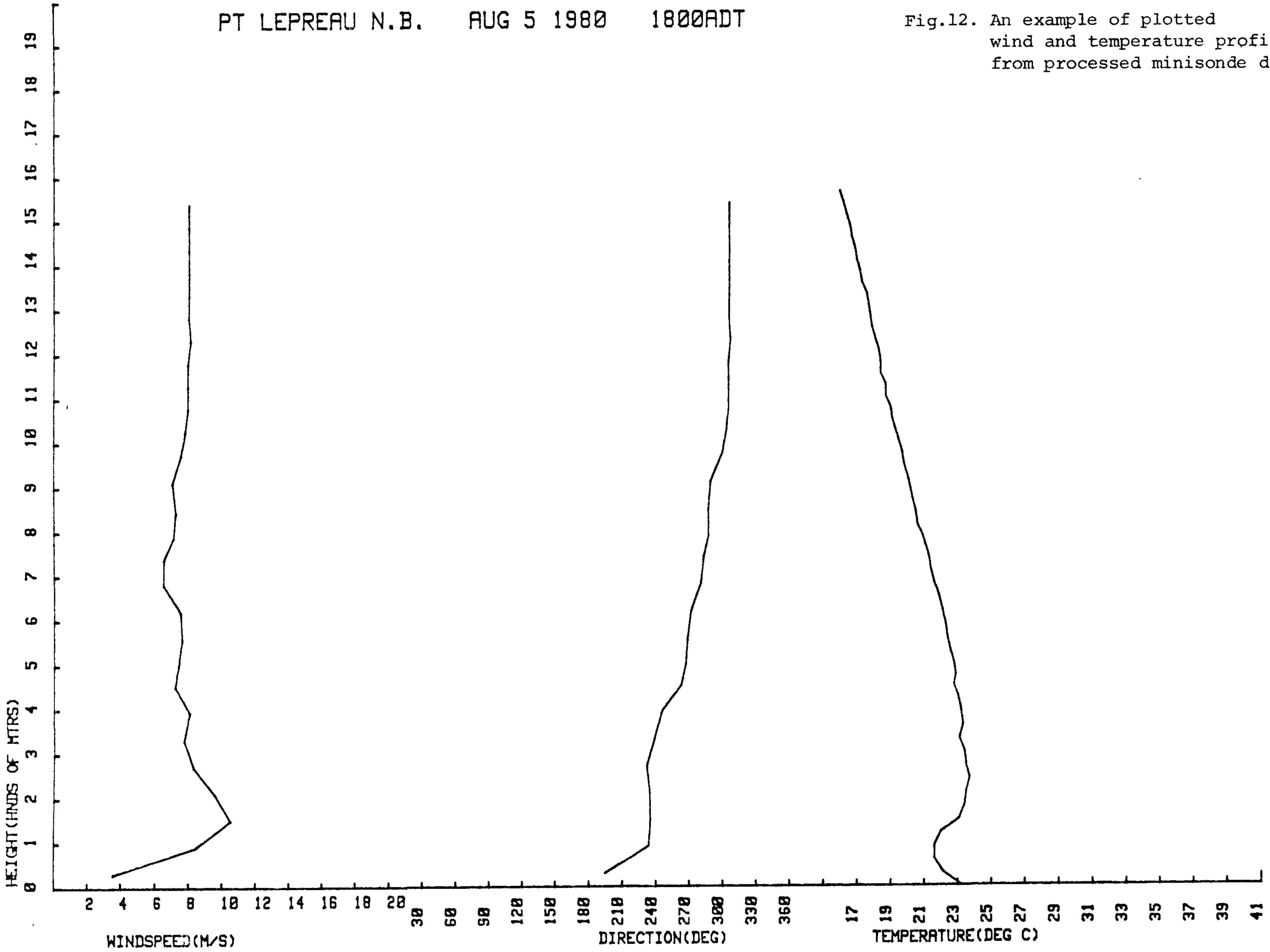

Fig.12. An example of plotted wind and temperature profiles from processed minisonde data

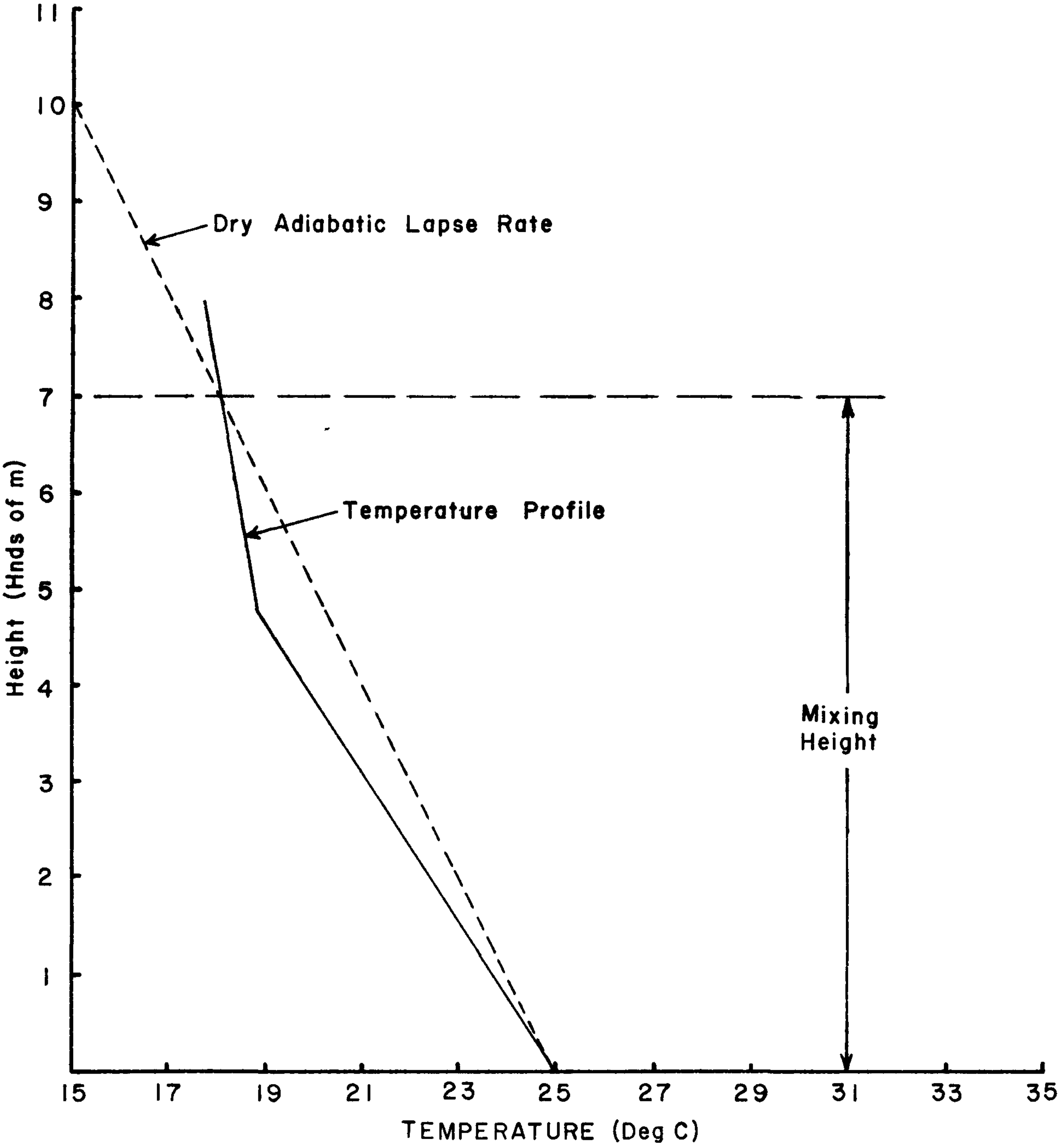

Fig.13. The measurement of mixing height from plotted temperature profile.

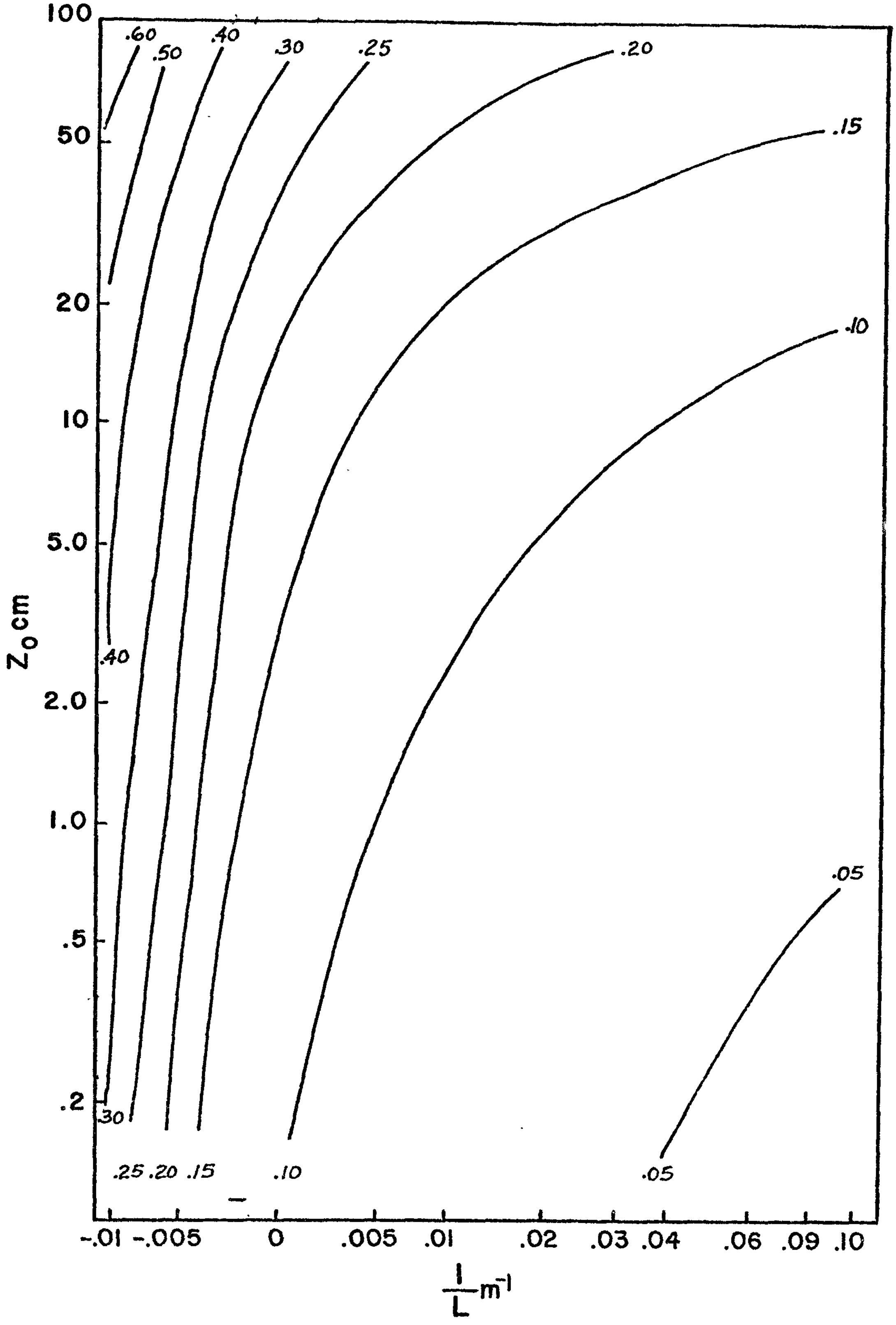

Figure 14. Theoretical variation of power law exponent as a function of Z_o and L. Zero value of 1/L corresponds to neutral stability.