POSSIBLE IMPROVEMENTS TO MATTHEWS TABLES IN AREAS OF CANADIAN DATA HOLDINGS

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ABSTRACT

Depth corrections applied to the nominal depths for echo sounders, set to a mean soundspeed of 1463, are calculated using Canadian data holdings. Calculations are made by ten degree square and one degree square. Correlation between correction and surface temperature and between correction and season are examined. Comparisons are made with the present calculations and Matthews Tables.

INTRODUCTION

An echo sounder fundamentally works as a clock, timing the interval ($2\Delta t$) between the transmittal of a sound signal and the receipt of its echo. Depth then is obtained by multiplication of Δt with a vertical mean of the sound speed ($\overline{v}$), which is usually defined as either 1 463 or 1 500 m/s, and can be read off the echo sound chart. Depth thus obtained is called "nominal" depth and should not be confused with "true" depth or "corrected" depth. True depth can be determined only if the soundspeed profile is measured and used to calculate depth Z:

$$Z = \frac{1}{2} \int_0^{2\Delta t} v(z_t)\, dt \qquad (1)$$

where $v(z_t)$ is the sound speed at the level z_t where the signal passes at the time $0 < t < 2\Delta t$. Corrected depth is derived from nominal depth by applying a correction according to a standardized procedure. One of the most widely used procedures is the application of the corrections tabulated by Matthews in "Tables of the Velocity of Sound in Pure Water and Sea

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Water for use in Echo-Sounding and Sound-Ranging", first published in 1927 and revised in 1939.

Matthews Tables give depth corrections to be applied to the nominal depths for echo sounders adjusted for a mean sound speed of 1 463 or 1 500 m/s. The corrections are given as a function of nominal depth and are tabulated for each of the 52 oceanic areas distinguished by Matthews.

The desirability of using either nominal depth or corrected depth in hydrographic charts is under much discussion. In the present report, however, the issue will be side stepped, and it will be assumed that true depth is needed for many purposes. The central questions to be discussed here are:

1. The number of available hydrographic stations has greatly increased since 1939. Can the procedure used to obtain corrected depth values be materially improved over the results obtained with Matthews Tables ?
2. What influence do variations in the water mass within an area have on the variability of corrected depth values ? Can this influence be reduced by taking such factors as season or surface temperature into account in the correction tables ?

These questions will be considered for waters in the northwest Atlantic, northeast Pacific and Arctic Oceans. All calculations in this report are based on $\bar{v}$ = 1 463 m/s. The second question will first be discussed, using the data available in CODC's OCEANS IV file in a number of test areas consisting of one or more ten-degree squares each. At the end, the results obtained for these test areas will be compared with the corrections tabulated in Matthews Tables. Corrections are defined on the basis of 10 and 1 degree squares rather than on the basis of water mass distributions as in Matthews Tables. The reason for this is that a system for the automatic (computerized) correction of the depth readings is much easier on this basis.

METHOD

The studies reported here are based on the data holdings in the OCEANS IV file at the Canadian Oceanographic Data Centre, after merging the American and Canadian files. To calculate the corrections, sound speed must be defined at an adequate number of levels for each station. The files therefore have been checked for observations in the following intervals:

00-25-60-125-175-275-375-550-750-1250-2250-3250-4250.

At most one interval above the depth at which the depth correction is calculated does not have an observation. The introduction of errors due to stations with an inadequate definition of the sound speed profile thus is minimized.

The calculation of sound speed at the observed levels with Wilson's equations has been described in detail in a report on the OCEANS IV system file (SWEERS, 1970) to which the reader is referred. Wherever necessary, sound speed is interpolated or extrapolated to the reference levels used in this study, but extrapolation is never extended beyond 1.1 times the depth of the deepest observed level.

True depth can be calculated only if a continuous sound speed profile has been measured. In practice, only a limited number of levels Z_i, $i = 1, 2, ..., I$, has been observed. The mean sound speed ($\bar{v}_I$) down to a depth Z_I then can be calculated by summing the travel times Δt_i in each interval (Z_i, Z_{i+1}):

$$\nu_I = \frac{Z_I}{T_I} = \frac{Z_I}{\sum_{i=1}^{I-1} \Delta t_i} \quad (2a)$$

where Δt_i is calculated as a function of $v(Z_i)$ and $v(Z_{i+1})$, assuming a constant gradient between Z_i and Z_{i+1}:

$$\Delta t_i = \frac{Z_{i+1} - Z_i}{\nu_{i+1} - \nu_i} \ln \frac{\nu(Z_{i+1})}{\nu(Z_i)} \quad (2b)$$

These equations are derived in more detail in RYAN and GRIM (1968).

The sounding correction (C) then is determined by comparison with a standard velocity of 1 463 m/s:

$$C = (\bar{\nu}_I - 1\,463)\,\Delta t$$

where $\Delta t = \Sigma_i \Delta t_i$ equals the travel time of the signal between ship and bottom. An analytically more correct solution would be obtained by now recalculating the mean sound speed to the observed depth and then making a second approximation of the correction, since the correction tables are not based on true but on observed depth. This second order effect, however, is negligibly small and therefore is not taken into account in this study.

SEASONAL VARIATIONS

To study the effect of seasonal variations, the data have been grouped in ten-degree squares. For each square the mean correction and its standard deviations have been calculated for a number of levels: 200, 500, 1 000, 2 000, 3 000 and 4 000 metres. Calculations have been made for all data in each ten-degree square and for sub-groups of the data consisting of all stations taken in the months January through March, April through June, July through September, and October through December, respectively.

Table 1 shows the results; improvements in the depth corrections are small and irregular in all three ocean areas studied. In the northwest Atlantic, for example, the seasonal correction is largest in the winter in one Marsden square (150), but smallest in the adjacent ten-degree square. This can probably be explained in terms of the variability of the original data. In the northwest Pacific and Arctic Oceans, seasonal effects are minimal.

TABLE 1-a

Seasonal variations in the depth correction in the Northwest Atlantic

MSQ	Depth	Par(*)	Results				
			All	Jan. to Mar.	Apr. to Jun.	Jul. to Sept.	Oct. to Dec.
149	500	N	2 290	27	1 921	267	75
		C	5.2	4.6	4.9	6.0	8.7
		SD	5.0	4.4	4.8	5.5	6.2
	2 000	N	218	2	148	54	14
		C	38.4	–	38.3	38.2	38.5
		SD	8.9	–	8.5	9.9	9.1
	4 000	N	85	0	60	18	7
		C	110.4	–	109.5	113.2	110.7
		SD	7.7	–	7.7	7.5	7.7
150	500	N	914	91	541	197	85
		C	6.2	9.1	5.3	6.8	7.8
		SD	5.2	4.4	5.4	4.9	3.5
	2 000	N	160	37	68	50	5
		C	35.2	35.8	34.5	35.8	35.8
		SD	6.4	5.7	7.3	5.9	3.4
	4 000	N	38	6	19	13	0
		C	102.8	102.8	101.7	104.0	–
		SD	3.8	2.2	3.6	4.5	–

(*) N = number of data; C = mean correction; SD = standard deviation.

CORRELATION BETWEEN CORRECTION AND SURFACE TEMPERATURE

To study the correlation between surface temperature and the depth correction, the data have been grouped into ten-degree squares. For each area the mean correction C and its variability SD_1 are calculated at depths of 200, 600, 1 000, 2 000, 3 000, and 4 000 m, using the formulas:

$$C = \frac{1}{N} \sum_i C_i \qquad (3)$$

$$SD_1 = \left\{ \frac{1}{N} \sum_i (C_i - C)^2 \right\}^{1/2} \qquad (4)$$

Two assumptions are made for the correlation between the correction for individual stations, C_i, and its surface temperature T_i:

$$C_i = \alpha + \beta T_i \qquad (5)$$

and

$$C_i = \alpha + \beta T_i + \gamma T_i^2 \tag{6}$$

The variability in the first of these cases, expressed as the standard deviation, SD_2, is calculated from the difference between calculated and predicted corrections:

$$SD_2 = \left[\frac{1}{N} \sum_i \{C_i - C(T_i)\}^2 \right]^{1/2} \tag{7}$$

where $C(T_i)$ is the correction calculated by substituting T_i in equation 5. The standard deviation SD_3 for the quadratic relationship is calculated similarly.

TABLE 1-b

Seasonal variations in the depth correction in the Northeast Pacific

MSQ	Depth	Par(*)	Results				
			All	Jan. to Mar.	Apr. to Jun.	Jul. to Sept.	Oct. to Dec.
158	500	N	509	92	176	171	70
		C	5.3	4.9	5.3	5.5	5.5
		SD	0.9	0.8	1.0	0.9	0.6
	2000	N	116	22	41	40	13
		C	25.2	24.3	25.3	25.6	25.3
		SD	1.7	0.9	1.6	2.0	1.0
	3000	N	47	9	14	19	
		C	48.4	47.8	48.7	48.5	
		SD	1.4	1.0	1.5	1.4	
194	500	N	563	115	134	240	74
		C	4.9	4.6	4.7	5.1	5.3
		SD	0.7	0.7	0.7	0.6	0.6
	2000	N	63	20	8	28	7
		C	24.4	24.4	24.1	24.3	24.7
		SD	0.9	1.2	0.8	0.9	0.5

(*) N = number of data; C = mean correction; SD = standard deviation.

From the calculated results it was immediately obvious that the variability of the correction for a ten-degree square decreases for some areas if a linear relationship between C and T is assumed. No further improvements, however, were found by assuming a quadratic relationship, and the improvements by using a linear relationship in a ten-degree square were often not better than looking at the mean correction per one-degree square (Table 2a). The following discussion of the results, therefore, will be limited to a comparison of the corrections and of variabilities calculated for a linear correlation between T and C (equations 3, 4, 5 and 7). The results are summarized in table 2.

TABLE 1-c

Seasonal variations in the depth correction in the Arctic

MSQ	Depth	Par(*)	Results				
			All	Jan. to Mar.	Apr. to Jun.	Jul. to Sept.	Oct. to Dec.
258	500	N	406	–	13	269	123
259		C	– 4.1	–	– 3.1	– 4.2	– 4.1
260		SD	0.7	–	– 0.3	0.6	0.7
261							
	1 000	N	69	–	–	44	25
		C	– 3.2	–	–	– 3.3	– 3.1
		SD	0.7	–	–	0.7	0.6
	2 000	N	27	–	–	12	15
		C	4.1	–	–	4.4	3.9
		SD	0.6	–	–	0.7	0.3
265	200	N	131	–	11	120	–
266		C	– 2.5	–	– 2.7	– 2.5	–
267		SD	0.4	–	0.1	0.4	–
230							
	500	N	26	–	4	22	–
		C	– 4.3	–	– 4.2	– 4.4	–
		SD	0.4	–	–	0.4	–
	1 000	N	11	–	–	10	–
		C	– 4.3	–	–	– 4.3	–
		SD	0.3	–	–	0.3	–

(*) N = number of data; C = mean correction; SD = standard deviation.

In the northwest Atlantic the variability of the correction is large. In Marsden square 149, for example, the standard deviation increases from 2.8 m at a depth of 200 m to 8.6 m at a depth of 2 000 m, and decreases slightly again at deeper levels. This is not surprising in an area influenced by the Gulf Stream. A correlation between the correction and the relative position of the station (inside or outside the meandering Gulf Stream) can be expected. This is confirmed by the findings: when a linear correlation between the correction and surface temperature is assumed, the standard deviations decrease to 1.4 m at the 200 m level and 5.8 m at the 2 000 m level and the correlation coefficients for the relation between C and T are:

$$C = -1.5 + 0.41\,T \text{ (at 200 m)}$$

$$C = 22.2 + 1.03\,T \text{ (at 2 000 m)}$$

with surface temperatures varying between −1.5 °C and +23.0 °C. Similar results are found for Marsden square 150.

In the northeast Pacific the variability is much smaller. In Marsden

TABLE 2-a

Correction by 10 and 1 degree square in geographical Grid

Marsden square : 150
Ten degree square : 1 305
Depth interval : 2 000

Total obsvns : 208
Overall mean : 34.7
Overall SD_1 : 7.2

0	0	0	0	0	0	0	0	0	0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0	0	0	0	0	0	0	0	0	0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0	0	0	0	0	0	0	0	0	0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0	0	0	0	0	0	0	0	0	0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0	0	0	0	0	0	0	0	0	0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		2	2	5	4	1	0	0	0
0.0	0.0	27.9	30.8	30.6	29.8	32.1	0.0	0.0	0.0
0.0	0.0	0.0	0.3	2.3	1.5	0.0	0.0	0.0	0.0
5	6	9	6	9	11	6	1	0	0
30.7	29.6	29.4	32.1	31.1	32.1	31.1	29.6	0.0	0.0
2.2	0.9	2.1	2.4	1.5	2.8	7.0	0.0	0.0	0.0
3	5	5	9	5	6	3	7	5	20
37.1	37.0	35.5	31.9	33.8	34.5	31.7	31.7	31.5	27.2
2.0	3.0	3.8	2.3	3.1	6.3	6.7	4.2	4.6	3.2
1	0	2	2	2	0	5	10	1	17
38.8	0.0	40.2	39.5	36.8	0.0	37.2	34.8	37.4	37.3
0.0	0.0	0.8	0.9	5.8	0.0	2.0	6.4	0.0	6.2
2	1	4	3	1	0	3	2	1	16
39.7	53.9	49.0	47.1	48.5	0.0	48.2	46.9	37.9	45.7
0.2	0.0	4.9	5.5	0.0	0.0	6.1	6.5	0.0	6.2

Alpha 24.6
Beta 0.73
SD_2 5.5

square 159, for example, it varies from 0.8 m at 200 m to 2 m at 2 000 m. The improvement in the results by correlating C to T is still apparent, but is much smaller (Table 2-c).

TABLE 2-b

Correlation between surface temperature and depth correction in the Northwest Atlantic

Depth	N	C	α	β	SD_1	SD_2
			MSQ 149			
200	5 383	1.8	− 1.5	0.41	2.8	1.4
600	4 148	7.1	− 0.52	0.88	5.9	2.9
1 000	3 448	12.8	− 3.2	1.05	6.9	3.6
2 000	216	35.9	22.2	1.03	8.6	5.8
3 000	143	63.9	50.9	0.99	8.6	6.2
4 000	54	103.5	90.2	0.91	8.0	6.4
			MSQ 150			
200	2 594	0.7	− 1.7	0.28	2.7	2.1
600	1 015	7.5	0.95	0.66	5.7	3.5
1 000	854	13.2	5.8	0.71	6.3	4.1
2 000	208	34.7	24.6	0.73	7.2	5.5
3 000	98	64.5	53.6	0.78	7.3	5.5
4 000	38	104.9	92.2	0.78	7.2	5.7

TABLE 2-c

Correlation between surface temperature and depth correction in the Northeast Pacific

Depth	N	C	α	β	SD_1	SD_2
			MSQ 158			
200	888	2.8	1.1	0.14	0.7	0.5
600	768	6.6	4.3	0.19	1.1	0.9
1 000	728	10.8	8.1	0.22	1.3	1.1
2 000	280	25.4	22.6	0.24	1.6	1.4
3 000	118	49.1	46.1	0.25	1.6	1.3
4 000	32	83.8	81.7	0.18	1.4	1.2
			MSQ 194			
200	1 333	2.1	1.1	0.10	0.5	0.5
600	689	5.8	4.8	0.10	0.8	0.7
1 000	587	9.9	8.9	0.10	1.0	1.0
2 000	123	24.1	23.1	0.10	1.0	0.9
3 000	23	47.4	47.3	0.01	0.7	0.7
4 000	1	82.9	82.9	0	–	–

In the Arctic the correction is virtually independent of the surface temperature and the variability is very small.

TABLE 2-d

Correlation between surface temperature and depth correction in the Arctic

Depth	N	C	α	β	SD_1	SD_2
MSQ 259						
200	95	– 2.5	– 2.5	0.03	0.3	0.3
600	60	– 3.9	– 3.8	- 0.07	0.8	0.8
1 000	41	– 3.2	– 3.2	0.04	0.7	0.7
2 000	30	3.9	3.9	0.07	0.5	0.5
MSQ 265						
200	57	– 2.6	– 2.8	0.07	0.3	0.2
600	9	– 4.7	– 4.7	0.03	0.1	0.1
1 000	8	– 4.5	– 4.5	0.04	0.1	0.1
2 000	6	2.4	2.4	0.08	0.2	0.2

TABLE 3-a

The effect of salinity on the calculated depth correction at a depth of 500 m

MSQ	N	C (T, S)	C (T, 35)	SD (T, S)	SD (T, 35)
148	279	14.1	13.9	1.8	1.7
149	2 290	5.2	5.3	5.0	4.8
150	914	6.2	6.4	5.2	5.0
151, 152	361	9.0	9.0	3.6	3.4
157	593	6.0	6.6	0.6	0.6
158	509	5.3	5.9	0.9	0.9
159	335	4.1	4.7	1.5	1.5
184, 185	664	4.5	4.6	2.3	2.2
186	321	2.4	2.5	0.9	0.9
187–190	3	1.2	1.4	–	–
193	91	6.0	6.9	0.9	1.3
194	563	4.9	5.5	0.7	0.7
195	560	3.3	3.9	0.6	0.6
220, 221	90	4.9	5.0	1.7	1.6
223–229	84	– 1.3	– 0.8	2.9	2.7
258–261	406	– 4.1	– 3.6	0.7	0.6
262–264	16	– 4.2	– 3.7	0.4	0.2
265–267	26	– 4.3	– 3.8	0.4	0.2

INFLUENCE OF SALINITY ON THE CORRECTIONS

In many areas the number of available hydrographic stations is relatively small. It may be desirable to augment the file with XBT data to calculate the depth corrections. To evaluate the effect of neglecting salinity variations, a number of calculations have been repeated assuming a constant salinity of 35.0‰ at all levels. The results are shown in Table 3.

TABLE 3-b

The effect of salinity on the calculated depth correction at a depth of 2 000 m

MSQ	N	C (T, S)	C (T, 35)	SD (T, S)	SD (T, 35)
148	88	45.0	44.7	4.0	3.9
149	218	38.4	38.3	8.9	8.6
150	160	35.2	35.3	6.4	6.2
151, 152	78	36.5	36.5	4.1	3.8
157	95	26.8	28.1	0.8	0.8
158	116	25.2	26.5	1.7	1.1
159	109	23.0	24.3	2.0	1.9
184, 185	347	27.9	28.0	3.2	3.1
186	128	24.9	25.2	1.1	1.1
187–190	0	–	–	–	–
193	0	–	–	–	–
194	63	24.4	25.7	0.9	0.9
195	167	22.2	23.4	1.0	1.0
220, 221	36	29.2	29.3	2.1	2.0
223–229	0	–	–	–	–
258–261	27	4.1	5.3	0.6	0.5
262–264	0	–	–	–	–
265–267	0	–	–	–	–

The influence of salinity on the corrections is small: it never is more than 0.6 m at 200 m, 1.3 m at 2 000 m and 2.0 m at a depth of 4 000 m. In a data sparse area in the open ocean, the hydrographic station data thus can be augmented by XBT and other temperature data to obtain more reliable estimates of the correction. The variability of the results is hardly influenced by the salinity effect.

TABLE 3-c

The effect of salinity on the calculated depth correction at a depth of 4 000 m

MSQ	N	C (T , S)	C (T , 35)	SD (T , S)	SD (T , 35)
148	26	110.7	110.5	4.8	4.7
149	85	110.4	110.2	7.7	7.5
150	38	102.7	102.8	3.8	3.6
151 , 152	8	106.2	106.2	6.1	5.8
157	0	–	–	–	–
158	1	–	–	–	–
159	36	80.8	82.5	1.2	0.6
184 , 185	21	97.1	97.4	4.0	3.9
186	0	–	–	–	–
187–190	0	–	–	–	–
193	0	–	–	–	–
194	0	–	–	–	–
195	53	80.1	82.1	0.7	0.6
220 , 221	0	–	–	–	–
223–229	0	–	–	–	–
258–261	0	–	–	–	–
262–264	0	–	–	–	–
265–267	0	–	–	–	–

COMPARISON WITH MATTHEWS TABLES

Since 1939 when Matthews Tables (revised) were published, better methods have been found for calculating sound speed. In most of the areas studied in this report this has resulted in a higher sound speed and therefore a higher depth correction. The large number of hydrographic stations have enabled the remapping of some of the areas and called into question others.

Calculations in the North West Atlantic indicate that corrections at the 200 m level are influenced by a Labrador current not noted in Matthews tables. Matthews areas 4, 5 and 6 south of Greenland frequently have the same corrections. Area five is never clearly indicated using the one degree square calculations. Accurate delineation of areas 5, 6, 7, 8, 9, 12 and 13 south of Newfoundland is difficult using one degree squares. It is felt that with the movement of the Gulf Stream, it is not appropriate to use a chart when determining depth corrections and that the best results can be achieved using the linear relationship between correction and surface temperature. (See figures 1).

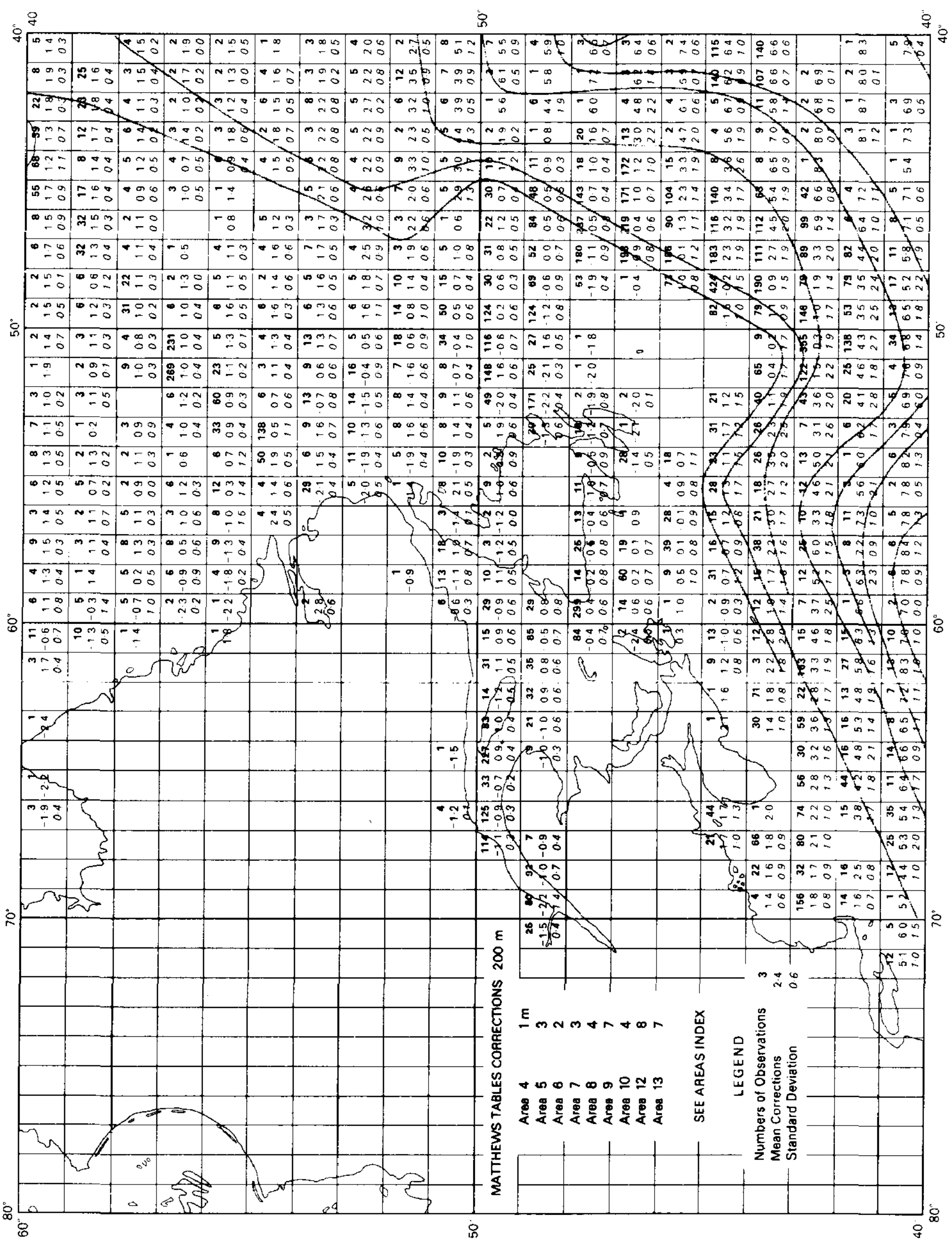

FIG. 1a. — North West Atlantic, 200 m Correction.

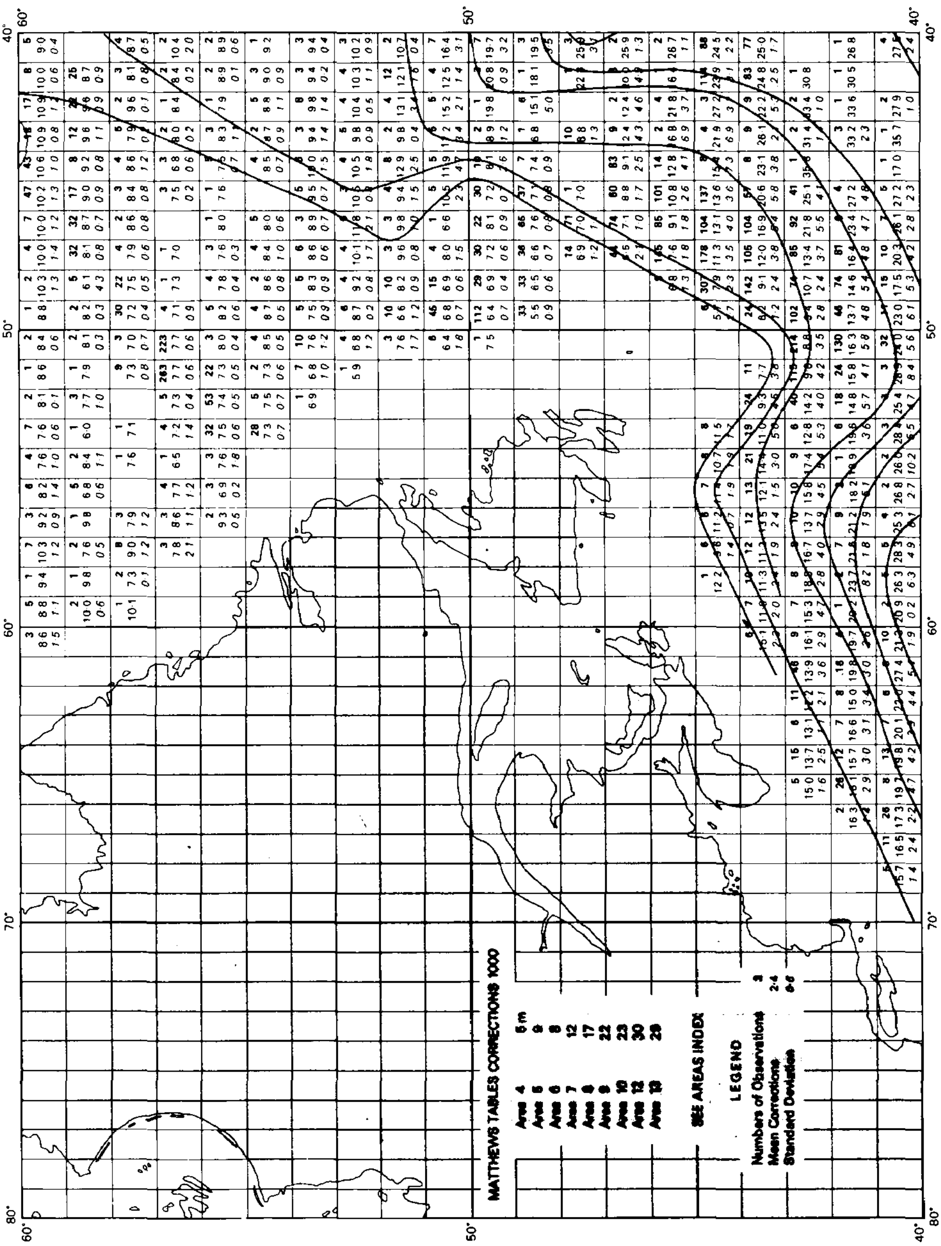

FIG. 1b. — North West Atlantic. 1 000 m Correction.

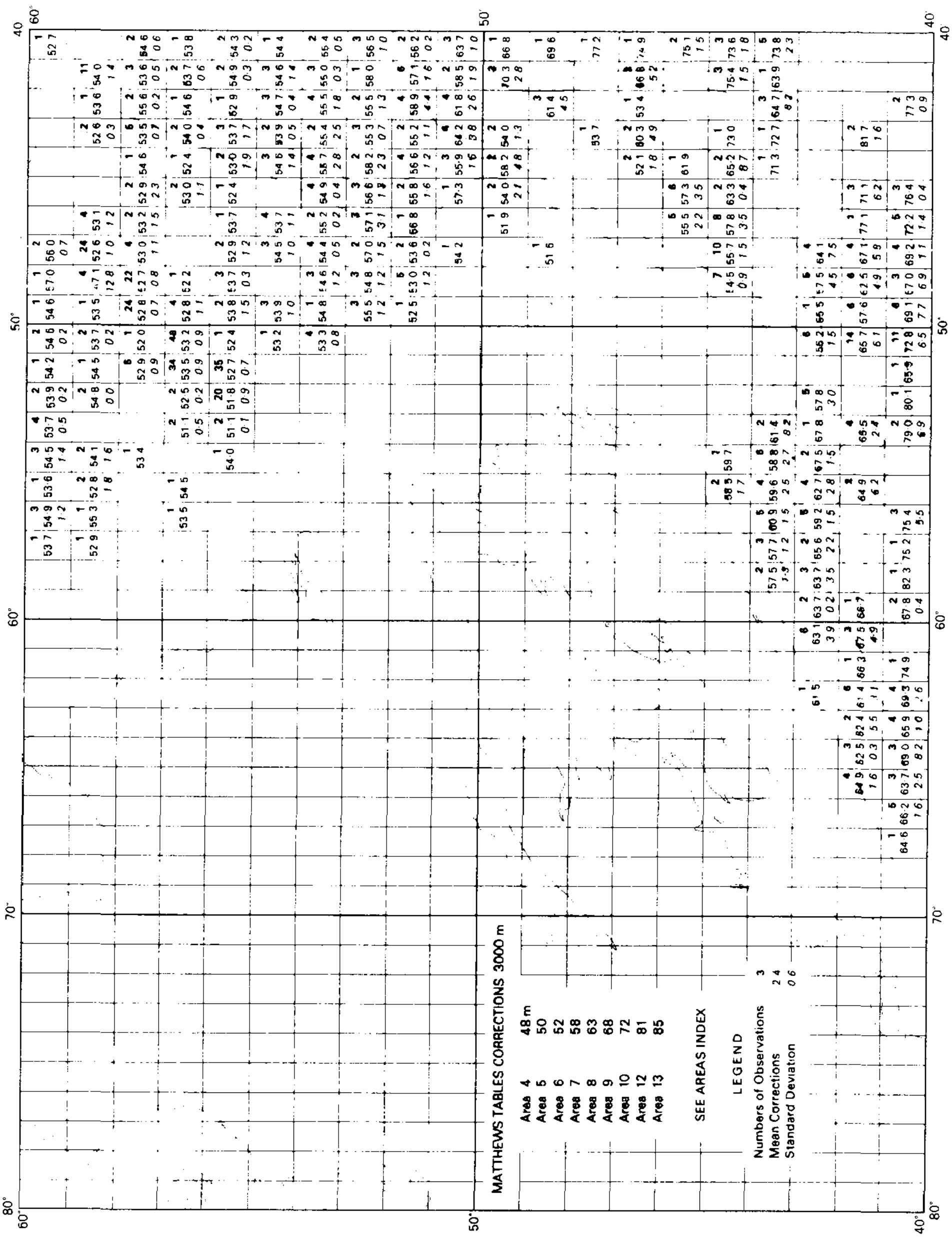

FIG. 1c. — North West Atlantic. 3 000 m Correction.

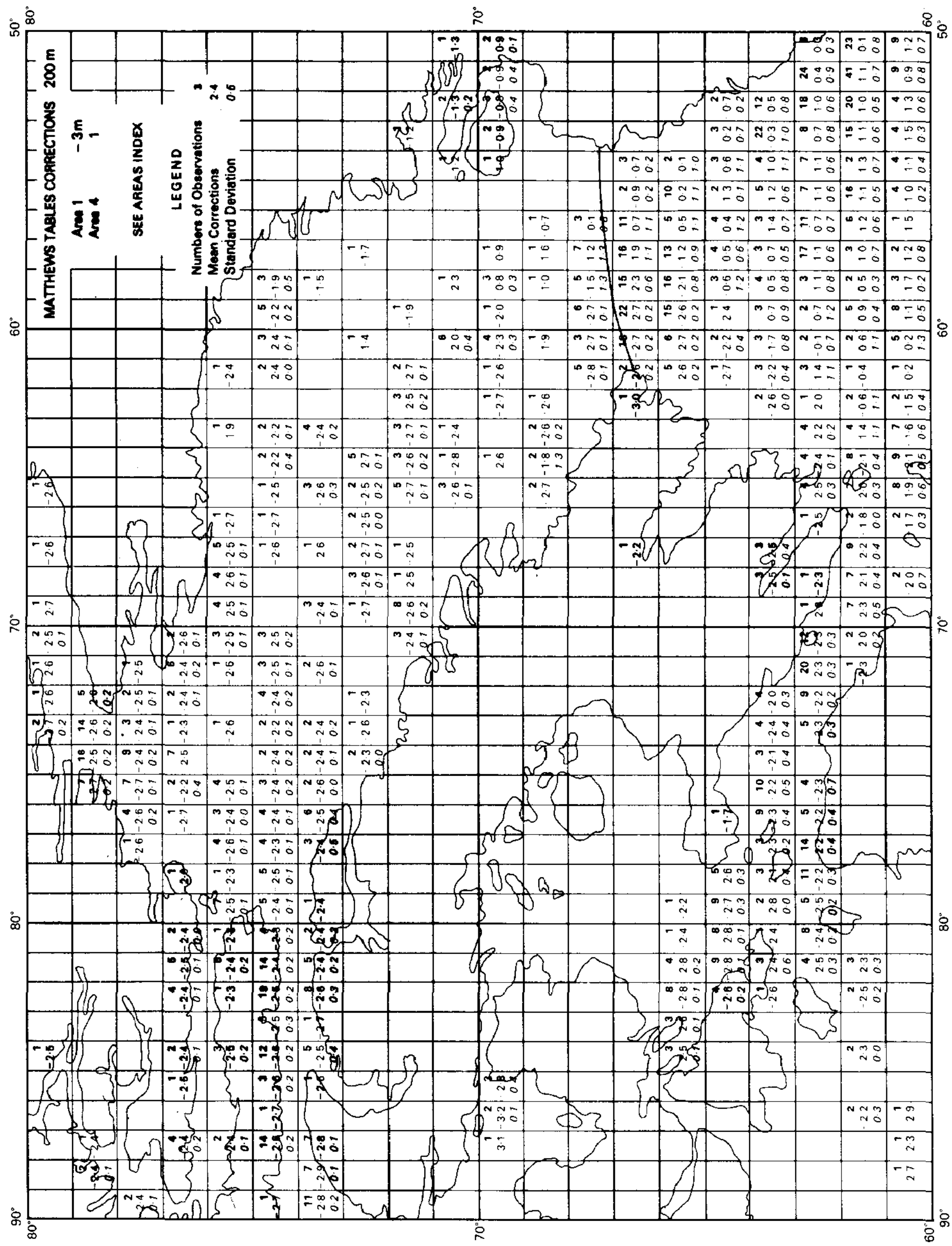

FIG. 2a. — Arctic. 200 m Correction.

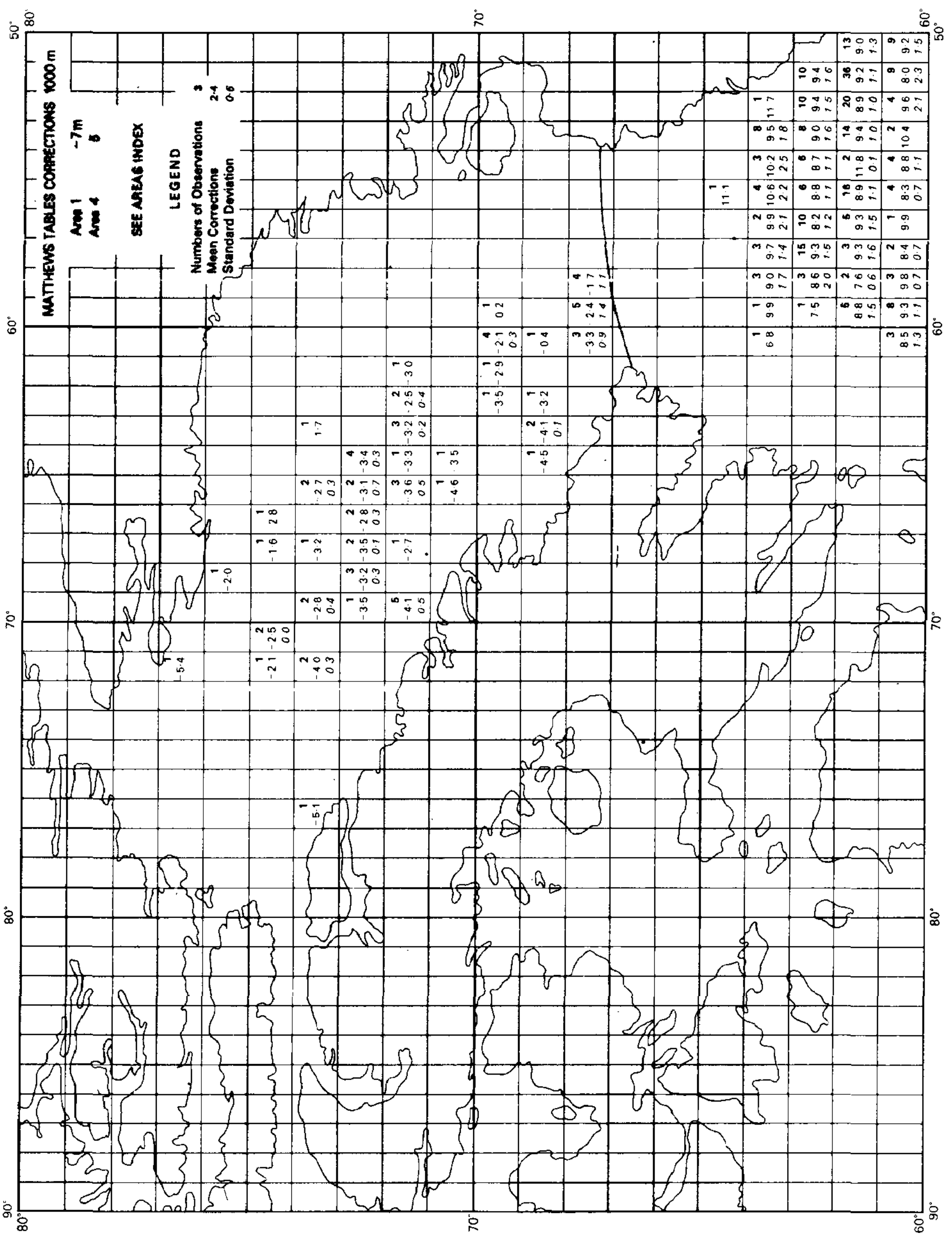

FIG. 2b. — Arctic, 1 000 m Correction.

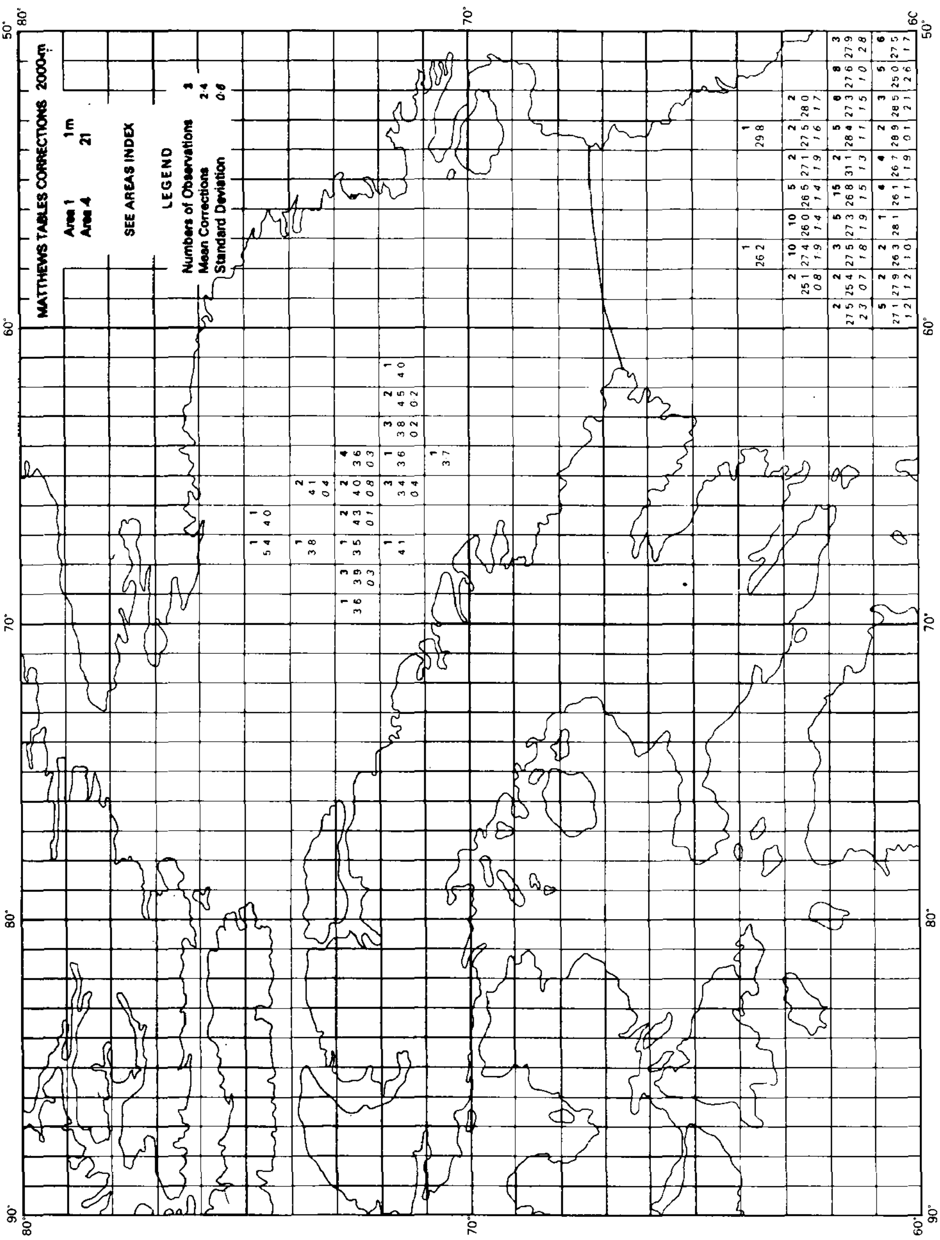

FIG. 2c. — Arctic. 2 000 m Correction.

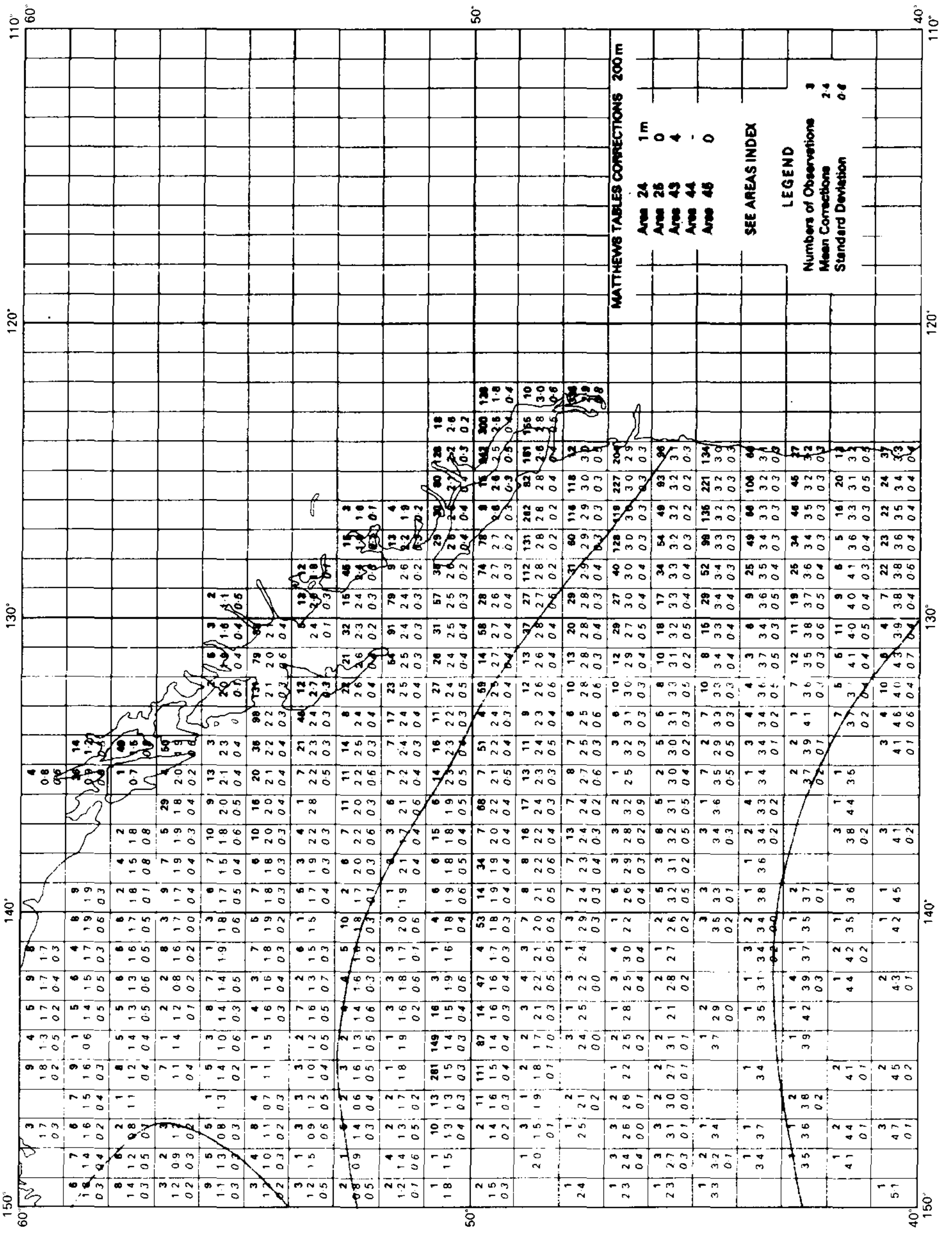

FIG. 3a. — North East Pacific. 200 m Correction.

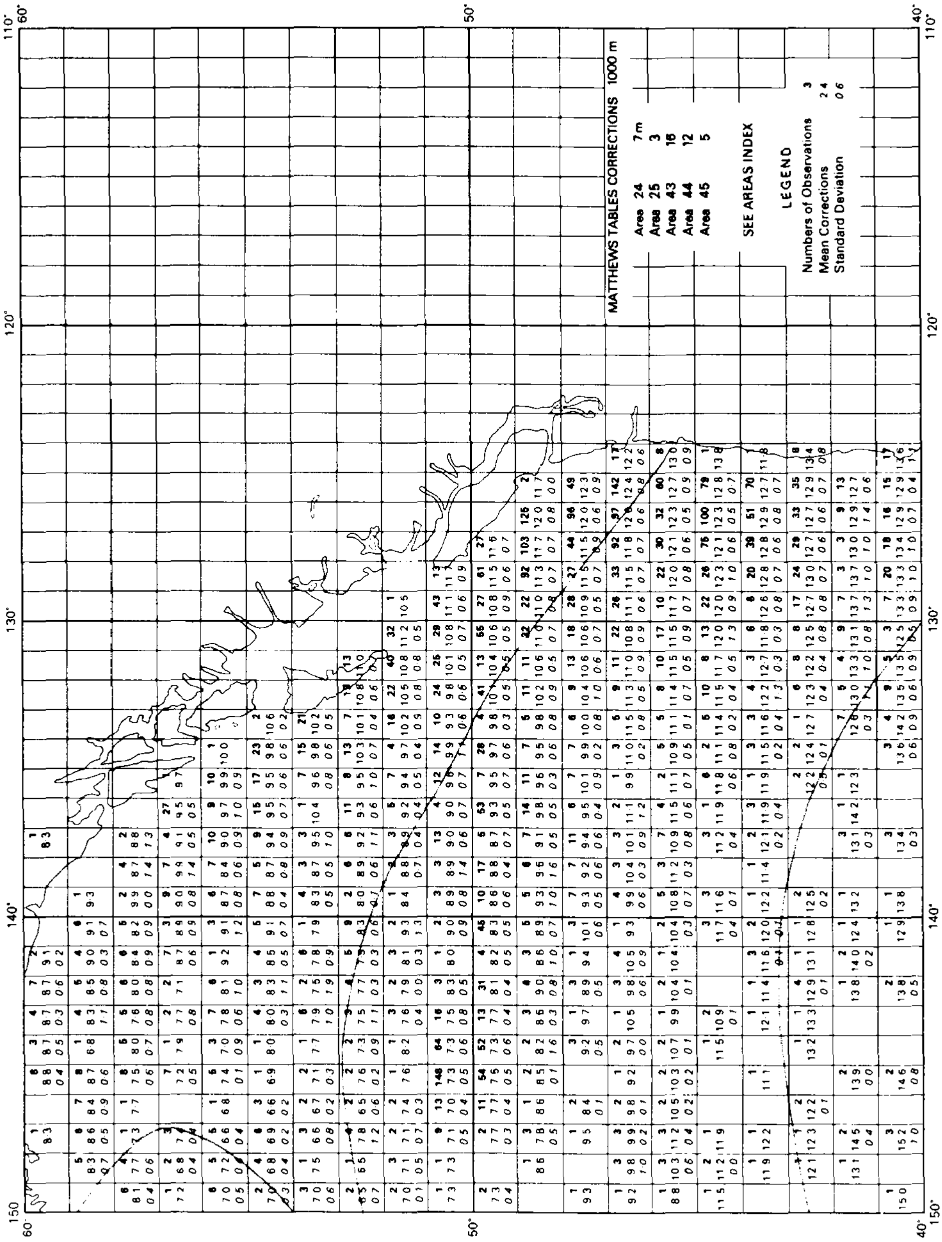

FIG. 3b. — North East Pacific. 1 000 m Correction.

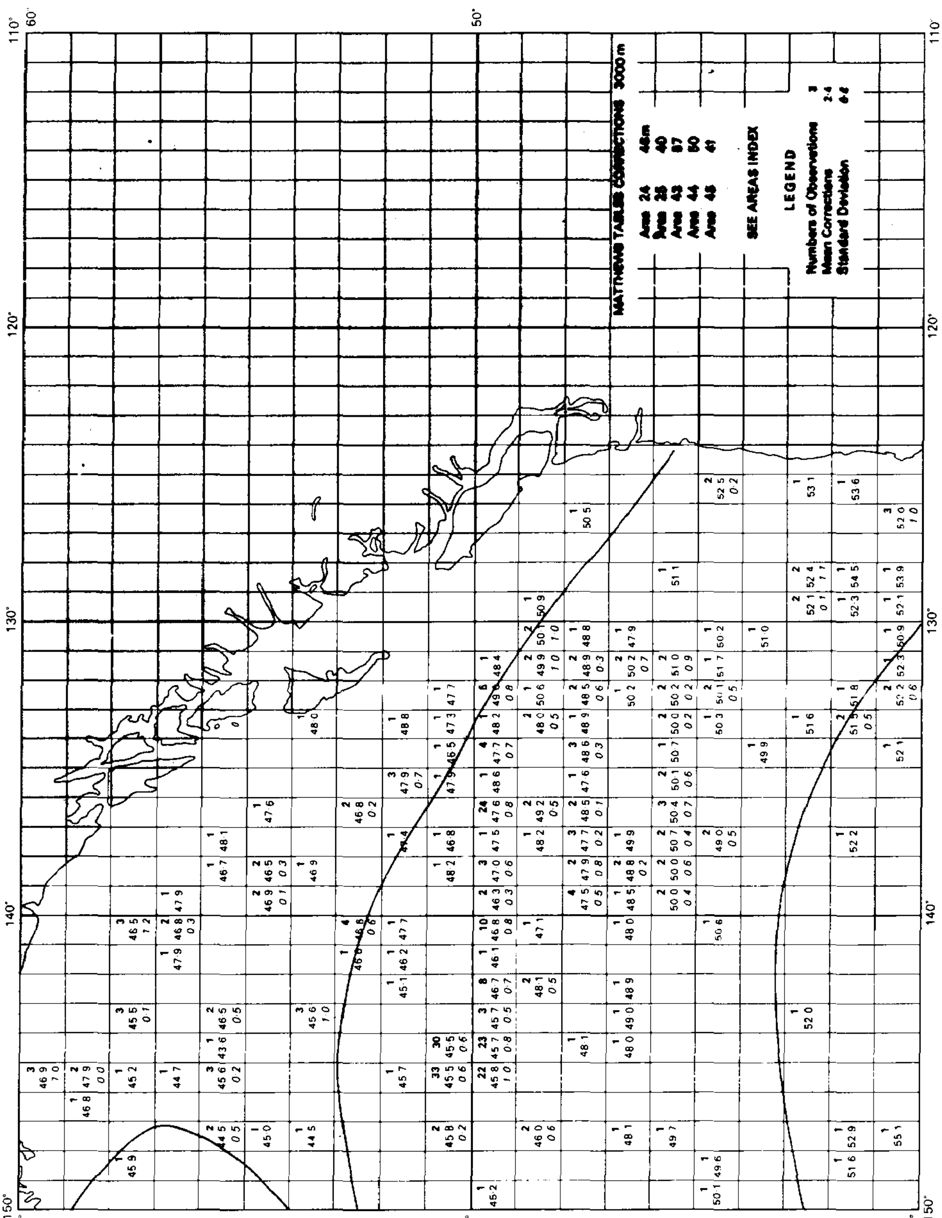

FIG. 3c. — North East Pacific. 3 000 m Correction.

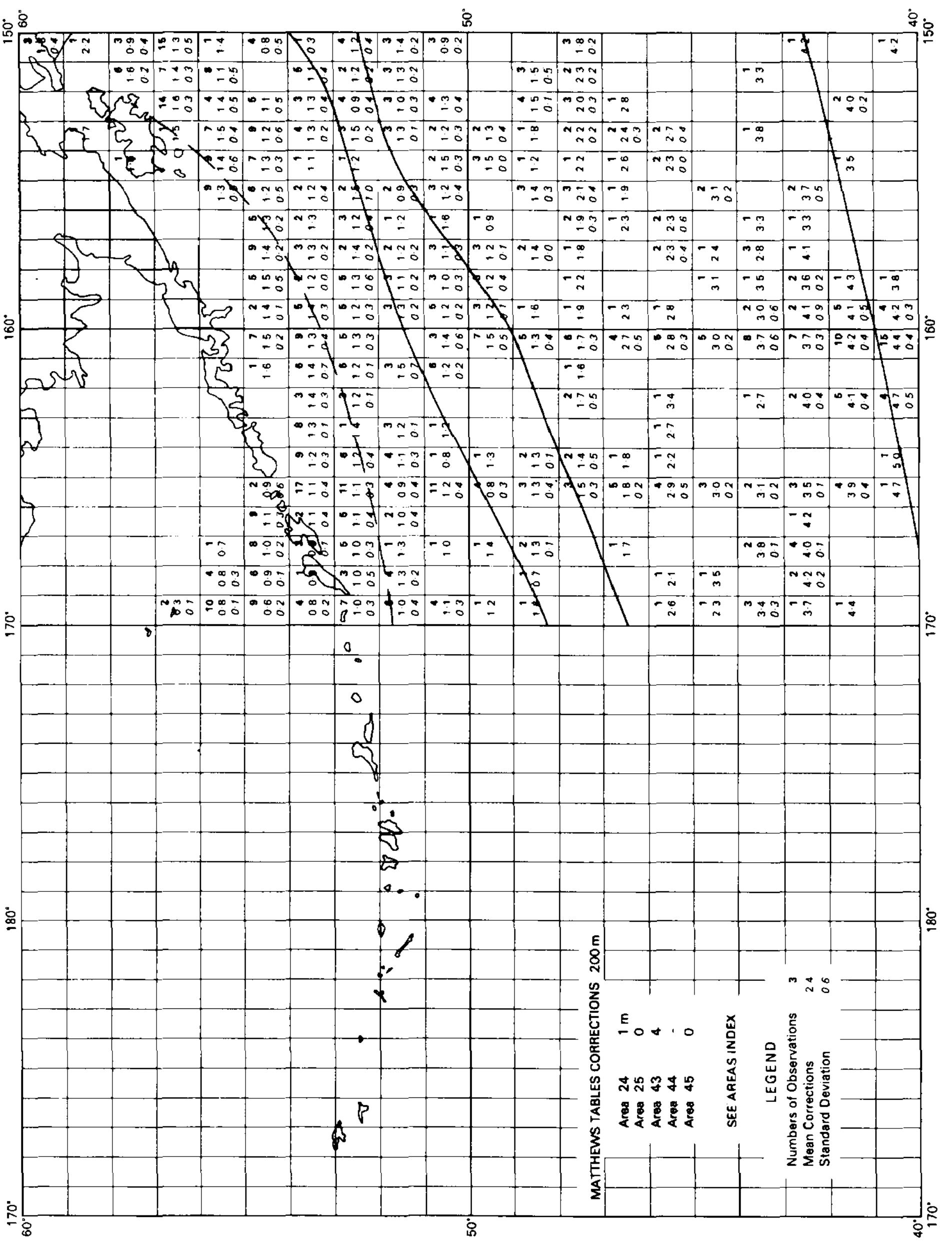

FIG. 3d. — North Central Pacific. 200 m Correction.

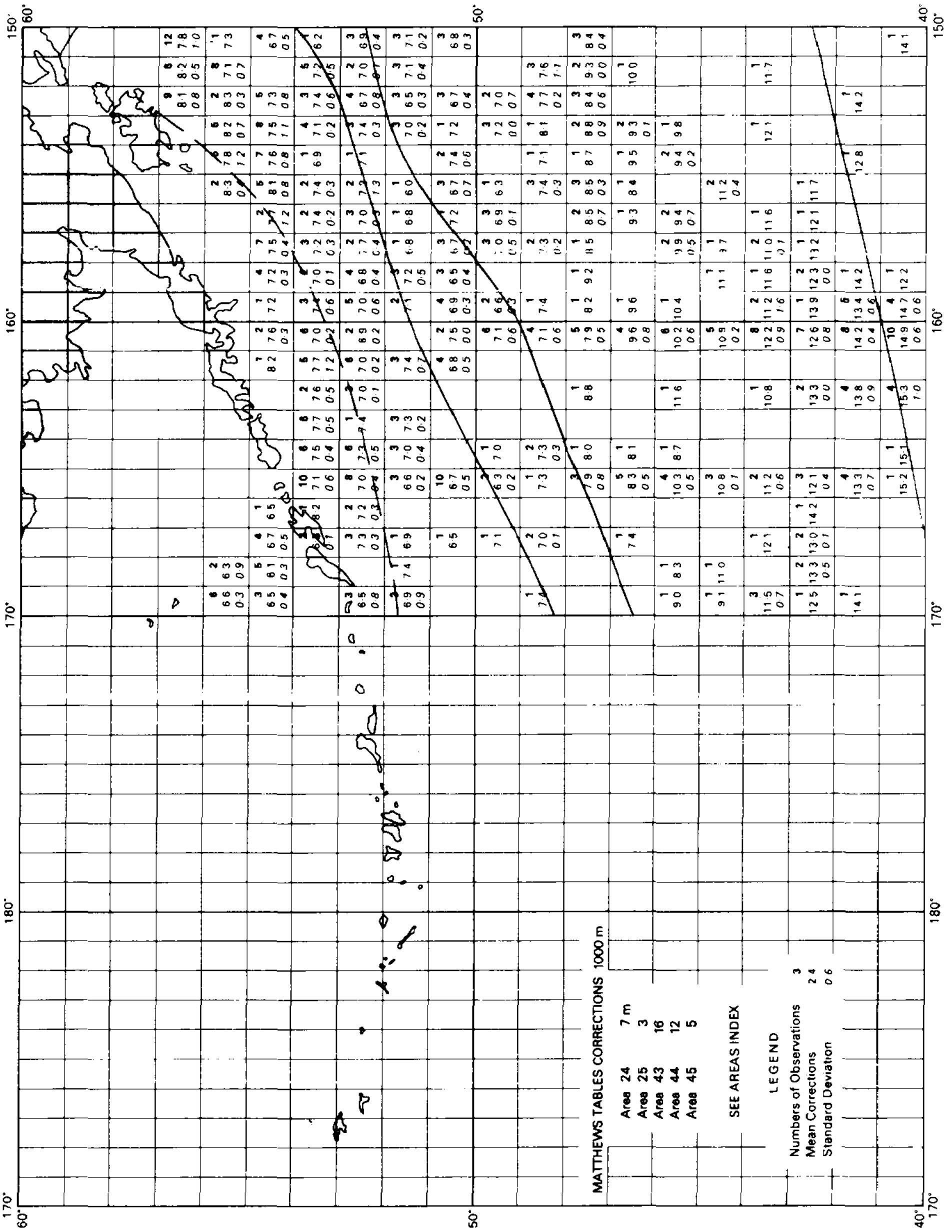

FIG. 3e. — North Central Pacific. 1 000 m Correction.

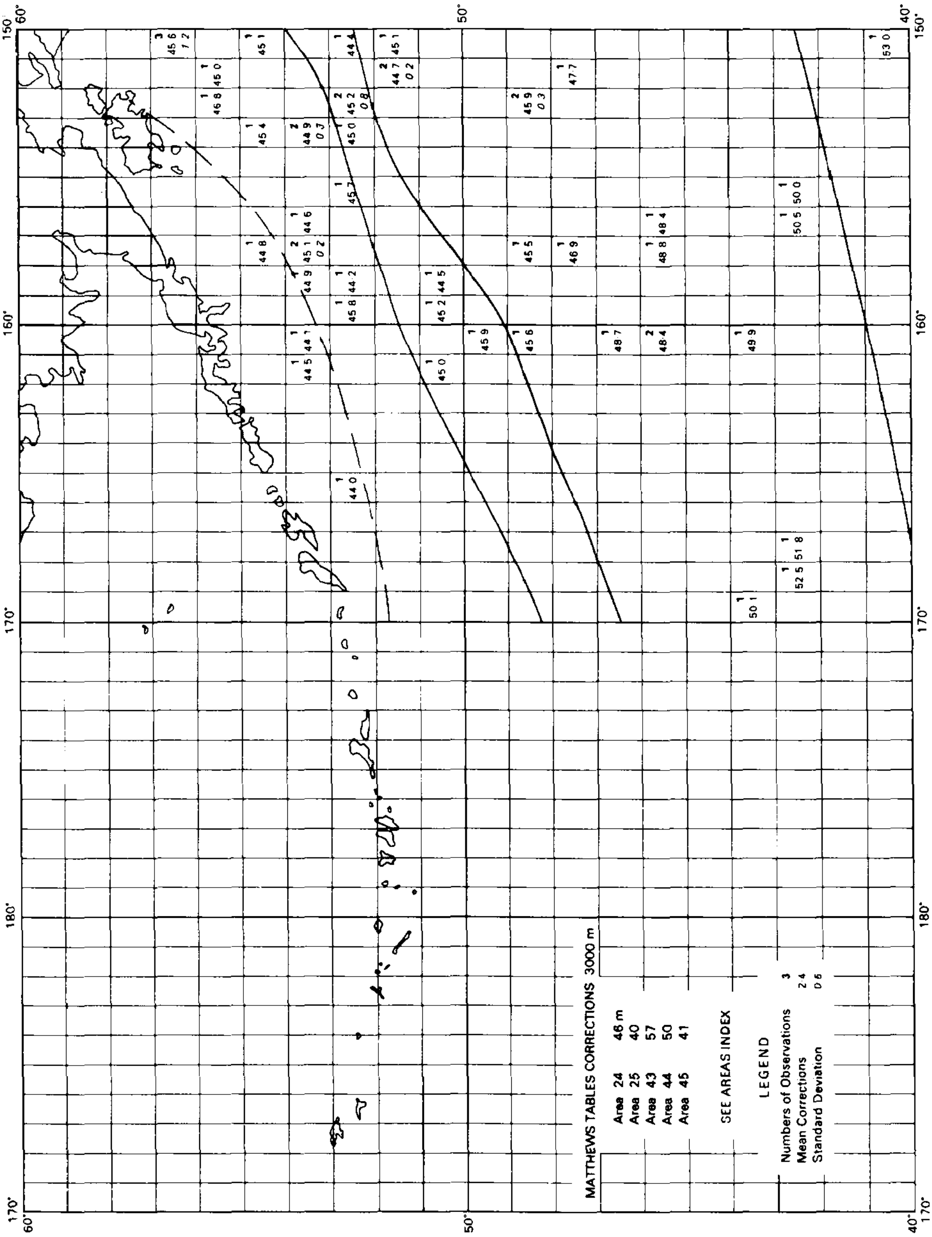

FIG. 3f. — North Central Pacific. 3 000 m Correction.

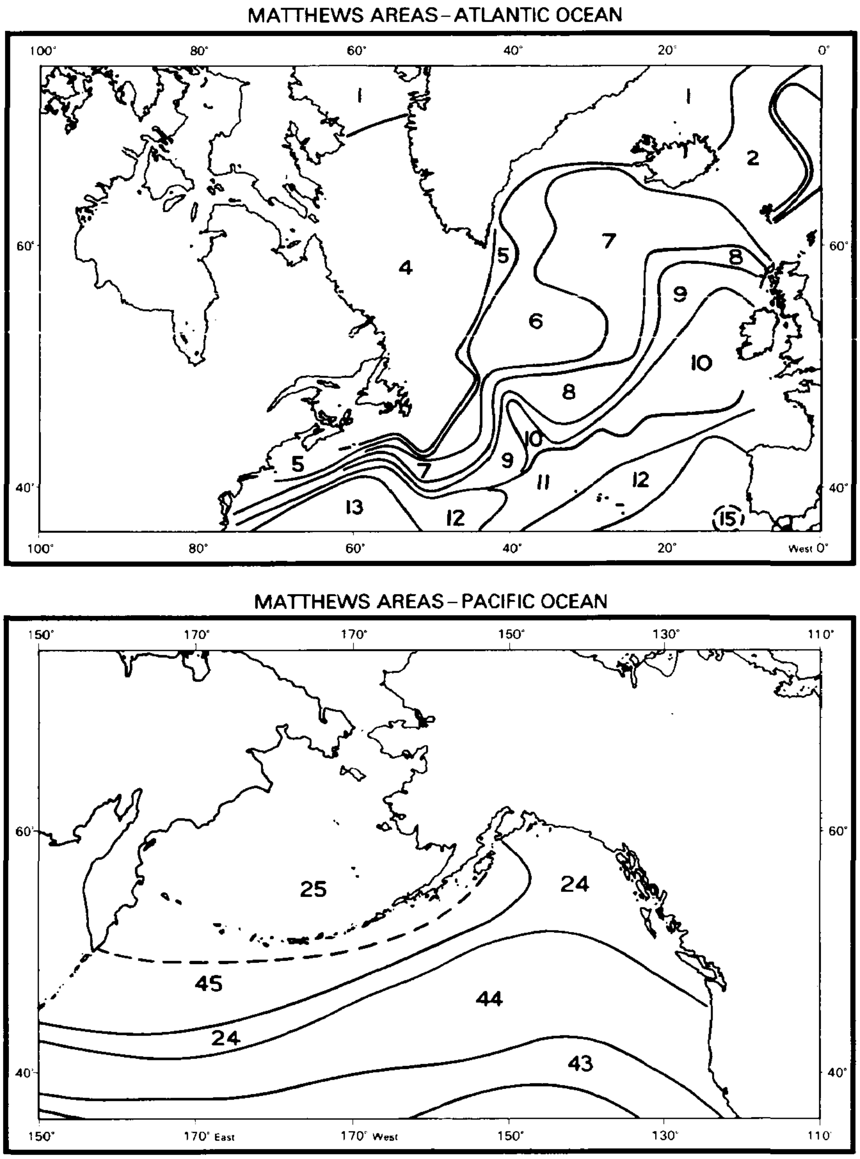

Fig. 4. — Matthews Area Index.

In the Canadian Arctic the corrections calculated are again higher than those given in Matthews tables. It is not clear whether Matthews Area 1 is meant to include the Arctic Islands and the Beaufort Sea as well as Baffin Bay. The present calculations give similar corrections in the three areas, with those in the Beaufort Sea being generally a little less. The dividing line between areas 1 and 4, where the relatively shallow Davis Strait separates Baffin Bay from the Labrador Sea, is accurate for the deeper corrections. At the 200 m level there appears to be a dividing line which joins Baffin Bay to the Labrador Current. (See figures 2).

In the North East Pacific, calculations are higher in the north and lower in the south than those given in the Matthews tables. The line separating Matthews Areas 24 and 44 appears to be wrongly placed. Present calculations indicate a dividing line further south of Alaska running north along Canada's West Coast. Areas 24, 25 and 45 have similar corrections and in the area studied could form one larger water mass. (See figures 3).

CONCLUSIONS

In the areas of this study, consistent differences have been found between presently calculated depth corrections, and those given in Matthews tables. The calculations by one degree square indicate changes in the lines separating different Matthews Areas. Correlating the correction with the surface temperature can be useful in areas affected by the Gulf Stream.

ACKNOWLEDGEMENTS

The authors are very much indebted to Mr. Paul ERWIN who did the comprehensive programming for this report, and Mr. G. GOUGH who prepared the illustrations.

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