THE USE OF A COMPUTER FOR CORRECTING OCEAN SOUNDINGS

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1. INTRODUCTION

The velocity of sound in water is a function of temperature, salinity and pressure. When an echo-sounder is used to make depth measurements, the time taken for a pulse to reach the ocean bed and return is measured. The machine is set to a standard sounding velocity, usually 800 or 820 fm/second (1463/1500 m/sec), and a nominal depth is recorded. This depth should then be corrected for the properties of the water. The "Tables of velocity of sound in pure water and sea water" by MATTHEWS [1] are commonly used for this purpose. MATTHEWS compiled his tables using soundings taken by a number of research ships all over the world. He divided the oceans into 52 areas, and for each area calculated a set of depth corrections from 200 m to the ocean bottom. Since the tables were published more accurate measurements of velocity as a function of temperature, salinity and pressure have been made. There are also many more observations than were available when the tables were compiled. However, as these tables are in general use, no attempt has been made in this paper to change the corrections, and any computer results are therefore no more accurate than the tables.

When correcting depths manually aboard ship, the following procedure is followed. The depth on the echo-sounder is noted and entered into a log book. The position of the ship is known using some standard method of navigation such as satellite, Decca, Loran or radar. Matthews maps (incorporated in the tables) are consulted to determine the Matthews area the ship is currently in, and finally the depth is corrected by reading the relevant table to obtain the correction at the required depth. The corrected depth and Matthews area are also recorded in a log book.

With the introduction of an IBM 1800 computer on R.R.S. *Discovery*, provision was made to enter the uncorrected depths, together with day and time of observation, in an off-line mode, into a file for storage and later retrieval. The next step was to store the depth corrections by some method in the computer; this is discussed in Section 3. At this time the Matthews area was up-dated by manual intervention. An attempt was next made to define Matthews area boundaries and store them in the computer, to permit automatic up-dating as the ship moved from one area to another. This is discussed in Section 2.

The computerized corrections have an agreement of ± 2 m with Matthews corrections, and the boundaries are accurate to ± 5 miles.

The following results are only valid in depths greater than 200 metres.

2. DEFINITION OF MATTHEWS' BOUNDARIES

The boundary lines used for defining the Matthews areas are taken from the original contours by Matthews [1]. They are to be found on a larger scale on the 1/36 million Admiralty Chart "Index of plotting areas" 1958, from which 1/1 million plots can be made of smaller areas.

The present study is limited to a region from 10-70° N and 5° E - 65° W in the Atlantic and Mediterranean, covering some 50 plotting sheets. It is an attempt, given the latitude and longitude, to retrieve the Matthews area from the computer with the maximum economy in storage.

The region was divided into 1° squares, within which the Matthews area boundary lines could generally be approximated to straight lines with reasonable accuracy. If no boundary lines intersected a 1° square, on the

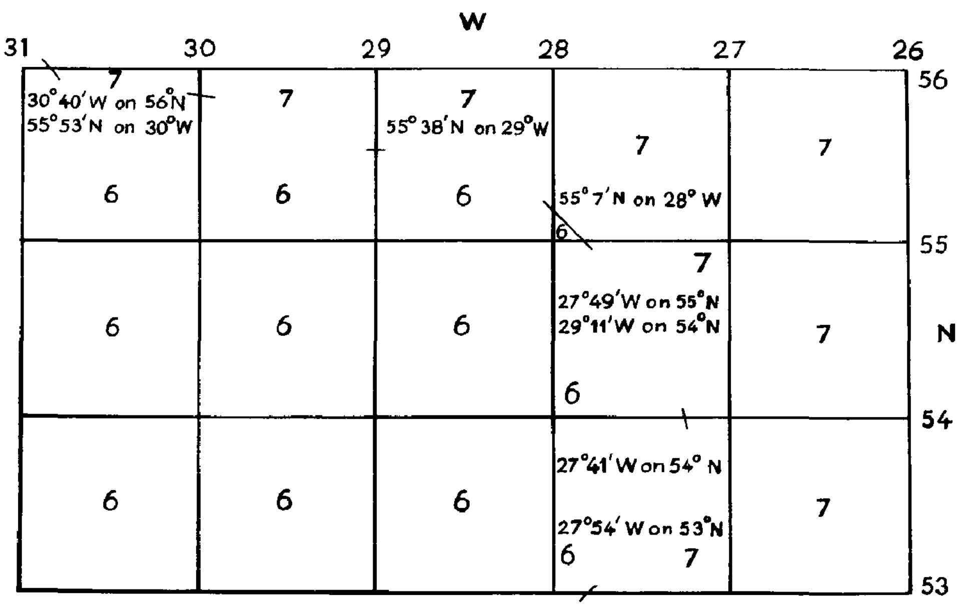

FIG. 1

plotting sheets the Matthews area was noted. Otherwise the points of intersection with the square were entered on to a grid (figure 1).

The data covers 4200 1-degree squares. In most intersection cases only one boundary line cuts the square. Theoretically, any number of them can cross a square but in practice three is the largest number to do so. This occurs where the water properties are changing rapidly in space (for example in the Gulf Stream). In approximately 50 of the 4200 cases two lines cut the squares.

Two data files were constructed to hold the data stored to disk. The first file contains 4200 records in 1-1 correspondence with the 1° squares. In the present study the first record in the file contains information about the 1° square at 10° N, 5° E, (each 1° square is defined by latitude and longitude at its SE corner).

The formula

$$60 \times \text{Absolute value (longitude} - 5) + (\text{latitude} - 9) \qquad \text{(a)}$$

establishes this correspondence for the region under study.

A generalized formula applicable to arbitrary regions in the northern hemisphere would be

$$A \times \text{Absolute value (longitude} - B) + (\text{latitude} - C + 1) \qquad \text{(b)}$$

where A is the range of latitude,

B is the most easterly longitude used,

C is the most southerly latitude used.

Approximately 15 % of the region is land, and is recognized by defining a pseudo Matthews area zero in the appropriate record. No further information is required, and storage requirements are reduced by this artifice. Areas on the continental shelf are also denoted by area zero implying that no corrections should be made.

Record structure — File 1.

For each 1° square there is a unique record on the file. If the 1° square contains no boundary lines, the file contains only the Matthews area number

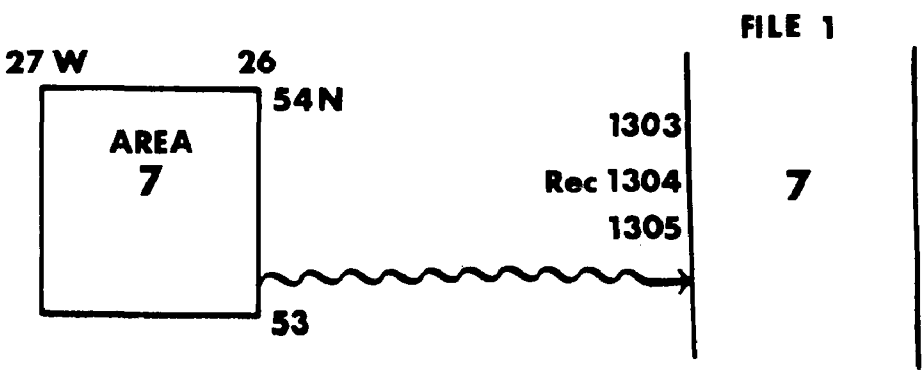

FIG. 2

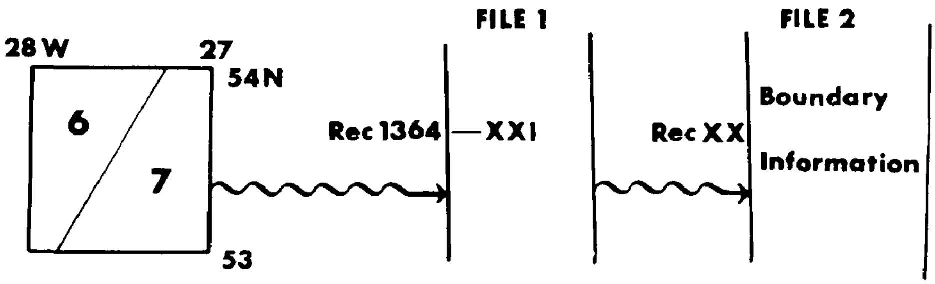

FIG. 3

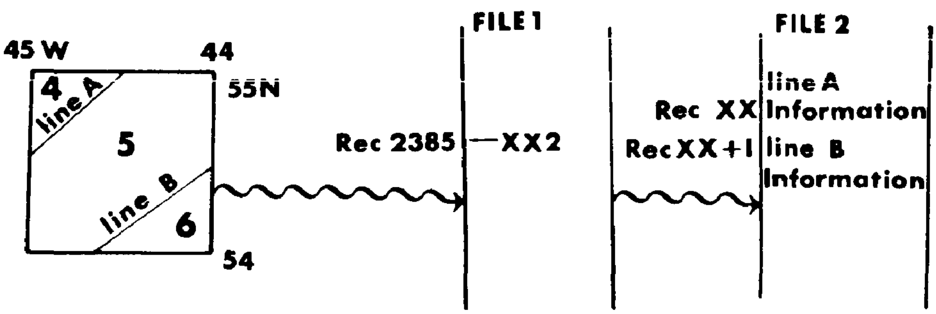

FIG. 4

(figure 2). If the 1° square contains a boundary line the record contains a negative number (figure 3). Its modulus is a composite number $10\,a + b$ where a is the record number to be read in the second file and b is the number of records to be read. Thus if the square is crossed by one line, one record is read, if crossed by two lines, two records are read (figure 4).

Record structure — File 2.

The second file contains the detailed information about the boundary lines of the Matthews areas. The number of records in this file depends on the number of boundary lines crossing 1° squares in the region considered. In this study it is 970. The structure of the file is such that in each record there are eleven integers as follows :

1. When a straight line cuts a square, the area between the line and

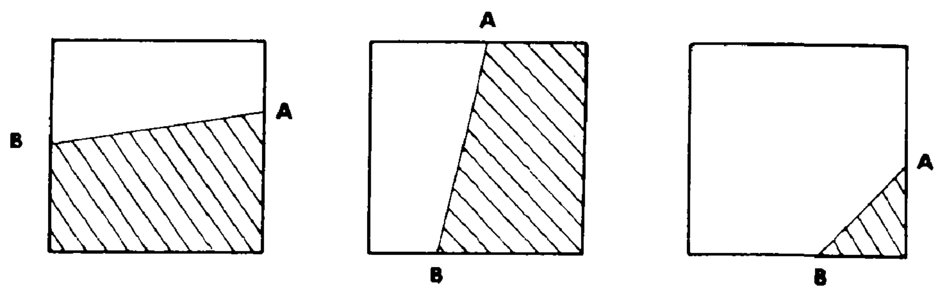

FIG. 5

the sides of the square forms either a three, four or five-sided figure (figure 5). The first integer is the number of sides so formed (See Appendix for details).

2 to 9. The latitude and longitude in degrees and minutes of points A and B.

10. The Matthews area within the figure considered.

11. The Matthews area outside the figure considered.

If two lines cut a 1° square, two records in the second file are accessed. The first record gives the information for points A and B (figure 6) and the second for points C and D. By default if the point under consideration is in neither of the shaded areas, it must be in the third unshaded area.

In approximately 5 % of the 1° squares the curving Matthews boundary line had a maximum deviation from the straight line approximation of between 9 and 25 miles (figure 7). These cases were dealt with in two ways.

(a) If the curved line was less than 10 miles from the straight line (figure 8), the line AB was moved to a new position CD. In this way the straight line approximation given by CD has deviations of a or b instead of $a + b$ thus reducing the error to less than 5 miles.

(b) If the curved line was greater than 10 miles from the straight line (figure 9), the deviation can be much reduced by setting up two records

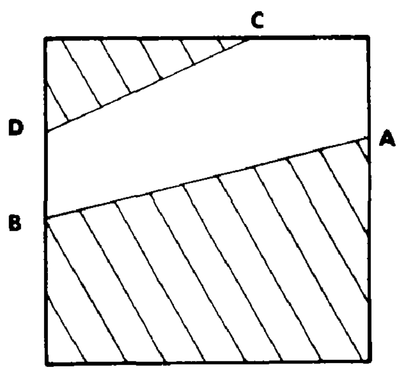

Fig. 6

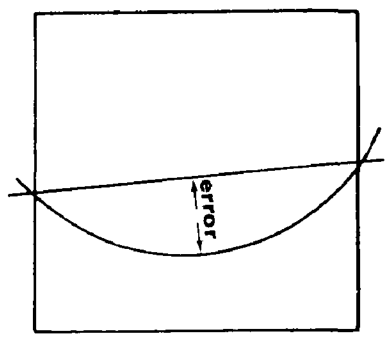

Fig. 7

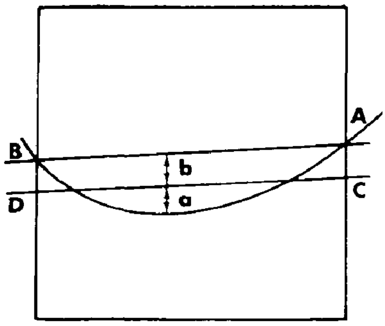

Fig. 8

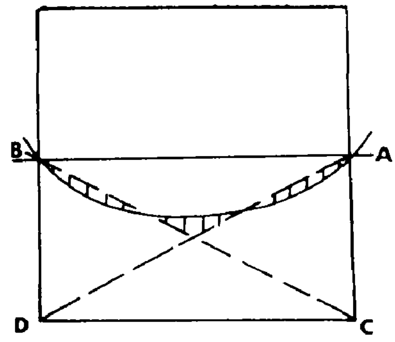

Fig. 9

in file 2, thus effectively creating two line segments AD and BC. Two separate tests, first to see whether the point considered is in BCD and if not whether it is in ACD will suffice to fix the Matthews area. C and D are not necessarily on the corner of the square.

3. DEFINING MATTHEWS DEPTH CORRECTIONS ON THE COMPUTER

The depth corrections are tabulated at 200 m intervals starting at 200 m. They are required in a form that can be easily stored on the computer. To this end a polynomial curve fitting program was applied to the corrections for each area. Different order curves were applied to each set of

TABLE I

Matthews area	Degree fitted	Maximum residual (metres)	Depth of max. residual (metres)	Mean square	Max. depth of eqn. (metres)
1	3	1.0	1 600	0.34	4 000
2	2	− 0.9	2 000	0.19	3 000
3	2	− 1.5	1 800	0.58	3 000
4	3	− 2.0	4 200	0.50	5 000
5	4	− 2.7	4 200	1.12	5 000
6	4	− 0.8	2 800	0.25	4 000
7	4	− 0.9	3 400	0.27	4 200
8	4	1.3	3 200	0.63	5 000
9	4	0.9	2 600	0.31	5 000
10	4	2.0	4 000	0.92	5 000
11	4	1.8	4 000	0.28	5 600
12 (to 5000 m)	3	− 0.2	200	1.32	5 000
13	3	− 1.0	2 600	0.30	5 000
14	5	1.5	3 000	0.91	6 000
16	4	2.3	400	0.78	3 600
17	4	− 1.0	4 800	0.35	5 000
18	4	− 2.5	200	1.16	6 000
19	4	− 2.2	2 000	1.60	5 000
20	4	− 1.3	200	0.52	5 000
47	2	− 0.7	800	0.28	1 600
48	2	0.9	1 000	0.31	3 000
49	2	1.5	2 800	0.63	4 000
50	2	− 1.5	1 800	0.49	4 000

TABLE II

Matthews area	$X^5 \times 10^{-17}$	$X^4 \times 10^{-13}$	$X^3 \times 10^{-9}$	$X^2 \times 10^{-6}$	$X \times 10^{-2}$	Constant
1	0.0	0.0	0.212	4.483	−0.981	−1.668
2	0.0	0.0	0.0	5.070	−1.093	2.470
3	0.0	0.0	0.0	3.424	−0.329	3.352
4	0.0	0.0	−0.221	7.140	−0.885	1.644
5	0.0	0.127	−0.317	7.298	−0.443	5.089
6	0.0	−0.179	0.626	2.485	0.459	0.844
7	0.0	−1.419	1.599	−0.544	0.978	1.051
8	0.0	−0.902	1.348	−1.093	1.368	2.333
9	0.0	−2.062	2.838	−7.352	2.400	2.876
10	0.0	−1.812	2.768	−8.840	3.119	−2.149
11	0.0	−1.952	2.790	−8.395	3.017	0.247
12 (25 pts)	0.0	0.0	0.934	2.872	2.510	5.316
13	0.0	0.0	0.823	−2.867	2.894	1.659
14	6.329	−11.723	8.429	−23.618	5.004	−0.128
16	0.0	−7.238	6.423	−13.460	2.459	3.584
17	0.0	−2.835	3.336	−7.322	2.302	5.342
18	0.0	−1.830	2.669	−6.776	2.584	6.550
19	0.0	−1.861	2.533	−5.957	2.064	5.516
20	0.9	−1.168	1.625	−2.159	1.495	5.393
47	0.0	0.0	0.0	7.440	2.375	0.036
48	0.0	0.0	0.0	6.690	2.555	0.789
49	0.0	0.0	0.0	6.518	2.688	1.096
50	0.0	0.0	0.0	6.573	2.747	1.788

data to give a maximum residual of the order of ± 2 metres (table II). The highest order curve used was 5.

The equations are intended for depth corrections in deep water and must not be used for depths less than 200 metres. This is because no constraint of zero correction at zero depth has been applied. In consequence errors at the surface can vary from 1 to 7 metres.

Tables I and II give the results. Table I shows the degree of curves fitted together with the maximum disagreement with Matthews tabular corrections and the depth to which the equations apply. Table II gives the coefficients of the equations to three decimal places.

Figures 10 to 14 show the fitted curves as a function of depth.

The tables for Area 12 go to 9 000 metres. It was found that two curves were needed to fit all the data points. The first curve extends to 5000 metres, the greatest depth found on the eastern Atlantic. If depths from 5000 to 9000 metres are required a second curve must be calculated for the bottom 4000 metres. In Area 13 the Matthews corrections do not extend to the

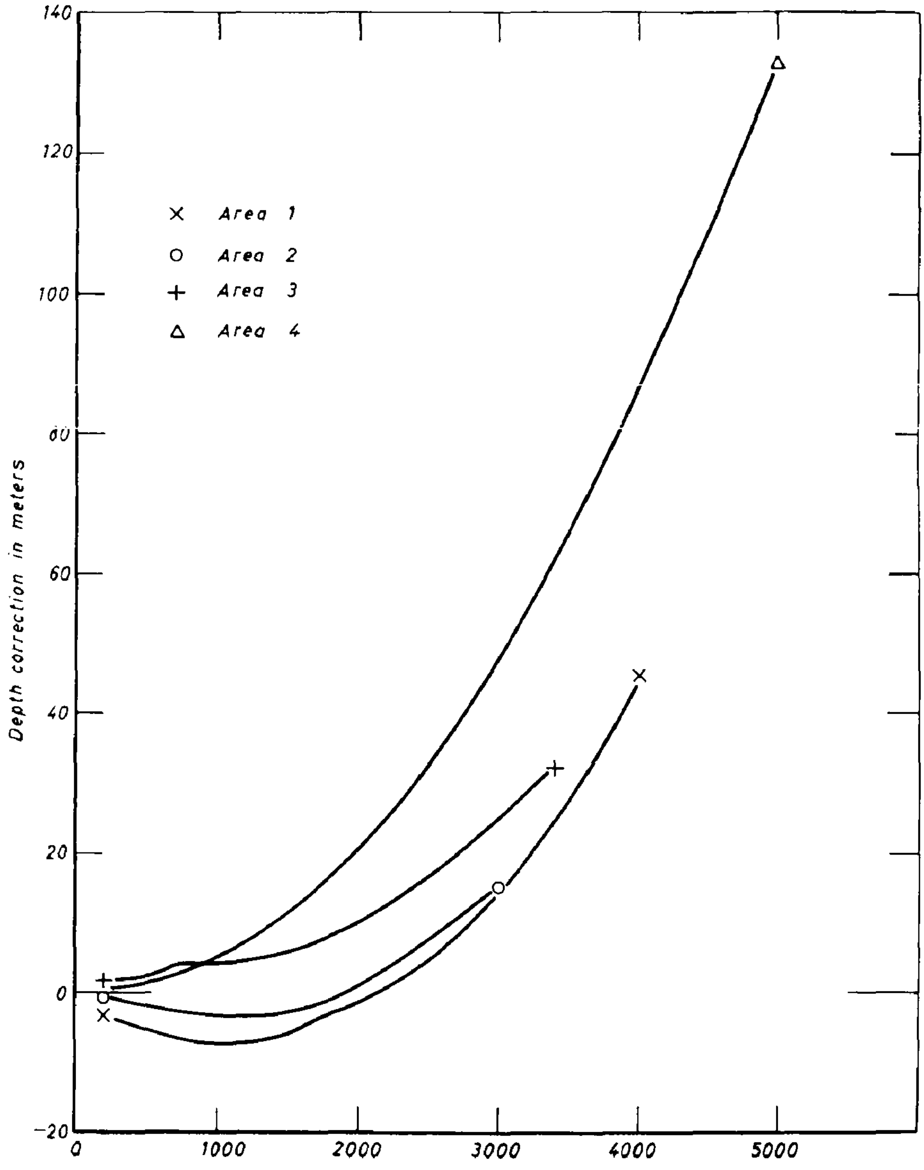

FIG. 10

greatest depths (5000 m). Extrapolation in cases such as this should be done with care. Area 14, which is near the Gulf Stream and isolated, fitted a fifth-order equation, the highest order curve fitted. Area 13 is used in place of Area 15.

Usage.

All the data for the depth corrections and the Matthews areas are stored in three data files on the computer. The first two files contain the information about the Matthews areas as defined in Section 1. The third

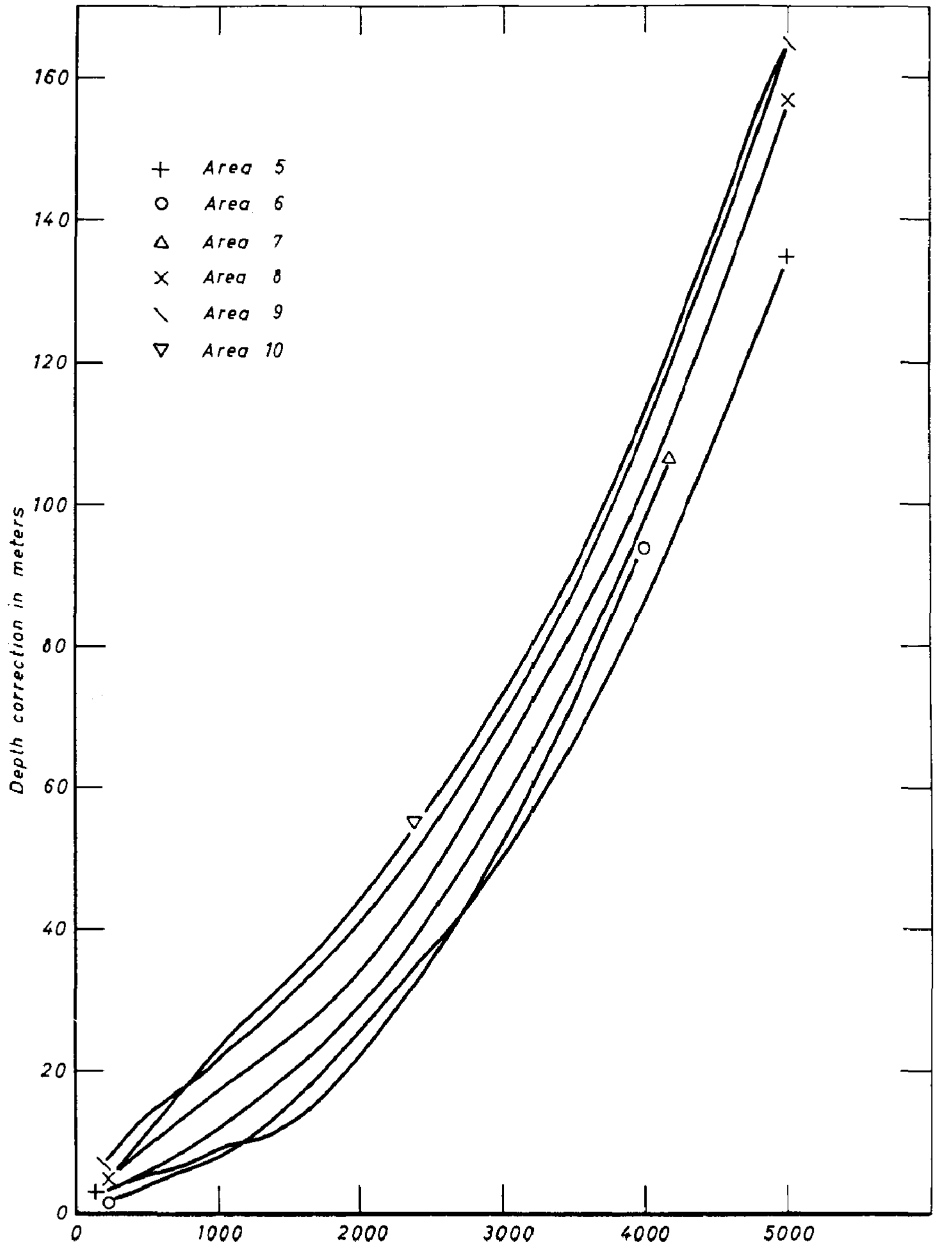

FIG. 11

file contains the coefficient of the depth correction equations, in such a way that record 1 contains the coefficients of Area 1, with a record number to area correspondence throughout the file.

The depths obtained from the echo-sounder are manually entered through a console into the computer. They do not have to be entered in chronological order as they are sorted within the computer. The current position of the ship is obtained by means of a satellite, Decca or Loran fix, and the ship's position is stored in the computer in a navigation file at 2-minute intervals.

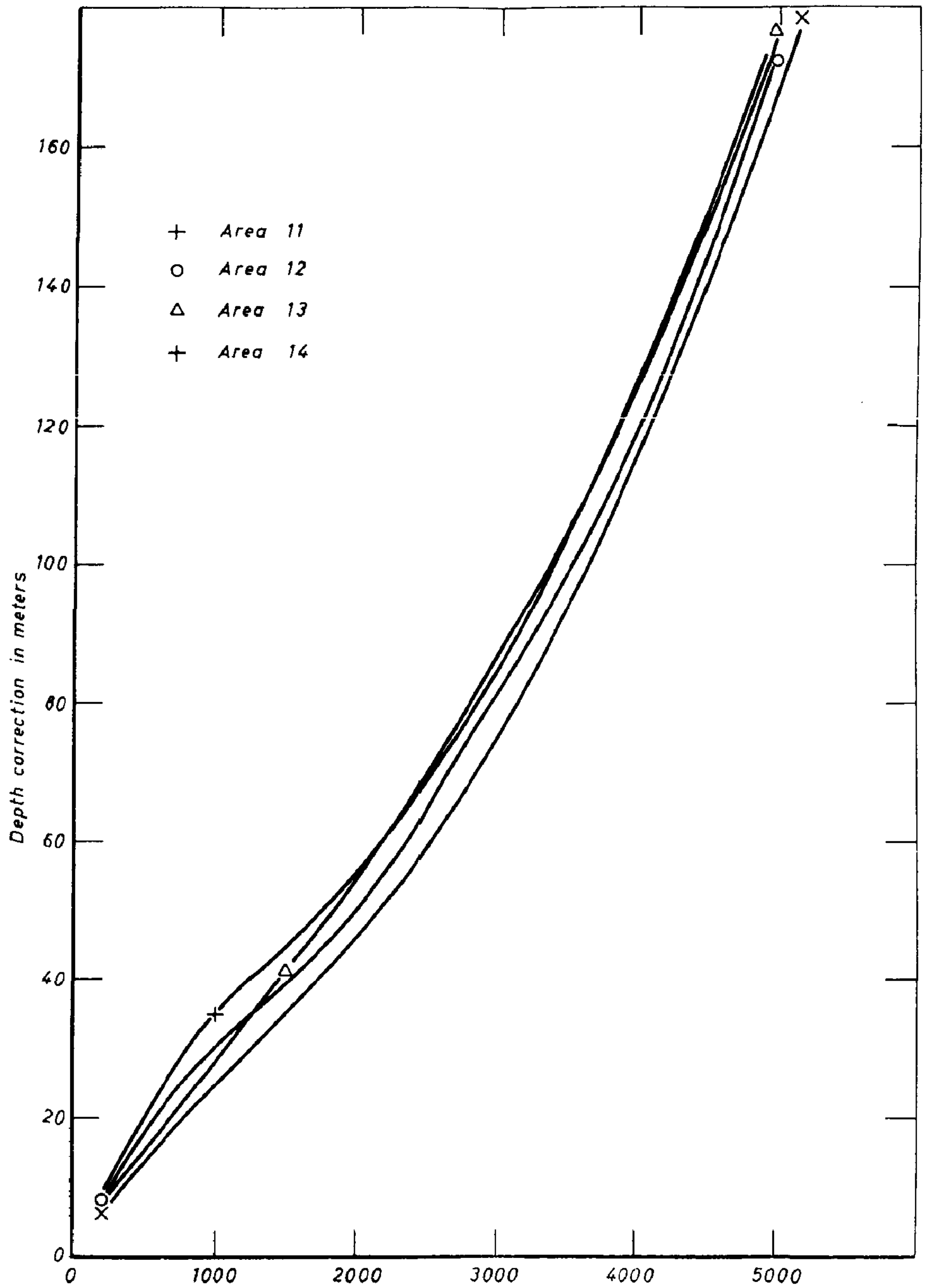

FIG. 12

Two programs have been written in Fortran to correct the depths. The first program compares the times of the echo-sounder entries with the navigation file to find the required latitude and longitude. The Matthews area number is then obtained from files 1 and 2 (see Section 2). The second program uses this Matthews area to correct the depth, reading the appropriate equation from file 1. The results are stored to disk for permanent storage in the form of uncorrected fathoms and corrected fathoms and metres, and output to a printer for inspection.

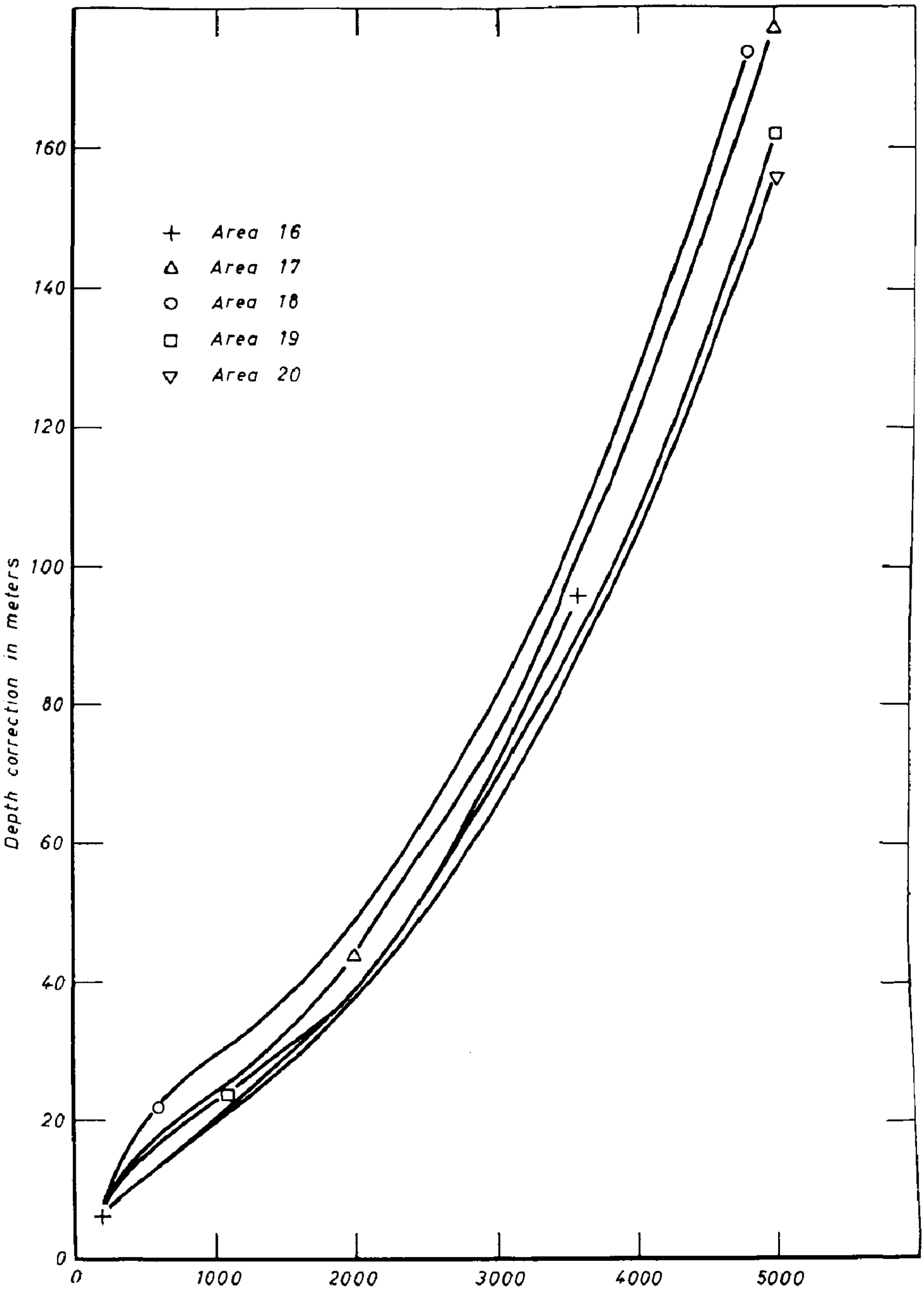

Fig. 13

Around coastlines or on the continental shelf, no Matthews corrections have been made. If corrections are required in these areas or if for some reason previously corrected depths are deemed to be in the wrong areas, an override program is available. This allows the user to alter records already corrected on disk but destroys the original corrections. Hopefully it will be used with discretion.

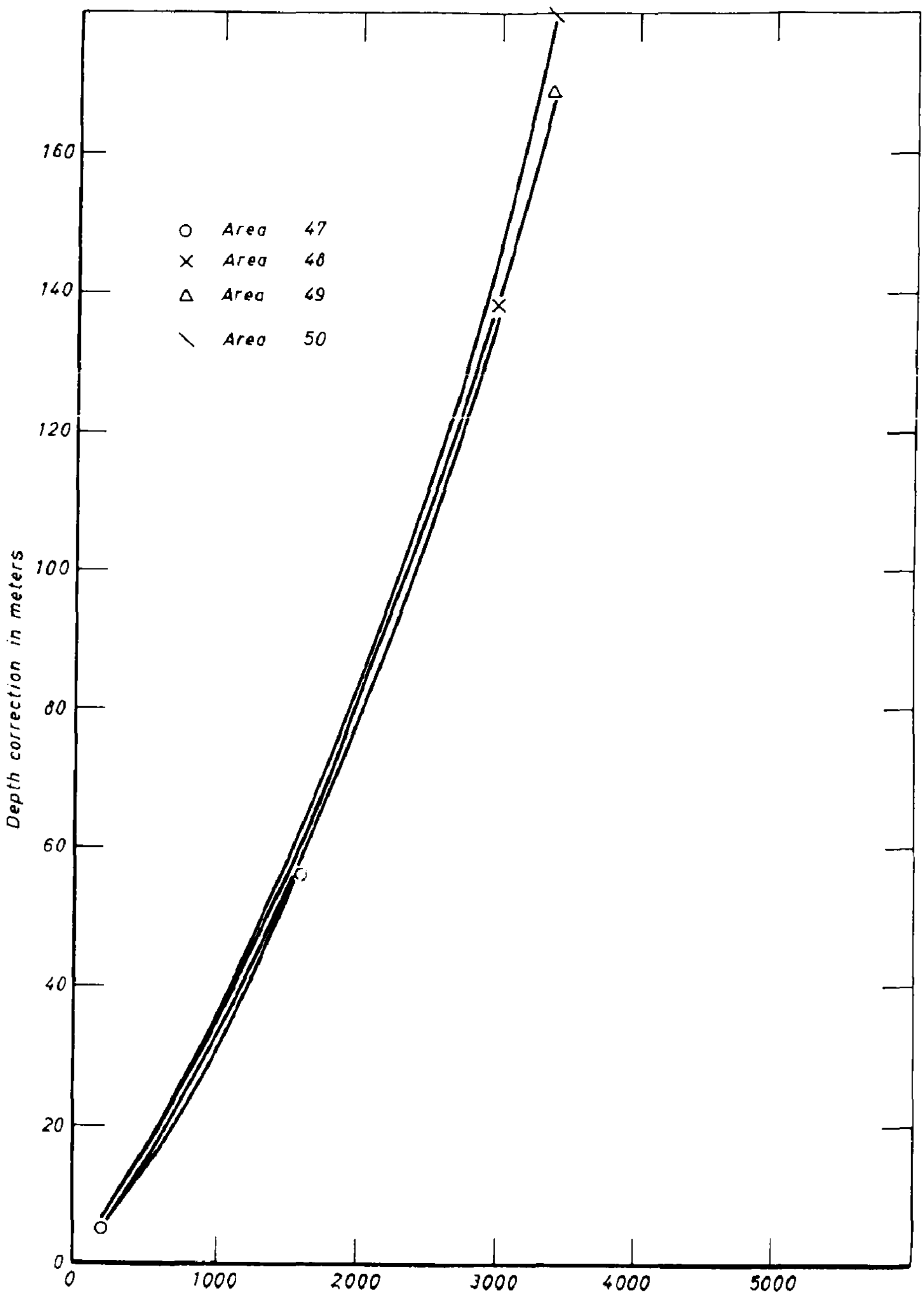

FIG. 14

Errors.

Manual corrections using a set of tables linearly interpolated to 1-metre intervals are used as a check. Comparing these corrections with those given by the equations an agreement of ± 2 metres is shown.

The Matthews areas calculated from the straight line approximations in the data files correspond to the 1/1 million charts to ± 5 miles.

4. CONCLUSION

This paper shows :

1) That reasonably low order curves can be fitted to Matthews corrections, and that the equations can be used, on a computer, to correct depths greater than 200 metres, giving a correlation with hand corrected data of ± 2 metres. Equations of this kind have been fitted to the existing Matthews correction figures in the North Atlantic and Mediterranean areas.

2) Matthews area boundaries can be defined by dividing the regions into 1° squares and approximating the curved boundaries to straight lines within these squares. This has been done for a 60 × 70 degree area in the North Atlantic. With suitable navigational data available, a depth entered into the computer can be automatically corrected. It would not be difficult to extend these results to the Matthews areas in other oceans.

ACKNOWLEDGEMENTS

I would like to thank the Marine Geophysics Group of the National Insitute of Oceanography (*) for producing the 1/1 million plotting charts; the Data Processing Group for their help in preparing the data; also Mr. B. J. HINDE, Mr. J. CREASE and Professor H. CHARNOCK for their very useful comments and criticism.

APPENDIX

When a 1° square is cut by a boundary line certain rules are observed when deciding which part of the square to consider.

1) If a square is cut by a boundary line such that two four-sided figures are formed, the part of the square containing the SE corner is always used.

2) If a three- and a five-sided figure are formed by the line intersections, the three-sided figure is chosen, whichever section of the square this should be in (figure 5).

If more than one line intersects a 1° square, the above rules apply to each intersection.

Having been given the two intersection points of the line with the square, the program calculates the remaining one or two corners of the polygon (which always lie on corners of the 1° square). A sub-routine can then be used to determine whether a given data point is inside or outside the polygon, thus determining which area it is in.

The computer programs used in calculating depth corrections are in Fortran (with a few special system read/write statements). These and the data files are available on request from the Data Processing Group of the National Institute of Oceanography (*).

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[2] Wilson, W.D. (1960) : Speed of sound in sea water, as a function of temperature, pressure and salinity. *J. Acoust. Soc. Am.*, Vol. 32, No. 6.

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(Manuscript submitted in English).

(*) Since the date this article was written the name of the Institute has been changed to Institute of Oceanographic Sciences.