VELOCITY OF SOUND IN THE ARABIAN SEA ALONG THE SOUTH MALABAR COAST DURING THE POST-MONSOON SEASON

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1. INTRODUCTION

THE knowledge of the sound distribution in the sea is of importance in fathmetry and in sonar studies. It is with a view to find the corrections to various echo-sounders with different 'sounding velocities' for use in the Arabian Sea, along the South-Western coast of India, this study has been undertaken. As a preliminary, the results for the period immediately after the South-West monsoon only, are given in this paper. As it would be of interest for further studies in locating the subsurface barriers by sonic method and because of the importance of the sound velocity in under-water acoustics, the distribution of sound velocity is fully discussed without making any special reference to the individual problems.

2. DATA AND METHODS

The velocity of sound in any medium is obtained from the formula:

$$V = \sqrt{\frac{\text{Elasticity}}{\text{Density}}}$$

and for sea-water this equation takes the form

$$V = \sqrt{\frac{\gamma}{\rho\beta}}$$

where γ is the ratio of specific heats Cp/Cv, ρ the density of the medium and β the isothermal compressibility. As these quantities can be derived from temperature, salinity and pressure and making use of some of the physical properties of sea-water, the velocity of sound can be computed from the basic oceanographic parameters. As the final expressions for different quantities involved are very complicated, different tables are in use for the computations.

Kuwahara's Tables (1939) are used for the present computations. These tables were based on various empirical formulæ derived by Knudsen (1901), Ekman (1908), etc. Further he had to take some of the physical constants whose values are questionable to some extent in the light of the modern techniques developed for the same. Thus, considering Del Grosso's (1952) recent formula, Beyer (1954) has concluded that Kuwahara's value are almost consistently smaller by about 3 m./sec. amounting to maximum error of 0·2%. The maximum correction to be applied to the echo-sounders up to 500 m. (to which depth this investigation is extended) does not exceed 20 m. For the same layer, with the sound velocities encountered, the error involved by using Kuwahara's Table for the computation of sound velocities, instead of Del Grosso's formula, would be nearly + 1 meter. But considering the standard deviation of about 3 m./sec. reckoned from the mean profile of the sound velocity against depth for the data used herein, from which the corrections are evaluated, the said uncertainty of Kuwahara's values is within the observational limits. Thus for the purpose, Kuwahara's values are quite adequate. The general discussion of the sound velocity distribution, also, will not be affected by the tables employed here.

The collection and the preliminary analysis of the data employed herein, are completely discussed separately by Rama Sastry and Myrland (1959). However, the station positions are indicated in the chart showing the sound velocity distributions (Fig. 10) for reference.

In the following sections, the computed sound velocities are represented diagrammatically both in vertical sections off the coast-line from Alleppey (9° 30′ N) to the Cape Comorin (8° N) and by horizontal charts corresponding to all the international levels from the sea-surface to 150 m.; though only four charts are reproduced.

3. Vertical Sections of Sound Velocity

It is profitable to have some knowledge about the oceanographic conditions of the region during the period before discussing the sound velocity distribution. The essential features are reproduced here from Rama Sastry and Myrland (19.9). During this season upwelling along the coast is limited only to the upper 75 m. and the intensity increases southwards. The northern boundary of intense upwelling can be considered as 9° N. The space time variation of salinity is from 34–36‰; and a subsurface zone of maximum salinity occurs at a mean depth of 300 m. Salinity is generally lower near the bottom of the continental shelf and the slope. A vertical plane at the edge of the continental shelf forms a boundary between the low saline coastal waters and the high saline oceanic waters. Vertically isothermal water mass, 'The Kerala Coastal Deepwater' forms over the bottom of the continental shelf and this water, during the season, is not continuous, but appears either very near the coast or near the edge of the shelf. With higher densities coastwards from surface up to 50 m., the main current is southerly. But at depths greater than 100 m. a northerly counter current entering in the southernmost region branches off westwards, north of 9° 30′ N. Between 50 m. and 75 m. circulation is transitory and an easterly

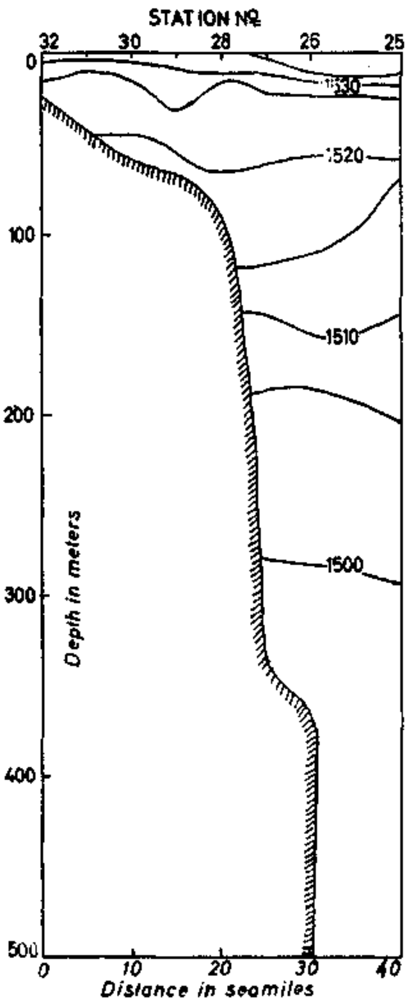

FIG. 1

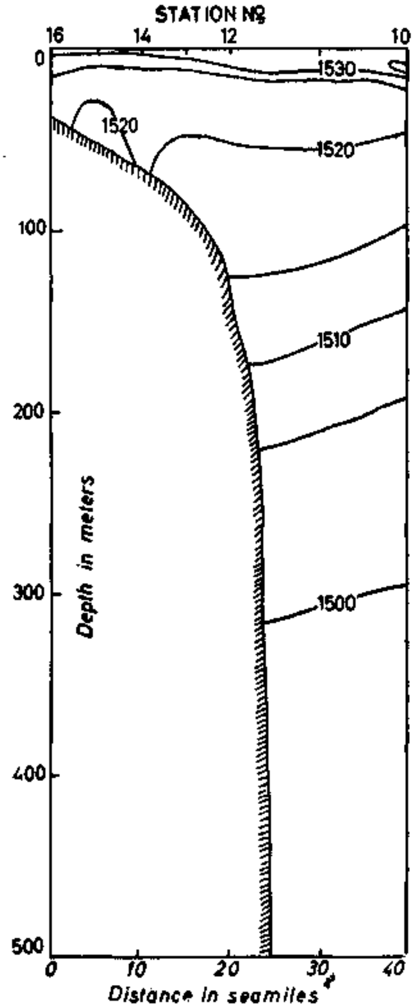

FIG. 2

FIG. 1. Distribution of sound velocity in a vertical section off Alleppey (Mean latitude 9°30′ N) on the 19th September 1957—vertical exaggeration is 371 and is constant for all vertical sections.

FIG. 2. Distribution of sound velocity in a vertical section at 10 miles south of Alleppey (mean latitude 9° 20′ N) on 18th September 1957.

flow is indicated in the southern region particularly at 50 m. Eddy circulations centered at 9° N and 76° E appear down to a maximum depth of 50 m.

Now bearing in mind all these facts, first we proceed to discuss the vertical section from the northernmost section, *i.e.*, off Alleppey. All the sections up to the Cape Comorin are running due west on different parallels except the southernmost one which is south-westerly.

As the distribution of temperature has profound influence, the isopleths of sound velocity follow closely the corresponding isotherms. Thus in Figs. 1 and 2 off Alleppey corresponding to the mean latitudes 9° 30′ N and 9°20′ N the isopleths of 1535–1520 m./sec. show an upward tilt coastwards associated with upwelling. The wave-like structure of the isopleths near the bottom of the continental shelf, in both these figures as well as the others to follow are the result of the Kerala coastal deepwater. But in the surface layers it is the result of surges of upwelling where either discontinuity in salinity or wave formation of isotherms could be noticed. The vertical gradient of sound velocity is uniform between 100 and 300 m. as a result of steady fall of temperature. Both because of the existence of a zone of subsurface maximum of salinity and of the influence of pressure (the isothermal compressibility) the rate of fall of sound velocity with depth in deepwaters below a depth of 300 m. is minimised.

In a section 10 miles north off Quilon (Fig. 3) with the increased thickness of the Kerala coastal deepwater between stations 14 and 15 a discontinuity in the isopleth of 1520 m./sec. is found. With reduced vertical gradients of temperature between 25 and 100 m., the gradient in sound velocity has also decreased. The downward tilt of the isopleths in this as well as in the following section off Quilon (Fig. 4) is the result of a corresponding reduction in density followed by the presence of low saline waters along the bottom. But off Quilon it is likely that the distribution is also affected by the bottom topography and internal waves. In the surface layers even from the sound velocity section, it is clear that intense upwelling starts here, with the result sound velocity near the coast in the surface layers has decreased by about 10 m./sec. compared to the previous section. Also with the subsurface counter-flow starting at about 50 m. which is being reflected near bottom producing turbulence (lateral mixing) resulted in eliminating the Kerala coastal water. But purely associated with the turbulence the isopleths of sound velocity are of wave form.

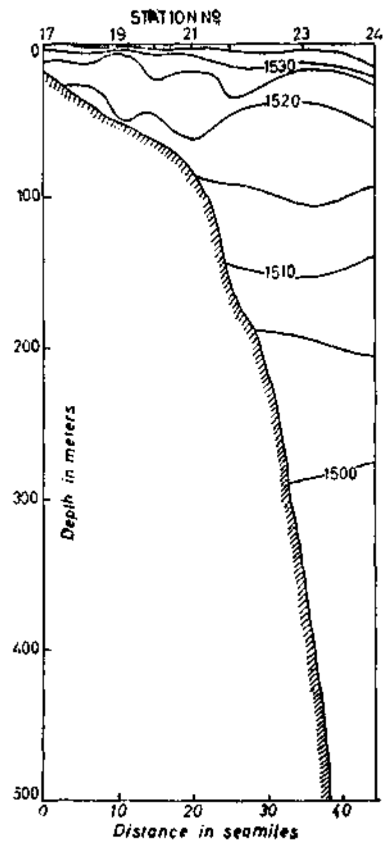

FIG. 3. Distribution of sound velocity in a vertical section running due east 10 miles north off Quilon (mean latitude 9° 10′ N) on the 18th September 1957.

Further south there is a general increase of sound velocity in the surface layers though there is no corresponding change in deep layers. This change is maximum in the clear oceanic waters (roughly beyond the continental slope) where the thermocline forms at about 30 m. The closed isopleths of 1540 m./sec. (Figs. 5 and 7) are in fact associated with temperature inversions found in the mixed layer. These may be considered as purely incidental as they occur in very shallow depths affected by the di.rnal variation of temperature, whose influence could not be eliminated in this investigation for want of data.

In Figs. 5 and 6 (between Quilon and Trivandrum) the ve: tical gradient of sound velocity near bottom is very small because of the "Kerala coastal deepwater," wherein in addition to the vertical gradient, the lateral gradient of temperature also is very small (less than 1° C. fall in about 10 miles seawards).

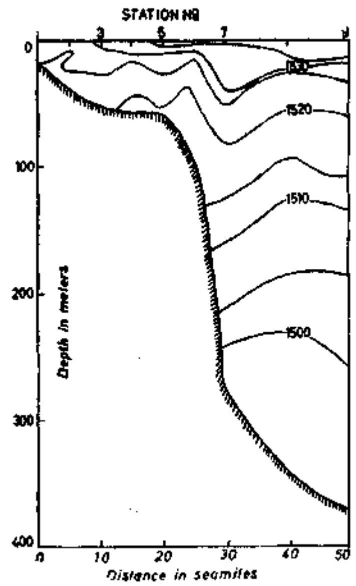

FIG. 4

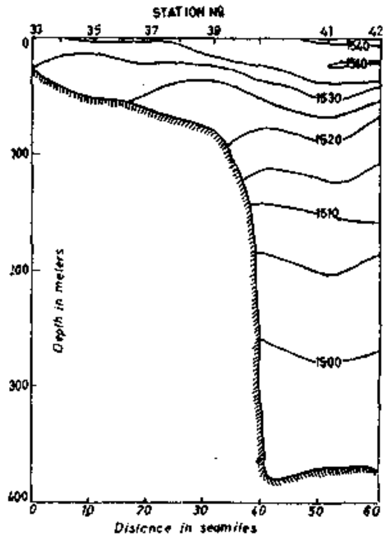

FIG. 5

FIG. 4. Distribution of sound velocity in a vertical section at Quilon (mean latitude 9° N) on 16th and 17th September 1957.

FIG. 5. Distribution of sound velocity in a vertical section at 7 miles south off Quilon (mean latitude 8° 45′ N) on the 5th October 1957.

Between Trivandrum and the Cape Comorin (Figs. 7 and 8) corresponding to latitudes 8° 15′ N and 8° N the velocity distribution of sound is similar to the previous sections in the upper 100 m. but below the depth the isopleths are more orderly. But in an oblique section of Cape Comorin (Fig. 9) associated with lateral mixing in the direction of the current the isopleths in the upper 100 m. show the characteristic wave form.

4. Distribution of Sound Velocity at Different Levels

Horizontal charts showing the sound velocity distribution at 0 m., 20 m., 50 m. and 100 m. are given in Fig. 10. However, the following discussion would include for other levels up to standard 150 m. so that the intermediate changes could be easily visualised.

At the sea-surface (Fig. 10 A) the sound velocity increases uniformly away from the coast and the isopleths from 1534–1540 m./sec. between 7° N and 9° N are nearly parallel to the coast. But off Quilon, the isopleths 1536–1540 m./sec. are eastwards, and north of 9° N associated eddy formations there is a break in the continuity of the isopleths. This break at 9° N forms a channel of rapidly increasing values southwards across it. This sound channel, at 10 m., with a velocity range from 1526–1534 m./sec.

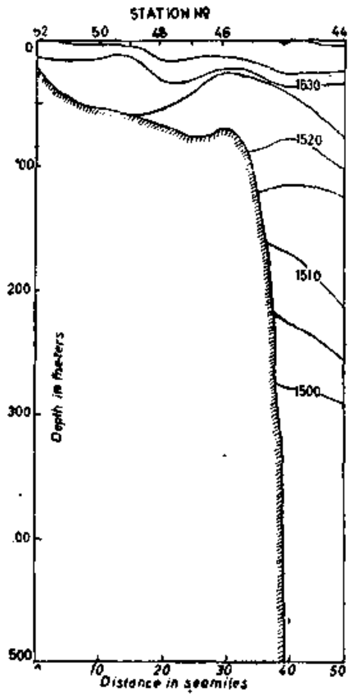

FIG. 6

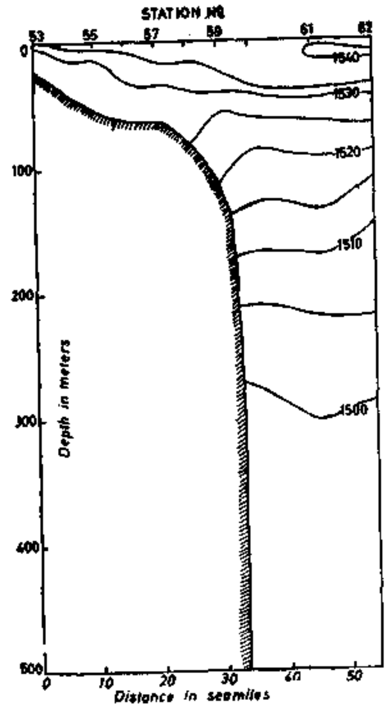

FIG. 7

FIG. 6. Distribution of sound velocity in a vertical section entering coastwards at about 7 miles north of Trivandrum (mean latitude 8° 30′ N) on 5th and 6th October 1957.

FIG. 7. Distribution of sound velocity in a vertical section at 8 miles south of Trivandrum (mean latitude 8° 15′ N) on 6th and 7th October 1957.

proceeds from Quilon in westerly direction converging at 9° N and 76° E where the mean width is only 7 miles (North to North-East) diverging as it proceeds north with a maximum separation of the same isopleths being about 20 miles off Alleppey. The isopleths of higher values up to 1540 m./sec. more or less retain their shape between 7° N and 9° N but turn north-easterly round the sound channel.

At least up to 20 miles off Quilon the sound channel is not very prominent at 20 m. (Fig. 10 B) but the maximum horizontal gradients occur approximately at the same position as at 10 m. and a change of 1524–1538 m./sec. occurs in 13 miles along 76° E. From this position two diverging channels one going northwards and the other running in an easterly direction. Though there is a fall of 2 m./sec. in 20 m. the isopleths south of 9° N are similar to those at the surface.

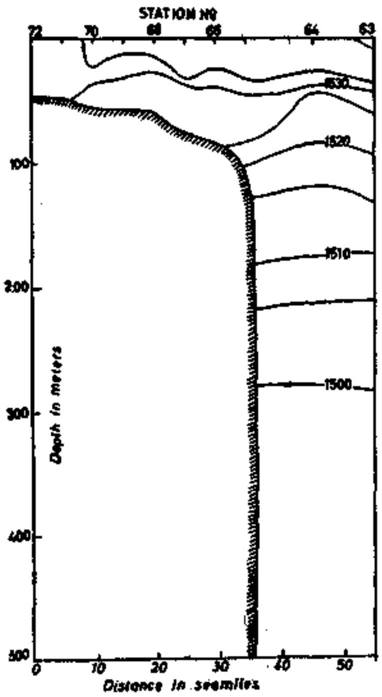

FIG. 8

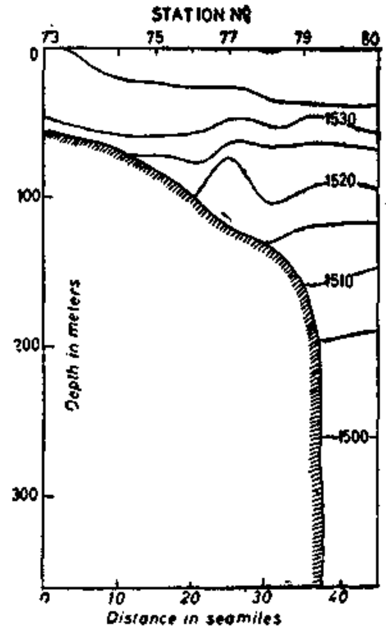

FIG. 9

FIG. 8. Distribution of sound velocity in a vertical section proceeding eastwards to the Cape Comorin (mean latitude 8° N) on the 7th October 1957.

FIG. 9. Distribution of sound velocity in a south-westerly vertical section of the Cape Comorin on 7th and 8th October 1957.

The isopleths running nearly parallel to the coast in the southern zone at 30 m. converge at 8° 30′ N and 76° 30′ E and then form two individual channels one converging nearly at the same point as at higher levels with the other isopleths northwards and the other continuing its north-westerly path. Both these systems merge together at 8° 50′ N and 75° 30′ E resulting a strong southerly horizontal gradient from 1528–1540 within 10 miles.

This characteristics still prevails at 50 m. (Fig. 10 C) where within a channel width of 10 miles the sound velocity increases from 1521–1526 and here this channel seems to turn towards south-west which in fact becomes south-westerly at 75 m. With the redistribution of mass at these transitory levels the isopleths in the south tend to be westerly to south-westerly. But between 7° 30′ and 8° 30′ at 75 m. the isolines run parallel to the coast beyond the continental slope. Thus the westerly increase of sound velocity in the upper layers has gradually turned to be a southerly increase.

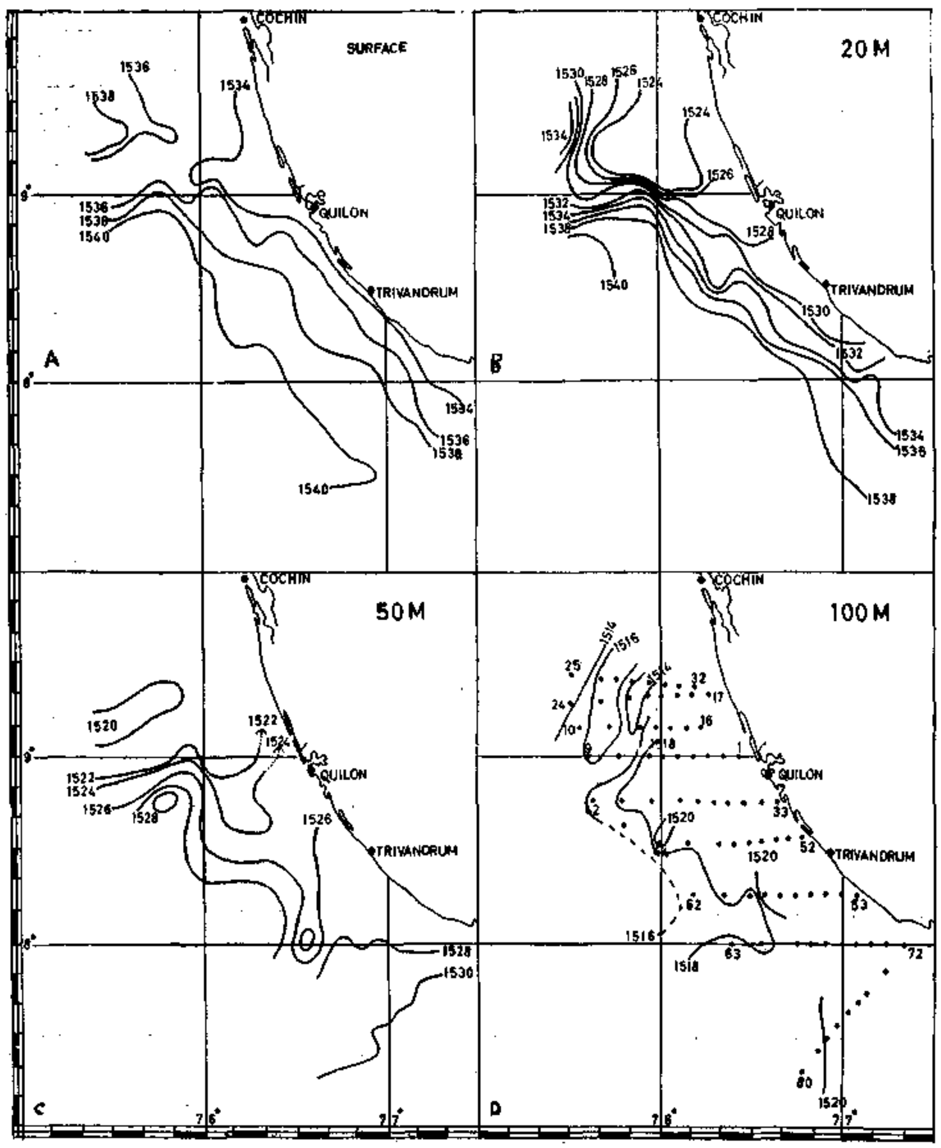

FIG. 10. Chart showing the distribution of sound velocity at 0 m, 20 m, 50 & 100 m depth levels—The station positions are indicated in the figure.

With lower temperatures and higher densities seawards, at 100 m. (Fig. 10 D) the sound velocity is decreasing away from the coast. With still unsettled conditions in the north and with initial stages of the branching of the subsurface flow towards north-west the isopleth of sound velocity are not continuous. It is in this region the velocity of sound still shows a rapid increase southwards. At 150 m. the range of the sound velocity encountered is only 4 m./sec. with a maximum horizontal range of 3 m./sec. (from 1513 m./sec. near the coast to 1510 m./sec. westwards). In the region north of Trivandrum the sound velocity is uniform with mean value of 1510 m./sec.

5. Correction Tables for Echo-Sounders

Corrections to be applied for echo-sounders of different sounding velocities ranging from 1450–1540 m./sec. are computed from a total of 512 computed velocities at individual levels in the region covered by 80 stations. At the first 32 stations covering the region north 9° N observations were made from 16th–19th September 1957, while the remaining stations covering the southern region were established between 5th–9th October. In order to see whether there is any effective change in the computed values by the time difference in making the observations each of the series were separately treated to arrive at the mean profiles of sound velocity against depth from which for any sounding velocity the required correction can be computed. It is found that even by combining these values, one could get the corrections within the reasonable limits of accuracy.

As the correction table is to be applicable to the entire region, for the post-monsoon season, the variability of the observations distributed both in space and time has been worked out and only the mean values of sound velocity at different depths for the individual months and for the whole season together with the standard deviations calculated from these means are given in Table I.

Most of the changes affecting the sound velocity occur in the upper 100 m. Thus when the upper 100 m. are not considered the stand deviation becomes half of the original value. Because of this degree of variance as has been said earlier, Kuwahara's computations would be within the desired accuracy.

In Table II the corrections to be added to the depth given by the echo-sounders of different sounding velocities are given. These values have been computed from the mean vertical distribution of sound velocity.

TABLE I

Time and space means of sound velocity together with the standard deviations aerived from them for the data

	Mean sound velocity m./sec.$^{-1}$			Standard deviations for
Depth (metres)	September	October	Post-monsoon	
0	1534·71	1537·75	1536·52	
10	1529·80	1536·21	1533·69	September = 2·72
20	1525·91	1534·23	1531·05	
30	1522·95	1531·99	1528·34	
50	1520·33	1527·02	1524·36	
75	1518·27	1523·00	1520·95	October = 2·88
100	1515·89	1518·70	1517·40	
150	1510·05	1511·75	1510·93	
200	1505·91	1505·61	1505·24	
300	1499·14	1499·01	1499·06	The season=2·81
400	1497·59	1497·60	1497·59	
500	1498·45	1496·92	1497·53	

6. CONCLUSION

1. Though Del Grosso's formulæ are expected to give more reliable values for sound velocity, for the computation of correction tables for use in limited regions during a particular period of the year, Kuwahara's sound velocity tables are sufficiently accurate.

2. Maximum vertical gradient of sound velocity occurs in the top 50 m., during the period of upwelling, and the gradient remains steady in the layer between 100–300 m. At still greater depths the decrease in sound velocity due to temperature change is compensated by the pressure and thus the rate of fall is very small.

TABLE II

Correction in metres to be added to the echo-sounder-readings for different sounding velocities of echo-sounders

Depth obtained from echo-sounder (m.)	Sound velocity m./sec.$^{-1}$									
	1450	1460	1470	1480	1490	1500	1510	1520	1530	1540
0	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00
10	0·55	0·49	0·42	0·36	0·29	0·23	0·16	0·10	0·03	—0·03
20	1·09	0·96	0·83	0·70	0·57	0·44	0·31	0·18	0·05	—0·08
30	1·61	1·42	1·22	1·02	0·83	0·63	0·44	0·24	0·04	—0·15
50	2·61	2·29	1·95	1·63	1·30	0·97	0·65	0·32	—0·01	—0·33
75	3·80	3·31	2·82	2·33	1·84	1·35	0·86	0·36	—0·13	—0·62
100	4·94	4·29	3·62	2·97	2·32	1·66	1·01	0·34	—0·31	—0·96
150	7·06	6·07	5·08	4·09	3·11	2·13	1·14	0·15	—0·84	—1·82
200	8·98	7·66	6·30	5·02	3·71	2·39	1·07	—0·26	—1·58	—2·88
300	12·43	10·45	8·41	6·47	4·49	2·51	0·53	—1·47	—3·46	—5·42
400	15·69	13·01	10·30	7·68	5·05	2·39	—0·75	—2·93	—5·59	—8·21
500	18·79	15·49	12·10	8·82	5·52	2·19	—1·12	—4·67	—7·79	—11·07

3. During the post-monsoon, in the region if an echo-sounder calibrated at a sounding velocity of 1510 m./sec. be used, corrections up to 500 m. will be very small.

4. A sound channel running westwards from Quilon to about 30 miles and there turning northwards is found between 10 m. and 50 m. depth. At deeper depths this channel seems to have an eastward branch with other isopleths converging with it at 9° N and 76° E.

7. References

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