

16-27

Acoustic characteristics of the waters of the Bay of Bengal

T V Ramana Murty, Y K Somayajulu, P V Chodankar & C S Murty
National Institute of Oceanography, Dona Paula, Goa 403 004, India
Received 23 October 1992, revised 18 June 1993

Acoustic eigen rays (rays connecting the source and receiver) have been identified and their turning depth, path length, travel time etc. evaluated. Acoustic intensity loss due to mean environmental conditions, vergence along acoustic rays and the low frequency absorption due to the presence of boric acid and magnesium sulphate, etc. have been estimated. For a source-receiver distance of 300 km, computed intensity loss due to spreading for different eigen rays varies between 92 and 116 dB while that due to absorption is about 4.25 dB at 0.2 kHz and 15.25 dB at 0.4 kHz source frequencies for ranges of 300 km. This analysis can be applied to, for target detection and source localization problems.

Acoustic wave propagation in the ocean depends on the physical properties and chemical composition of the seawater. Variations in propagation occur due to changes in environmental parameters caused both by internal and external forcings. These changes can best be understood if the real time data on environmental conditions are available for large spatial scales. The present day remote sensing methods, taking advantage of acoustic propagation in the sea, aim at monitoring the oceanic mesoscale features through sampling of data in real time. For the design of sources and receivers for such experiments a detailed knowledge on the acoustic field/signal intensity levels over different ranges and frequencies for different seasons become essential.

Acoustic signals are subjected to 2 types of degradations: i) change in the direction of the path resulting from refraction, reflection, dispersion and scattering and consequent changes in intensity and ii) absorption which results in a reduction in the energy level. The spreading loss dominates near the source whereas the absorption loss becomes significant at long range and is frequency dependent. The former is computed using ray tube method to estimate acoustic intensity along the path while the later is computed using semi empirical equations based on the relaxation theory. In the present article, the methodology followed for intensity calculations starting from the oceanographic parameters and the results obtained thereof for the Bay of Bengal have been detailed.

Methods

Loss due to spreading—Following Arthur *et al.*¹

the geometric path of the acoustic ray is computed. For the computation of acoustic intensity due to spreading, co-ordinates of an eigen ray and another adjacent ray (separated by 0.01° ; Fig. 1) are stored in computer memory assuming that i) changes in intensity occur only due to contraction or expansion of the ray tube and ii) conservation of the acoustic power between the 2 adjacent rays. The intensity (I) at any point (X) along the ray path is given by Moler and Solomon². Relative acoustic pressure at the receiver point for the different eigen rays is computed by taking square root of intensity of the individual rays at the receiver. The information on travel time has been stored in memory for estimating cumulative intensity². The interpolated values of temperature, salinity, sound speed, pH and depth along the eigen rays are retained in memory during integration for computing acoustic absorption loss.

Loss due to absorption—Absorption loss is contributed by the following mechanisms³, each predominating over a different frequency band, (a) viscous relaxation, (b) thermal relaxation,

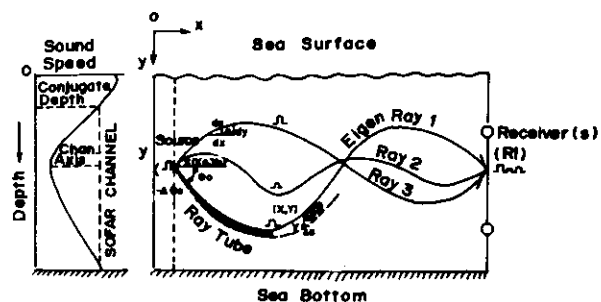


Fig. 1—Schematic presentation of acoustic rays from source to receiver

(c) structural relaxation, (d) ionic relaxation- $MgSO_4$ and (e) leakage out of deep sound channel. The general equation⁴ for absorption of sound in seawater is given as the sum of the contributions due to boric acid, magnesium sulphate and pure water.

Environmental data collected on board *ORV Sagar Kanya*, along 2 diagonal transects (Fig. 2) in the Bay of Bengal using MICOM STTM recorder during March/April of 1988 were utilized in this study. Hydrographic data from all standard depths up to the bottom were considered for carrying out the analysis. The mean profiles of temperature vs depth and salinity vs depth were used to construct the mean sound speed profile employing the formulae of Chen and Millero⁵. Mean pH profile for the Bay of Bengal was obtained from archived oceanographic data from the Indian National Oceanographic Data Centre (IN-ODC) covering different seasons. In all, pH data at 55 locations in the Bay of Bengal collected mainly from cruises on board *RV Gaveshani* were used for this purpose. Weighted parabolic method was used for interpolating the values at standard depths from the otherwise irregularly spaced data.

Results and Discussion

Mean profiles of temperature, salinity, sound speed and pH (Fig. 3) show the presence of steep negative gradients in the temperature up to 200 m depth followed by gradual decrease thereafter up to the bottom. Salinity increases from the surface to 400 m depth (from 33.1×10^{-3} to about 35.12×10^{-3}) and decreases thereafter with depth. Vertical sound speed profile presents magnitudes of 1541.1 and 1506.9 $m \text{ sec}^{-1}$ at the surface and bottom respectively with a sound speed minimum of 1492 $m \text{ sec}^{-1}$ occurring at 1600 m water depth. The pH values at surface and near bottom in the Bay of Bengal are respectively 8.237 and 7.692 with maximum variation (8.237 to 8.093) in the upper 75 m. These are the basic input profiles used to compute acoustic absorption along the eigen rays.

Eigen rays—Numerical ray tracing software⁶ is used for numerical computation of eigen rays. The nature of environment in the Bay of Bengal permits surface refracted and bottom reflected rays (RBR). For propagation range of 300 km or more, the refracted rays reaching the receiver are the only source of information on the characteristics of the medium since the reflected rays usually undergo multiple bottom bounces before reaching the receiver. The refracted rays are confined to vertical water column between 226 and 2883 m

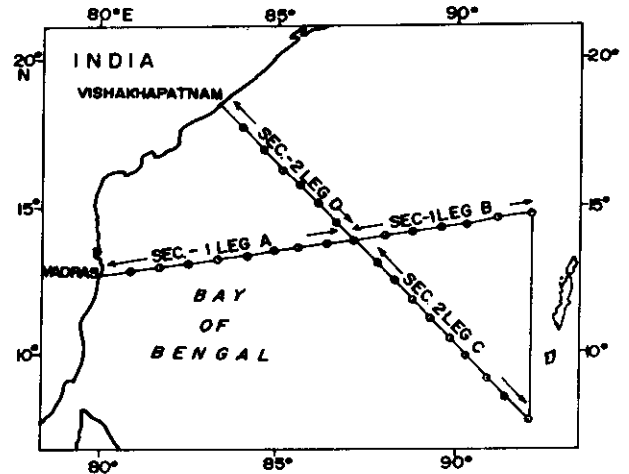


Fig. 2—Station locations

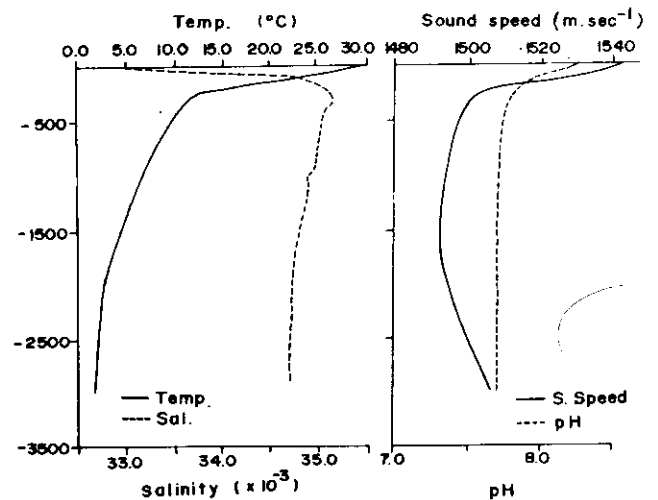


Fig. 3—Vertical profile of temperature, salinity, sound speed and pH

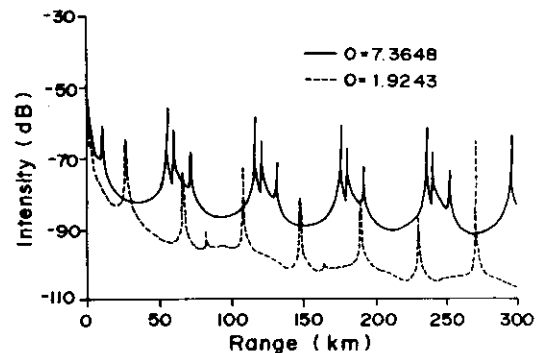


Fig. 4—Range vs intensity along typical ray paths

(Table 1) due to the depth limited nature of the sound speed profile.

Intensity loss due to spreading—Figure 4 depicts the intensity vs range for 2 typical eigen rays with emergence angles of 7.36° and 1.92°. The intensity falls (from -50 dB) rapidly with range up to

about 30 km in the vicinity of the source. The peaks seen on the intensity curve are associated with the ray turning points where the vertical spacing between the rays constituting the ray tube will be minimum, i.e. ray convergence. A comparison of intensity curve of the above rays indicate higher loss for the ray with emergence angle of 1.92° . The intensity loss due to spreading for each of the eigen rays at the receiver is presented in Table 2.

Ray travel time vs signal intensity (Fig. 5A) for different eigen rays shows that the flat angle rays reach the receiver first followed by the steep rays covering a total arrival span of 190 m sec. Intensity due to spreading for various rays range be-

tween -91.96 and -116.85 dB. The plot of frequency vs intensity (Fig. 5B) shows symmetry with intensity peaks resulting for every 500 Hz interval of frequency though the amplitudes differ.

Absorption loss along eigen rays—Absorption loss (for rays with 1.92° -flat and 7.36° -steep angles of emergence) due to $B(OH)_3$ and $MgSO_4$ and for pure water at low frequencies of 0.2 and 0.4 kHz are depicted in Figs 6 and 7. At 0.2 kHz, absorption due to $B(OH)_3$ dominates that due to $MgSO_4$ which decreases an order of magnitude with increase in frequency from 0.2 to 0.4 kHz. For the steep ray, the amplitude of variation of absorption coefficient is higher compared to the flat one. For both the cases the range vs loss fol-

Table 1—Acoustic ray parameters
(source depth = 1500m; receiver depth = 1600 m; range = 300 km)

S. ang	Loop len	Fra. len (km)	No. loops & R. Ident	T. depl (m)	T. vel 1 (m.sec ⁻¹)	T. dep2 (M)	T. vel2 (m.sec ⁻¹)	P. len (km)	T. time (sec)	R. ang (deg.)
7.364	60.152	59.394	4 (5, -5)	-226.6	1505.6	-2883.4	1504.6	301.594	201.3708	7.419
5.399	66.100	35.601	4 (5, -4)	-357.1	1498.9	-2448.0	1498.9	300.931	201.2567	-5.460
2.093	75.676	72.972	3 (4, -4)	-942.4	1493.2	-1930.5	1493.2	300.316	201.1943	2.255
1.924	81.819	54.542	3 (4, -3)	-965.9	1493.0	-1912.9	1493.0	300.291	201.1805	-2.096
0.700	51.197	44.013	5 (6, -6)	-1470.8	1492.3	-1800.2	1492.3	300.229	201.1965	1.096
0.147	69.842	20.631	4 (5, -4)	-1497.6	1492.2	-1773.2	1492.2	300.212	201.1883	-0.846
-0.133	70.636	17.456	4 (4, -4)	-1772.8	1492.2	-1498.1	1492.2	300.212	201.1884	-0.837
-0.999	67.169	31.322	4 (4, -5)	-1820.6	1492.4	-1390.5	1492.4	300.235	201.1885	1.306
-2.135	74.347	2.614	4 (4, -4)	-1935.3	1493.2	-938.1	1493.2	300.324	201.1992	-2.293
-2.827	68.353	26.589	4 (4, -5)	-2023.4	1494.0	-833.0	1494.0	300.416	201.2174	2.949
-3.193	68.168	27.329	4 (4, -5)	-2072.3	1494.5	-766.0	1494.5	300.466	201.2172	3.302
-5.173	67.387	30.452	4 (4, -5)	-2407.0	1498.3	-386.7	1498.3	300.850	201.2226	5.239

[S. ang = ray emergence angle at source, Loop len = length of each ray cycle, Fra. len = fractional length of the last cycle near receiver, No. loops & R. ident = no. of cycles & turnings, T. depl = first turning depth of the ray (upper/lower), T. vel 1 = sound speed at the first turning depth, T. dep2 = second turning depth of the ray (upper/lower), T. vel 2 = sound speed at the second turning depth, P. len = total ray path length from source to receiver, T. time = pulse travel time to cover the path length, R. ang = angle at the receiver point.]

Table 2—Intensity losses due to spreading and chemical absorption

Eigen ray angle	Spreading - dB	Freq. 0.2 kHz				Freq. 0.4 kHz			
		$B(OH)_3$	$MgSO_4$	P.W	TL	$B(OH)_3$	$MgSO_4$	P.W	TL
7.36	91.96	3.82	.47	.022	96.27	13.41	1.88	.089	107.33
5.40	94.09	3.70	.48	.021	98.29	13.09	1.92	.086	109.18
2.09	106.85	3.70	.49	.022	110.04	13.05	1.97	.089	121.96
1.92	107.07	3.68	.49	.022	111.24	13.00	1.97	.088	122.13
0.70	106.26	3.83	.49	.023	110.60	13.37	1.98	.092	121.70
0.14	111.46	3.82	.49	.023	115.79	13.36	1.98	.092	126.89
-0.13	116.85	3.82	.49	.023	121.18	13.37	1.98	.092	132.29
-0.99	110.54	3.79	.49	.022	114.84	13.28	1.98	.091	125.89
-2.14	104.79	3.71	.49	.022	109.01	13.07	1.97	.089	119.92
-2.83	103.81	3.73	.49	.022	108.05	13.14	1.97	.089	119.01
-3.19	97.13	3.73	.49	.022	101.37	13.14	1.96	.089	112.32
-5.17	95.42	3.74	.48	.022	99.66	13.18	1.92	.088	110.61

P.W-pure water; TL-total transmission loss

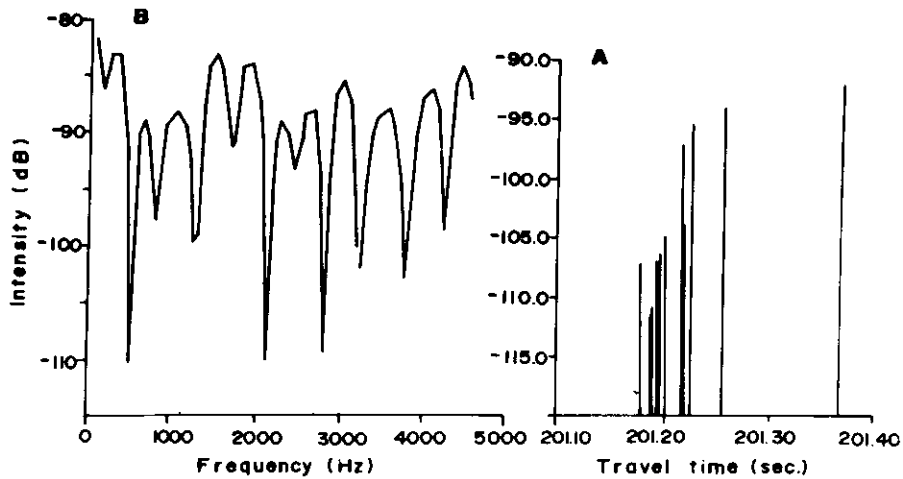


Fig. 5—(A) Travel time vs intensity of eigen rays at the receiver. (B) frequency of propagation vs coherent sum of intensity of received pulse arrivals

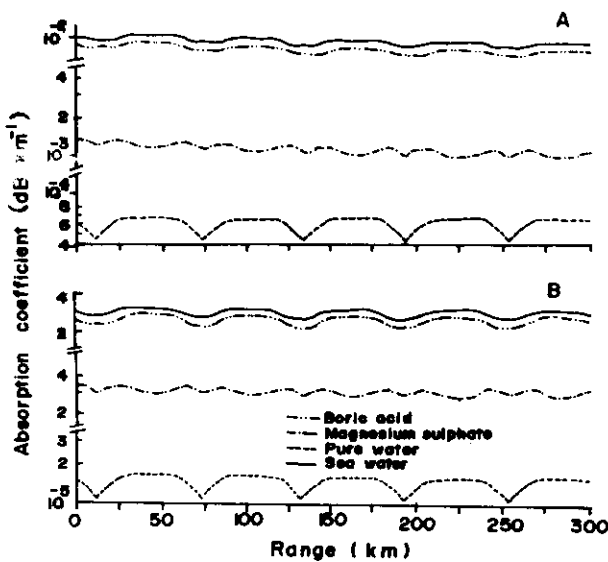


Fig. 6—Absorption losses due to boric acid, magnesium sulphate, pure water and total loss along eigen ray path ($\theta_0 = 7.36^\circ$). A) $f = 0.2$ kHz, B) $f = 0.4$ kHz

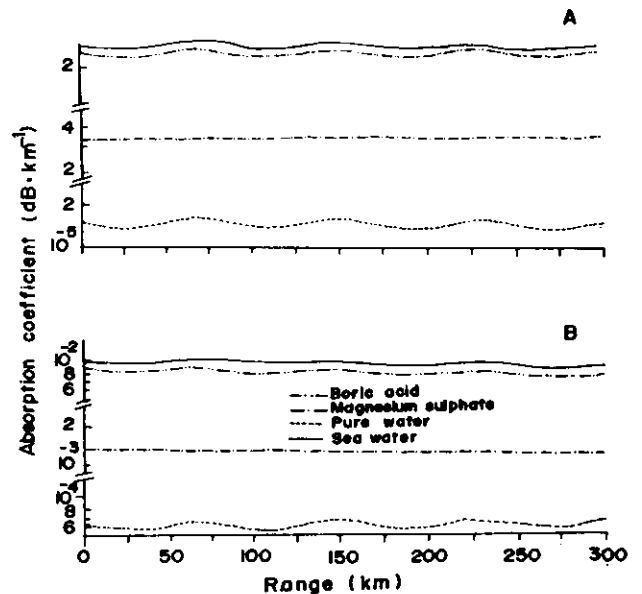


Fig. 7—Absorption losses due to boric acid, magnesium sulphate, pure water and total loss along eigen ray path ($\theta_0 = 1.92^\circ$). A) $f = 0.2$ kHz, B) $f = 0.4$ kHz

lows a wavy pattern which indicates the influence of the depth of scan by the ray. Loss due to pure water at 0.2 kHz is negligibly small. These diagrams delineate individual contributions of each of the components on the absorption.

For the hypothetical receiver location at a depth of 1600 m the corresponding hydrographic parameters are $T = 3.83^\circ\text{C}$, $S = 34.79 \times 10^{-3}$, $\text{pH} = 7.69$, $C = 1492.08 \text{ m sec}^{-1}$. These values are used to estimate absorption losses for different source frequencies between 0.2 and 2 kHz (Fig. 8). Here, contribution of $\text{B}(\text{OH})_3$, MgSO_4 , pure water and total loss for varying frequencies 0.2 to 2 kHz respectively in $\text{dB} \cdot \text{km}^{-1}$ are $2.53 \times$

10^{-3} to 4.38×10^{-2} , 3.29×10^{-4} to 3.29×10^{-2} , 1.53×10^{-5} to 1.53×10^{-3} and 0.28×10^{-2} to 7.83×10^{-2} respectively. At 0.2 kHz, contributions of $\text{B}(\text{OH})_3$ and MgSO_4 on absorption are 88 and 11.4 % respectively while at 2 kHz, contribution of $\text{B}(\text{OH})_3$ is reduced to 32 % and MgSO_4 increased to 31 % i.e. contributions are equal. Other quantities like attenuation per cycle, relaxation frequency and the relaxation time for the above assumed parameters at the receiver are also computed. Attenuation per cycle due to boric acid and MgSO_4 obtained are 0.0126 and 0.0016 at relaxation frequencies 5.58 and 332.6 kHz respectively. Relaxation periods of molecular proce-

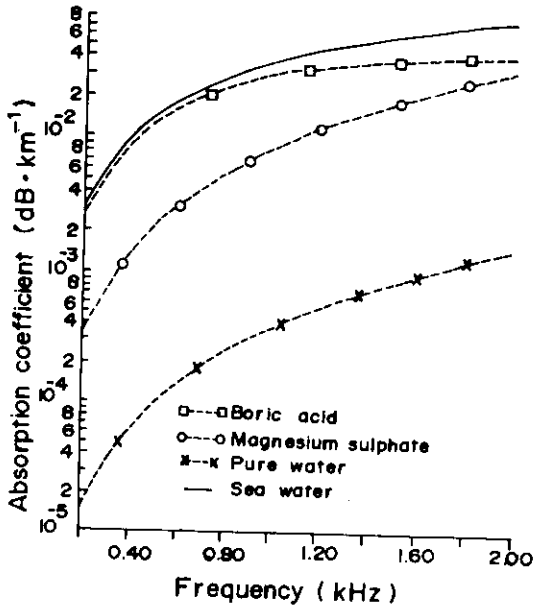


Fig. 8—Absorption coefficients due to boric acid, magnesium sulphate, pure water and total loss for different source frequencies

ses for $B(OH)_3$ and $MgSO_4$ are 0.179 sec and 0.003 sec. Figure 9 shows absorption coefficient vs depth at 2 frequencies 0.2 and 0.4 kHz. Acoustic absorption indicates influence of $B(OH)_2$ to the tune of 89 to 95% while for magnesium sulphate the values were between 5 to 9% of total absorption at the surface and deeper layers of the sea. Absorption loss along the eigen ray path presented in Figs. 6 and 7 show a feature which is wavy in nature. This is symmetric in range similar to acoustic ray loop consisting of an upper and lower turning points. The variation of depth coordinate along a ray causes this feature, since absorption also is depth dependent.

Absorption losses computed along the ray paths have been presented in Table 2. These va-

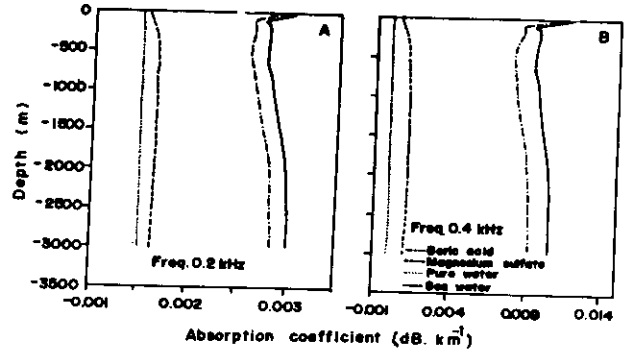


Fig. 9—Vertical plot of absorption coefficients due to boric acid, magnesium sulphate, pure water and total loss for source frequencies. A) $f = 0.2$ kHz, B) $f = 0.4$ kHz

lues are 5 times larger than the estimates based on spot values for any frequency. It can be concluded that the estimates obtained through cumulation along ray path provide more meaningful information on the propagation loss of the acoustic signal.

Acknowledgement

Financial support from the Department of Ocean Development, Govt. of India, New Delhi is gratefully acknowledged.

References

- 1 Arthur R S, Munk W H & Issacs J D, *Trans Am Geophys Un*, 37 (1952) 855.
- 2 Moler C B & Solomon L P, *J Acoust Soc Am*, 48 (1970) 739.
- 3 Urick R J, *Principles of under water sound*, (Mc Graw-Hill Book Co, New York) 1967, pp 342.
- 4 Francois R E & Garrison G R, *J Acoust Soc Am*, 72 (1982) 1879.
- 5 Chen C T & Millero F J, *J Acoust Soc Am*, 55 (1977) 129.
- 6 Mahadevan R, Somayajulu Y K, Ramana Murty T V, Murty C S & Sastry J S, *Tomographic forward problem: Computational details for preparation of data kernel*, Tech Rept No 7/89, (National Institute of Oceanography, Goa, India) 1989, pp 30.