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Short Communications

Acoustic propagation within a surface duct in the western Bay of Bengal

S Prasanna Kumar, G S Navelkar, T V Ramana Murty & C S Murty
National Institute of Oceanography, Dona Paula, Goa 403 004, India

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Sound speed structure forms a surface duct in the upper 50 m layer in the western Bay of Bengal during late July. A range-dependent acoustic ray computation shows that some rays emanating from a source within the upper 30 m, get trapped within this duct while the untrapped rays propagating as refracted bottom-reflected (RBR) rays. The extent of acoustic energy trapped depends on the critical angle of approximately 1 degree. When the source depth coincides with the axis of the surface duct, all the rays within the above critical angle get trapped fully. With further decrease in the source depth, the limit of energy trapping reduces to 0.5 of a degree. The intensity level for a trapped ray is 10-15 dB higher than that of an untrapped RBR ray. The leakage of + 0.6 degree ray out of the surface duct can clearly be seen as change in the intensity level of about 15-20 dB which is attributed to the weakening of the duct at that range.

One of the most striking feature of the acoustic character of the ocean is the formation of sound channel within the upper 1500 m depth layer. In tropics two such channels (ducts)-the shallow ($<$ 100 m) and the deep - are usually encountered. The surface channel forms when the upper layer exhibits isothermalcy leading to depth wise increase in the sound speed due to increase in hydrostatic pressure. In this case, the axis of the channel lies close to the sea surface. If an acoustic source is placed within this layer, one expects the acoustic energy to get trapped within this channel. The critical angle limiting the cone of acoustic rays propagating within this channel could be obtained from Snell's law. The rays leaving the source with angles less than the critical angle propagate with multiple reflections at the surface. If the ocean surface is smooth, the rays remain in the sound channel giving rise to propagation within the waveguide. On the other hand, if the ocean surface is rough, part of the energy gets scattered into deeper levels.

Studies on acoustic propagation in the presence of a surface duct — both theoretical and experimental are reported[1-5]. However, studies related to specific oceanographic conditions are limited. In the present study, the authors attempt to address the acoustic propagational characteristics within the surface duct in the northwestern Bay of Bengal.

The Conductivity Temperature Depth (CTD) data used for the present study, were collected during 21 to 29 July 1984 on board *ORV Sagar Kanya* in the northwestern Bay of Bengal. Out of 42 CTD stations (Fig. 1), data from 3 stations (sts 33, 40 and 56) parallel to western boundary were used to compute sound speed[6]. To simulate the acoustic propagation, the sound speed profiles for every 10 km spacing along the track beginning with st. 33 on the southwest to st. 56 on the northeast (a distance of 310 km) passing through the above 3 stations, were interpolated using a 3-point lagrangian method.

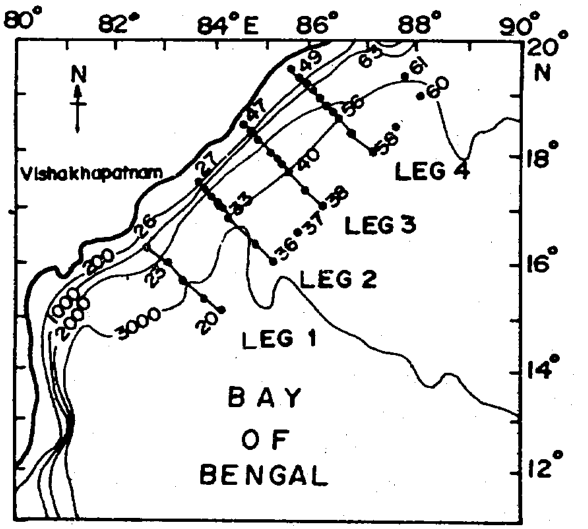

Fig. 1—Study area with bathymetry and Conductivity Temperature Depth (CTD) station locations

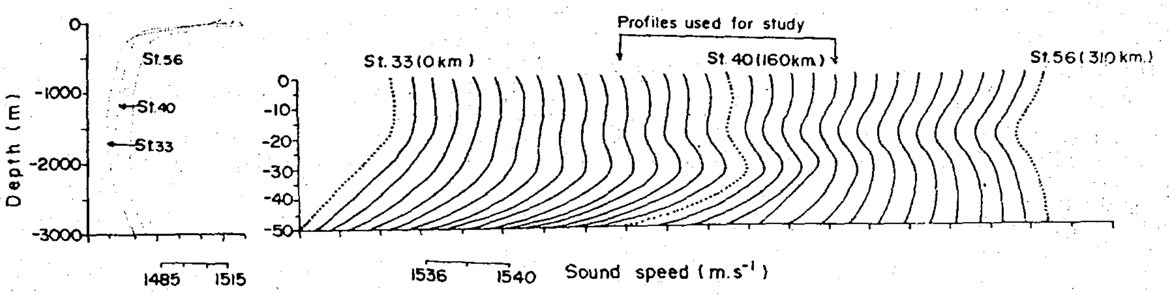

Fig. 2—Computed sound speed profiles at sts 33, 40 and 565, along with interpolated profiles

Sound speed profile—Three sound speed profiles in the upper 50m depth layer along with those interpolated (Fig. 2) show a surface duct in the upper 30 m with its axis around 20 m depth. Though the duct is weak in general, between 110 to 210 km it is comparatively stronger. Relatively strong sound speed gradients prevail below 30 m depth. The surface duct becomes less pronounced beyond 210 km.

Ray geometry—Ray theory has been adopted for computing the trajectories of acoustic signal[7]. The ray geometry equation[7] was integrated numerically using Runge-Kutta[8] for determining the ray path. The critical angle, to be considered for duct propagation has been determined[9], prior to proceeding with ray tracing. The critical angle was found to be ± 1 degree, suggesting that the surface duct is very weak and limit the trapped rays to confine to 1 degree cone. Hence, the ray tracing was carried out using a range dependent program with launch angles of -1 to $+1$ degree in steps of 0.1 degree. Two source depths (10 m, 20 m) were chosen to examine the effect of changes in the source depth in the ray geometry over a range of 100 km. When the acoustic source is at 10 m depth, the rays between -0.5 to $+0.5$ degree got trapped within the surface waveguide (Fig. 3A) while rays with launch angle $> +0.5$ degree and < -0.5 degree propagated as refracted bottom-reflected rays (RBR, Fig.3A). The trapping of rays could be due to the enhanced magnitudes of sound speed gradient within the surface duct. Beyond 175 km range, for rays with launch angles of $+0.1$ and -0.6 degree, the energy leakage could be traced to the deep channel which is due to the weakening of the duct (decreasing sound speed gradient in the vertical - Fig. 2). The quantum of leakage depends mainly on thickness of the duct and the sound speed gradient within and below the duct. For the source depth at 20 m, all the rays between $+1.0$ and -1.0 degree propagated within the surface duct as the source depth approached the depth of the axis of the duct. When the source is well below the duct, the rays which penetrate into the duct are trapped. However, rays which have turning depths below the duct are unaffected.

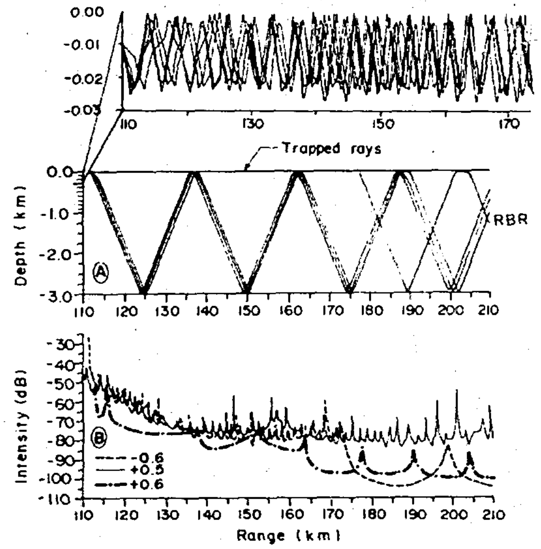

Fig. 3—(A) Ray geometry for a source located at 10 m depth over a range of 100 km, (B) acoustic intensity level (dB) along rays with launch angles—0.6, +0.5 and +0.6 degrees

Intensity along the ray—Acoustic intensity along the ray path was calculated based on the assumption that change in the intensity occurs only due to the contraction or expansion of the ray tube and the power transmitted within a ray tube is conserved. For the present study we consider that two adjacent rays are separated by one hundredth of a degree. The intensity along the ray[10] at any point is given by

$$I(x)/I_0 = (\sin \theta_o/x \cos \theta).\ (\Delta\theta_o/\Delta y)$$

where I_o is the reference intensity at source, θ_o is launch angle of the ray, θ is ray angle at any point along the ray, x is distance from the source to the point of measurement, Δy is vertical distance between the adjacent rays at the point of measurement and $\Delta\theta_o$ is angle between the adjacent rays.

The computed intensity is converted to the practical acoustic unit, decibel (dB), by the formula 20 log $[I(x)/I_0]$.

Intensity along the ray was computed for all the rays between − 1.0 and + 1.0 degree. However, only a few typical cases are presented here for brevity for source depth of 10 m (Fig. 3B). The intensity level along the fully trapped rays are always higher than that of refracted bottom-reflected (RBR) rays. For example +0.5 degree ray, fully trapped, shows intensity level of about 10-15 dB more than +0.6 degree ray (Fig. 3B) which is untrapped (RBR). The intensity along the ray with a launch angle of −0.6 degree highlights the energy leakage into the deep channel by way of sudden decrease in the intensity level (about 15-20 dB) at around 175 km.

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