Spatial Distribution of Sound Channel and Its Parameters in North Indian Ocean

K.Ashalatha¹, T.V.R.Murty² and K.V.S.R.Prasad¹

1. Department of Meteorology & Oceanography, Andhra University, Visakhapatnam, India

2. National Institute of Oceanography – Regional centre, Visakhapatnam, India

Abstract: The Present work reports the variability of the derived sound channel and its parameters (surface sound velocity, conjugate depth, SLD (Sonic Layer depth) and SOFAR(Sound Fixing and Ranging) depth) has been presented over the Bay of Bengal and Arabian Sea. We use World Ocean Atlas Annual data (2013) on temperature; salinity of North Indian Ocean (0°–25°N; 50°–95°E) and its bathymetry have been utilized for the present computation. The depth of the sound channel axis increases towards the northern latitudes in the Arabian Sea, while it decreases in the Bay of Bengal. Coming to the conjugate depth, it shows variation from 120-400 m in the Bay of Bengal and 50-320 m in the Arabian Sea. The range of SLD is varying between 20-40 m in the Bay of Bengal and 10-30 m in the Arabian Sea. The Bay of Bengal and the Arabian Sea have depth limited nature of the profile, i.e. surface sound speed exceeds the near bottom values. This has an important implication in the sound propagation in the SOFAR channel. Anticipated acoustic rays in an ocean with depth limited profile will propagate as surface refracted, bottom reflected (RBR) rays. As a result, the effective sound channel lies much below the sea surface.

Key words: SOFAR channel, sonic layer, conjugates depth, WOA climatology.

1. Introduction

Sound is the prime source of energy to explore into the ocean interior. It can use for long range underwater communication, detection of underwater targets, etc. and also to determine the depth of the Ocean. Variability of sound in the ocean depends on temperature, salinity and pressure. Temperature and salinity show both spatial and temporal variations but pressure does not show any seasonal variation but only changes with depth. Thus, spatial and temporal variability of temperature and salinity affect the sound speed. In the surface layers, sound speed increases with depth. The depth up to which the sound increases in the vertical is known as the SLD (sonic layer depth) or the surface duct. Below the mixed layer sound speed decreases with depth to decrease of temperature and the depth where the minimum sound speed occurs in the profile is known as the SOFAR channel. It is the

cumulative effect of temperature, salinity and pressure and it acts as a waveguide for acoustics (Hareesh kumar, 2013). Change in 1 °C of temperature can lead to > 4 m/s change in sound speed and 1 psu of salinity leads to > 1 m/s change. Sound can fulfill all the three requirements: (1) penetrative range is more (2) High resolving power and (3) High velocity of transmission. Acoustic waves, which travel long distances in the ocean in the form of ducted propagation with less attenuation, relative to other forms of energy, are used in the large number of applications in the ocean (Uric, 1983). For example submarine signaling and detection, precise bathymetric measurements, sub-bottom profiling, fish finding etc. This some of the common forms of ducts are: mixed layer sound channel, deep sound channel and shallow water sound channel. The surface sound channel occurs when the upper layer exhibits isothermally leading to depth wise increase in the sound velocity, due to hydrostatic pressure. In the axis of the channel lies close to the sea surface. If an acoustic source is placed within this layer of constant

Corresponding author: Karakavalasa Ashalatha, M.Sc, junior research fellow, research fields: acoustics and physical oceanography.

velocity gradient, the acoustic energy gets trapped within this channel and propagation take place along the rays that are in the form of arc of circles of radius curvature. In the case of deep sound channel transmission experiments, sound and receivers are both placed preferably around the SOFAR (Sound Fixing and Ranging) channel. It has been proved that the existence of SOFAR channel in the ocean makes possible propagation of sound pulses over long distances (Ewing and Worzel, 1948). In the later case, long-range experiment has been conducted from Australia to Bermuda to prove that sound is used for world-wide communication and to study the global warming issues. During second world-war a series of sound pulses are bombard from Australia to Bermuda triangle and it was observed that for every interval of time 2 pulses are reaching destination. Here one signal is having higher amplitude and the other is having less amplitude. Scientists could not find the reason for these pulses but they prepared analogue charts. By studying these analogue charts for several it was found that the reason for the arrival two pulses has being found. The reason for the arrival of higher amplitude pulse is that the pulse is following the direct path from Australia to Bermuda Triangle. Here three theories were developed to know the path from Australia to Bermuda Triangle. They are: (1) Greater circular path (2) Geo Detic path and (3) Refracted Geo Detic path. Greater circle path is an ideal assumption and here is assumed to be circular in shape. While considering this assumption the sound signals are striking the South Africa. Hence, this assumption was proved to be wrong. Now the Geo Detic theory was considered. Here earth was proved to be in elliptical in shape. When the path of the signal was considered it was found that the sound pulses are striking the tip of the South Africa. Hence, this assumption was proved to be wrong. Then refracted geo Detic path theory came into existence. Here the signals were assumed to refracted path. By considering this assumption the exact path has been found. Hence the scientists confirmed that during travelling the

pulses followed refracted Geo Detic path and this considered as the direct path. Here the absorption of signal by surrounding was found to be less. Hence signal is having higher amplitude. Now by considering about the existence of less amplitude signal, it was found that sound pulses have travelled in the opposite direction to direct path so it was called indirect path or anti pod direction. Here the signal has travelled very long distance inside the ocean. As the pulses travelled long distance there is absorption of energy by the surrounding and because of this, sound pulses reached there have less amplitude. Hence this experiment proved that sound waves can be used for long distance communication. For studying all the above aspects, sound channel and its parameters are needed based on the back ground hydrographic data of the region of interest for acoustic model simulations.

2. Data and Methodology

Data on temperature, salinity profiles of North Indian Ocean (0° – 25° N, 50° – 95° E) and bathymetry have been taken from Levitus data base (website: www.nodc.noaa.gov/OC5/woa13/). All the derived parameters (sound velocity and density) from these profiles have been computed (Chen and Millerio (1977), Millerio (1980)). The data were subjected to cubic spline (for continuous data) (Ralston and Wilf, 1967) and weighted parabolic interpolation (Reininger and Ros, 1968) (for discrete data) to obtain observations in closely spaced depth intervals (10 m). The sound channel parameters: surface sound speed (sound speed at the top of the ocean surface), conjugate depth (depth below the sea surface at which the sound velocity equals the near bottom values), Sonic Layer depth (the depth at which the sound speed reaches maximum at surface layers) and SOFAR channel depth (the depth at which the minimum sound speed occurs) have been picked up from closely interpolated values. While picking up the conjugate depth and SLD, the closely interpolated sound velocities have been arranged in the ascending order by calling subroutine

arrange, then minimum value placed in the first value and last value gives conjugate depth and SLD and respective velocities. While calculating SLD, the criterion is used as “depth of maximum near-surface sound speed above the deep sound channel”. For this process, the values of sound velocities and their respective depths are stored, which are below the sonic depth in the separate arrays. The hydrographic parameters at the depths of sonic layer depth, conjugate depth and SOFAR depth have been computed. Spatial Maps of these parameters have been generated utilizing Surfer package

3. Results and Discussion

In underwater acoustics, that region in the water column where the sound speed first decreases to a minimum value with depth and then increases in value, due to pressure. Above the depth of minimum value, sound rays are bent downward; below the depth of minimum value, rays are bent upward, resulting in the rays being trapped in this channel and permitting their detection at great ranges from the sound source. In general, there are four classes of rays be anticipated: 1) R/R (purely refracted both above and beneath the axis, 2) SR/R (surface reflected and refracted), 3) R/BR (refracted and bottom reflected) 4) SR/BR (surface and bottom reflected). There is a minimum in sound speed at a depth of roughly 1,000 m in mid-latitudes. Sound speed near the surface decreases with increasing depth due to decreasing temperature. The sound speed at the surface is fast because the ocean is warmed by the sun heating the upper layers of the ocean. As the depth increases, the water temperature gets colder and colder until it reaches a nearly constant value of about 2°C for depths below roughly 1,000 m. Where temperature is nearly constant, the pressure of the water has the largest effect on sound speed. Because pressure increases with depth, sound speed increases with depth. Salinity has a much smaller effect on sound speed than temperature or pressure at most locations in the ocean. This is because the effect of

salinity on sound speed is small and salinity changes in the open ocean are also small. It is interesting to note that in the Bay of Bengal, long-range acoustical transmission paths are mostly refracted/bottom-reflected, (R/BR), and refracted/refracted, (R/R). The followings are the required sound channel parameters of the Bay of Bengal and anticipated the acoustic signal transmission.

3.1 Surface Sound Speed

The speed at which sound travels in the ocean is affected by temperature, salinity, and pressure. Sound travels faster with increasing temperature, salinity, and pressure. In the deep ocean at mid-latitudes, roughly half-way between the equator and the North or South poles, water temperature decreases with depth, salinity can either increase or decrease with depth, and pressure always increases with depth. The sound speed gets maximum because the sea surface temperature is high. Mainly the sound speed is depending on the temperature and the pressure. The Arabian Sea and the Bay of Bengal are the depth limited nature of the profile i.e. Surface sound speed exceeds the near bottom sound speed. Here Figure.1 represents the spatial distribution of surface sound speed over North Indian Ocean. Sound velocity at the surface decreases from 1,541 m/sec in the southern Bay to 1,537 m/sec near the head Bay. The average sound velocity in the Bay of Bengal is 1,492 m/sec. The average sound velocity in the Arabian Sea is 1,493 m/sec and 1,539 m/sec in the Arabian Sea. In the Arabia Sea sound speed shows maximum spatial variations within the depth levels 200-1,500 m. This is due to the combined effect of variations in salinity and temperature. In general at any depth sound speed values in the Arabian Sea are higher than the corresponding values of the Bay of Bengal.

3.2 SLD (Sonic Layer Depth)

The depth at which the sound velocity reaches at

maximum at surface layers called the sonic layer depth (SLD). Temperature is uniform within the SLD, but salinity may increase with depth. Within the SLD, sound rays from a shallow source propagate with multiple reflections from the sea surface. If the sea surface is smooth, these rays remain in the surface layer regardless of the distance from the source. Figure.2 represents the spatial distribution of the sonic layer depth over North Indian Ocean. The range of SLD is varying between and 20-40 m in the Bay of Bengal and 10-30 m in the Arabian Sea. SLD is very less in the

Arabian Sea comparing with the Bay of Bengal because intruded of Persian Gulf and Red Sea. The sonic layer increases from 32 m near the equator to over 40 m at the central Bay of Bengal.

3.3 Conjugate Depth

The depth below the sea surface at which the sound speed equals the near bottom values called the conjugate depth. Figure.3 represents the spatial distribution of conjugate depth over North Indian Ocean. The range of the conjugate depth varied between

Fig. 1 Spatial distribution of surface sound speed over the North Indian Ocean.

Fig. 2 Spatial distribution of sonic layer depth over the North Indian Ocean.

Fig. 3 Spatial distribution of conjugate depth over North Indian Ocean.

Fig. 4 Spatial distribution of SOFAR channel depth over North Indian Ocean.

80-350 m in the Bay of Bengal and 50-320m in the Arabian Sea. This variation in the conjugate depth is primarily due to the spatial variation in bottom depth. As a result, the effective sound channel lies much below the sea surface.

3.4 SOFAR Depth (Deep Sound Channel)

A sound channel exists in the ocean that allows low-frequency sound to travel great distances. This channel is called the sound Fixing and Ranging or SOFAR channel. Sound waves are bending in this

region with minimum sound velocity due to refraction thus sound channel forms where the speed of sound is at a minimum in the ocean. The subsurface duct centered on the axis of the channel is known as the SOFAR channel. In general, the depth of the channel axis increases towards the northern latitudes in the Arabian Sea while it decreases in the Bay of Bengal. This variation is brought about by presence of low saline cold water in the northern Bay of Bengal (fresh water discharge), reducing sound velocity. Figure. 4 represents the spatial distribution of the SOFAR

channel depths over North Indian Ocean. The range of the SOFAR depths varied from 1,100-1,750 m over Bay of Bengal and 1,750-1,900 m over Arabian Sea. The upper boundary of the SOFAR channel is observed at a shallower depth near the equator compared to the central Bay of Bengal, whereas its axis is consistently seen around 1,700 m depth near the equator. The Eastern Bay and the Andaman Sea are characterized by low axial depth and high axial sound speeds.

4. Conclusions

The work reports the sound channel and its parameters (*SOFAR channel, channel depth, axial sound velocity, and conjugate depth, Sonic Layer depth (SLD)*) in the North Indian Ocean. Annual *Levitus* data on temperature, salinity of Northern Indian Ocean (0° – 25° N; 78.5° – 100.5° E) and its bathymetry have been utilized for the present computation. The sound speed in the Bay of Bengal shows an upper sound velocity maximum at 1,542 m/sec and intermediate minimum at 1,536 m/sec. while in the Arabian Sea the upper sound velocity maximum at 1,543 m/sec and minimum at 1,538 m/sec. The sound speed in the Arabian Sea shows the presence of large gradients above the axis of SOFAR channel in contrast to that in the Bay of Bengal and relatively higher sound velocity values at any given depth indicating a strong waveguide. Horizontal gradients in sound speed noticed were generally less due to small gradients in temperature, salinity and pressure and the effective sound profile tends to be zonal in nature both for the Arabian Sea and Bay of Bengal. Also, in general sound speed is higher in the Arabian Sea compared to Bay of Bengal at standard depths. The Sonic layer depth increases from 30 m near the equator to over 42 m at the central Bay of Bengal. The conjugate depth shows 80-350 m variation in the Bay of Bengal and 50-320 m in the Arabian Sea. The range of the SOFAR depths varied from 1,100-1,750 m over Bay of Bengal and 1,750-1,900 m over Arabian Sea. This variation is brought about by presence of low saline cold water in the northern Bay of Bengal (fresh

water discharge), reducing sound velocity. Both Bay of Bengal and the Arabian Sea are depth limited nature of the profile, i.e. surface sound velocity exceeds the near bottom values. This has an important implication in the sound propagation in the SOFAR channel. As a result, the effective sound channel lies much below the sea surface.

References

- [1] Ewing, W. M., and Worzel, J. L. 1948. "Long Range Sound Transmission." *Geol. Soc. Am. Mem.* 27, 1-35.
- [2] Ramasastry, A. A., and Balaramamurty, C. 1957. "Thermal Fields and Oceanic Circulation along the East Coast of India." *Proceedings of Indian Academy of Science* (46): 293-323.
- [3] Chen, C. T., and Millero, F. J. 1977. "Speed of Sound in Sea Water at Higher Pressure." *J. Acoust. Soc. America* (60): 129-35.
- [4] MODE group. 1978. "Mid-ocean Dynamics Experiment". *Deep sea Res.* (25):859-910.
- [5] Rao, D. P., and Sastry, J. S. 1981. "Circulation and Distribution of Some Hydrographical Properties during the Late Winter in the Bay of Bengal." *Mahasagar-Bull. Natl.Inst. Oceanogr.* (14): 1-16.
- [6] Urlick R. J., 1983. *Principles of Underwater Sound*. New York: McGraw-Hill, Inc.
- [7] Robinson, A.R. 1983. *Eddies in Marine Sciences*. New York: Springer Verlag.
- [8] Babu, M.T.Sharma, Y.V.B., and Murty, V.S.N., and Vethamony, P. 2003, "On the circulation in the Bay of Bengal during northern spring winter monsoon (March-April) 1987." *Deep Sea Res.* II50, 855-65.
- [9] Munk, W. H., and Forbes, A. M. G. 1989. "Global Ocean Warming: An Acoustic Measure?" *J. Phys. Oceanogr.* (19): 1765-78.
- [10] RamanaMurty, T. V., Prasanna Kumar, S., Somayajulu, Y. K., Sastry, J. S., and De Figueiredo, R. J. P., 1989. "Canonical Sound Speed Profile for the Central Bay of Bengal." *J. Earth. Sys. Science*, 253-63.
- [11] RamanaMurty, T. V., Somayajulu, Y. K., and Sastry, J. S. 1990. "Computation of Some Acoustic Ray Parameters in the Bay of Bengal." *Indian J. Mar. Sci.* (90): 235-45.
- [12] RamanaMurty, T. V., Somayajulu, Y. K., Mahadevan, R., Murty, C. S., and Sastry, J. S. 1992. "A Solution to the Inverse Problem in Ocean Acoustics." *Defence Science Journal*, (42): 89-101.
- [13] Robinson, A.R., and Lee, D.1994. "Oceanography and Acoustics". AIP press,257.
- [14] Prasanna Kumar, S., Nuncio, M., Narvekar Jayu, Kumar

- Ajay, Sardesai, S., Desouza, S. N., Gauns Mangesh, Ramaiah, N., and Madhupratap, M. 2004. "Are Eddies Nature's Trigger to Enhance Biological Productivity in the Bay of Bengal?" *Geophys. Res. Lett.* : 31.
- [15] Swaminathan V. S., and Bhaskaran, P. K. 2009. "Variability in Sound Speed Structure and SOFAR Channel Depth in the Indian Ocean." *Journal of Ship Technology* (5): 53-72.
- [16] Hareeshkumar, P. V. 2013. "The Sound Channel Characteristics in the South Central Bay of Bengal." *International Journal of Innovative Technology and Exploring Engineering* (3): 61-5.