MARITIME RESEARCH CENTER
FOUNDATION FOR UNDERWATER DOMAIN AWARENESS

Research Note

E-Learning Module – 2

Tropical Waters and Unique Characteristics: Acoustic Challenges in the Indian Ocean

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Introduction

Acoustic problems are getting worse in the Indian Ocean, which is very big and has a lot of different kinds of plants and animals. People mostly cause these problems, which are very dangerous to marine life and habitats. Changes in water speed affect the spread of acoustic waves in the Indian Ocean, mainly in terms of depth and range. The speed increases as the temperature, salinity, and depth increase, and bands of similar temperatures go from east to west. The water is the warmest along the equator and gets cooler as you get closer to Antarctica. The speed drops quickly as you go deeper and is at its slowest at the Sofar channel axis. After this depth, the speed goes up in a straight line with the hydroacoustic pressure. Changes in the bathymetry along the line of the wave also affect how the wave moves. The Indian Ocean basin is the youngest and shallowest of the major basins. It has ridges that can change the way hydroacoustic waves travel. These ridges include three active mid-ocean ridges and two dormant volcanic ridges.[1]

Sound underwater is vital for marine life because it helps them communicate, find their way, and hear their prey and enemies. Noise from ship engines, propellers, and other nautical activities can make it hard for marine mammals to talk to each other, change how they look for food, and cause them to get stuck. Noise levels in the ocean have increased because of shipping, industry, and naval drills. Anthropogenic noise is also made by industrial processes like offshore drilling, which affects marine habitats and the health of sound-sensitive marine creatures. This study note talks about the problems with sound in the Indian Ocean and gives ideas on making and using sound sensors to help with sediment management.

[1] Piserchia, P. F., & Dordain, P. M. (2000). Indian Ocean Hydroacoustic Wave Propagation Characteristics.

Seabed Topography

Like the landmasses that make up continents, the seafloor has many traits that belong to the land. Bathymetric blockage is the idea that underwater hills and seamounts can stop sound from travelling. When seamounts are regularly surveyed, they can hide important targets by making false targets or casting shadows on them. Loose sediments cover much of the bottom and are about 500 m thick on average. These sands can be put into two groups based on their origin: terrigenous and pelagic. However, there are only a few agreed-upon ways to group them. Terrigenous sands come from the land and are most common near where big rivers meet the sea. The pelagic sediments, on the other hand, can be biological or inorganic.[2]

Scientists have divided The IOR's underwater conditions into hypsometric and sound. According to the hypsometric classification, shallow water is found where continental edges are less than 200 m deep. When sound travels through the water and interacts with the water's top and bottom several times, this is called "shallow water." This means that some places where the water is hypsometrically shallow may be acoustically deep and the other way around. Reflecting and scattering boundaries have a significant effect on areas with shallow water. Different structures and compositions of the bottom cause differences between regions. The sea floor is a crucial difference between how shallow and deep water moves.[3]

Like the sea surface, the sea floor acts as a boundary for reflecting and scattering waves. It has layered structures with different sound speeds and densities. Sounds that come from it range from hard rock to soft mud. The sea floor changes because of wind speed changes, sediment deposition, and erosion.[4] This contrasts the sea top, which stays mostly the same. This change makes it harder for sound waves to travel, which hurts the efficiency of tools like sonars, sub-bottom profilers, and acoustic Doppler current profilers (ADCP).

Speed of Sound

Temperature, salt, and pressure can change the ocean's sound speed. Because these things aren't always the same in the Indian Ocean, especially in its warmer northern parts, the sound speed can be faster than in colder and less salty seas[5]. The sound speed is fastest in the deep Indian Ocean at mid-latitudes, where temperatures drop with depth and salt changes. This is because the surface of the water is very hot.

In the Arabian Sea and the Bay of Bengal, the profile is depth-limited, which means that the sound speed at the top is faster than the sound speed near the bottom. This has significant

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[2] Acoustical Oceanography. (2013). Underwater Acoustic Modeling and Simulation, Fourth Edition, 21–60. doi:10.1201/b13906-3

[3] Arnab Das (2013): Effective Underwater Weapon Systems and the Indian Ocean Region, Journal of Defence Studies, Vol-7, Issue-3. pp- 159-168

[4] Acoustical Oceanography. (2013). Underwater Acoustic Modeling and Simulation, Fourth Edition, 21–60. doi:10.1201/b13906-3

[5] Shridhar Prabhuraman & Arnab Das. Analysis of Sound Speed Profile and its Application in Ocean Studies. Retrieved From: https://mrc.foundationforuda.in/documents/Analysis%20of%20sound%20speed%20profiling%20and%20their%20applications%20in%20ocean%20studies%20Mod%20AD%2021%20May.pdf

effects on how sound travels. Sound waves moving through an ocean with a depth-limited shape will be surface-refracted bottom-reflected (RBR) waves. Software that tracks rays shows that middle-order rays launched from the Arabian Sea at angles of ±6.5 to ±7.5 degrees get to the listener first. Weak slopes in the SOFAR channel cause axial beams to arrive early in the Bay of Bengal.[6]

The average sound speed in the Bay of Bengal is 1,492 m/s. There is an average sound speed of 1,539 m/s in the Arabian Sea. Within the deep range of 200 to 1,500 metres in the Arabian Sea, there are significant differences in the sound speed. In the Arabian Sea, the sound speed closely tracks the temperature spread horizontally and vertically. In the Bay of Bengal, the salt rises at 100 m compared to 50 m and the surface, but the sound speed drops at 100 m after temperature. This means that temperature, not salt, is the main factor that affects sound speed[7]. Generally, the Arabian Sea has a faster sound speed than the Bay of Bengal at normal levels[8]. Strong winds moving almost parallel to the coasts of Somalia and Arabia cause the water to rise, which lowers the temperature and the speed of sound. Following the temperature trend, the sound speed increases from west to east near this area.[9]

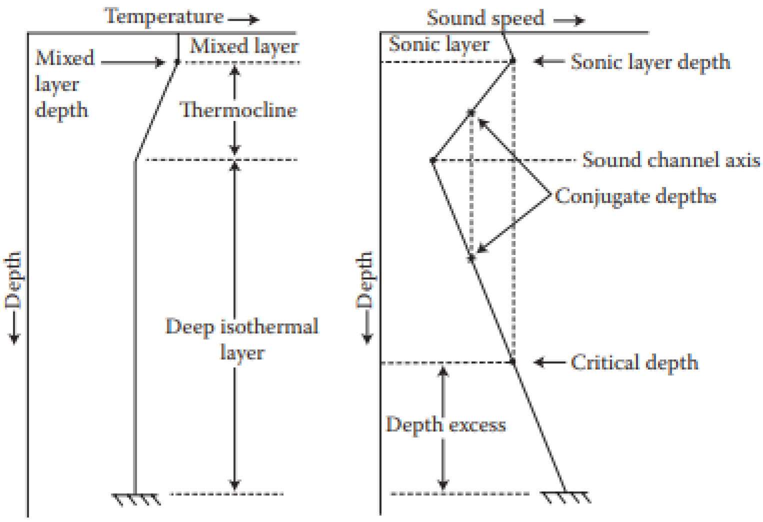

Figure 1: Schematic relationship between temperature and sound-speed profiles in the deep ocean. [10]

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[6] Kumar, S. P., Navelkar, G. S., Murty, T. V., Somayajulu, Y. K., & Murty, C. S. (1993). Sound speed structure in the Arabian Sea and the Bay of Bengal.

[7] Ali, M. M., Jain, S., & Ramachandran, R. (2011). Effect of temperature and salinity on sound speed in the central Arabian Sea. *The open Ocean Engineering Journal*, *4*(1).

[8] Ashalatha, K., Murty, T. V. R., & Prasad, K. V. S. R. (2015). Spatial Distribution of Sound Channel and Its Parameters in North Indian Ocean. *Journal of Shipping and Ocean Engineering*, *5*, 334-340.

[9] Ali, M. M., Jain, S., & Ramachandran, R. (2011). Effect of temperature and salinity on sound speed in the central Arabian Sea. *The open Ocean Engineering Journal*, *4*(1).

[10] Acoustical Oceanography. (2013). Underwater Acoustic Modeling and Simulation, Fourth Edition, 21–60. doi:10.1201/b13906-3

Because of this, the sound path is located a long way below the water's surface. When you move farther north in the Arabian Sea, the depth of the channel axis usually goes up, but when you move farther south in the Bay of Bengal, it usually goes down. Axial depths are shallow, with high sound speeds in the eastern Bay and the Andaman Sea.[11]

Underwater Noise

Shipping traffic is spread over many different areas, significantly affecting many areas. Because underwater-radiated noise from ships is low frequency, it doesn't lose much power as it travels, so its effects can be heard over very long distances. The results can be seen worldwide because shipping traffic is spread worldwide. It is not politically possible for governments in poor countries in the third world to make rules that limit underwater radiated noise (URN) from marine platforms.[12]

In the Indian Ocean, the sound floor has risen over the last ten years. Looking at trends over decades shows that shipping dramatically affects the sound time series. Things like more ships, faster winds, higher waves, earthquakes, and the number of blue whales have been looked at to understand the effects of human-made noise. The Indian Ocean is a hub for many human activities, such as fishing, ships, offshore drilling, and trade between countries. These activities create noise caused by people, like engine noise, propeller cavitation, and seismic surveys. This noise can get through important sonar messages and mix with other noise sources. There are also underwater lines in the Indian Ocean that make it easier to send large amounts of data between countries.[13] The combined sound interference from these cables could make it harder for sonar devices in the area to work properly. So, it is imperative to look at the damage to acoustic habitats along the warm littoral edges of the Indian Ocean.[14]

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[11] Kumar, S. P., Navelkar, G. S., Murty, T. V., Somayajulu, Y. K., & Murty, C. S. (1993). Sound speed structure in the Arabian Sea and the Bay of Bengal.

[12] Das, A. (2019). Acoustic Habitat Degradation Due to Shipping in the Indian Ocean Region. In *Changing Ecosystems and Their Services* (p. 49). IntechOpen.

[13] Soham Agarwal & Vice Admiral Pradeep Chauhan. Underwater Communication Cables: Vulnerabilities And Protective Measures Relevant To India. Part-1. Retrieved From: https://maritimeindia.org/underwater-communication-cables-vulnerabilities-and-protective-measures-relevant-to-india-part-1/

[14] Das, A. (2019). Acoustic Habitat Degradation Due to Shipping in the Indian Ocean Region. In *Changing Ecosystems and Their Services* (p. 49). IntechOpen.

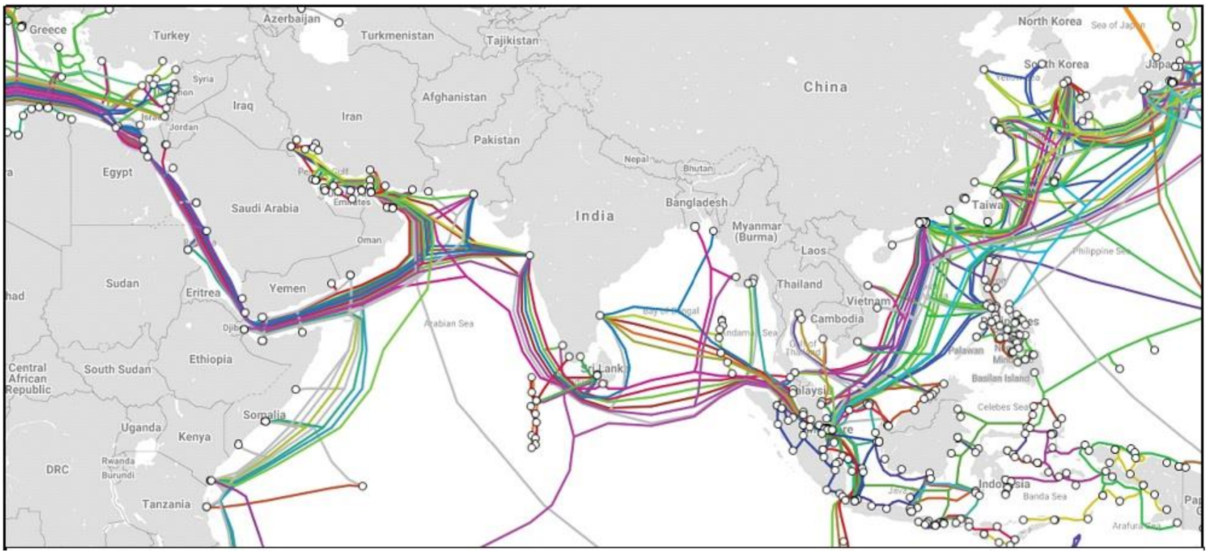

Figure 2: Submarine Cables Map.[15]

Because the sound recording in this area is so complicated, only some sources can fully explain how it works. In the same way, no single sound level or frequency measure fully describes how the sound is changing.[16]

SOFAR Channel Depth

Two crucial parts of sound transmission in the IOR are the Sonic Layer Depth (SLD)[17] channel and the Sound Fixing and Ranging (SOFAR)[18] channel. SLD, which stands for the depth of the fastest sound above the deep sound channel line, is important strategically because it defines surface acoustic ducts[19]. The SLD ranges from 32 m near the equator to more than 40 m in the middle of the Bay of Bengal. The SLD ranges from 20 to 40 metres in the Bay of Bengal. In the Arabian Sea, it ranges from 10 to 30 metres. The Arabian Sea has a smaller SLD because of the Persian Gulf and the Red Sea. The SOFAR channel has depths between 1,100 and 1,750 metres over the Bay of Bengal and between 1,750 and 1,900 metres over the Arabian Sea. This channel lets low-frequency sound move long distances. Near the equator, the upper edge of the SOFAR channel is shallower than the middle Bay of Bengal. However, the channel's axis stays at a depth of about 1,700 m.[20]

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[15] Submarine Cable Map. Retrieved From: https://www.submarinecablemap.com/#/submarine-cable

[16] Miksis-Olds, J. L., Bradley, D. L., & Maggie Niu, X. (2013). Decadal trends in Indian Ocean ambient sound. *The Journal of the Acoustical Society of America*, *134*(5), 3464-3475.

[17] Helber, R. W., Barron, C. N., Carnes, M. R., & Zingarelli, R. A. (2008). Evaluating the sonic layer depth relative to the mixed layer depth. *Journal of Geophysical Research: Oceans*, *113*(C7).

[18] Webb, D. C., & Tucker, M. J. (1970). Transmission characteristics of the SOFAR channel. *The Journal of the Acoustical Society of America*, *48*(3B), 767-769.

[19] Bhaskar, T. V. S., & Swain, D. (2016). Relation between Sonic Layer and Mixed layer depth in the Arabian Sea.

[20] Ashalatha, K., Murty, T. V. R., & Prasad, K. V. S. R. (2015). Spatial Distribution of Sound Channel and Its Parameters in North Indian Ocean. *Journal of Shipping and Ocean Engineering*, *5*, 334-340.

Above the SOFAR channel line, significant changes in the speed of sound can be seen in the Arabian Sea[21]. This shows that there is a robust waveguide. On the other hand, the Bay of Bengal has relatively flat terrain and faster sound speeds at all depths. The eastern Bay and the Andaman Sea have little axial depth and high axial sound speeds. Generally, as you move farther north in the Arabian Sea, the channel axis becomes deeper, while it becomes shallower in the Bay of Bengal.[22] The cold causes this change, and low-salinity water in the northern Bay of Bengal slows down sound waves. There are a few differences in the speed of sound across the horizontal plane. This means the Arabian Sea and the Bay of Bengal sound profile is zoned. Because of this, the sound path is located a long way below the water's surface.[23]

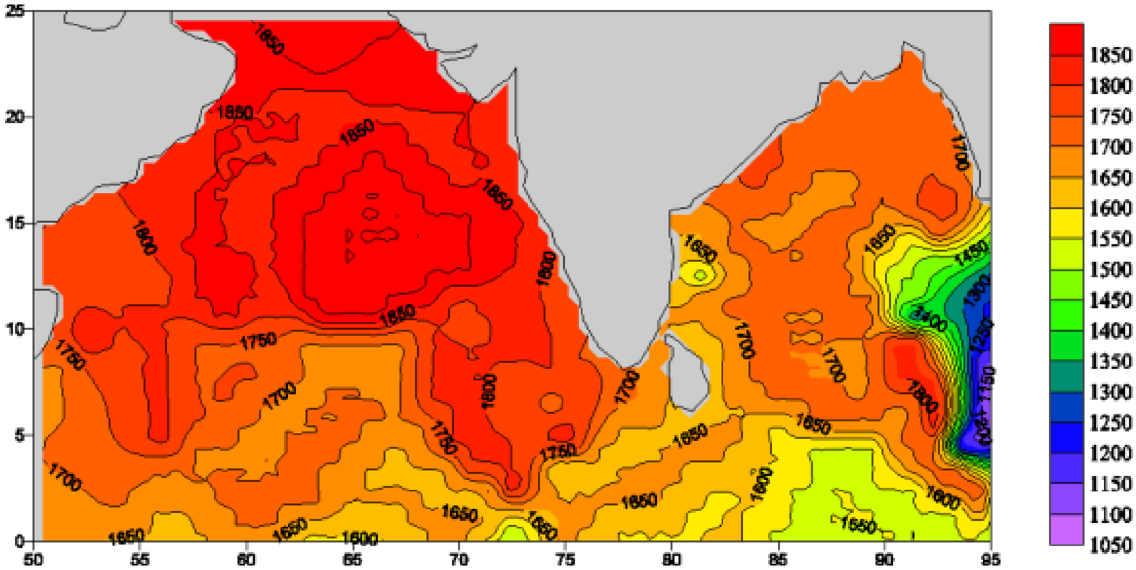

Figure 3: Geographical distribution of SOFAR channel depths in the North Indian Ocean.[24]

Biologics

Deep-sea trenches and ridges, unique traits of the Indian Ocean's underwater landscape, make for a wide range of habitats for marine life. Many species, such as whales, dolphins, and other marine animals, live in the pelagic parts of the Indian Ocean. These live things change how sounds move underwater by making noise, weakening signals, and scattering them. Some coastal animals, especially those that live near continental shelves, make noise that can be heard in the background. Examples include snapping prawns, whales, porpoises, and fish like

[21] Sound Travel in the SOFAR Channel. Retrieved From: https://dosits.org/science/movement/sofar-channel/sound-travel-in-the-sofar-channel/

[22] Kumar, S. P., Somayajulu, Y. K., & Ramana Murty, T. V. (1997). Acoustic propagational characteristics and tomography studies of the Northern Indian Ocean. *Acoustic Remote Sensing Applications*, 551-581.

[23] Ashalatha, K., Murty, T. V. R., & Prasad, K. V. S. R. (2015). Spatial Distribution of Sound Channel and Its Parameters in North Indian Ocean. *Journal of Shipping and Ocean Engineering*, *5*, 334-340.

[24] Ashalatha, K., Murty, T. V. R., & Prasad, K. V. S. R. (2015). Spatial Distribution of Sound Channel and Its Parameters in North Indian Ocean. *Journal of Shipping and Ocean Engineering*, *5*, 334-340.

croakers and drum fish. Other living things, like groups of fish, dense plankton populations, and floating kelp, can weaken signals. Active sonars may see whales or groups of fish as real targets when they are not. Barnacles and other fouling organisms can affect sonar performance indirectly by building up sonar domes and sensor faces. They can also add to hull noise on ships called self-noise. [25]

Marine creatures make biological noise when they mate, feed, and talk to each other. This is called biophony. These natural sounds can affect the transmission of sound waves. The level of biological noise and its regularity depends on the kinds of marine life that live in an area and how many there are.

The deep scattering layer (DSL) is one of the most critical ways sea life affects active sonars. Fish and other sea creatures with swim bladders, gas floats, plankton, and nekton are mostly blamed for this layer's strong scattering properties. Understanding the structure and timing of scattering layers is essential for using active sonar to find and follow underwater objects.[26] [27] These layers are usually found in temperate areas. Active sonar signals may have trouble penetrating the layer, making it hard to see the target below, like a submarine, or returned signals may be too weak to see targets below the scattering layer. This means that submarines can use the DSL to hide.[28]

Way Ahead

Traditional sonars, initially designed for deep-sea operations, face challenges in littoral regions due to the unique characteristics of the underwater channel. In the Indian Ocean Region (IOR), tropical waters exacerbate sonar performance issues with unpredictable fluctuations in surface parameters like temperature and wind.

- Developing adaptive signal processing in modern sonars to mitigate underwater channel distortions and ambient noise.
- A comprehensive effort to collect and analyse scientific oceanographic data and map ambient noise along the extensive Indian coastline is essential.
- Enhancing current sonar performance in tropical waters.
- Collaborating with industries and academic institutes to develop acoustic devices catered to tropical conditions.

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[25] Acoustical Oceanography. (2013). Underwater Acoustic Modeling and Simulation, Fourth Edition, 21–60. doi:10.1201/b13906-3

[26] Acoustical Oceanography. (2013). Underwater Acoustic Modeling and Simulation, Fourth Edition, 21–60. doi:10.1201/b13906-3

[27] Das, A. (2019). Acoustic Habitat Degradation Due to Shipping in the Indian Ocean Region. In *Changing Ecosystems and Their Services* (p. 49). IntechOpen.

[28] Sound Scattering Layers. Retrieved From: https://dosits.org/science/movement/sound-scattering-layers/