Influence of haline stratification and thermal inversion on the sonic layer depth in the Bay of Bengal from Argo float observations (2011-2020)

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Key points:

1. Sonic Layer Depth (SLD) deepens (65m) in winter, shoals above 10m in pre-monsoon, with spatial gradient reversing from spring to monsoon.
2. Freshwater stratification decouples SLD from MLD in the north; weaker stratification in the south maintains SLD, ILD, and MLD coherence.
3. ILD is a more consistent proxy for SLD than MLD, except during strong temperature inversion events.

Keywords: Bay of Bengal, Sonic layer depth, Mixed layer depth, Isothermal layer depth, Haline stratification, Temperature inversion.

Abstract

Sonic layer depth (SLD) plays a critical role in upper-ocean acoustics and is strongly modulated by stratification processes. Using a decade-long dataset of Argo float observations (2011–2020), this study examines structural characteristics and spatiotemporal variability of the SLD across the Bay of Bengal and quantifies the relative contributions of thermal and haline stratification. SLD exhibits pronounced variability, exceeding 65 m during winter (January–February) in the northern and central basin in association with subsurface temperature inversions within the barrier layer. During the pre-monsoon (April–May), intensified surface heating enhances thermal stratification, leading to a shallow SLD (<10 m). A distinct seasonally reversing spatial gradient is identified, with north-westward deepening in spring and a reversal in summer. Freshwater-driven barrier layer formation in the northern basin results in a decoupling of SLD from mixed layer depth (MLD), while maintaining correspondence with isothermal layer depth (ILD), except under strong thermal-inversion conditions. In the southern basin, weaker haline stratification leads to greater coherence among SLD, MLD, and ILD. Case-specific analyses further reveal that salinity-driven stratification associated with surface freshening can substantially modulate SLD, in some instances overriding thermal controls. These results underscore the coupled influence of temperature and salinity in governing SLD variability and its implications for acoustic propagation.

Plain Language Summary

Sound travels through the ocean in ways that depend on temperature and salinity. The Sonic Layer Depth (SLD) is the depth of first maximum sound speed below the surface. SLD provides a boundary for the sound speed channel which is important for underwater navigation, communication and search-and-rescue operations. In most tropical oceans, SLD is mainly controlled by temperature, usually matching other layers like the mixed layer depth (MLD) and isothermal layer depth (ILD). However, in the Bay of Bengal, complication arises because a lot of freshwater sits over saltier water. This study uses data from autonomous ocean floats to understand how the SLD changes across the Bay. We find that in winter, this layer becomes deeper due to unusual temperature structures below the surface, while in warmer months it becomes very shallow because the surface heats up. In regions where large amounts of freshwater enter the ocean, usually from rivers and rainfall, salinity differences create layers that strongly affect sound propagation.

These salinity effects can sometimes dominate over temperature effects. Overall, the results show both temperature and salinity must be considered to better understand how sound travels in the ocean, which is important for underwater communication and environmental studies.

1. Introduction

The sonic layer depth (SLD) is a crucial parameter in the upper ocean that characterizes the bottom boundary of a surface acoustic duct that traps the acoustic energy through refraction, preventing it from penetrating the deeper layers. This trapping within the surface duct helps sound to propagate over long distances with minimal loss (e.g., Buckingham, 1991). Accurate knowledge of the SLD is essential for effective underwater communications and search operations. The SLD is defined as the depth where the sound speed attains its maximum near the ocean surface. Typically, the sonic layer forms because the temperature and salinity remain mostly uniform within the upper well-mixed layer above the mixed layer depth (MLD), while the sound speed increases with depth due to increasing hydrostatic pressure until the temperature starts decreasing in the thermocline layer. As a result, the MLD is usually directly related to the SLD in many oceanic regions and is commonly used as a proxy for the same in various scientific and operational activities. However, this relationship can be altered by the uneven distribution of temperature and salinity in the upper ocean because, unlike density, sound speed is significantly more sensitive to temperature than salinity. Complex interplay between the vertical distributions of temperature and salinity can complicate the SLD, leading to deviations from the MLD (e.g., Helber, et al., 2008; Bhaskar, and Swain, 2016).

The BoB is one such region that exhibits complex temperature and salinity structures, characterized by pronounced seasonal and spatial variability (Murty *et al*., 1992; Shetye *et al*., 1996; Narvekar & Prasanna Kumar, 2006; Benshila *et al*., 2014). These variabilities are driven by semiannually reversing monsoon winds and ensuing upper ocean circulation (Vinayachandran *et al*., 1996; Shankar *et al*., 2002). The thermohaline characteristics of the BoB and their variability are shaped by a range of physical processes. These include substantial freshwater input from southwest/summer monsoon (June-September) precipitation (Prasad, 1997) and accompanying river runoff (Subramanian, 1993; Varkey *et al*., 1996; Durand *et al*., 2011; Jana *et al*., 2015; Behra *et al*., 2016), seasonally reversing currents along the western boundary (Legeckis, 1987; Shetye *et al*., 1993; Durand *et al*., 2008; Mukherjee *et al*. 2014; Mukhopadhyay *et al*., 2020), penetration of