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Improved sound speed estimation from XBT profiles: a new approach

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Original Article

Abstract

The accurate determination of sound speed in the ocean is an important requirement for naval operations related to acoustic communication and detection of under-water targets. Sound speed profile in the ocean is determined either by measuring directly the sound speed using velocity probes or it derived as a function of temperature, salinity and depth from Conductivity Temperature Depth (CTD) sensors. In some cases the mean-monthly profile of salinity is used to compute sound speed from eXpendable Bathy Thermograph (XBT) profile from onboard a ship. In the present work, an inter-comparison of measured sound velocity profile against that derived from XBT and CTD profiles are carried out. The inter-comparison showed that sound speed estimation using different techniques often coincide, however at salinity dominant locations it differs, *i.e.* Sonic Layer Depth (SLD) showed a difference of more than 12 m. For XBT profiles, in place of mean monthly salinity profile, we demonstrate a new approach based on Stommel's idea of co-variability between temperature and salinity to choose the best salinity corresponding to the available XBT profile. This approach significantly improves the sound speed estimation from XBT profiles even at locations of large salinity variability.

Keywords: *Sound velocity profile, sound speed estimation, XBT, Arabian Sea*

Introduction

Accurate determination of sound speed structure in the ocean is important for acoustic applications like acoustic communications, acoustic tomography and naval applications of hiding and detecting underwater vessels (Urick, 1983). The largest fluctuations in Sound Velocity Profile (SVP) occur in upper layers of the ocean, mainly attributed to the seasonal and diurnal variations of temperature and salinity. The vertical distance from the ocean surface to the depth of a sound speed maximum is called Sonic Layer Depth (SLD) which is estimated from SVP. The SLD is of interest because it characterizes acoustic ducts in the ocean. When sound travels in a duct, it is prevented from spreading in depth and remains confined between the boundaries of the duct and can be transmitted for great distances.

The sound speed in the ocean is either measured directly through velocity probes or estimated using empirical models. Usually, Expendable Bathy Thermographs (XBT) are being used in naval ships for sonar range predictions. XBT temperature and mean monthly salinities are used to estimate sound speed profile (Udaya Bhaskar *et al.*, 2008). However, at salinity dominated regions, estimation of SVP using climatological salinity exhibits discrepancies. Thus to make an accurate estimation of sound speed, we demonstrate a new approach for the selection of suitable salinity corresponds to the temperature profile obtained from XBT.

Material and methods

Study area

The southeastern Arabian Sea (SEAS) between lat. 9° and 10.75´ and long. 74-76° C is chosen as the region to validate our approach (Fig. 1) mainly because the data available for carrying out the study is sufficient to verify the methodology and secondly the region is an area where two distinct water-masses, low saline Bay of Bengal at the surface and Arabian Sea High Salinity Water-mass (ASHSW) at sub-surface, occupies in the upper layers. Hence this approach has direct relevance in the region.

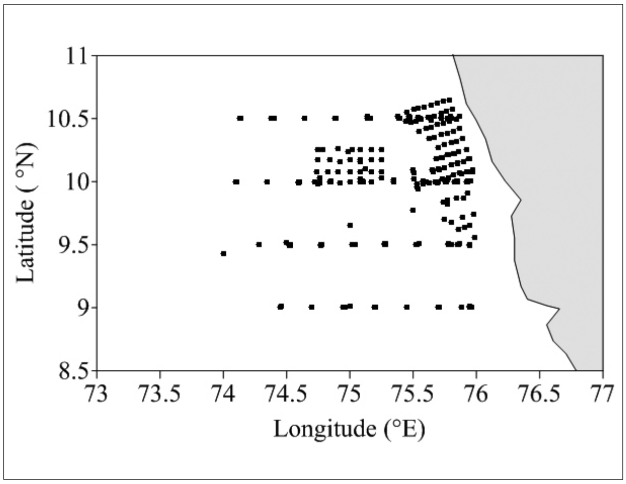

Fig. 1. Distribution of CTD observations in the South-Eastern Arabian Sea (SEAS) during winter

Preparation of CTD, XBT and SVP data

The CTD data collected under various oceanographic programs of Naval Physical and Oceanographic Laboratory (NPOL) have been utilized for this study. A total of 332 CTD profiles, spanning years 2000-2014, during the winter monsoon were selected for the analysis. All data sets have been quality controlled and interpolated as per the standard procedures of World Ocean Atlas (Conkright *et al.*, 2002). A modified Reiniger – Ross (1968) scheme was employed to make all profiles at 1m intervals. Reiniger-Ross, a widely used method for interpolating oceanographic data, uses four observed values surrounding a depth to which an interpolated value is to be calculated. From these four points, two above the level and two below, three point Lagrangian interpolations are computed. These two interpolated values are then averaged as described in Reininger and Ross (1968). Profiles of sound velocity are measured directly using the velocity probe (Make: Valeport, UK), which provides depth, temperature and sound velocity. Seventeen such profiles are used in this study. All SVP and XBT profiles are quality controlled and checked for outliers and spurious values.

Sound speed computation and Sonic Layer Depth

Several formulas have been proposed to compute sound speed from temperature, salinity and pressure or depth in the sea water (Del Grosso and Mader, 1972; Mackenzie, 1981; Chen and Millero, 1977; Leroy *et al.*, 2008). The differences among the formulas never exceed 0.2 m/s in the surface layers, while at greater depths the discrepancies are higher than 1.2 m/s (Salon *et al.*, 2003). In this work, the equation by Leroy *et al.* (2008) was chosen; as it is computationally efficient and has accuracy better than 0.2 m/s in all oceans.

We used the SVP measured directly using the velocity probe as *in situ* SVP and denote SVPi. SVP is also computed using *in situ* temperature and salinity from the mean-monthly climatology (Chatterjee *et al.*, 2012) and denoted as SVPc. Similarly, SVP is computed from *in situ* temperature and salinity obtained from the new approach mentioned in section 2.4 and is denoted as SVPn.

Sonic Layer Depth (SLD): SLD is measured by conducting a search in each SVP from the surface downward for the depth of a sound speed local maximum that is larger than any shallower value and larger than the next deeper value.

Selection of suitable salinity profile

Quality controlled (QC) CTD dataset at 1 m intervals are used for the selection of suitable salinity profile. Stommel (1947) recognized the co-variability of salinity with temperature and many have exploited this idea for estimating salinity (Hansen and Thacker, 1999; Thacker, 2007). The basic idea is that much of salinity's variability is due to the vertical displacements of waters with relatively well defined salinity and temperature: the salinity to expect for a given temperature is essentially what was observed previously at this same temperature. We have utilized his idea of co-variability of temperature and salinity to develop this new approach. QC temperature of XBT is compared with that of CTD database. Since oceanographic features in the Arabian Sea have spatio-temporal variability, our comparison is not confined to a grid or a month. In order to select a best suitable salinity profile, Root Mean Square Difference (RMSD) between the observed temperature and temperature gradients of XBT and CTD data are calculated for all profiles within a search radius of 220km (spatial) and 45 days (temporal) scale. The RMSD is computed as follows:

RMSD=SQRT$\sum^{n}_{i=0}$(xi-yi)^2/n+ SQRT∑_(i=0)^(n-1)▒(xgi-ygi)^2/((n-1))▒

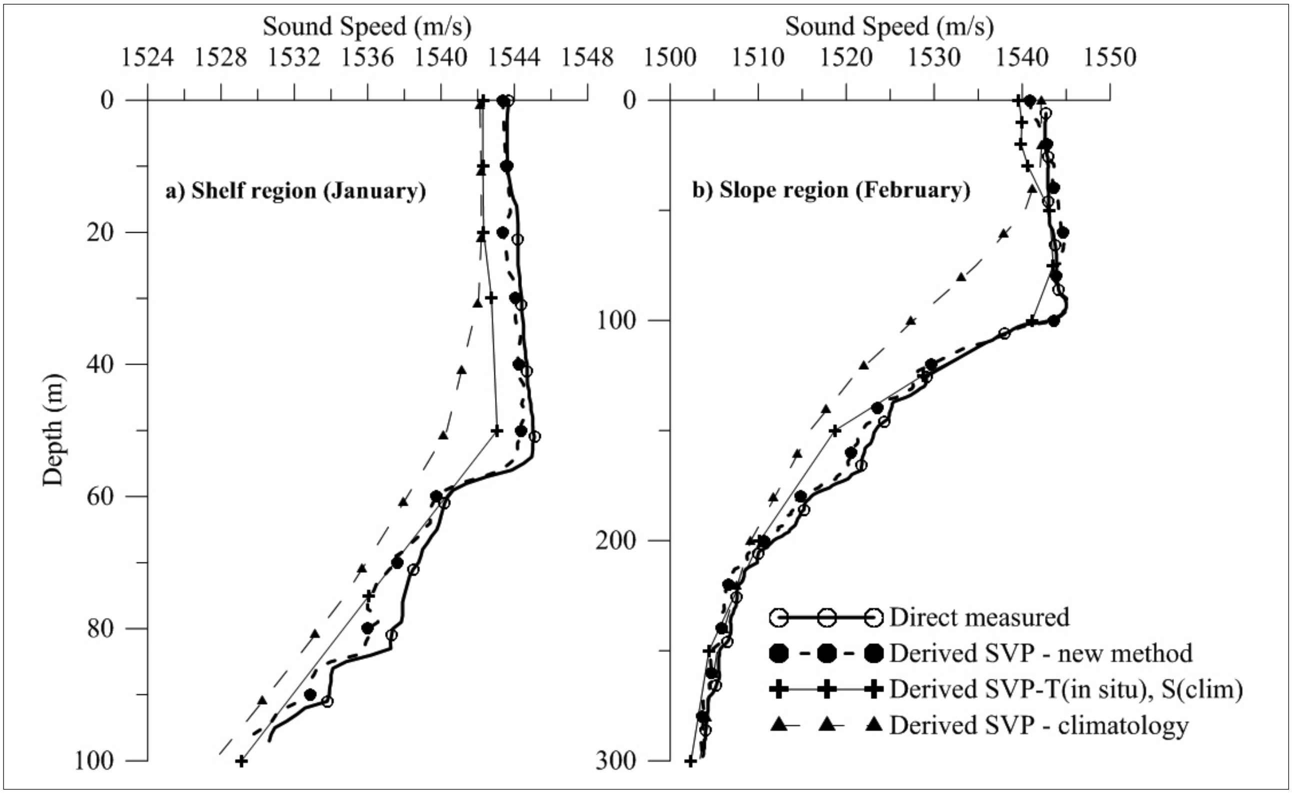

Fig. 2. Comparison of *in situ* and derived sound velocity profiles at a) shelf region and b) slope region off Kochi

Where xi and yi are the i^{th} value of temperature data of XBT and CTD respectively and n is the number of data points in the profile. Smilarly, xgi and ygi are temperature gradient of i^{th} point of XBT and CTD respectively.

The CTD profiles having minimum RMSD within the search radius is chosen as the best CTD profile suitable to XBT and the corresponding salinity values are then used to estimate sound speed.

Results and discussion

Fig. 2 illustrates the difference between the sound speed profiles estimated by two methods against the *in situ* sound velocity profile. Since the *in situ* measurements are very less, we cannot quantify the differences. Two typical profiles off Kochi, one at shelf region during January and other at slope region during February are plotted in the Fig. 2a and 2b respectively. Though the SVP_n and SVP_c showed agreement with the SVP_i, the SVPn exhibits close resemblance with *in situ* profile especially in the shelf region. In Fig. 3, we plotted the SLD measured for all 17 sound velocity probes against the SLD estimated from SVP_n and SVP_c. From this figure it is observed that the average deviation of SLDc from SLD_i is about 7m and in shelf region during winter, it is always more than 12 m. But the average deviation of SLDn from SLD_i is around 3.5 m in both regions. This result confirms the effectiveness of computing SLD from XBT using climatological salinity (Udaya Bhaskar *et al.*, 2008). They found that in more than 90% of cases in the Arabian Sea, SLD matched exactly, with the root mean square deviation ranging from 3 – 12 m with

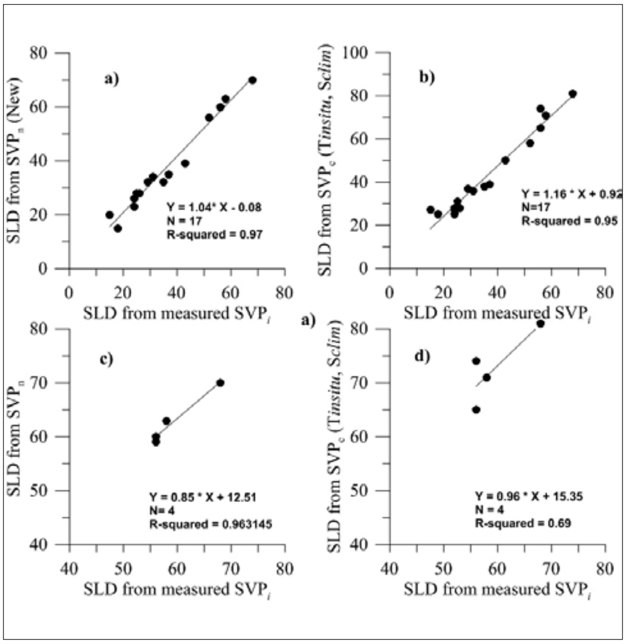

Fig. 3. Sonic Layer Depths (SLD) comparison between a) SLDi and SLDn b) SLDi and SLDc c) SLDi and SLDn in the shelf region and d) SLDi and SLDc in shelf region during winter. SLDi, SLDn and SLDc are defined in the text.

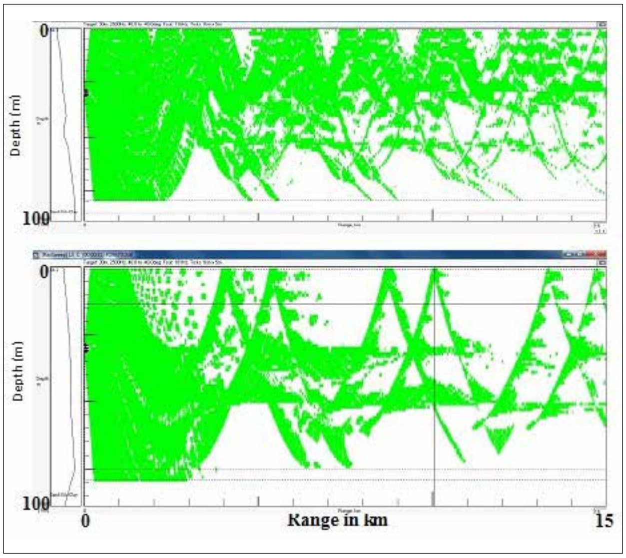

Fig. 4. Range-Depth plots of detection mosaic computed using the range independent ray model at frequency of 2500Hz, source at 50m for SVP (top) derived from temperature and salinity from CTD (bottom) derived from temperature from CTD and salinity from NIO climatology.

an average of 7 m. However there are significant deviations in the salinity dominated shelf region. The reason is that climatological datasets are gridded spatially and temporally to a certain point and often miss the coastal representation. Moreover, the salinity variability in the surface layers during winter is more than that of temperature variability.

To emphasize the significance of salinity in the shelf region range-independent ray model was run for a profile occupied at shelf region (depth~100 m) off Kochi during December 2010. The SVP estimated from CTD and that estimated from temperature of CTD and salinity of climatology is used as input profile to the acoustic model. The output detection mosaics of the model for the two SVP profiles are shown in Fig. 4. It can be seen that detection mosaics for both profiles differs remarkably. This suggests that the true representation of salinity is essential for an accurate prediction of sonar range.

Although sound velocity is more sensitive to temperature than to salinity, during winter, the surface layers of SEAS exhibited more variability in salinity than that of temperature (Shenoi *et al*., 2005). Salon *et al*., 2003 demonstrated the importance of salinity uncertainty in the sound speed estimation. The gridded climatology often misses the coastal points and short-term gradients. Since it is available at standard depths, the gradients occurs often in the surface layer may not be capture in the climatology, which are significant in acoustic modeling. In view of this, if we have sufficient number of CTD profiles in the areas of interest, our approach of the selection of suitable salinity profile for the *in situ* XBT profile improves the sound speed estimation.

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