Defence Science Journal, Vol. 69, No. 2, March 2019, pp. 115-119, DOI : 10.14429/dsj.69.14222

Winter Thermohaline Features along 10 °N in the Bay of Bengal

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ABSTRACT

To commemorate the contributions made by Indian Naval Ship (INS) *Kistna* during the first International Indian Ocean Expedition programme a scientific cruise was planned in the Bay of Bengal during November 2017 onboard *INS Sagardhwani*. The objective was to study the thermohaline properties along 10 °N in the Bay of Bengal and understand the sound channel characteristics in the region. A fresh water cap of ~20 m thickness was noticed in the top layers of the Bay of Bengal occupying the region extending from 83 °E – 93 °E. A prominent anti-cyclonic eddy was noticed around 10 °N centered between 90 °E and 93 °E, a negative sea level (west of 90 °E) co-existed with a positive sea level anomaly to its east along the observational tracks along 10 °N. The climatological temperature and salinity sections also showed the same features as observed along the transect. The study also sheds light on the deep sound channel characteristics along 10 °N.

Keywords: Bay of Bengal, Sound channel; Anti-cyclonic eddy

1. INTRODUCTION

The Bay of Bengal (BoB) is a semi-enclosed basin located on the eastern side of the Northern Indian Ocean and is distinguished by a strongly stratified surface layer[1,2]. In the Bay, surface salinity is low compared to the subsurface layer because of fresh water influxes from river discharge. During winter, the fresh waters spread over the basin as a thin cap and invade the northern half of the Bay[3]. The strong stratification maintains the stability in the surface layer and helps the formation of a barrier layer (BL), a layer between the mixed layer and isothermal layer[4,5]. Barrier layer restricts mixing within the mixed layer[6,7]. During winter the circulation pattern is mainly cyclonic in EICC region, and the presence of several other mesoscale features, in the form of cyclonic and anticyclonic eddies can be noticed[8,9]. These eddies play an important role in the mixing processes and redistribution of subsurface waters. The existence of deep sound channel in the Bay of Bengal has been reported by a number of researchers based on climatological sound speed profiles. Kumar[10] studied the sound channel in the western side of the Andaman and Nicobar Islands during February from a dataset collected on board the research vessel, RV Knorr. He observed that the upper boundary of the SOFAR channel occurs at shallower depth near the equator compared to the central BoB. It was also reported that, in the channel, the sound speed at the bottom is less than the top and hence the channel thickness could not be well defined.

As a part of the golden jubilee celebrations of International Indian Ocean Expedition (IIOE), DRDO-Naval Physical and Oceanographic Laboratory had planned a scientific cruise in the north Indian Ocean. A revisit of the selected tracks made by *INS Kistna* between 1962 and 1965 was planned to commemorate the contributions made by this ship during the IIOE programme. During 16 - 23 November 2017, *INS Sagardhwani* made a revisit in the Bay of Bengal along 10 degree extending from 83 °E - 93 °E with objective to study the thermohaline properties along 10 °N in the Bay of Bengal. The stratification observed in the upper 200 m, and the dynamics controlling its formation along with acoustic implications based on sub surface features are addressed in this paper.

Received : 05 January 2019, Revised : 07 February 2019
Accepted : 10 February 2019, Online published : 06 March 2019

2. DATA AND METHODS

In-situ data used in this study were collected on board *INS Sagardhwani* during 16 - 23 November 2017. The survey was conducted from the Andaman sea to the western Bay of Bengal (along 10 ºN from 83 ºE – 93 ºE with stations at every 1 degree interval (Fig. 1). Hydrographic data were collected along these transects using the Indronaut CTD. The data were collected up to a maximum depth of about 2000 m at 1 s sampling rate.

3. RESULTS AND DISCUSSION

3.1 Upper 200 m Hydrography along 10°N during November 2017 in Bay of Bengal

During the survey from the eastern end of the transect i.e 93 °E along 10 °N, the temperature sections depicts a deeper isothermal layer towards the eastern end of the transects as in Fig. 2 (a) i.e near 93 ºE revealing the presence of a sinking (downwelling) of isotherms. The upper 0 m - 60 m revealed a warm layer of nearly 28 ºC. The salinity section shows the presence of layers of fresh water occupying along of nearly 20 m and extending to 60 m at the eastern end of the transect.

The surface salinity was around 32.2 psu - 34.2 psu. A low salinity plume of 32.8 psu - 33 psu was observed to be of precipitation and fresh water discharge which was covering an area of 84 ºE - 88 ºE. A sub surface divergence of watermass was also observed at 90 °E. This is reflected in the salinity structure as the 34.3 psu contour was observed to be uplifted by 20 m. The intense spatial and vertical gradients are observed within sub-mesoscale structures. The salinity varied from 32.9 psu - 33.5 psu in the surface. Within depths from 0 m - 60 m a difference of 2.2 can be observed. The zonal section reveals warm low salinity water, at the west and east margins, more so at the central portion. This water may have advected from the northern BoB margin. In the eastern region which encompasses the Andaman margin this lower salinity surface water at the east, denote an anticyclonic circulation. The anticlyconic and cyclonic eddy caused lifting of waters in 82 °E - 87 °E and sinking of waters east of 91 °E. The junction of these two eddies cause an upliftment of waters at 90 °E along 10 °N. In the temperature and salinity sections a similar trend can be observed at 90 °E. A preliminary analysis of the region was also carried out using the climatology of temperature and salinity from the (Fig. 3.) World Ocean Atlas (WOA)'13[11,12]. The temperature sections depict deepening of isothermal layer towards the eastern end of the transects as seen in Fig. 4 i.e near 93 °E, revealing the presence of a sinking (downwelling) of isotherms. The upper 0 m - 50 m is nearly 28 ºC - 29 ºC. The salinity section shows the presence of layers of fresh water occupying a layer of nearly 20 m and extending to 60 m at the eastern end of the transect. The surface salinity varies from 33 psu - 33.7 psu. A low salinity

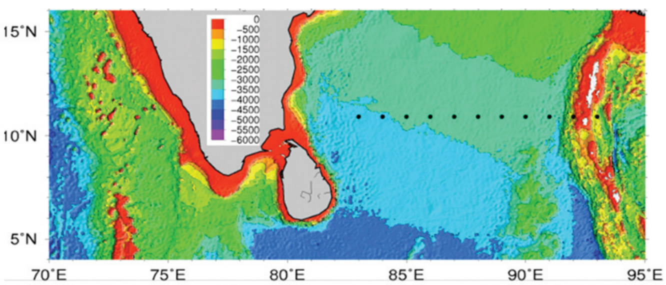

Figure 1. Map of the study area showing station locations in black dots (total 11 stations). The bottom contour is plotted in the background with 500 m depth interval.

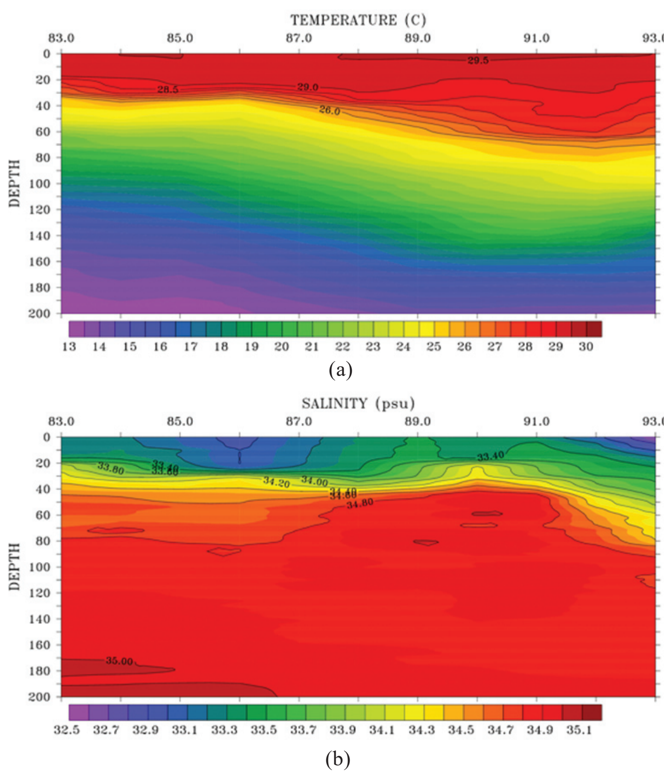

Figure 2. Vertical cross sections of (a) temperature (°C), (b) salinity for the transect from the CTD observations (along 10 °N from 83 °E –93 °E).

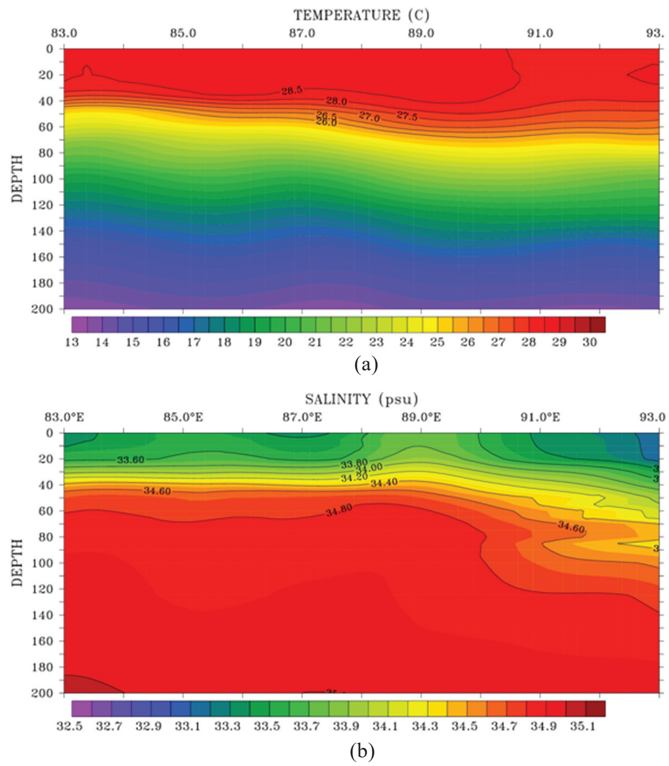

Figure 3. Vertical cross sections of (a) temperature (°C), (b) salinity for the transect from WOA'13 (along 10 °N from 83 °E – 93 °E).

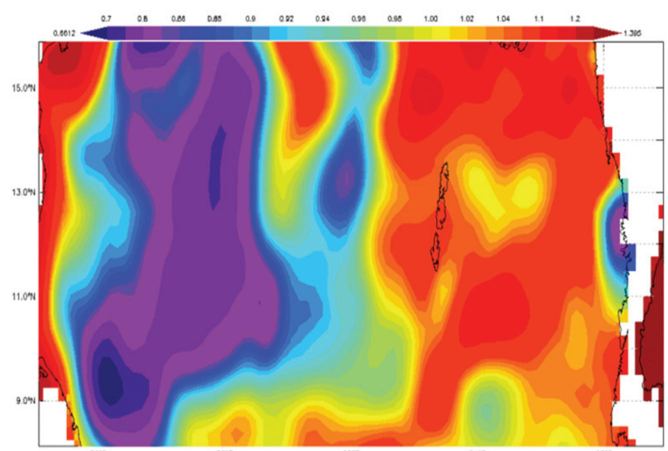

Figure 4. Dynamic topography for the Bay of Bengal during November 2017.

plume of 32.9 psu - 33.1 psu is observed to be covering an area of from 92 °E - 93 °E. A sub surface divergence of watermass is observed at 89 °E. This is reflected in the salinity structure as the 34.3 psu contour is observed to be uplifted by 20 m. The climatology sections mimic the same features as observed from the in situ collected data. The downsloping of isotherms towards the eastern end of the Bay of Bengal and the presence of a deeper freshwater layer (60 m) is the eastern part. The fresh water influx from the *Ganges, Brahmaputra* and *Irrawady* contributes to these thick layers of freshening. The general process that controls these phenomenon is the piling of surface water mass towards the eastern part. The circulation patterns and wind induced stress are the main processes contributing to these features.

3.2 Dynamic Topography along 10 °N

From the dynamic topography chart it can be observed that a high exist in eastern side of the transect. The sea surface high caused a piling of low salinity water at the eastern side of the Bay and thereby causing downwelling. The piling causes the water to sink and this is reflected in the temperature and salinity sections as in Fig. 3. A large cyclonic eddy can be seen dominating the western Bay of Bengal and influencing the circulation along the coasts of eastern land mass. The EICC is influenced by this eddy. However the uplifting of isotherms at 90 °E is not influenced by this eddy as no low is seen at this location.

3.3 Wind Stress Curl along 10 °N

To investigate the uplifting of isotherms at 90 °E, the wind stress curl was computed from the ASCAT data for November (Fig. 5). Wind stress curl is the measure of the rotation of the wind stress and it was computed using the following relation:

$$Curl(\tau) = \partial\tau y/\partial x - \partial\tau x/\partial y$$

where τx is the Zonal wind stress, τy is the meridional wind stress. The positive curl around 90 °E shows indicates a cyclonic wind (anticlockwise circulation). This anticlockwise circulation should induce an Ekman transport away from the centre i.e. upwelling at the center or surface divergence. This phenomenon should induce uplifting of isotherms, thus wind stress curl is the generating mechanism of the cyclonic eddy.

3.4 Sound Speed Structure along 10 °N Channel

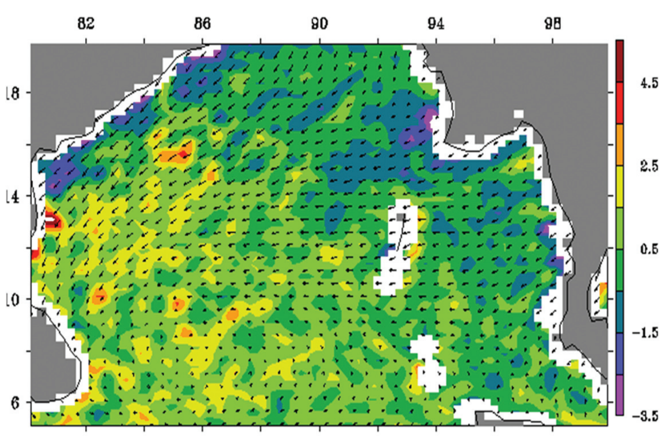

Figure 5. Winds stress curl (10^{-7} N/m³) in the Bay of Bengal during November 2017.

Sound fixing and ranging (SOFAR) channel, is an acoustic wave guide which is caused due to effect of decreasing sound speed as it reaches a minimum value at a certain depth in the ocean. The formation of SOFAR channel is because the sound speed is a function of temperature and pressure. In the thermocline region, the sound speed decreases with depth as the temperature decreases with increasing depth. Below the main thermocline, the temperature gradient decreases and hence variation in the sound speed is influenced by the pressure gradient. Thus the sound speed increases with increasing depth below the main thermocline. The depth of the sound channel is mostly altered by the effect of underlying topographic variations, which decide the mixing between deeper and shallower water masses. During the survey along 10 °N in the Bay of Bengal, the sound speed was estimated from the CTD cast. The sound speed equation[13] was used in the range of interest for the Bay of Bengal. The sound speed profile was blended up to bottom to estimate the deep sound channel axis. The surface sound speed in the BoB is influenced by the upper atmospheric disturbances and eddies. The sound speed distribution, in the upper thermocline region, reflects well that of the temperature, presenting a east-west gradient with a winter minimum sound speed of around 1490 m/s at depths of 1300 m - 1900 m, in the eastern end and western end of the transect and maxima (1542 m/s) at the surface (Fig. 6). In the Bay of Bengal, the sound speed profile is characterised by a strong decrease along the depth i.e. from ~1542 m/s at the surface to ~1522 m/s at depth of 100 m. Here the minimum (1490 m/s) is found within a 500 m thick uniform layer, increasing constantly with depth (1490 m/s around 2000 m) right down to the bottom. The

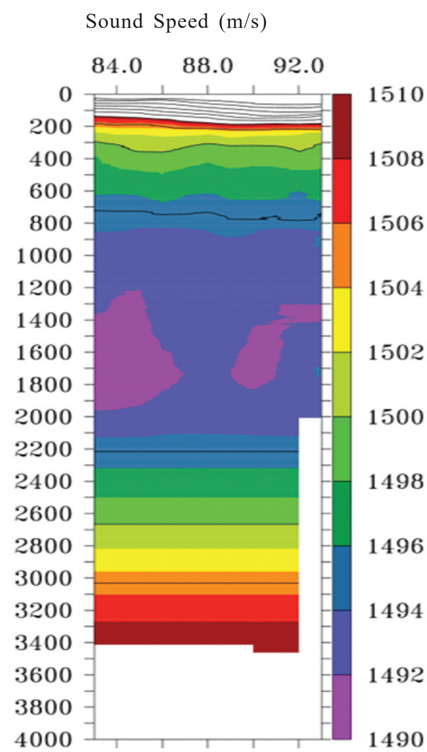

Figure 6. Vertical cross sections of sound speed for the transect (along 10 °N from 83 °E – 93 °E).

SOFAR channel is observed to be extending in the east-west direction with its axis at a depth of about 1800 m, except in central Bay where the weak stratification cannot maintain a velocity minimum and the channel loses its identity at these depths.

4. CONCLUSIONS

To commemorate the contributions made by *INS Kistna* between 1962 and 1965 during its first IIOE programme, a cruise was planned in the Bay of Bengal during November 2017 onboard *INS Sagardhwani*. A noticeable feature was the presence of a salinity cap from 83 °E to 93 °E where it extended to deeper levels (60 m). The upliftment of sub surface saline waters towards the surface was observed at 90 °E. During this period, a prominent anti-cyclonic eddy was noticed in the study region. At the 10 °N the anti-cyclonic eddy was observed (centered between 90 °E and 93 °E), a negative sea level (west of 90 °E) co-exists with a positive sea level anomaly to its east along the observational track. The upward pumping occurred at the boundary between the negative and positive sea level, which may possibly due to the divergence at the periphery of the anti-cyclonic eddy. The climatological sections resembled the same features as observed along the CTD transect. This proves that these eddies are dynamically stable in terms of its spatial and temporal occurrence on a climatological scale. In the upper thermocline region, the sound speed shows an east-west gradient (similar to temperature variation) with a minimum sound speed of ~1490 m/s at depths of 1300 m - 1900 m, in the eastern end and western end of the transect and maximum sound speed of ~1542 m/s at the surface. The study also revealed the existence of a sound fixing and ranging channel extending in the east-west direction with its axis at a depth of about 1800 m, except in central Bay where the channel loses its characteristics at these depths.

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ACKNOWLEDGMENT

The authors are grateful to Director, DRDO-NPOL, Kochi for the support and encouragement given for carrying out this study.

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