Thermohaline features of the subsurface cyclonic eddy in the south central Bay of Bengal during August 1999

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Analysis of the spatial data collected along two sections of temperature and salinity from Chennai to 13°N and 87°E and back to Chennai onboard INS Sagardhwani during the Bay of Bengal Monsoon Experiment (BOBMEX) from 10th to 20th August 1999 revealed the presence of a prominent cyclonic eddy centered around 280 km away from the coast. Analysis of the dissipation rate of the cyclonic eddy from transect one to transect two and from the analysis of the TOPEX data, it may be inferred that the cyclonic eddy is possibly due to the presence of westward propagating Rossby waves in the Bay of Bengal.

1. Introduction

The Bay of Bengal, influenced by the unique seasonal reversing monsoons and transient cyclonic storms, is an area of intense air-sea interaction. Mesoscale features of the Bay of Bengal are more prominent during the summer monsoon. The major manifestation of the oceanic mesoscale features are eddies. Oceanic eddies are circulating water bodies and they are generally formed either by separation of a meander or due to the force exerted by the wind stress curl. Water converges/diverges at the center of the eddy resulting in downward/upward motion of water in the case of anticyclonic/cyclonic eddies. Hence, the vertical thermal sections show troughs and ridges in the isothermal patterns (Gopalan *et al* 2000). Information on oceanic eddies is important in many ocean and atmospheric studies like acoustic propagation, heat transport, delineating good/bad monsoons, identifying potential fishery zones etc. Observations in the Bay of Bengal are very meager to reveal these eddies (Shetye *et al* 1993; Sanilkumar *et al* 1997). Under the Indian Climate Research Programme (ICRP) Implementation Plan (1998) a field experiment called the Bay of Bengal Monsoon Experiment (BOBMEX) was planned with the specific aim to study the linkage between the ocean and atmosphere during the summer monsoon of 1999. During the period from 10th to 20th August 1999, INS Sagardhwani made two spatial surveys along 13°N from 81°E to 87°E. Initial results of the data collected during the above cruise are presented in this study.

2. Data

A spatial section along 13°N from 81° to 87°E (10th–12th August 1999) was covered with stations separated by 30 nautical miles interval (transect one) and it was repeated after 4 days (16th–18th August 1999) along the same track (transect two) (figure 1). Data were collected from all the stations using a mini-conductivity-temperature-depth recorder and standard meteorological instruments.

3. Results and discussion

3.1 *Vertical sections (transects one and two)*

Vertical sections of temperature and salinity (figures 2 and 3) revealed many interesting features. Warmer (28.75°C) and low saline waters

Keywords. Sagardhwani; BOBMEX; cyclonic eddy; TOPEX; Rossby wave.

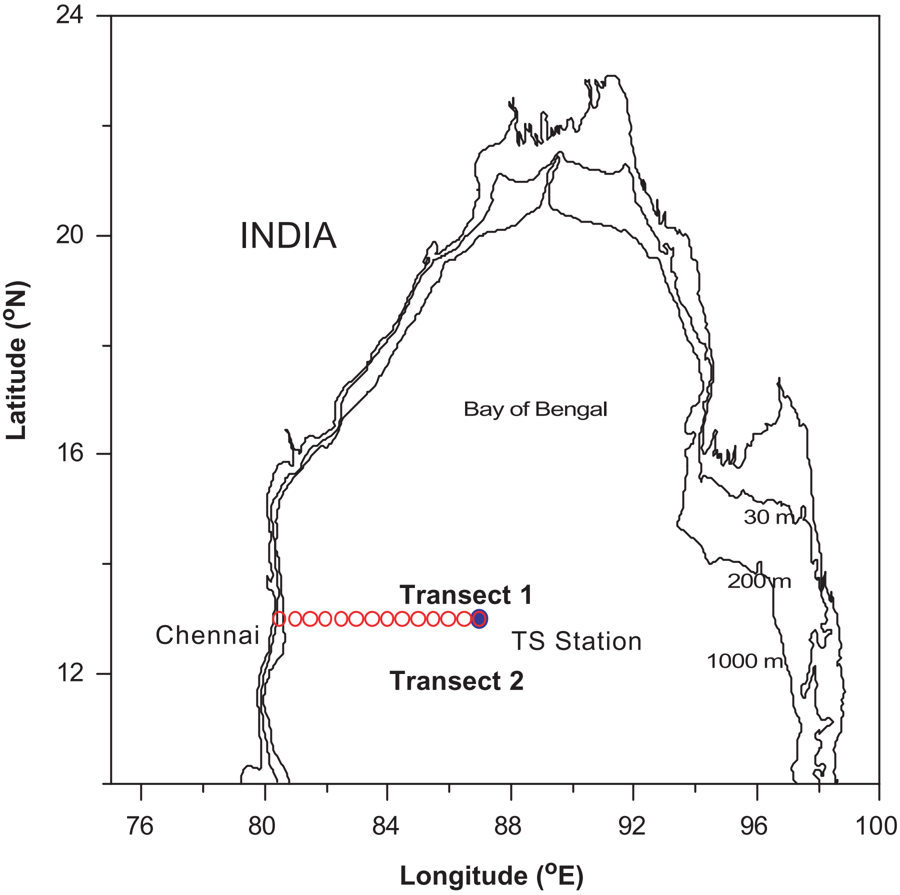

Figure 1. Station location map.

(> 33.8 PSU) are noticed in the surface. The central Bay of Bengal at 87°E appears to be warmer (0.2 − 0.4°C) and more saline (0.85 PSU) compared to the western Bay. The sea surface salinity was around 33.2 PSU and increases towards the subsurface depths (figure 3). The mixed layer depth increased from 20 m near the Chennai coast to 60 m 200 nm offshore and shoaled to 30 m near 85°E and thereafter it deepened to 70 m around 87°E in transect one. Whereas in transect two, the mixed layer deepened from 20 m near the Chennai coast to 50 m 100 nm offshore and gradually shoaled to 40 m around 85°E and from there it increased 60 m at about 87°E. Below the surface layer the isotherms and isohalines exhibit a downward slope from Chennai coast to 200 nm offshore in transect one and 100 nm offshore in transect two. The downward sloping of the isotherms indicates a northerly flow west of 83°E (Sanilkumar *et al* 1997). Another remarkable feature in this section is the presence of a ridge like structure centered around 280 km away from the coast in transect one, whereas it is slightly stretched in transect two. A strong halocline structure is noticed around 50 m depth and it shows a ridge pattern between 200 and 300 km away from the coast in transect one and a diffused ridge pattern in transect two. The erosion of 28°C isotherm west of this ridge in transect one indicates a temperature increase of 1°C per 1 nm and 1°C per 5 nm in transect two. The upslope of 34.2 isohaline showed an increase of 0.1 PSU per 2 nm in transect one and 0.1 PSU per 3 nm in transect two. The downslope of 28°C isotherm east of the ridge reveals a temperature decrease of 1°C per 1 nm in transect one and 1°C per 5 nm in transect two and 34.2 isohaline deepens 0.1 PSU per 3 nm in both the transects. Water diverges at the center of the eddy resulting in the upward motion of water in the case of cyclonic eddy. Hence, the vertical thermal sections show ridge in the isothermal pattern (Gopalan *et al* 2000). When the upward motion of water occurs, it diverges at the surface, creating a depression at the surface because of the cold dense water at the surface. This can be seen from the upsloping of 28°C isotherm almost at the surface of the ocean at 13°N and 85°E. Hence, the ridge structure may be interpreted as a cyclonic cold core eddy with a spatial scale of the order of 100–150 km as noticed in the thermal structure between 200 and 350 km

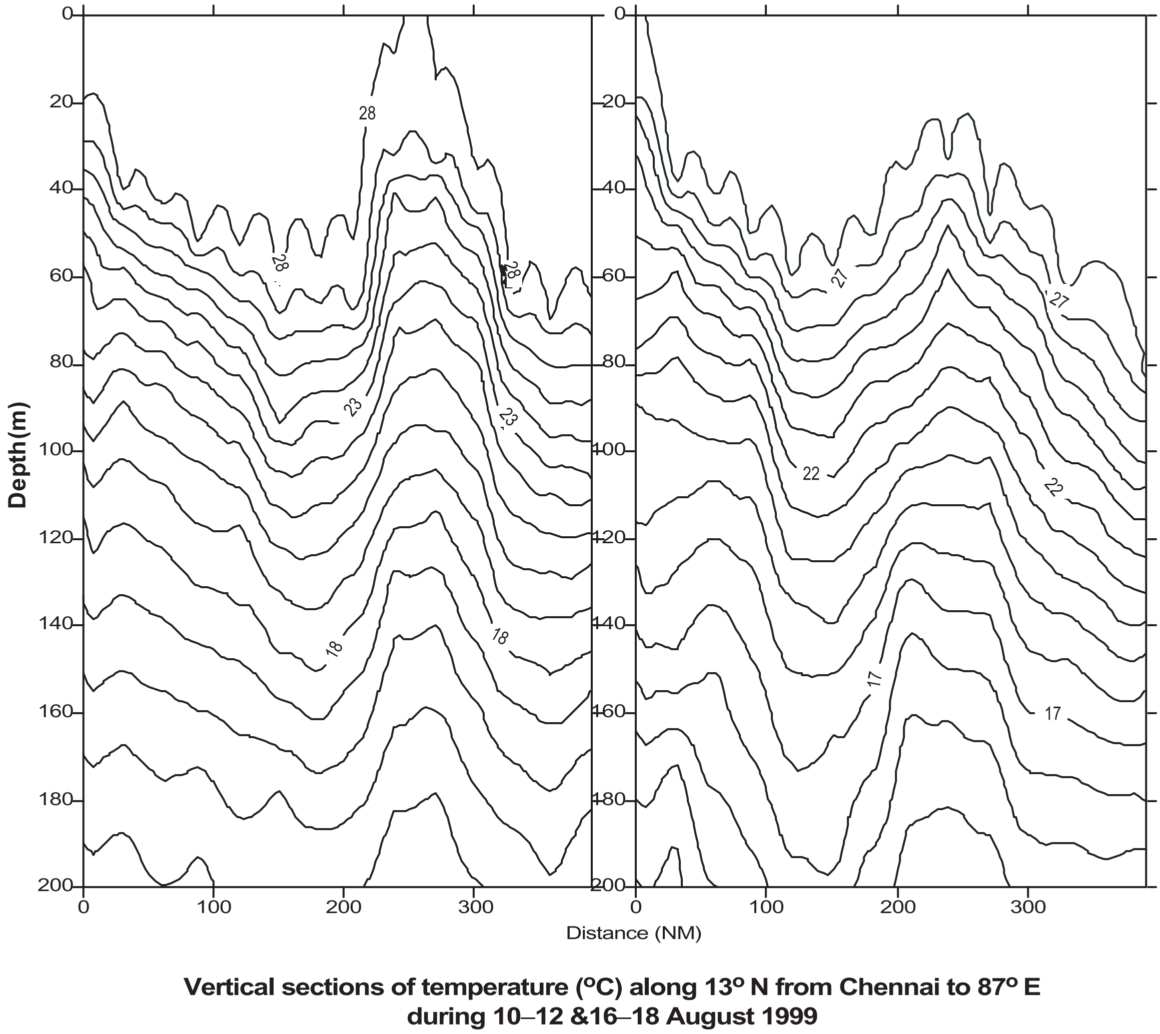

Figure 2. Vertical section of temperature along 13°N for the two transects.

away from the coast. The vertical extent of this cold core eddy lies between the surface and more than 500 m depth. The rate of dissipation of temperature and salinity from transect one to transect two after a period of 4 days showed that ridge structure reduced 6 m per day in temperature and 2.5 m/day in salinity fields. From these dissipation rates if one indirectly computes the periodicity of a propagating wave, it is possible to infer the presence of long period waves around 16 to 24 days.

Under the influence of this eddy the mixed layer exhibits variations from west to east. The thermocline and its gradients also showed large variation. Relatively high salinity cells around 34.9 PSU were noticed below 200 m depth east of 100 km away from the coast. The thermal and salinity gradients were very weak below 100 m (Gopalakrishna *et al* 1996).

As mentioned in the introduction, oceanic eddies are generally formed either by separation of a meander or due to the force exerted by the wind stress curl and maintained by the balance between the pressure gradient, centrifugal and coriolis forces, or due to the westward propagation of long period Rossby waves. The Bay of Bengal influenced by the seasonal reversing monsoon and cyclonic storms and fresh water discharges is dominated by oceanic eddies. TOPEX altimeter observations show several eddies in the Bay of Bengal almost throughout the year (Ali *et al* 1998). The geostrophic flow regime was dominated by the presence of eddies. The dome shaped temperature contours near the east coast of India at 14°N indicate the presence of a cyclonic eddy about 200 km in diameter (Sanilkumar *et al* 1997). Murty *et al* (1993) reported eddy at 12°N near the east coast of India. Babu *et al* (1991) have reported the presence of a cyclonic eddy in the northern Bay.

Recent investigations in the Bay of Bengal (Gopalan *et al* 2000 and Babu *et al* 1991) also

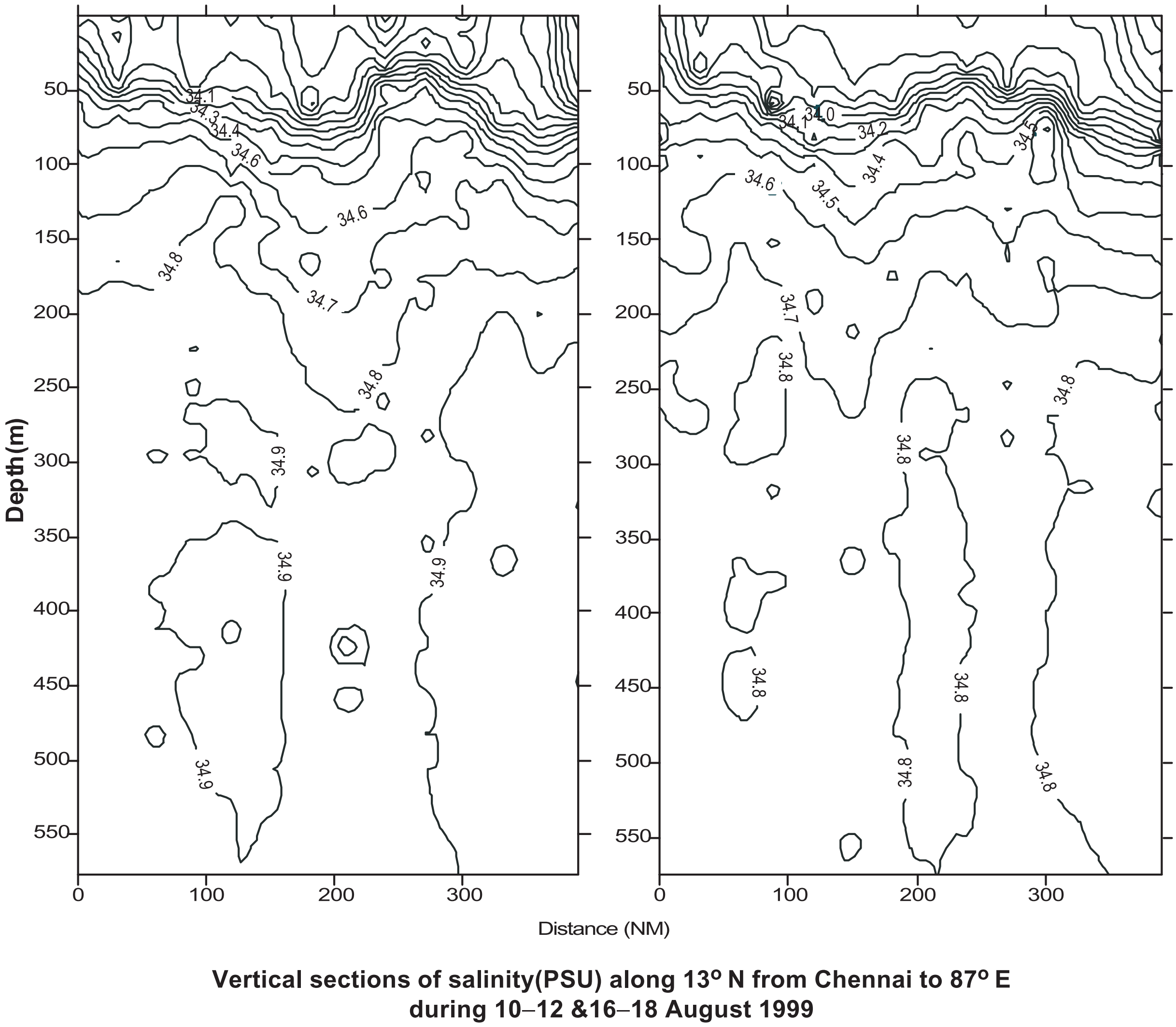

Figure 3. Vertical sections of salinity along 13°N for the two transects.

support the present findings of the cyclonic eddy between Chennai and Andaman. Snapshots of thermal structures along the Chennai–Andaman XBT sections during 14th–16th August 1993, 9th–11th August 1994, 26th–28th August 1995 and 17th–19th August 1996 also exhibit a cyclonic eddy near the same area. Sea Surface Height (SSH) observations derived from TOPEX altimeter observations during August 11th–20th, 1993, August 5th–14th, 1994, August 22nd–31st, 1995 and August 14th–23rd, 1996 over the Bay of Bengal revealed cyclonic eddies with a depression of 15 to 20 cm centered around 14°N and 85°E (Gopalan *et al* 2000).

Analysis of TOPEX/Poseidon data during the BOBMEX period reveals several eddies in the Bay of Bengal. There also we found a cyclonic eddy around 13°N and 85°E with a depression of SSH around 12–15 cm. Gopalan *et al* (2000) have used both temperature and TOPEX/Poseidon data to document eddies in the Bay of Bengal. They also noted a subsurface ridge in the temperature section and a depression of SSH of about 15–20 cm near 13°N and 85°E in the TOPEX/Poseidon analysis. When the upward motion of water occurs, it diverges at the surface creating a depression in SSH because of the cold dense water at the surface. This can be seen from the upsloping of 28°C isotherm almost at the surface of the ocean at 13°N and 85°E.

A scan through the wind field in the area during the study period indicated a break monsoon with wind speed less than 7 m/sec with variable wind direction. Hence, surface wind cannot be taken as a causative factor for the formation of the eddy. From the dissipation rate the role of long period wave can be considered. Kelvin waves are found to be generated in the equatorial region as the result of local wind forcing (Potemra *et al* 1991; Yu *et al* 1991). These waves move eastward and reflect towards the north along the eastern boundary of the Bay. While traveling northward, these coastal Kelvin waves radiate long Rossby waves, which propagate westward. These westward propagating Rossby waves in the Bay of Bengal may cause the observed undulations noticed in the vertical sections. Hence the ridge structure noticed in the vertical sections may be due to these westward propagating Rossby waves.

The spectral analysis of currents in the Bay of Bengal by Potemra *et al* (1991) suggested the presence of oscillations of 20 to 30 day periodicity and attributed it to long period Rossby waves excited by remote-forced Kelvin waves. Winds, currents, air temperature and SST collected from the moored buoy near 13°N, 87°E during 19th July to 23rd September 1999 were subjected to spectral analysis (Hareesh Kumar *et al* 2001) and the results revealed the presence of intra-seasonal oscillations of 10 to 32 days. Hence, the subsurface cyclonic eddy may be due to the presence of westward propagating Rossby waves in the Bay of Bengal.

4. Conclusions

- From the temperature and salinity sections, it is found that the central Bay of Bengal at 87°E appears to be warmer (0.2 – 0.4°C) and more saline (0.85 PSU) compared to the western Bay. The thickness of the thermocline is around 30–40 m and halocline is about 20–30 m and lies in the upper 100 m.
- An interesting feature in the temperature and salinity fields is the presence of a cyclonic eddy with a spatial scale of the order of 100–150 km around 280 km away from the coast. The mixed layer depth shoaled to 10 m in the first transect and 30 m in the second transect because of this eddy.
- From the analysis of the dissipation rate from transect one to transect two and the analysis of the TOPEX data, it may be inferred that the cyclonic eddy is possibly due to the presence of westward propagating Rossby waves in the Bay of Bengal.

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