

DETECTION OF BAY OF BENGAL EDDIES FROM TOPEX AND *INSITU* OBSERVATIONS

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ABSTRACT

Oceanic eddies are characterised by gradients in the sea surface height (SSH) and temperature both at the surface and the subsurface. However, since the Bay of Bengal waters are more stratified, the gradients in SST may not develop though the subsurface temperature sections and the SSH show prominent eddy signatures. In this investigation, TOPEX altimeter derived SSH and the XBT temperature sections along the Madras Andaman coast have been analysed to study the Bay of Bengal eddies. A well defined anticyclonic eddy is located around 13° N and 83° E from the TOPEX observations averaged over 10-19 August 1993. The thermal sections pass through the southern periphery of the eddy with a prominent trough over the eddy region. The crest noticed around 87° E along the XBT track is due to the presence of a cyclonic eddy adjoining the earlier anticyclonic eddy. Due to the synoptic coverage of the altimeter observations, eddy structures are clear from the satellite observations while only troughs or crests are seen in the XBT sections. Besides these, several cyclonic and anticyclonic eddies have also been located from both the insitu and altimeter observations.

Introduction:

The Bay of Bengal, influenced by the unique seasonal reversing monsoon, transient cyclonic storms and freshwater discharges, forms an integral part of the TOGA and WOCE international research programs. This region is land locked on three sides and is an area of intense air-sea interaction. These structures are

dominated by upwelling derived plumes, wedges of cold waters, and ocean eddies. These features are forced by meteorological conditions of winter and summer monsoonal winds and positioned by coastal topography and points of land. Major manifestations of the oceanic mesoscale features are eddies. Using insitu observations, Babu et al (1991) have reported the

presence of a sub-surface cyclonic eddy in the northern bay, while Sanil Kumar et al (1997) have reported presence of eddies in association with poleward flowing western boundary current. However, formation of these eddies are not supported with any other independent data sets such as altimeter derived sea surface heights (SSH). Oceanic eddies are characterised by gradients in SST and sea surface slope besides rotational velocities. Under the influence of the fresh water discharge, Bay of Bengal waters are relatively stratified and the gradients in SST are not easily discernible. However, the TOPEX derived sea surface height observations clearly show the gradients indicating the presence of eddies. The atlas of the north Indian Ocean eddies detected from the TOPEX altimeter observations show several eddies in the Bay of Bengal almost through out the year (Ali et al. 1998). In this paper both in situ and altimeter observations have been used to detect eddies in the Bay of Bengal.

Data:

TOPEX altimeter-derived SSH observations during August 1993 over the Bay of Bengal spanning 5° - 25° N and 80° - 100° E have been analysed. Geophysical Data Records (GDR) of TOPEX altimeter data alone have been used. GPS tracking data are used to compute TOPEX orbits to 3 cm accuracy. All the environmental and geophysical corrections have been applied to the altimeter observations. The details of the corrections applied and the processing of altimeter data are given by Ali et al. (1998). To retain mesoscale variabilities and to remove very low/high spatial frequencies, a

band pass filter has been applied to remove the SSH signals with wavelengths less than 1° and greater than 8° . The values have been binned into $0.5^{\circ} \times 0.5^{\circ}$ latitude \times longitude boxes by inverse square interpolation with a search radius of 2 degrees. Under the Indian TOGA XBT program, upper layer thermal data are collected by the scientific observers using ships of opportunity employing M/S. Sippican Inc USA make T7 (0-760m depth range, $\pm 0.2^{\circ}$ C temperature accuracy) probes and PC based Mark-12 data acquisition system. XBTs are operated at 50 km spatial intervals close to the Madras coast (up to 82° E) and at 100 km intervals in the interior at near-bi-monthly temporal intervals. The distance of about 1300 Km (Madras - Andamans) is covered in about two to three days and typically 15-18 XBTs are deployed in each survey. Processed temperature data are used to prepare vertical sections using GMT software. Since most of the XBT surveys are of two to three days, the corresponding altimeter data are analysed so that the period of XBT survey are centered over ten days (repeat cycle of TOPEX).

Results and discussions:

TOPEX altimeter derived SSH observations during August 10-19, 1993 over the Bay of Bengal (fig. 1) show a strong anticyclonic eddy with an elevation of 20 cm centered around 14° N and 83° E. Adjoining this eddy, an elongated cyclonic eddy with a depression of about 6 cm is also present. The in situ temperature sections during 14-16 August 1993 along the Madras-Andaman track ($13^{\circ} 03'$ N; $80^{\circ} 40'$ E to $11^{\circ} 28'$ N; $91^{\circ} 05'$ E) show two

August 10-19, 1993

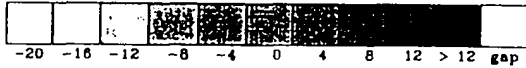
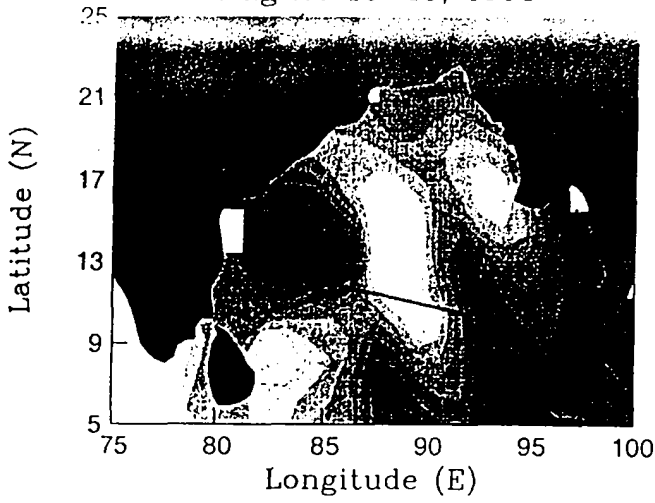


Fig 1.

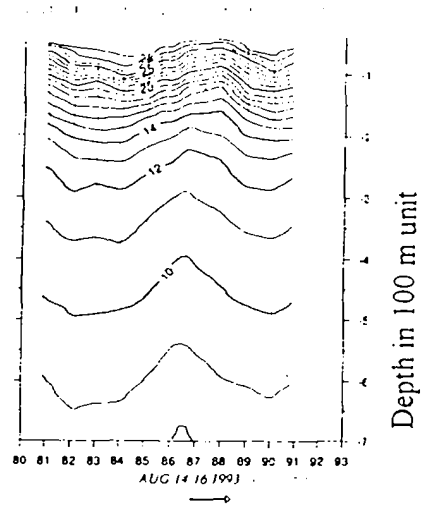


Fig 2

December 16-25, 1994

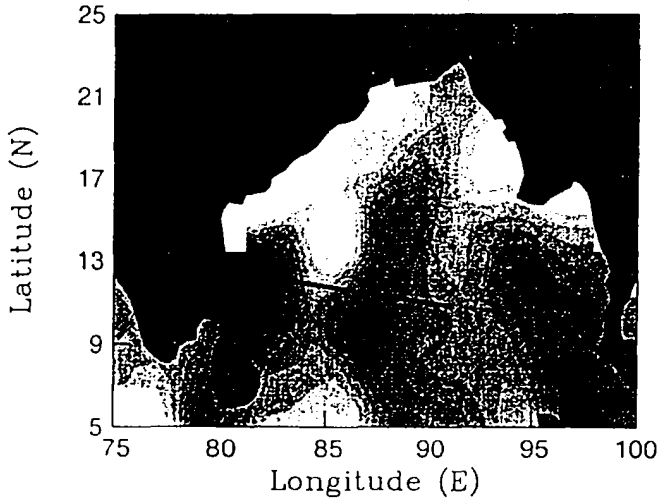


Fig 3

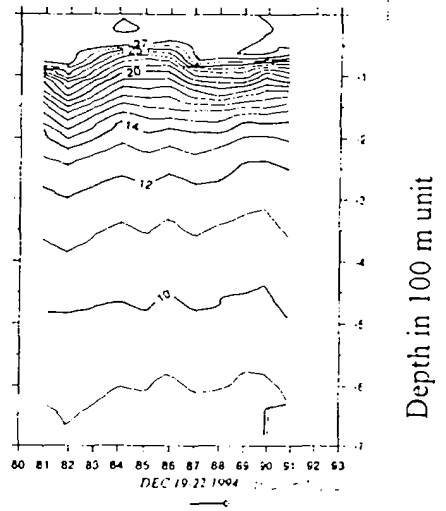


Fig 4

January 21-30, 1997

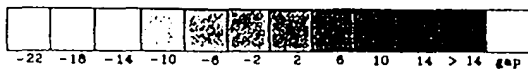
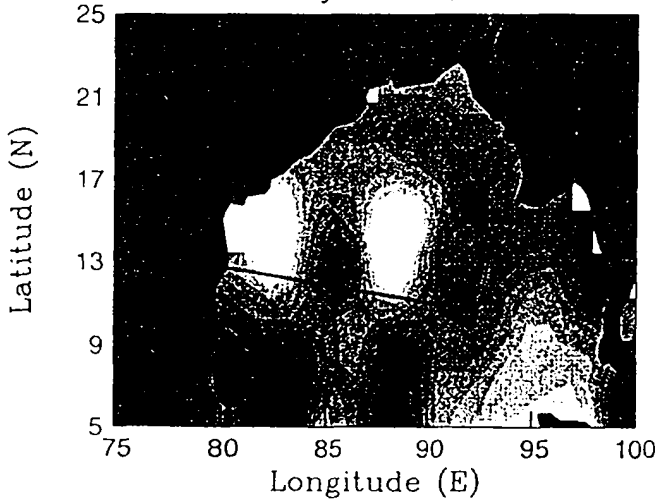


Fig 5.

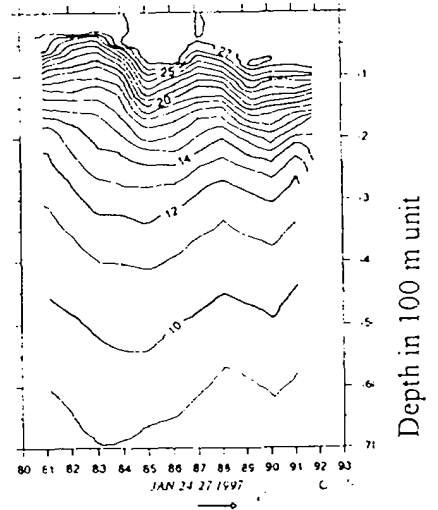


Fig 6.

troughs and one ridge patterns (fig. 2). The first trough observed between 81 to 85° E is due to the presence of the anticyclonic eddy located from altimeter observations while the ridge is due to the cyclonic eddy noticed in fig. 1 (the track of the thermal sections is shown as a straight line in fig. 1). In case of anticyclonic (cyclonic) eddies, water converges (diverges) at the centre of the eddy resulting in downward (upward) motion of water. Hence vertical thermal section show trough (ridge) structure in the isothermal patterns. Sometimes when thermal sections show opposite features, altimeter derived sea SSHs represent net integrated value of the entire water column. The second trough is due to elevation observed in the TOPEX observations at the periphery of the elongated anticyclonic eddy present closer to the equator. The eddies identified from the sub-surface temperature sections are not discernible in the surface temperatures as the Bay of Bengal waters are more stratified. Other than these eddies identified along the XBT track, two more cyclonic eddies, one in the north east Bay and the other on south of Sri Lankan coast are clearly noticeable from the TOPEX observations. Thus due to the synoptic coverage a clear picture of the eddies can be obtained from the altimeter observations where as only troughs and ridges can be noticed from the in situ profiles. Secondly, more eddies could also be identified from the TOPEX data. The troughs and ridges noticed in the temperature profiles would have been more pronounced if the section had passed through the centres of the eddies. Similarly, two anticyclonic and one cyclonic eddies are detected during 16-25 December 1994 (fig. 3) and two

cyclonic and one anticyclonic eddies observed during 21-30 January 1997 (fig. 5) are clearly reflected in the corresponding subsurface thermal sections (fig. 4 and fig. 6 respectively). During December, the XBT track cuts the anticyclones at the northern periphery while it cuts the cyclonic eddy at the southern periphery. Hence the troughs and the ridges are not very prominent. On the other hand, During January 1997, the track almost passes closer to the centres of the eddies and hence the troughs and the ridges are more prominent compared to the other sections, particularly over the anticyclonic eddy. Bay of Bengal is covered with more number of eddies during January 1997, compared to the other two periods. During all these three periods, a west to east wave, embedded with cyclones and anticyclones, is present in the SSH observations in the central Bay of Bengal. Study of the propagation of this wave would be taken up in a separate study. Besides these, several other eddies have also been identified from both altimeter and in situ observations which could not be presented in this paper due to the limitation of space.

Conclusions:

The cyclonic and anticyclonic eddies identified in the Bay of Bengal from the TOPEX altimeter observations are confirmed by the independent in situ temperature sections. Since these waters are more stratified, the subsurface thermal signals of eddies are not reflected in the surface temperatures. Thus altimeter data is very useful in detecting oceanic eddies. A wave pattern is also noticed in altimeter observations in

the central Bay. Due to the synoptic nature of remote sensing observations, the exact position of the eddies can be located from altimeter derived SSHs which otherwise cannot be achieved from the in situ temperature profiles having limited coverage.

REFERENCES

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Sanilkumar, K.V; T.V.Kuruvilla; D.Jogendranath and R.R.Rao (1997) Observations of the western boundary current of the Bay of Bengal from a hydrographic survey during March 1993. Deep Sea Research, 44, 135-145.

FIGURE CAPTIONS:

Figures 1,3 and 5 are sea surface height observations in cm obtained from TOPEX altimeter for the dates specified in the figures.

Figures 2,4 and 6 are the subsurface temperature sections corresponding to figs 1,3 and 5.