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A subsurface cyclonic eddy in the Bay of Bengal

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ABSTRACT

CTD data collected from the northwestern Bay of Bengal during late July 1984 reveal the existence of a cold core subsurface eddy centered at 17°40′N and 85°19′E. The thermal structure observed across the eddy indicates that it was confined to a level well below the mixed layer, between 50 and 300 db, and that it had a diameter of about 200 km. A temperature drop of 4–5°C as compared with the surroundings was observed at the center of the eddy. A plausible mechanism for the eddy generation is baroclinic instability at the interface of two opposing boundary currents present along the shelf edge of the western boundary of the Bay of Bengal. The southward current in the northern bay results partly from fresh water influx and to a larger extent from the action of wind stress curl while in the southern part the northward current is purely wind-driven. High stratification caused by fresh water influx prevented the eddy from being detected at the surface.

1. Introduction

Two major factors influence the upper layer circulation in the Bay of Bengal. First is the semi-enclosed nature of the Bay which causes its southern, relatively fresh waters to interact with the high saline waters of the Indian Ocean; this takes place across a frontal boundary, while in the north the density gradient resulting from immense quanties of freshwater influx from hinterland rivers drives the geostrophic circulation. Second is the seasonally-reversing monsoon winds which act upon the ambient geostrophic flow to influence the general circulation in the bay. Though there have been several attempts to understand the general regional hydrography, various aspects of the circulation and its seasonal dependence have remained

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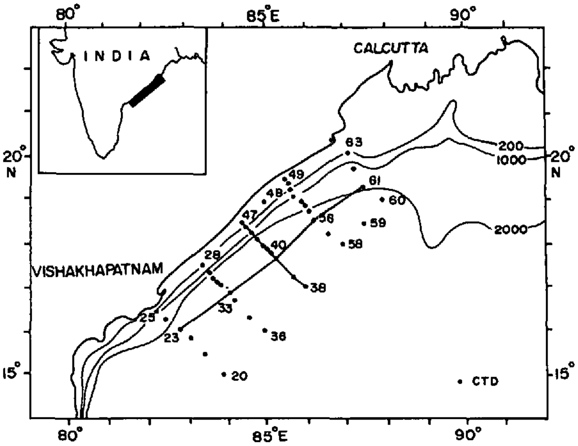

Figure 1. Station location of *ORV Sagar Kanya* cruise, 20–28 July 1984 (CTD stations).

elusive. However, recent studies by Scherbinin *et al.* (1979) and Legeckis (1987) have brought new insights into the existence of western boundary currents (WBCs) in the bay. In general, WBCs—such as the Gulf Stream and Brazil Current in the Atlantic, Kuroshio and East Australian Currents in the Pacific and the Aghulhas Current in the southern Indian Ocean have the potential for generating warm/cold core eddies which are an integral part of the general circulation. However, no observations of eddies are available for the Bay of Bengal, although some indications for them can be seen in the work of Swallow (1983) where it was suggested that eddies have probably escaped detection due to coarse sampling.

In the present study the thermohaline characteristics of a cold-core eddy and the associated circulation in the Bay of Bengal, together with a plausible generating mechanism for the eddy, are presented.

2. Data and method

Under the project entitled 'The seasonal, annual and interannual variability of the Bay of Bengal' extensive oceanographic surveys were carried out during 1983 to 1987. As a part of this project, closely spaced (20 to 40 km apart) CTD (Meerestechnik Electronik, Germany make) stations were occupied during 21–29 July 1984 on board ORV *Sagar Kanya* near the western boundary of the Bay of Bengal (Fig. 1). Altogether 42 CTD stations were occupied followed by an XBT survey conducted during 1–3 August 1984. CTD salinity has been calibrated against water samples collected simultaneously by a rosette sampler and analysed with a Guildline 8400A autosal. The conversion of conductivity to salinity was carried out using the modified Unesco formula (Anonymous, 1981).

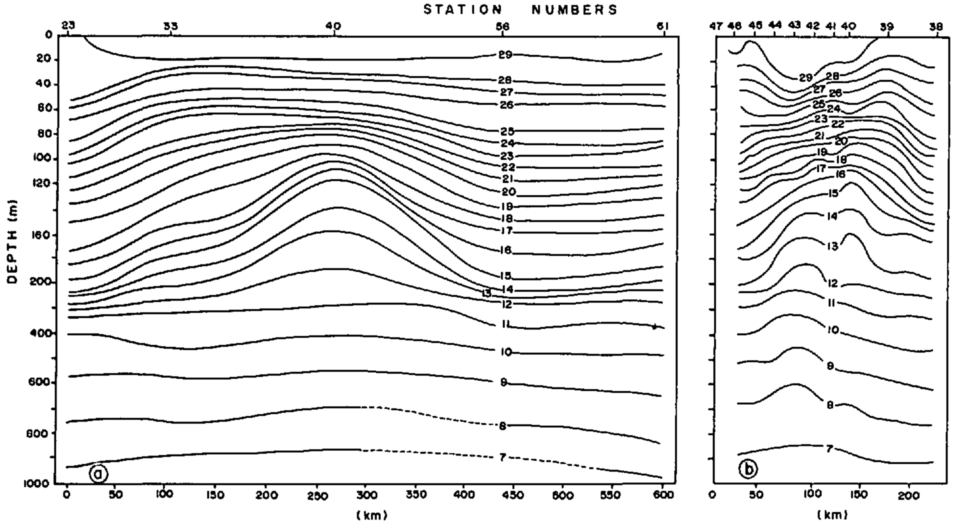

Figure 2. Vertical distribution of temperature (°C) across the eddy along transects (a) parallel and (b) normal to the coast. (Note break in scale at 200 db.)

3. Results

a. Thermohaline characteristics of the eddy. Two lines of stations crossing through eddy (normal and parallel to the coast, Fig. 1) reveal its vertical thermal structure (Fig. 2a, b). The presence of the eddy is reflected by the uplifting of isotherms in each section. The isotherms between 50 and 300 db have vertical displacements reaching several tens of meters; the maximum displacement is with the 15°C isotherm which is about 100 db (Fig. 2a). At the centre of the eddy, temperatures are 4–5°C lower than the waters of the periphery. The eddy has little signature beneath 300 db, nor is it recognized in the surface layers (0–50 db), suggesting that it was mainly a subsurface feature.

Considering the subsurface nature of the eddy, the topography of the 25, 23, 19 and 15°C isotherms are derived (Fig. 3a–d). It is evident that just below the mixed layer the eddy was elliptical in shape with a major axis of about 400 km and a minor axis of 200 km (Fig. 3a, b). At the center of the eddy, the 15°C isotherm (Fig. 3d) rose to 120 db, or about 100 db above its surrounding levels (see also Fig. 2). The topography of this isotherm indicates a more circular eddy than the shallower ones. The intersection of the 15°C isotherm with the 160 db isobar gives a representative indication of eddy size, about 200 km diameter, as it is well above the background level and there are sharp gradients toward the center of the eddy. An estimation of the baroclinic Rossby radius (L_R) which is often associated with the natural scales of phenomena like the boundary currents, fronts and eddies (Gill, 1982), shows that in the eddy region L_R is 180 km. It is comparable with the eddy diameter ($\sim$200 km) obtained from the topography of 15°C isotherm.

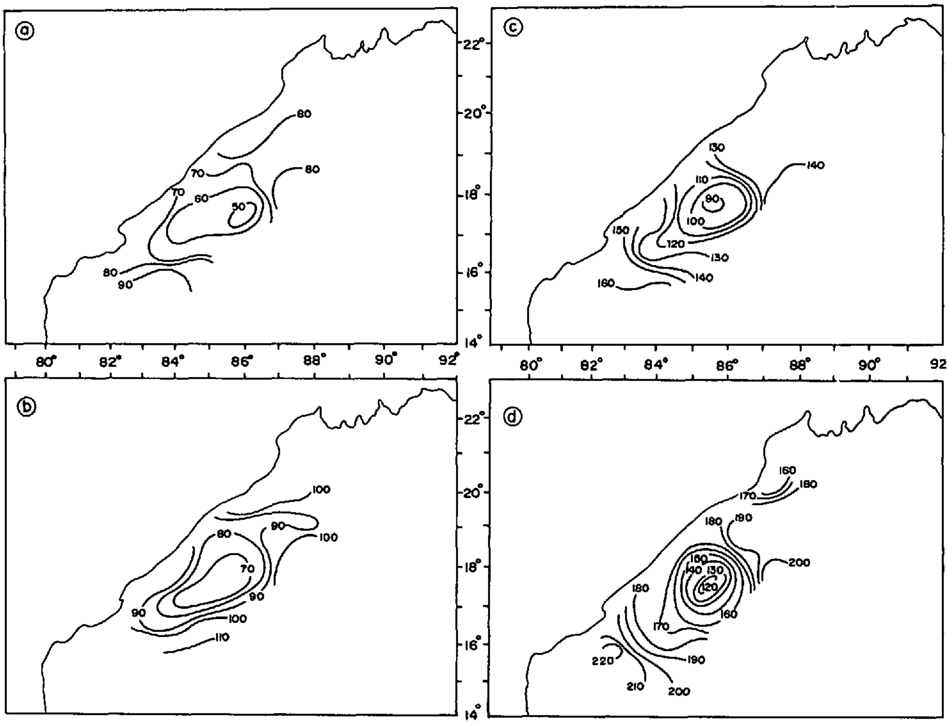

Figure 3. Topography (in meters) of the (a) 25°C, (b) 23°C, (c) 19°C and (d) 15°C isotherms.

The salinity distributions (along the same sections parallel and normal to the coast) also indicate the presence of the eddy (Fig. 4). As the upper layer is highly stratified, the rising of isohalines is confined to the layer between 150 to 300 m depth. An important feature is the presence of high saline water (35.07) at the eddy core. Rochford (1964) suggested the existence of two high saline watermasses of Persian Gulf and Red Sea origin in the upper 1000 m of the Bay of Bengal. In a recent study Sastry *et al.* (1985) identified that the high salinity layer was confined to the depth range 200 to 900 m in the Bay of Bengal. It is evident from the eddy core salinity distribution that the high salinity water which otherwise existed at about 200 m in the ambient was lifted upto 150 m at the centre of the eddy.

b. Circulation in the eddy region. The surface dynamic topography derived from the CTD data, relative to 500 db shows that the eddy center was depressed by approximately 10 dyn cm as compared with the waters adjacent to the 200 km wide eddy (Fig. 5), thus indicating cyclonic circulation. The dynamic topography stream lines show that in the northern part of the western Bay of Bengal a strong southward current was present, which presumably resulted at least in part from large density gradients caused by fresh water influx ($1.47 \times 10^{12} m^3$/year). This southward flow was further strengthened by cyclonic wind stress curl which prevails in the region during August.

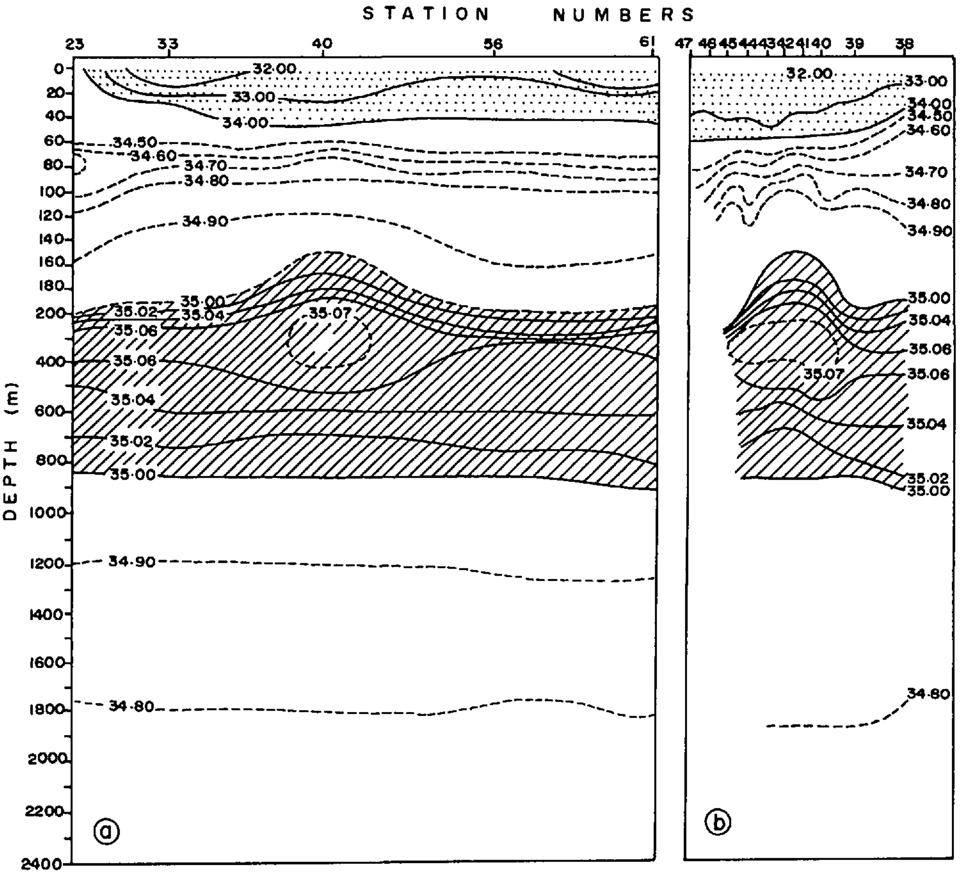

Figure 4. Vertical distribution of salinity across the eddy along transects (a) parallel and (b) normal to the coast. The upper dotted region denotes the layer of fresh water influence while the lower stippled region indicates the Bay of Bengal high salinity water. (Note break in scale at 200 db.)

From the climatological atlas of Hastenrath and Lamb (1979), the wind stress curl as applied to the Sverdrup model (Sverdrup, 1947) yields transport stream lines which are northward in the Sverdrup interior north of 15N (Fig. 6). These streamlines, when closed along the western boundary, give rise to a southward western boundary current along the coast (Babu, 1987). In an earlier study based on the upper thermal structure in the Bay of Bengal, Ramasastry and Balaramamurty (1957) also found evidence for southward flow along the western boundary during the southwest monsoon. More recently, Gopalakrishna and Sastry, (1985) used the vertical temperature and salinity sections to find sinking along the shelf regions associated with the southward flow. Also associated with the southward flow in our survey was a downward sloping of isotherms toward the coast from the offshore region (see Fig. 2b).

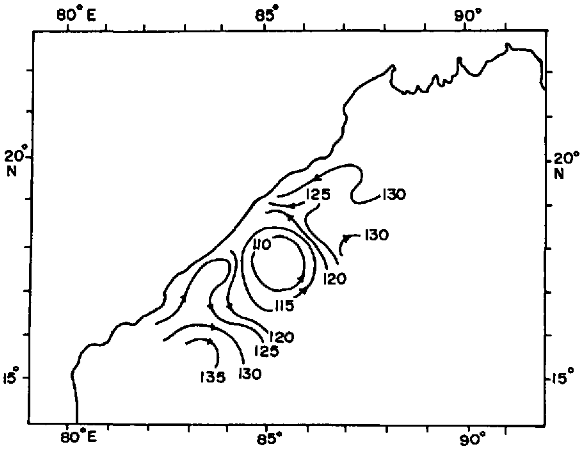

Figure 5. Surface dynamic topography (in dynamic cm) relative to 500 db.

4. Conclusions

We have documented the existence of a cold core eddy in the northwestern Bay of Bengal, and Figure 7 gives a schematic view of it and the regional currents. The eddy was apparently generated at the interface of two opposing flows along the western boundary of the Bay of Bengal, the southward flow being forced partly by fresh water

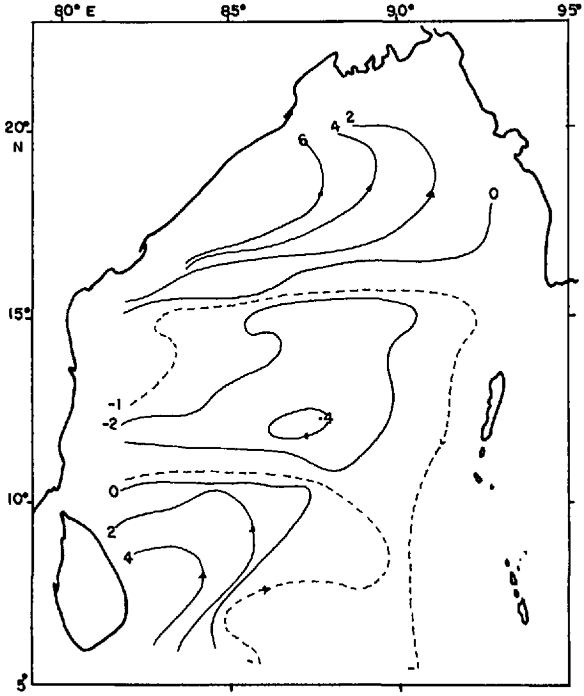

Figure 6. Sverdrup transport stream function ($10^6 m^3 s^{-1}$) derived from mean wind stress curl for August.

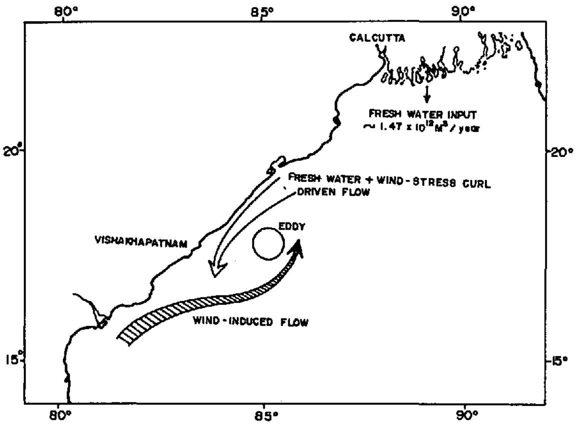

Figure 7. Schematic representation of the eddy and associated currents.

influx and to a large extent by the wind stress curl while the northward flow is purely wind induced. The high stratification in the upper layer caused by fresh water inhibits the eddy signal from being seen in the surface temperature and salinity fields. Consequently, it appears that the eddy is confined to a depth range of 50 to 300 m.

The mechanisms which generate eddies in the open ocean include baroclinic instability of large scale currents, topographic steering and direct atmospheric forcing (Kamenkovich *et al.*, 1986; Ikeda *et al.*, 1989). As the observed eddy was well above the bottom (average depth is 2500 m) topographic effects are presumed to have small significance. Baroclinic instability and wind forcing are thus likely the most important factors. The large scale positive wind stress curl existing over the area seems to generate baroclinic instability which in turn impart the required energy to drive the eddy. The eddy diameter is found to be determined by the Rossby radius of deformation which was previously confirmed for this eddy.

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