CHAPTER

24

UPWELLING OVER THE EASTERN ARABIAN SEA

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Introduction

Upwelling is a vital oceanographic phenomena determining the biological productivity of the coastal oceanic provinces in a greater extent. The annual pelagic fisheries of coastal rim countries, adjacent to the eastern boundary of the Ocean, over the trade wind zone are greatly dependent on upwelling. Over the North India Ocean (NIO), west coast of India, adjacent to the eastern Arabian Sea is well known for its seasonal occurrence of upwelling and downwelling annually. Over the past, several authors have studied upwelling along the west coast of India (Banse 1959, 1968; Sharma 1978; Johannessen *et al.*, 1987; Gopalakrishna *et al.*, 2008; Smitha *et al.*, 2008; Jayaram *et al.*, 2010: Shah *et al.*, 2015). Smith (1962) provided a generally accepted definition of upwelling in 1962 and as follows. "Upwelling is the ascending motion of some minimum duration and extent by which water from the subsurface layers is brought in to the surface layer and is removed from the area of upwelling by means of horizontal flow". Wherever they occur, upwelling was characterized by upward movement of Isotherms/Isopycnals, lowering of sea surface height, cooling of sea surface temperature than the surrounding areas and enhanced primary productivity.

According to the previous studies, upwelling sets in during April/May at deeper levels along the southern tip of India (8°N) and progressively advances to the northern latitudes as the summer monsoon progresses. Surface manifestation of upwelling along the west coast of India is less conspicuous towards north above 15°N latitude. Most intense upwelling was observed during July from 8°N to 15°N. Nevertheless summer monsoon winds are conducive for upwelling over the eastern Arabian Sea.

Rest of this tutorial will discusses the several proxies used in the study of vertical circulation and provided some insight on general phenomenon of upwelling and downwelling with a special emphasis to the eastern Arabian Sea.

Indices used for the study of upwelling

Several proxies are used in the study of upwelling and downwelling, some of them are based on the causative forces or the generation mechanisms, while the others are relies on the aftermath of these vertical motions.

Ekman mass transport due to the alongshore wind

Classical explanation of upwelling favors wind induced Ekman divergence as a fundamental forcing mechanism for the generation of upwelling. Along the west coast of India whenever the alongshore wind is parallel to the coast and is equatorward, it will leads to the offshore transport of surface water from the coast and consequently the surface water is replaced by subsurface water. This process is generally referred as upwelling. The offshore transport due to the alongshore wind is calculated as follows

$$\text{Mass transport due to alongshore wind, } M_{ev} = \tau_y / f$$

where τ_y is the alongshore wind stress and f is the Coriolis parameter ($2\Omega\sin\varphi$), Ω is the angular frequency of earth and φ is the latitude. The alongshore wind stress is calculated as follows

$$\text{Alongshore wind stress, } \tau_y = \rho_a C_d \, w \, v$$

where ρ_a is the air density, Cd is the nonlinear drag coefficient, w and v are the magnitude and alongshore component of the wind speed. Negative values of M_{ev} represents offshore transport and positive values indicates onshore transport. Along the west coast of India offshore Ekman transport was observed during the summer monsoon from May to

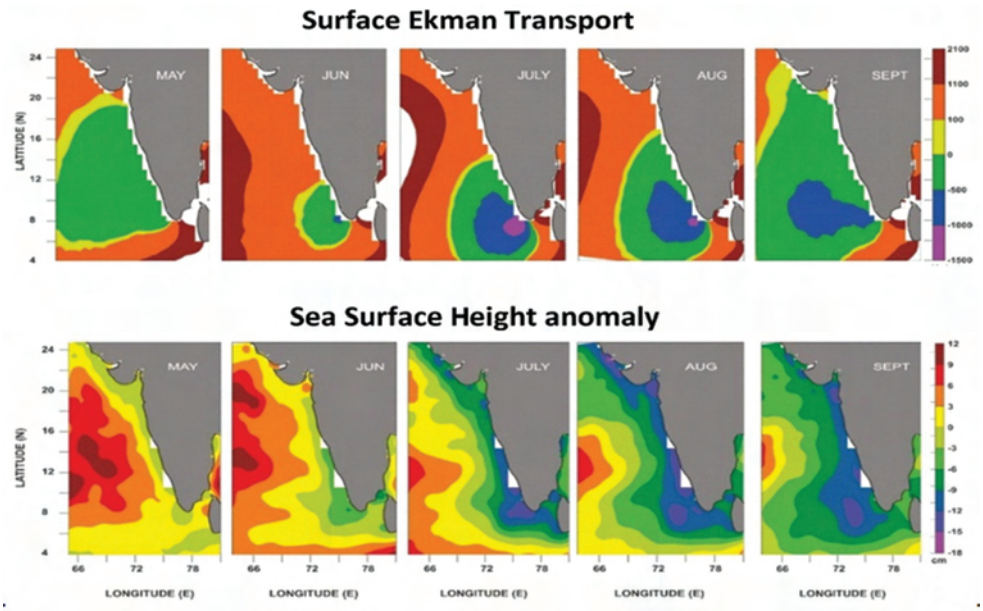

Fig. 1. Climatology of surface Ekman mass transport due to the alongshore wind (kg/m/s) [Upper panel] and Sea Surface Height Anomaly (cm) [Lower panel] along the west coast of India during the summer monsoon [Figure courtesy: Shah, 2016].

September and intense offshore transport and upwelling was noticed during the peak summer monsoon month July. Figure 1 (upper panel) represents the surface transport due to the alongshore wind.

Vertical movement of Isotherms

Since the upwelling areas are characterized by the replacement of the surface water by the subsurface water, upward movement of isotherms are used as a proxy for the study of upwelling. The analyses of figure 2 represents these upward movements are happened during May to September along the west coast of India. This is also substantiate the generation of upwelling during the summer monsoon months. Compared to the surrounding areas upwelling areas are cool because of the presence of subsurface water.

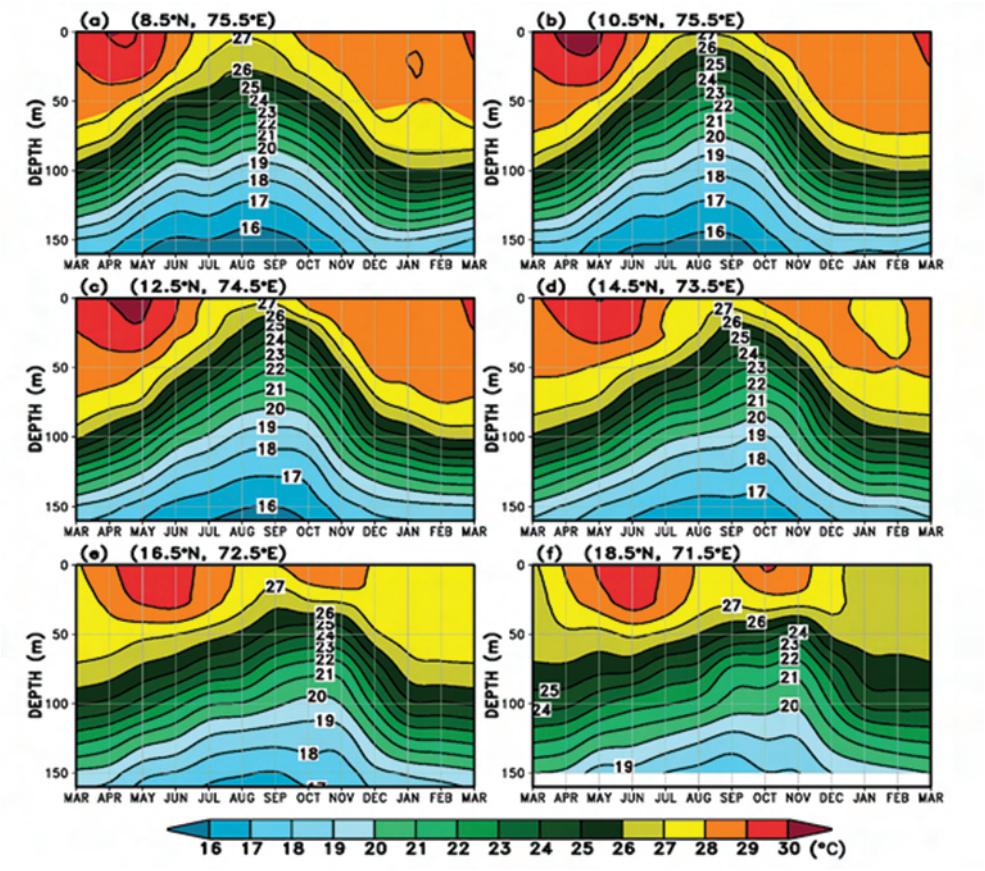

Fig. 2. Vertical oscillation of isotherms at particular latitudes along the west coast of India during a year (Climatology).

Sea Surface Height Anomaly

Because of the presence of subsurface water upwelling areas are characterized by sea surface cooling compared to the surrounding areas. Hence, inorder to maintain the isostatic balance upwelling areas are experienced by lowering of sea level than the surroundings. In tune with the observations on sea surface temperature, isotherms and Ekman mass transport, analysis on sea level anomaly along the west coast of India also shown a fall in Sea level anomaly during the summer monsoon and this fall is intensified during July (Fig.2, lower panel).

Chlorophyll-a

Along the west coast of India, upwelling enhances the nutrient concentration in the surface water during the summer monsoon from May to September. Consequently chlorophyll-a concentration along the coast increases compared to the surroundings (Fig. 3). Hence Chlorophyll-a concentration along coastal areas are used as a suggested proxy for the study of upwelling.

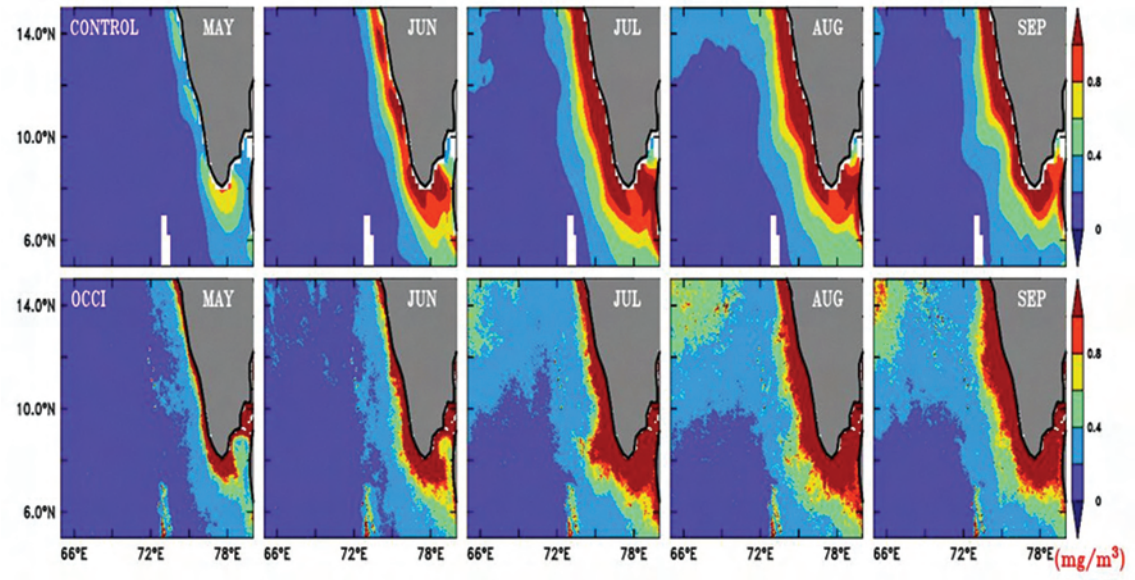

Fig 3. Chlorophyll -a concentration along the west coast of India during summer monsoon [climatology]

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