A NEW CONCEPT OF COASTAL WATER UPWELLING

ABSTRACT

The situations of coastal water upwelling of the world oceans and the limitations of the classical theory of the process are discussed. A linkage is envisaged between the generation of coastal upwelling along the eastern boundary of the ocean with the intensification of western boundary current as a paired set situated at the longitudinal wings of the subtropical gyre.

WHILE the equatorial upwelling is associated with diffusion of thermocline (Knauss and Taft, 1964), the coastal upwelling is associated with the strengthening of thermocline (Sverdrup *et al.*, 1942; Murty, 1981). Coastal water upwelling is generally attributed to the Ekman drift atleast theoretically. The mean flow within the Ekman layer is 45° towards right of the surface flow (in the Northern Hemisphere). However, the coastal upwelling necessitates coast-normal mean flow or atleast a considerable component of the latter directed away from the coast into the sea. This condition would be effectively fulfilled only when the surface flow makes into sea 45° to the coastline (assuming the coast is to the left of the flow). However, the coastal water flow is usually parallel to the coast with considerable variations in speed across the coast-normal. These horizontal variations in the flow of coastal waters will let prominent the other forces which are neglected in the Ekman balance. Under such practical circumstances, the system of coastal water movement is complicated and becomes beyond the scope of the simple Ekman model.

The forces in the Ekman model invite comment on their physical nature. Consider a unit mass of water at any point within the Ekman layer. According to the Ekman theory, the unit mass is in (horizontal) motion under the action of only two forces. They are the horizontal component of internal frictional force and the Coriolis force. These two forces nullify each other to set the unit mass in uniform motion in a particular direction determined by the mathematical model of "vertically spirlaling horizontal velocities". It is needless to say that the Coriolis force acts at right angles and to the right of the direction of velocity. Hence necessarily, the frictional force should act at right angles only to the left of the direction of velocity to counter-act the Coriolis force in order to bring a state of dynamic equilibrium in the motion of the unit mass. Therefore the Ekman model leads to the conclusion that the internal frictional force acts at right angles to the left of the direction of velocity leaving no scope for any component of frictional force in the line of the direction of velocity.

However, it is conventional in physics to treat a major portion of the internal frictional force, if not the entire force, in a direction opposite to that of the velocity *i.e.* in the line of direction of velocity. The famous Stommel theory of intensification of the western boundary currents (Stommel, 1948) is based on this convention. If the Ekman layer extends to one or two hundred metres of depth from the surface, the angular difference of directions of velocities between any two adjacent thin layers each of a centimetre thickness will not be markedly large enough to create frictional force at right angles to the velocity without any component of it in the direction of velocity.

From an observation of the coastal system of upwellings, it sounds reasonable that the upwelling of the eastern boundary of the ocean and the intensified meridional flow along the western boundary constitute the two parts of the subtropical gyre in each of the oceans. Example : In the North Atlantic Gyre, the Gulf Stream on the west faces the Northwest African upwelling on the eastern side of the gyre. The Kuroshio Current in the North Pacific Gyre faces the California upwelling on the east of the gyre. The Brazil Current in the South Atlantic is paired with the southwest African upwelling in the South Atlantic Subtropical Gyre. The East Australian Current in the South Pacific may be likewise paired with the Peruvian upwelling in the South Pacific Gyre. Similarly, the Mozambique current in the South Indian Ocean has the west Australian upwelling as its counterpart in the South Indian Ocean Subtropical Gyre. However, the Somali Current which is the only cross-equatorial western boundary current in the world oceans and the Somali upwelling are, of course, exceptions from this generalisation. Nevertheless, the Somali Current and the Indian West Coast upwelling may, in a way, be considered as counterparts to one another in the Arabian Sea.

It may therefore be construed that each oceanic subtropical gyre contained intensification of currents on the western boundary with generation of upwelling on its eastern boundary. The difference of horizontal vorticity gradient in the eastern and the western wings of the gyre was taken into consideration by Stommel (1948) to explain the western intensification of boundary currents. Hence, it may be suggestive that the essential reason for the generation of the eastern boundary upwelling may be sought from a comprehensive study of the three-dimentional vorticity of the subtropical gyre.

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