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UPWELLING AND TRANSPORT

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ABSTRACT

It is shown that the transport of water due to a wind blowing over the sea surface is towards right of the wind direction in the northern hemisphere and towards left in the southern hemisphere. This requires inflow of water from left (right) of the wind direction to replace the flow towards right (left). Now, consider if the wind is blowing parallel to a coastline which is on the left of the wind direction in the northern hemisphere. The wind causes the surface water to move to the right, i.e., away from the coast, but because of the presence of the coast, there is no supply of surface water on the left of the wind for replacement. Therefore, water from below comes to the surface. This process is known as upwelling.

The upwelled water does not come from great depths. Studies of the properties of the water indicate that it comes from depths of 200-300 m. As the upwelled water has high nutrient content, the productivity may be enhanced and therefore, this process is important biologically.

If the wind direction is such that the coast is towards its right, then the transport towards the coast piles up the surface water and the opposite of upwelling - downwelling - occurs.

Upwelling/downwelling away from the boundaries:

Over the ocean surface the variations of wind in speed and direction at different locations induce convergences and divergences. This results in upwelling/downwelling in the open ocean, away from any boundaries.

Bottom friction and shallow water effect:

The effect of friction on the flow near the bottom is to generate an Ekman spiral current pattern above the bottom with the direction of rotation of the spiral reversed relative to the wind driven Ekman layer near the surface. This is because, if we assume that we have a geostrophic flow with Coriolis force acting to the right and the pressure gradient, which is independent of depth (for a barotropic case) to the left. Due to the bottom friction, the flow slows down and the Coriolis force decreases. Now, the pressure gradient force to the left is not balanced completely, and therefore, the flow swings to the left.

Limitations of Ekman Theory:

The limitations of Ekman theory is related to its various assumptions,

i.e., the assumption that;

- 1) No boundaries and infinitely deep water - not a realistic one.
- 2) Constant eddy viscosity - may not be true.
- 3) Homogeneous water - unreal.
- 4) Steady state solution and steady wind - neither wind nor sea is steady.

Sverdrup's solution to wind driven circulation:

Ekman has ignored the pressure gradient term in his solution by assuming a homogeneous ocean. However, Sverdrup in his solution has retained the pressure gradient term along with the wind driving and tried to find out total transport in x and y directions in the wind affected layer. So Sverdrup's solution includes the wind driven current and the geostrophic current. Sverdrup's solution allows the possibility of having a coastal boundary at one side of the ocean - a step towards more realistic than Ekman. It is also no longer bound by the homogenous ocean assumption and so the solution has this additional feature of the real ocean.

Vorticity and westward intensification:

Every object on the surface of the earth possesses planetary vorticity depending upon its latitudinal position. Vorticity can be shown to be equal to twice the angular velocity; that means, vorticity = $2\omega \sin \phi = f$, the Coriolis parameter. Therefore, f can be symbolised as planetary vorticity. Also, when objects move on the earth's surface relative to the earth, they possess relative vorticity, ζ . For horizontal movements in the ocean the conservation of angular momentum requires that the absolute vorticity, $(f + \zeta)$ must remain constant, i.e. when f becomes

more positive, becomes more negative.

Now, consider water moving northward (e.g. Gulf stream) in the northern hemisphere. It is moving into high f values, therefore, for $(f + \zeta)$ to be constant, ζ has to be more negative. That means, the water will have more negative vorticity, i.e. anticlockwise motion. At the same time, the winds in the northern hemisphere impart an anticlockwise rotation to the water. These two add up in the western boundary and the currents along this boundary will be swift. This is called westward intensification of the currents. Along the eastern side, these two forcings oppose and effect is a weak eastern boundary current.

Equatorial Undercurrents:

Beneath the surface and embedded in the westward flowing Pacific Equatorial Current, there exists a flow - the equatorial under current. This flows

eastward centered on the equator. Maximum speeds are about 1 m/sec at a depth of about 100 m. Similar current exists in the Atlantic also. How do these currents arise? At the equator, we have wind blowing towards west and the current also moves towards west. As there is landmass at the western side, water piles up there producing a surface slope and a pressure gradient force towards east. At the surface, this pressure gradient force is balanced by the westward wind stress but below the surface wind stress decreases and it can no longer balance the pressure gradient towards east. Thus flow occurs at that depth towards east.