

## OCEANIC SURFACE MIXED LAYER

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Typical temperature variation with depth in the middle of the Arabian Sea is shown in Fig. 1. The surface mixed layer (SML) is bounded on the top by the air-sea interface and on the bottom by a region of rapid decrease in temperature. Though the height of SML ( $\sim 20-120$  m in the Arabian Sea) is small in comparison to the total depth ( $\sim 3500$  m) the behavior of the layer affects both the ocean below and the atmosphere above: influence of atmospheric forcing is felt by the ocean interior through the mixed layer; heat distribution in SML affects atmospheric circulation. Here we briefly review both the salient observed features of the mixed layer, and the attempts at modelling them.

Observations generally show that within SML temperature, salinity and velocity vary little in the vertical (see Fig. 2). The magnitude of horizontal velocity in SML is usually much larger than that in the thermocline. The bottom of SML is marked by a step-like change in density and velocity. This region of high shear and strong density variation becomes a zone of active entrainment during deepening of the layer. The important external factors influencing the processes within SML are: (1) Buoyancy flux across the sea-surface due to evaporation, precipitation, sensible heat exchange and solar heat flux; (2) Surface momentum flux i.e. wind stress. An example of the evolution of SML in response to some of the functions above is given in Fig. 2.

Both experimental and theoretical studies over the last two decades conclude that SML dynamics are dominated by three-dimensional turbulent motions. The intensity of these motions is so large that the behavior of the mixed layer is decoupled from the underlying relatively quiescent thermocline. Dominance of turbulence and negligible influence of terms involving horizontal gradients allow writing of simplified equations for mean velocity, salinity and temperature in SML:

$$\frac{\partial \bar{u}}{\partial t} = f \bar{v} - \frac{\partial}{\partial z} \overline{u'w'} \quad (1),$$

$$\frac{\partial \bar{v}}{\partial t} = -f \bar{u} - \frac{\partial}{\partial z} \overline{v'w'} \quad (2),$$

$$\frac{\partial \bar{T}}{\partial t} = -\frac{1}{\rho_0 c} \frac{\partial I}{\partial z} - \frac{\partial}{\partial z} \overline{w'T'} \quad (3),$$

$$\frac{\partial \bar{S}}{\partial t} = - \frac{\partial}{\partial z} \overline{w'S'} \quad (4).$$

Here  $\bar{u}$ ,  $\bar{v}$  are mean horizontal velocities;  $\bar{T}$  and  $\bar{S}$  are mean temperature and salinity respectively.  $f$  is the coriolis parameter,  $I$  is the penetrating component of the solar radiation.  $\overline{u'w'}$ ,  $\overline{v'w'}$  .... are the turbulent vertical fluxes. These four equations form a closed set provided explicit expressions for the turbulent fluxes are known.

At the oceanic surface the turbulent fluxes are determined from atmospheric and surface solar

radiation data. Determination of the fluxes elsewhere is the central problem of the mixed layer studies. It appears that to handle this problem successfully two processes are of particular importance in SML and need to be properly accounted for. These are: entrainment at the bottom of the layer; and dissipation of turbulence within SML. So far, a combination of in situ observations, laboratory experiments and dimensional analysis has been used to model these two processes. Adjustable parameters invariably occur in such models.

Most of the attempts at solving equations fall in one of the following two categories:

(1) Turbulence closure models: In these the turbulent fluxes are modelled in terms of computable quantities. The simplest of such models use the classical approach of eddy diffusion; the more sophisticated employ higher order closure schemes. (See for example, Mellor and Durbin (1975)).

(2) 'Slab-models' of SML: This approach has so far provided the most effective tool for predicting sea surface temperature and heat storage of the upper ocean. The fact that within the mixed layer vertical distribution of  $\bar{s}$ ,  $\bar{T}$ ,  $\bar{u}$  and  $\bar{v}$  is almost uniform permits vertical integration of Equations (1) - (4) to yield expressions for turbulent transport in terms of fluxes at the surface and those in the entrainment zone. The vertical integration, however, introduces a new variable, the depth of the mixed layer. To close the system an additional equation for the turbulent mechanical energy is written.

Details concerning the two categories of models are given in Niiler and Kraus (1977). Excellent reviews of surface mixed layer studies can also be found in Turner (1981) and Niiler (1982).

One of the principal assumptions of the present SML models is that the behavior of the layer is controlled by local forcing alone; horizontal advection is considered negligible. Favourable comparison between model predictions and in situ observation such as the one in Fig. 2 supports this assumption. However, it remains to be seen if the same will hold true in the Arabian Sea, an area of interest to Indian meteorologists and oceanographers.

References:

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Figure Captions:

- Fig. 1 : Typical temperature variation in the central Arabian Sea (Wyrtki (1971)).
- Fig. 2 : Observed (dashed curve) and simulated (solid curve) upper-ocean changes at ocean weather station PAPA (50°N, 145°W) (Denman and Miyake (1973)).