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VERTICAL STRUCTURE OF THE BOUNDARY LAYER A-COMPARISON BETWEEN LAND AND SEA

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ABSTRACT

The structure and the energetics of the boundary layer have been studied simultaneously over land and sea off Goa coast just before the onset of south-west monsoon. The Radiosonde data obtained at 00 GMT (0530 IST) are used in the present computations. The 'Mixing heights' which are useful in studying the atmospheric dispersion characteristics of aerosol and water vapour across the costal zone, are also studied.

The study indicates significant differences in the structure of the boundary layer over land and the sea. The depth of the mixed layer is found to be high over sea than land and this feature can be attributed to the convection at the surface. The maximum mixing height is mainly controlled by the lapse rate in the atmosphere, in addition to the heat input at the surface.

Key-words : Mixed layer, Boundary layer, Cloud layer, Atmospheric stability.

It is recognised that boundary layer studies are likely to play an important role in improving our understanding of monsoon (Varma. 1981). The 'boundary layer' is the lowest part of the atmosphere where energy exchanges are predominantly taking place between air and sea/land. The height of the boundary layer varies with space and time as it is controlled by several factors like inversions, convection, and heat exchanges at the surface.

During undisturbed conditions the 'tropical boundary layer' has a well defined vertical layering. Riehl, Yeh, Malkus and Laseur (1951) and Malkus (1956) have characterised these layers as:

Surface layer

This layer extends from the surface to a height between 20 to 100 m, with a slight decrease in potential temperature with height and a stronger decrease moisture content.

Mixed layer

This layer extends from the top of the surface layer to about 100 m below cloud base, with nearly constant potential temperature and constant or slightly decreasing moisture content.

Transition layer

This layer extends to cloud base and separates the regime of cloud convection and mechanical convection below and is marked by stable potential temperature and a marked decrease in moisture content.

Cloud layer

This layer extends from cloud base to the base of inversion with nearly a moist adiabatic temperature lapse rate and a decrease in moisture content.

Inversion layer

This layer tops the undisturbed boundary layer, marked by extremely stable temperature gradient and a strong decrease in humidity.

But during disturbed conditions the boundary layer is ill defined.

In this paper the structure and energetics of the boundary layer have been studied and an intercomparison is made between land and sea. Unfortunately the wind data over sea was not available for studying the kinematic structure of the boundary layer. In addition to this the variation of 'Mixing height' which is slightly different from the mixed layer is also studied. 'Mixing height' may be defined as the height above the surface through which rigorous mixing occurs (Holzworth, 1972). In the absence of reliable offshore meteorological data a model to forecast offshore mixing height based on land station data is important in practical applications such as defining atmospheric dispersion characteristics of aerosol and water vapour across the coastal zone or the control of offshore burning resulting from accidents in offshore oil and natural gas operations (Hsu, 1979). Here, the variation of 'Maximum mixing height' (MMH) over land and sea is presented.

Upper air data collected simultaneously over land and sea are used in this study. During the 138th cruise of *R V Gaveshani*, Radiosonde observations were carried out at a stationary position (15° 06'N 73° 18'E) in the sea off Goa coast in the pre-monsoon season (from 10-5-84 to 20-5-84). The surface meteorological parameters were measured throughout the study period at hourly intervals.

The upper air data and data of maximum surface temperatures recorded at Goa observatory, Altino, Panaji (15° 29'N; 73° 49'E) during the same period were used. The upper air data collected at 00 GMT ((0530 IST) are used for computing the parameters required for the study of boundary layer. The following equations are used for the computations;

$$\theta = T\ [1000 / P]^{R/C_P} \qquad \dots \quad \dots \qquad (1)$$

$$\theta_V = \theta\ [1 + 0.61\, q] \qquad \dots \quad \dots \qquad (2)$$

$$\theta_E = \theta e^{Lq / C_p T} \quad \ldots \quad \ldots \quad (3)$$

$$\phi = g Z \quad \ldots \quad \ldots \quad (4)$$

$$E_d = C_p T + \phi \quad \ldots \quad \ldots \quad (5)$$

$$E_m = C_p \; T + \phi + L q \quad \ldots \quad \ldots \quad (6)$$

where

T = Dry bulb temperature (K); P = Atmospheric pressure (mb); C_p = Specific heat of air at constant pressure; θ = Potential temperature (K); θ_v = Virtual potential temperature (K); θ_E = Equivalent potential temperature (K); q = Specific humidity (g/Kg); Lq = Latent heat (cal/g); C_pT = Enthalpy (cal/g); ϕ = Geopotential energy (cal/g); g = Acceleration due to gravity (980 cm/sec); Z = Height of the isobar (cms); Ed = Dry static energy (cal/g); Em = Moist static energy (cal/g);

Based on temperature lapse rate method (Holzworth, 1972) over land and sea the MMH is comptued. It is the intersection of the dry adiabat from the maximum surface temperature, with the early morning 00 GMT (0530 IST) sounding.

The structure & energetics of the boundary layer are shown in figure and MMH'S are given in table I.

TABLE — I . Daily mean MMH over land and sea during May 1984

DATE	MAX. Surf. temp. (°C)		MMH (m)		LAPSE RATE (°C/100 m)	
	Land	Sea	Land	Sea	Land	Sea
11	34.6	30.7	1090	540	–0.03	0.50
12	34.4	30.9	1010	1140	0.32	1.23
13	33.9	30.9	1230	245	0.40	0.38
14	34.4	30.9	1575	300	0.68	0.33
15	34.3	30.8	1040	1065	0.34	1.19
16	33.8	31.0	920	820	0.24	0.71
17	34.4	30.6	1080	380	0.42	0.55
18	34.0	30.4	—	110	—	0.29
19	34.4	30.8	1170	210	0.41	0.39
20	34.4	30.7	—	470	—	0.88

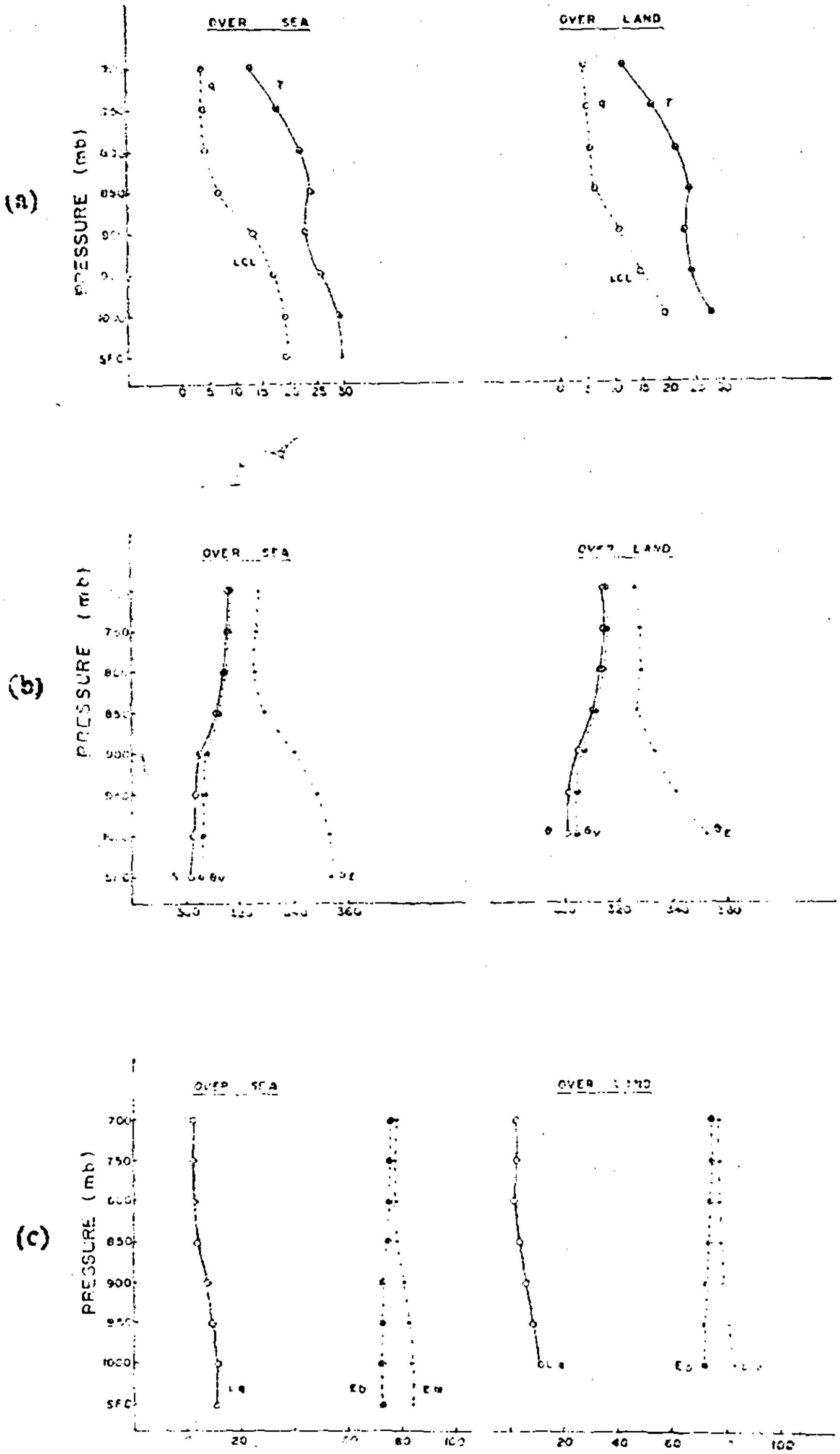

Fig. 1. Depiction of the structure and energetics of the boundary layer.

The profiles of temperature and specific humidity are constructed from surface to 700 mb level ($\approx$ 3 Km) over land and sea (Fig. 1).

Based on standard classification, which is applicable for tropical atmosphere, the boundary layer in this region is mainly divided into three layers:

The neturally stratified mixed layer

This layer extends from surface to a height of 950 mb over sea and 970 mb over land. The distribution of Θ_V is almost constant in this layer (Fig. 1.b) temperature nearly dry adiabatic and Specific humidity sharply decreases over land compared with sea, in this layer (Fig. 1,a).

The transition layer

This layer is shallow and the thickness is approximately 100 m over land and about 150 m over sea.

The cloud layer

This layer extends from the top of the lifting condensation level (LCL) to the base of inversion layer or stable layer. The thickness of this inversion layer is slightly more over land than the sea and above this the inversion layer is present in both the cases. Shallow cloud layer was also observed by Pant (1978) in the region north of 10°N and west of 60°E of the Arabian sea.

The height of the base of the cloud is estimated over sea based on the following equation suggested by Berry, Bollay and Beers (1945).

$$H = 120\ (T - Td) \qquad \ldots \qquad \ldots \qquad (7)$$

where H = height of the base of the cloud (m); T = dry bulb temperature (°C); Td = dew point temperature (°C).

Based on the equation (7), the approximate height of the base of the cloud is found to be 564 m where as the LCL is at 603 m above the sea surface.

The equivalent potential temperature (Θ_E) was almost constant in the lowest layer over the sea and gradually decreased over land (Fig. 1, b) This constancy in, Θ_E over sea was due to the thorough mixing in the lower layer. This does not happen over land because the land surface is cooler during early morning hours and the lowest layer thus becomes stable. The variation of Θ_E in the upper layer was similar in both the cases.

Fig. 1,c depicts the vertical profiles of latent heat energy (Lq), dry static Static energy (E_d) and moist static energy Em. There were no significant differences in the energies observed over land and sea. The moist static energy almost followed, ΘE which is quite obvious from the relation.

$$C_p\ \Theta_E = C_p\ T + L_q + \phi$$

In general, it can be said that the structure of the boundary layer over sea is different from that of land even though the distance is small between the observational points (about 50 miles in the present case). Since in early morning hours the sea surface is warmer than the land, one can expect instability over sea and stability over land. This leads to a higher mixed layer (= 500m) over sea than land ($\approx$ 330m) in the morning time.

The 'Maximum Mixing heights' (MMH's) are shown in Table I. It is nothing but the expected mixing height when the heat input at the surface is maximum. The mean MMH was higher over land compared with sea in most of the occasions. The maximum surface temperatures are always higher than the maximum sea surface temperatures and the observed range is about 4°C. Here the lapse rate seems to be the dominant factor in controlling the MMH, because the day to day changes in the maximum surface temperatures over land as well as sea are very small. The mean values of MMH over land and sea are found to be around 1150 m and 500 m respectively.

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