# A CONVECTIVELY-DRIVEN BOUNDARY LAYER IN THE MONSOON TROUGH

*(Research Note)*

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**Abstract.** Characteristic features of the convectively driven monsoon-trough boundary layer have been explored using the conserved-variable method of analysis. Aerological observations during the Monsoon Trough Boundary Layer Experiment 1990 (MONTBLEX-90) during 18–20 August have been used to investigate the thermodynamic features of the Convective Boundary Layer (CBL). Thermodynamic parameters such as $\theta_e$, $\theta_{es}$ have been used to study the dynamical aspects of the CBL. Also, mixed-layer heights at an inland station, in the monsoon trough region, obtained from SODAR, are used to document the saturation of the mixed layer after the onset of the monsoon.

## 1. Introduction

During the summer in India, dry convection develops and the mixed-layer height reaches up to 1–2 km in the afternoon due to enormous solar heating (Parasnis and Goyal, 1990). Atmospheric conditions change when the southwest monsoon sets in over the Indian Peninsula during the second week of June. Analysis of ISMEX-1973 observations showed that after the onset of the monsoon, the mixed layers over the Arabian sea regions were saturated (Ramanathan, 1978). This was attributed to the transformation from dry to moist convection due to the intrusion of moisture into the boundary layer. The observed saturation of the mixed layer during deep moist convective activity associated with the transient disturbances in the southwest monsoon has been documented further over land regions.

The aerological observations at Calcutta, Bhubaneswar, New Delhi and Jodhpur obtained during MONTBLEX-90 for the period 18–20 August,1990 have been used to study the thermodynamic features of the CBL. The mixed-layer heights at an inland station, obtained from SODAR are used to document the saturation of mixed-layers after the onset phase of the monsoon.

The thermodynamic structure of the CBL over the tropical oceanic region has been studied using the conserved-variable method of analysis (Betts, 1982; Betts and Albrecht, 1987), and will be used here. The characteristic variations in CBL structure observed over the Deccan Plateau region during the summer monsoon have been documented (Parasnis, 1991; Parasnis and Morwal, 1991). These studies reveal the usefulness of the conserved-variable method for characterising the thermodynamic features of the CBL.

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## 2. Observations and Meteorological Conditions

The Indian Institute of Tropical Meteorology installed a Doppler SODAR at an inland station, Kharagpur (22°30′ N, 87°20′ E, 83 m ASL). The system gives mixed-layer height. Mean hourly mixed-layer heights during 3–15 June 1990, were used in this study. Also surface hourly dry-bulb ($T$) and wet-bulb ($T_w$) temperatures were measured. During this period the monsoon trough was in its formative stage with associated easterlies over northeast India. On June 13th, a well marked low pressure area developed over the northern Bay of Bengal which concentrated into a depression on 14th June. A monsoon trough was apparently established and the axis of the trough was extended from west Madhya Pradesh to the northern Bay of Bengal through Varanasi. The cyclonic circulation associated with the low/depression extended to mid-tropospheric levels.

Aerological observations were carried out at Calcutta (22°39′ N, 88°28′ E, 6 m ASL), Bhubaneswar (20°15′ N, 85°50′ E, 45 m ASL), New Delhi (28°35′ N, 77°12′ E, 273 m ASL) and Jodhpur (26°18′ N, 73° E, 220 m ASL) during the period 18–20 August, 1990. The daytime observations were used for studying the CBL structure. As far as the position of the monsoon trough is concerned, its axis ran from Jodhpur, Sagar, Ambikapur and thence to the northern Bay of Bengal on August 19th. This trough became well marked and concentrated into a depression by the evening of August 20th. Figure 1 shows the locations of the four stations and the position of the monsoon trough.

## 3. Method of Analysis

The hourly $T$ and $T_w$ values at Kharagpur during 3–15 June 1990 were used to obtain Lifting Condensation Level (LCL) heights, using the following formulae (Parasnis, 1990).

$$T_c = T_d - 0.62(T - T_d)$$

$$G = 15.77T_c/(2501 - 2.37T_d)$$

$$H = (T - T_d)/(9.76 - G)$$

where $T$ and $T_d$ are dry bulb and dew point temperatures (°C), and $G$ and $T_c$ are intermediate parameters involved in the computation of $H$, the LCL height.

The aerological observations for 18–20 August 1990 (surface to 500 hPa) at Calcutta, Jodhpur, New Delhi and Bhubaneswar were interpolated at 10 hpa intervals and then averaged for each hour. The averaged values of $T$ and $T_d$ were used to compute the thermodynamic parameters such as virtual potential temperature ($\theta_v, K$), equivalent potential temperature ($\theta_e, K$), saturated equivalent potential temperature ($\theta_{es}, K$), mixing ratio ($q$, gm kg$^{-1}$) and the saturation level pressure ($p_{SL}$, hPa). The saturation pressure differences were obtained as

$$\mathcal{P} = p_{SL} - p$$

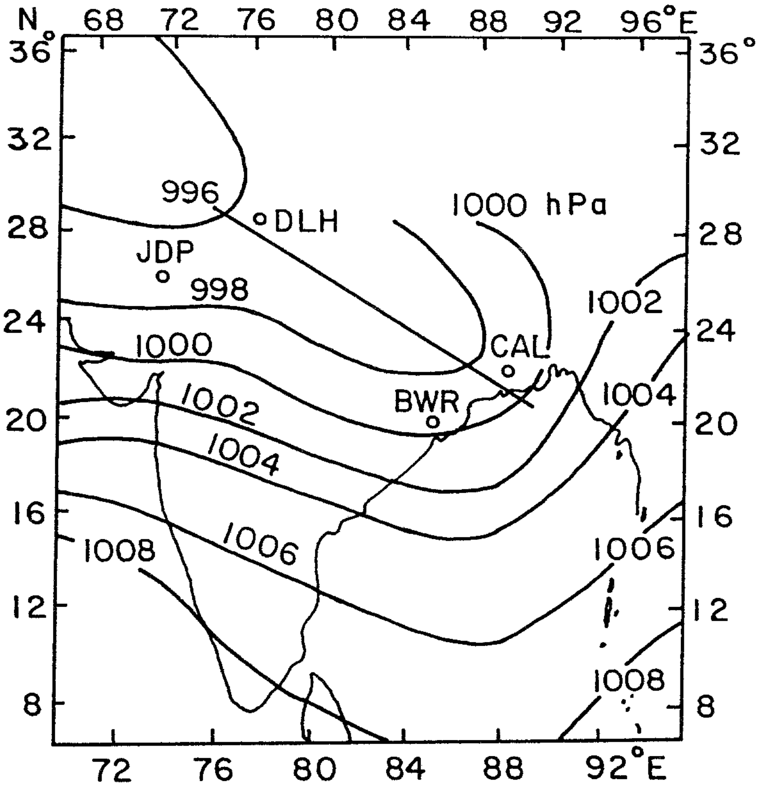


Fig. 1. Locations of the four stations and the position of the monsoon trough (BWR: Bhubaneswar; CAL: Calcutta; DLH: New Delhi; JDP: Jodhpur).

where $p$ is the air pressure for which $p_{SL}$ is the saturation level pressure (Betts, 1982).

## 4. Results and Discussion

### 4.1. Saturation of Mixed Layers

The hourly mean values of mixed-layer heights for the period 3–15 June 1990 at Kharagpur obtained from SODAR observations are shown in Figure 2. The generation and growth of the mixed layer, in the absence of any disturbances, depends on solar heating, with a peak at 0.8–1.0 km during afternoon hours (1100–1300 IST). These results are in agreement with those reported in an earlier study (Parasnis and Goyal, 1990).

The mixed-layer heights obtained from SODAR and the LCL heights are shown in Figure 3. On most days, LCL heights (solid line) were higher than mixed-layer heights (dashed line). This indicates that the mixed layers were

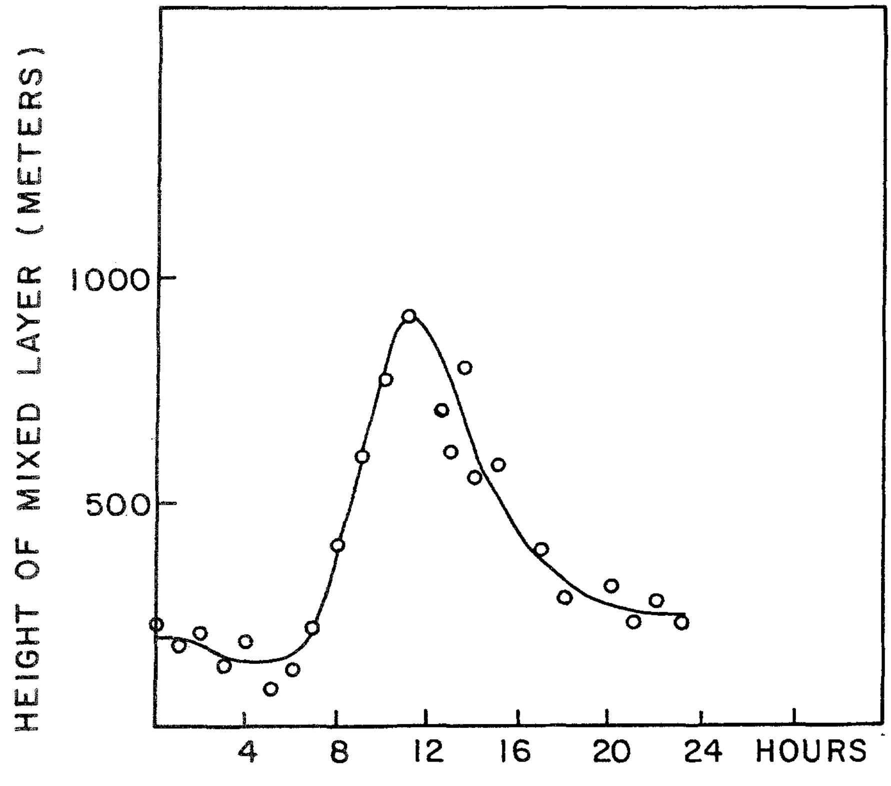


Fig. 2. Diurnal variation of mixed-layer heights for 3–15 June 1990 at Kharagpur.

unsaturated. On June 15th however, the LCL heights are lower than the mixed-layer heights, indicating mixed-layer saturation (Ramanathan, 1978). On June 6th the mixed-layer and the LCL heights were same, which means that the mixed layers were well mixed and nearly saturated. This day coincided with the arrival of the monsoon over Calcutta, although it did not move any farther inland during the next week. The mixed layers were thus unsaturated until June 13th when a low pressure area formed over the northern Bay of Bengal.

### 4.2. CBL CHARACTERISTICS

Averaged profiles of $q$, $\theta_v$, $\theta_e$, $\theta_{es}$ and $\mathcal{P}$ for Bhubaneswar, Calcutta, New Delhi and Jodhpur are shown in Figure 4(A–D). Only observations at 1700 h were considered because the 1100 h observations extended up to only 650 hPa and the CBL could be higher than that (Parasnis, 1991).

From Figure 4B, it is seen that at Calcutta there is a mixed layer (with nearly constant $\theta_v$), up to 950 hPa. A cloud layer extends from 900 to 700 hPa with a steady decrease of $q$ and a constant subsaturation ($\mathcal{P} \approx -30$ hPa). The overlying stable layer is associated with a marked decrease in $q$. The CBL top (and the

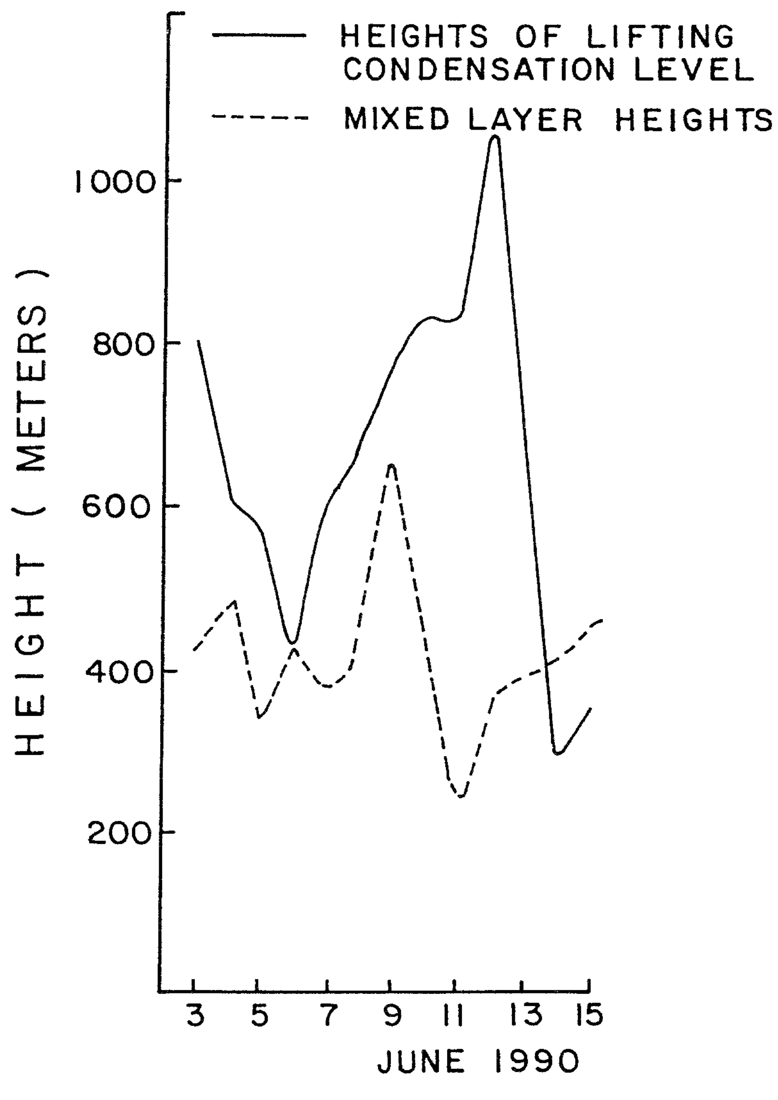


Fig. 3. Mixed-layer heights (- - -) and LCL heights (—) at Kharagpur during 3–15 June 1990.

stable-layer top) is at 600 hPa where minimum values of $\mathcal{P}$ and $\theta_e$ are observed. From Figure 4A, it is seen that at Bhubaneswar the mixed layer is quite shallow (up to 970 hPa). The cloud layer between 950–625 hPa is associated with values of $\mathcal{P}$ of $\approx -25$ hPa, capped by a stable layer of 50 hPa thickness with a sharp decrease in $q$. The top of the stable layer and of the CBL is at 550 hPa which is associated with minimum values of $\theta_e$ and $\mathcal{P}$. A $\theta_{es}$ maximum value was not observed in the absence of an inversion layer. At New Delhi (Figure 4C), the mixed layer extends up to 875 hPa. The stable layer with almost constant

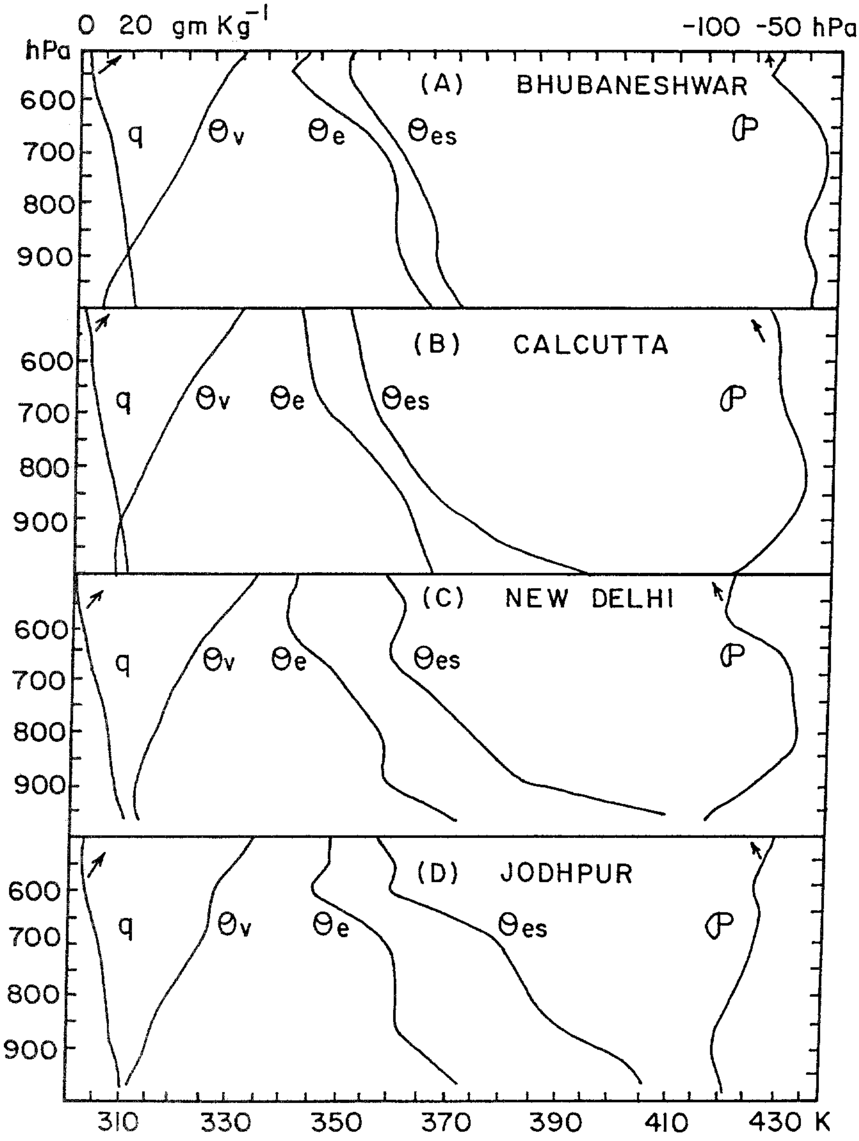


Fig. 4. Averaged vertical profiles of $q$, $\theta_v$, $\theta_e$, $\theta_{es}$ and $\mathcal{P}$ for Bhubaneswar, Calcutta, New Delhi and Jodhpur.

subsaturation ($\mathcal{P} \approx -35$ hPa) lies between 850 and 700 hPa, capped by a more stable layer of 100 hPa thickness. The base and top of the stable layer is marked by minimum and maximum values of $\theta_{es}$, respectively. The CBL top in this case is at 570 hPa, which is associated with minimum values of $\mathcal{P}$ and $\theta_e$ and a maximum value $\theta_{es}$. The CBL structure at Jodhpur (Figure 4D) is quite different, the individual soundings at Jodhpur showing multiple inversion layers at 900 and 600 hPa. The mean $\theta_e$ and $\theta_{es}$ profiles (Figure 4D) indicate suppression of convective activity between 900–700 hPa. The layer between 700 and 600 hPa shows shallow convection up to 600 hPa. The top of the CBL cannot be defined in this case. Other characteristic features of the CBL are not seen at Jodhpur.

### 4.3. Low-level stability

For assessment of low-level stability, the $\theta_e$ and $\theta_{es}$ soundings at the four stations were examined. Over the tropical Pacific Oceanic region during FGGE, the $\theta_e$ and $\theta_{es}$ profiles were used for characterising the differences in the thermodynamic structure of the boundary layer associated with deep convection, shallow convection and complete suppression of convection (Firestone and Albrecht, 1986; Kloesel and Albrecht, 1989). This method is simple and quite useful for qualitative assessment of convective activity.

In Figure 4(A–D), straight lines if drawn upward from the LCL level ($\theta_e$ path) at Bhubaneswar and Calcutta cut the $\theta_{es}$ profiles at 780 and 810 hPa, respectively. Above the LCL, the difference between this path and the $\theta_{es}$ profile is proportional to the temperature difference between the parcel and its environment. The $\theta_e$ values are higher than $\theta_{es}$ above these levels. This indicates that the parcel of air will have positive buoyancy from these levels upward. The $\theta_e$ paths from the LCL levels at New Delhi and Jodhpur do not cut the $\theta_{es}$ profile below 600 hPa, which shows suppression of convective activity. The soundings at Bhubaneswar and Calcutta can be classified as High Theta E soundings (Kloesel and Albrecht, 1989) which means that conditions are favourable for deep moist convection. The soundings at New Delhi and Jodhpur are classified as Low Theta E soundings, indicating suppression of convective activity. The above results are consistent with prevailing meteorological conditions.

## 5. Conclusions

Study of the thermodynamic features of the convectively driven monsoon-trough boundary layer as revealed by the MONTBLEX-90 data, suggests the following:

(a) The mixed layers which were unsaturated before the onset of the monsoon became saturated due to intrusion of moisture into the boundary layer.

(b) The mixed-layer heights indicated a diurnal cycle, with a peak at 0.8–1.0 km between 1100–1300 h IST.

(c) The thermodynamic conditions at Bhubaneswar and Calcutta, as seen from $\theta_e$ and $\theta_{es}$ were favourable for deep convection whereas those at New Delhi and Jodhpur indicated suppression of convective activity.

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