BOUNDARY-LAYER HEIGHTS OVER THE MONSOON TROUGH REGION DURING ACTIVE AND BREAK PHASES

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Abstract. The thermodynamic structure and the heights of the boundary layer over the monsoon trough region of the Indian southwest monsoon are presented for the active and break phases of the monsoon. Results indicate significant and consistent variation in boundary-layer heights between the active and break phases.

1. Introduction

The dynamics of the Indian southwest monsoon trough affects the monsoon circulation significantly (Ramage, 1971). Location of the monsoon trough on the other hand has been observed to depend on the monsoon strength amongst other factors. In general, it is located along the Gangetic plain dipping into the Bay of Bengal for the period, June to September during the active phase of the monsoon. When there is a break in the monsoon, it generally shifts northward. Planetary Boundary Layer (PBL) processes constitute an important physical input in the numerical simulations of the monsoon [e.g., Rao (1988), Krishnamurti *et al.* (1973), Manabe *et al.* (1974), Shukla *et al.* (1981)]. PBL physics is usually incorporated by adopting a suitable parameterization scheme.

Boundary-layer height is an important scaling factor for the height above the surface and for the mean and turbulent structure of this layer where the bulk of the heat and moisture exchanges take place. The implication of the variation of this height in the large-scale processes has to be significant but is not well known. One of the processes by which this interaction could take place is at the top of this layer where penetrative convection and entrainment are important. If the convective velocity scale,

$$w_* = \left\{ \frac{hg}{\Theta} \overline{(w\theta)_0} \right\}^{1/3}$$

where h is the PBL height, g is acceleration due to gravity, Θ is mean potential temperature and $\overline{(w\theta)_0}$ is the surface turbulent heat flux, can be considered an indicator of the vigorous interaction between the PBL and the free atmosphere, the PBL height does seem to play a role in the "conditioning" of the atmosphere for the occurrence of weather events such as the reactivation of the monsoon, in this case by causing the atmosphere to become unstable. The value of w_* increases by a factor of about two as the PBL height increases by a factor of about six for the same surface turbulent heat flux. There have been several studies on tropical boundary layers over the oceans, such as GATE and MONEX79, but very few over land in the tropics. The objective of this paper is to present results from a study on the spatial variation in boundary-layer heights over the monsoon trough region during active and break phases of the monsoon using MONEX79 radiosonde data. Boundary-layer heights are then related to the dynamics of the monsoon trough and the precipitation patterns during the monsoon.

2. Data and Analysis

For the present analysis, the basic MONEX79 sounding data of air temperature, dew point temperature and surface pressure are used for the month of August 1979. These observations were taken at 12 Z every day, at 50 mb intervals from the surface to a height of 100 mb for the 15 stations shown in Figure 1. These stations lie in and around the general monsoon trough region. During 1979 one of the active periods of the monsoon extended from August 3 to 12 and a break period, August 21 to 30. Average rainfall distributions characteristic of the active and the break periods are shown in Figures 2 and 3, respectively. The boundary-layer height was obtained as the height of the base of the capping inversion from virtual potential temperature profiles observed over the stations indicated in Figure 1. Typical soundings at Jodhpur (JDP) for active and break monsoon days are shown in Figures 4a and 4b respectively. PBL height was 1500 m for the active phase and 3600 m for the break phase.

3. Discussion of Results

Figure 5 shows the variation of boundary-layer heights for August 1979 for the stations Jodhpur (JDP), Lucknow (LKN), Calcutta (CAL) and Nagpur (NGP). These stations were chosen for their representativeness of different regimes of the monsoon trough. Jodhpur is in an area of dry convective activity, Lucknow in an area of alternating dry and moist convective activity and Calcutta represents the deep moist convection of the monsoon trough. Nagpur lies to the south of the mean position of the monsoon trough and could provide information about an area not affected by the trough. Temporal variation of the height of the boundary layer and the rainfall for August 1979 for Jodhpur, Calcutta and Nagpur are shown in Figures 5a–d, respectively. Variation of rainfall indicates in general the active and break phases of the monsoon. Temporal variation in the height of the boundary layer is quite pronounced. Boundary-layer heights varied from about 700 to 3500 m over these four stations. Although the amount of variability is different between the stations, one common feature is the occurrence of shallow boundary layers (about 500 m) during the active phase of the monsoon. On the contrary,

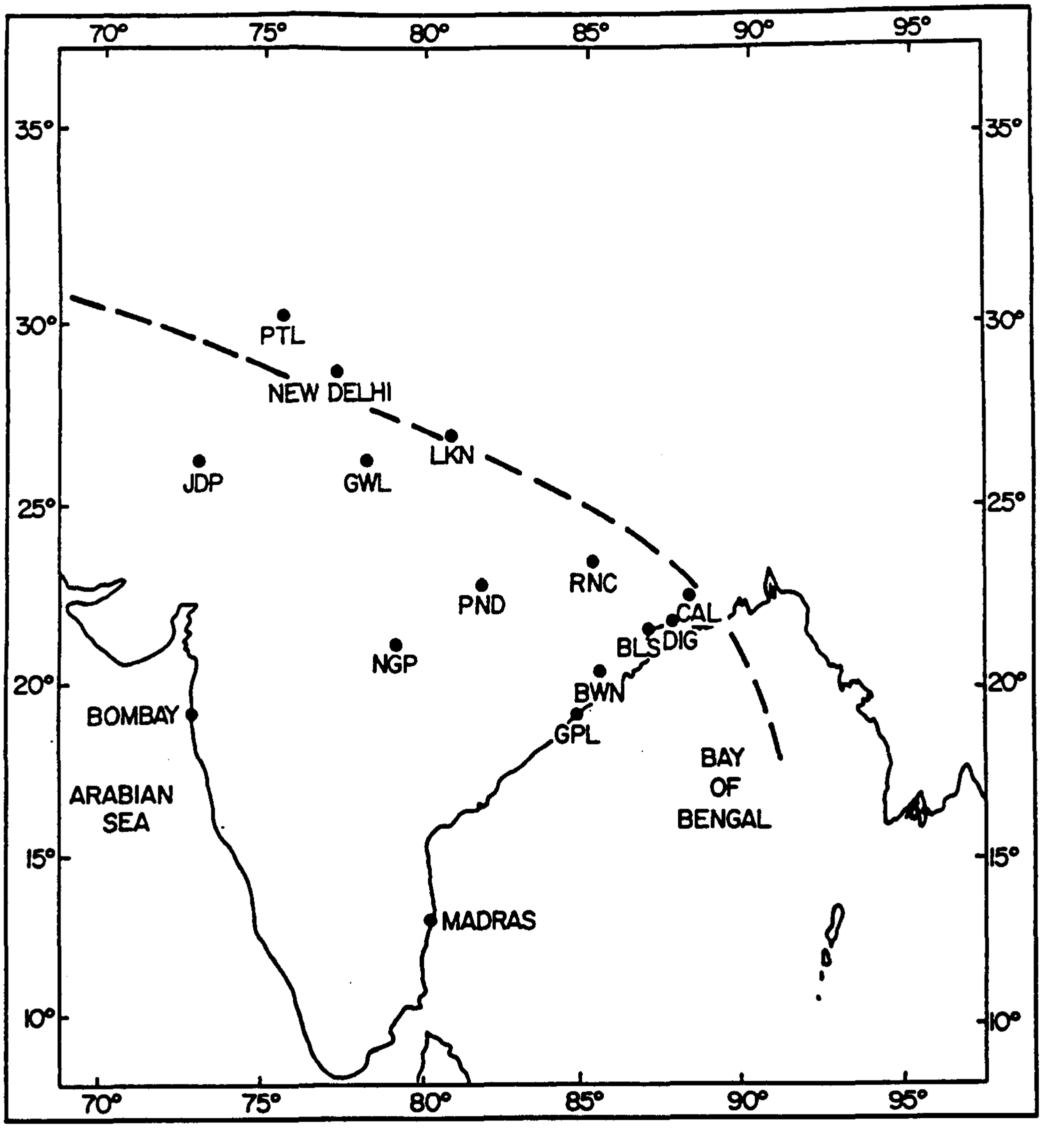

Fig. 1. Meteorological stations in the monsoon trough region where radiosonde observations were made. Dashed line indicates the typical mean trough axis.

the boundary layers were deep with heights of about 3000 m during breaks in the monsoon.

Another interesting feature that one can infer from Figure 5 is the slow increase in the height of the boundary layer as the large-scale monsoon flow shifts from the active to the break phase. During the active phase, the monsoon trough is generally located along the Gangetic plain as shown in Figure 1 and there is widespread precipitation as shown in Figure 2. During the break phase, the trough moves north to the foothills of the Himalayas with a significant decrease in rainfall (Figure 3). Growth of the convective boundary layer to large heights during the daytime after the end of the active phase thus appears to be related to soil moisture depletion occurring slowly. Judging from inland stations, it seems to take about

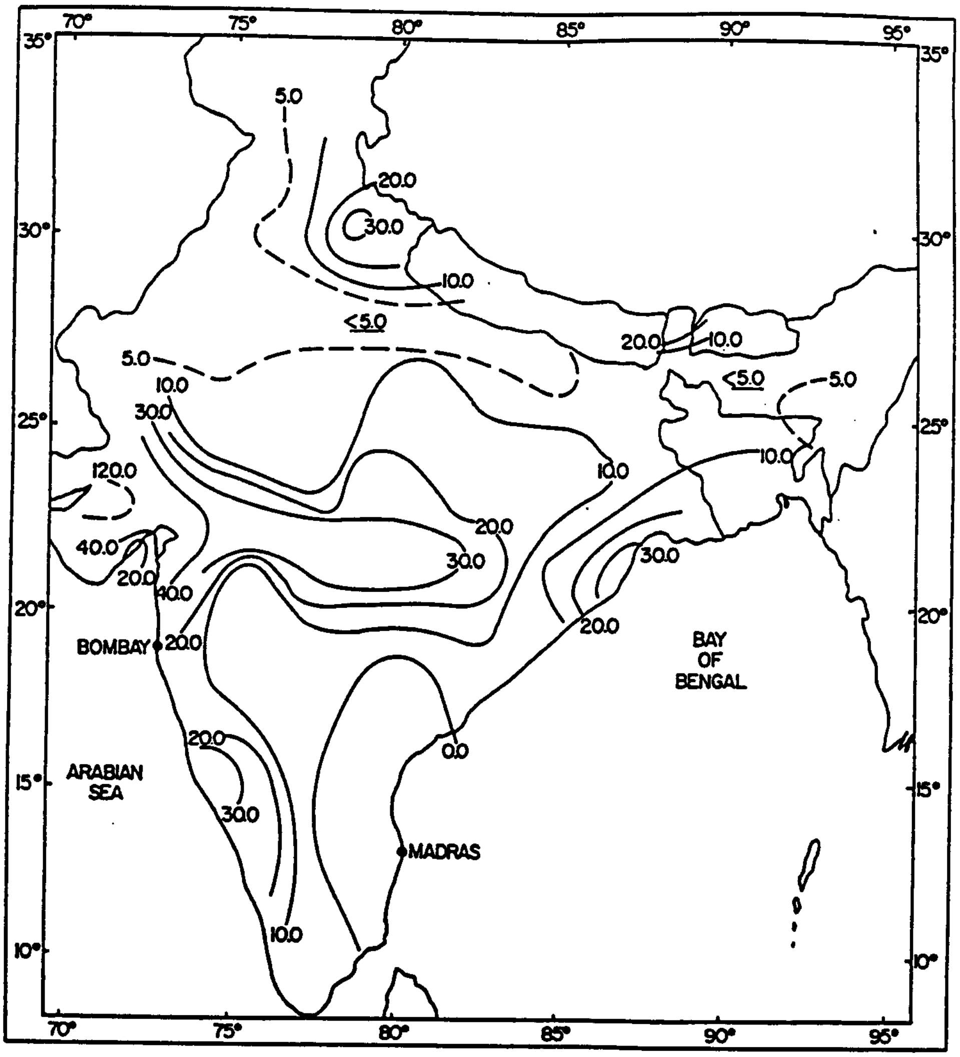

Fig. 2. Average rainfall distribution in mm per day for the period August 7–11, 1979. Monsoon was active during this period.

10 days for the soil to become dry again and in turn to cause a higher boundary layer.

Considering the three stations (Jodhpur, Lucknow and Calcutta) in the monsoon trough region, the two inland ones, Jodhpur and Lucknow behave somewhat differently from Calcutta close to the coast with respect to the variation of PBL height, as one would expect. But the correlation between precipitation and height still exists, with increased heights during the break phase. Convective conditions with larger background moisture in the coastal areas could have been the reason for the precipitation events around August 26. Considering Figure 5d for Nagpur located outside the mean monsoon trough region, trends in the variation of the boundary-layer heights are the same as for the other inland stations along the trough. Somewhat larger heights were observed during the transition from an

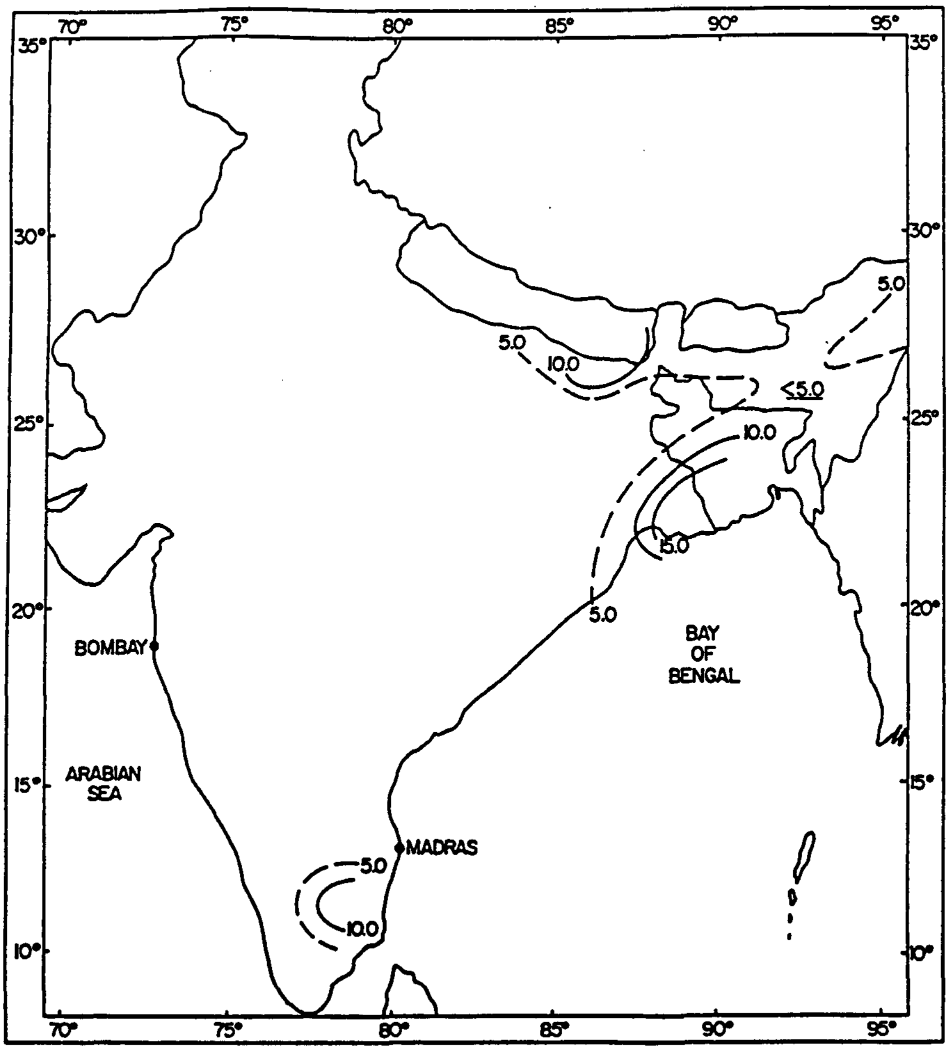

Fig. 3. Average rainfall distribution in mm per day for the period August 21–26, 1979. Monsoon was inactive during this period.

active to a break phase. Large precipitation of about 110 mm per day on August 8 at Nagpur is due to the movement of a tropical cyclone into the region.

Spatial variation of the mean daytime boundary-layer heights during the active and break phases of the monsoon at various stations in the monsoon trough region are shown in Figure 6. Again, shallow boundary layers occur during the active phase and deeper ones during the break phase except near the coast where they tend to be lower, possibly due to the development of thermal internal boundary layers (Stunder and Raman, 1986). There is a tendency for the PBL heights to increase inland closer to the heat low generally situated over the western region of the Indian subcontinent (around 20–30 °N, 65–75 °E). Heights of the PBL observed over the Bay of Bengal and the Arabian sea during MONEX79 were about 800 m during the active phase and about 100 m during the break phase (Holt and Raman, 1989). In a recent experiment, Raman *et al.* (1990) found the pre-

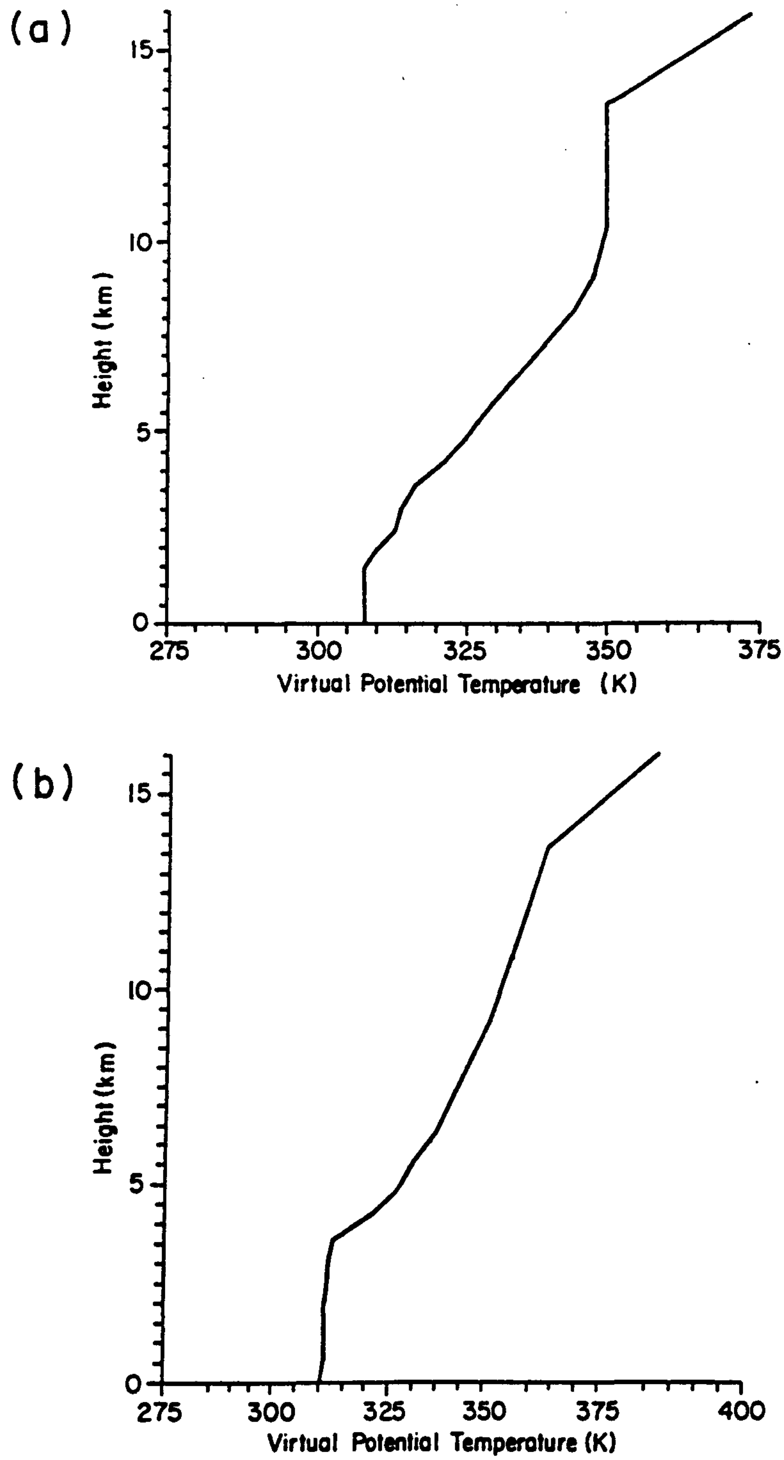

Fig. 4. A typical profile of virtual potential temperature at Jodhpur (a) on August 9, 1979 for an active monsoon condition (b) on August 29, 1979 for a break monsoon condition.

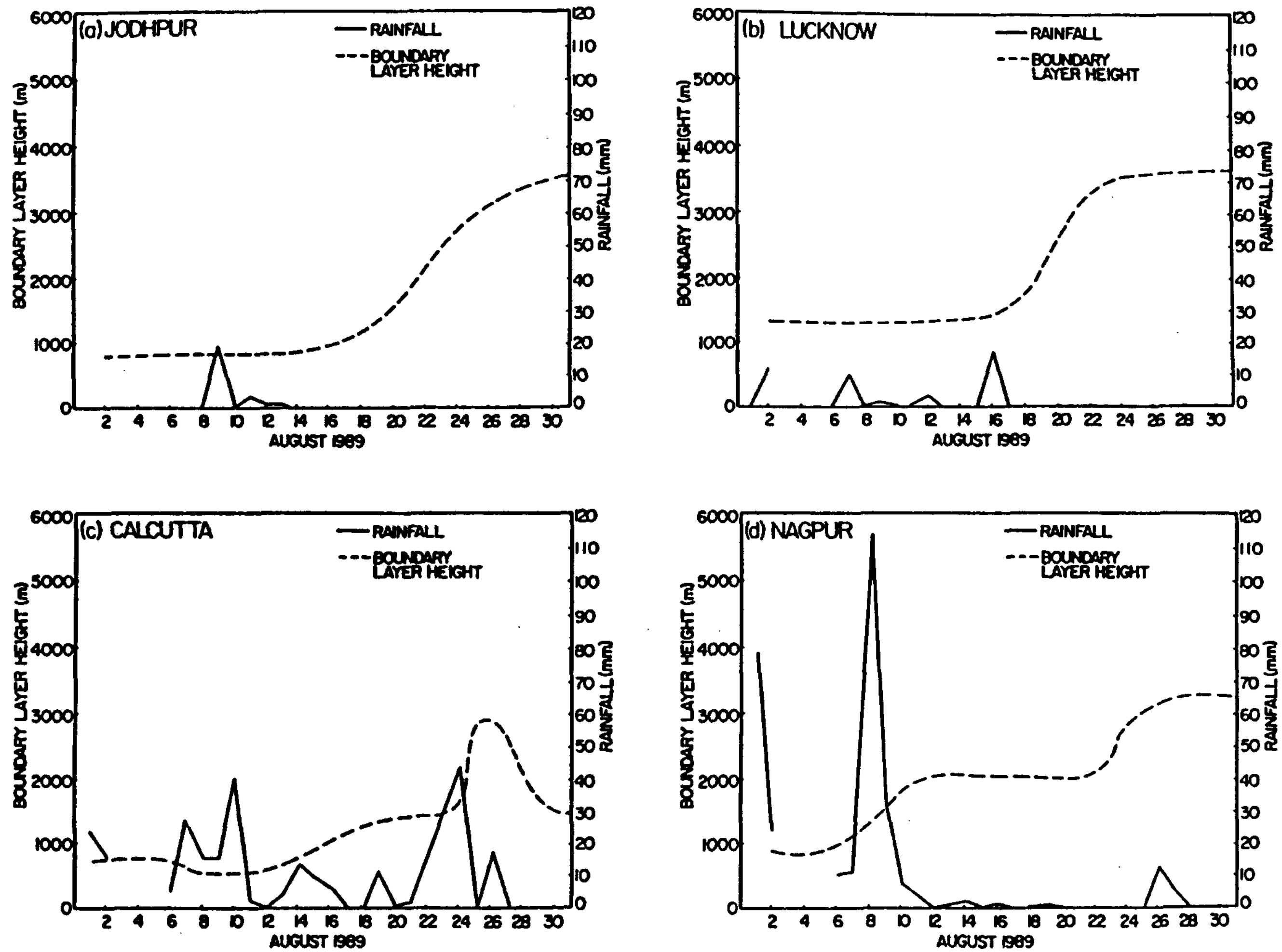

Fig. 5. Temporal variation of boundary-layer heights in m and daily rainfall in mm for August 1979 for the stations Jodhpur (JDP), Lucknow (LKN), Calcutta (CAL) and Nagpur (NGP).

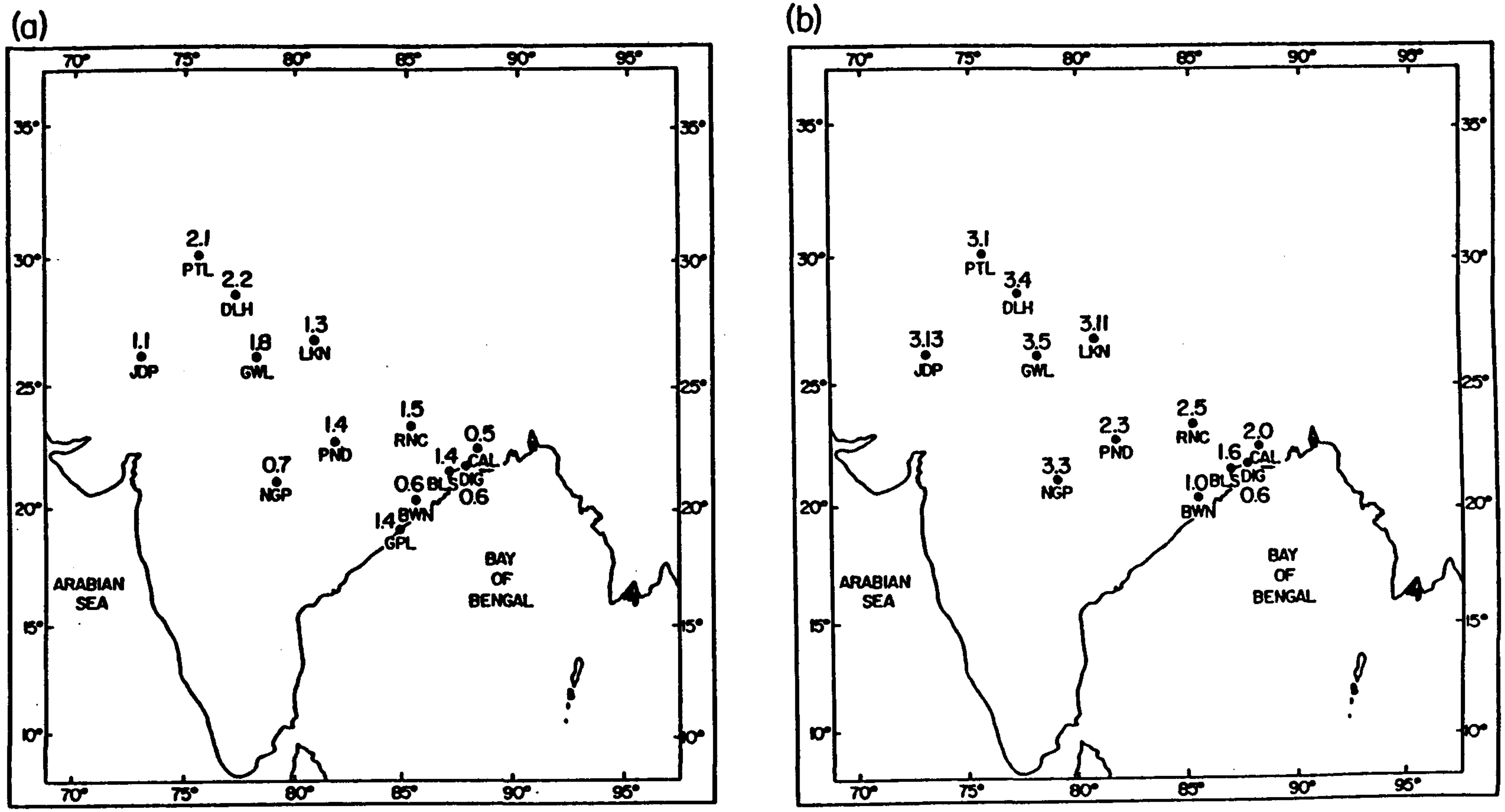

Fig. 6. Spatial variation of average boundary-layer heights (in km) (a) during an active phase (August 3–9, 1979) and (b) during a break phase (August 24–30, 1979).

monsoon boundary layer to have heights varying from 2300 to 3500 m at New Delhi. Height of the monsoon boundary layer at Bangalore was about 800 m, similar to values found over the Arabian sea during MONEX79 (Holt and Raman, 1986).

4. Conclusion

There is a significant variation of daytime boundary-layer heights over land along the monsoon trough during the Indian southwest monsoon. With break monsoon conditions, boundary-layer heights reach maximum values induced by strong surface heating and convection. Lower heights are found for active monsoon conditions when cloudy conditions are prevalent. The rate of increase from minimum to maximum boundary-layer height at any location appears to depend on soil moisture depletion. Maximum heights for both the active and the break phase occur over the desert region and minimum heights near the coast.

Many numerical models use a one-layer PBL of constant height contrary to the findings of this study leading to possible misrepresentation of the physics of the atmosphere. Improved physics in the PBL with better resolution (Holt and Raman, 1989) would be able to account for these changes in the structure of the boundary layer. The recently concluded Monsoon Trough Boundary Layer Experiment (Goel and Srivastava, 1990) should lead to increased understanding of this important phenomenon.

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