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THERMODYNAMIC FEATURES OF THE ATMOSPHERIC BOUNDARY LAYER DURING THE SUMMER MONSOON

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Abstract—Characteristic variations in the thermodynamic parameters of the atmospheric boundary layer at Pune (18°32′N, 73°51′E, 559 m a.s.l.) have been studied using the aerological observations collected during the summer monsoon seasons of 1980 and 1981, and temperature observations from aircraft during the summer monsoons of 1976, 1979–1981. This study showed suppression of the mixed layer, absence of inversion/stable layers and decreased convective instability in the lower layers during the period of active monsoon conditions. The reverse was observed during the periods of weak/break monsoon conditions. Temperature stratification of sub-cloud layer has been classified into four different categories depending on the extent of the mixed layer and the gradient of potential temperature in the overlying stable layer. It was observed that these categories cover all types of weather conditions which prevailed during the monsoon season. The results are discussed with the possible association of the weather conditions prevailed during the active and break monsoon periods.

Key word index: Atmospheric boundary layer, monsoon boundary layer, variations in monsoon boundary layer, monsoon activity and boundary layer.

1. INTRODUCTION

Information on variations in the atmospheric boundary layer (ABL) characteristics during different weather conditions is important in understanding the role of ABL in the large scale weather systems and in the dispersion of dust and pollutants (Ching *et al.*, 1988; Hong and Carmichael, 1986). The transformation of the ABL accompanying the onset of deep convection was studied by different workers (Emmitt, 1978; Johnson, 1981; Echternacht and Garstang, 1976). Such studies over the Indian region during summer monsoon are scanty (Srinivasan and Sadasivan, 1975; Parasnis *et al.*, 1985). The variations in the ABL parameters at Pune (18°32′N, 73°51′E, 559 m a.s.l.) during two periods of contrasting synoptic weather conditions have been studied using the aerological observations during the summer monsoon of 1980. The two periods were chosen on the basis of the positions of monsoon trough, cyclonic circulation etc. When the monsoon trough is located along the Gangetic plains protruding into the Bay of Bengal, active monsoon conditions seem to prevail over the major part of India (Rao, 1976). When the trough migrates farther to the north and lies along the foothills of the Himalayas, it coincides with a break in the monsoon (Sikka, 1978). Active monsoon conditions are usually periods of heavier rainfall while break monsoon conditions show a dramatic decrease in rainfall.

Boundary layers observed during the monsoon season in which a number of not yet fully understood processes of different scales interact greatly affect the lowest levels of the atmosphere. The influence of large scale monsoon features such as monsoon trough, depressions and low-level jets on the boundary layer, and *vice versa*, are not well understood (Holt and Sethuraman, 1987). Using the aerological observations at Pune during the summer monsoon seasons of 1980 and 1981, the variations and steadiness of the thermodynamic parameters of the ABL and their pattern of distribution have been brought out. Although the variations in the meteorological parameters in the ABL are mostly governed by the large scale weather systems such as the SW monsoon, they more or less follow a normal distribution pattern.

An understanding of the stratification of sub-cloud layer during the various facets of the summer monsoon has an important bearing with the responses of the boundary layer to the large scale weather systems (Parasnis *et al.*, 1980). Temperature observations collected by aircraft during the summer monsoon seasons of 1976, 1979–1981 have been used to study the temperature stratification of the lowest 1500 m (a.s.l.) layer. Since the cloud base height over this region during the monsoon season corresponds to this height (Selvam *et al.*, 1980), this layer is therefore termed as sub-cloud layer in this paper. The stratification has been classified into four different categories depending on the extent of the mixed layer (layer of constant potential temperature) and the gradient of potential temperature in the overlying stable layer. The purpose of this paper is to present and discuss the characteristic variations of the thermodynamic parameters and the stratification of ABL during different weather conditions prevailing in the summer monsoon season. The location of observations is shown in Fig. 1.

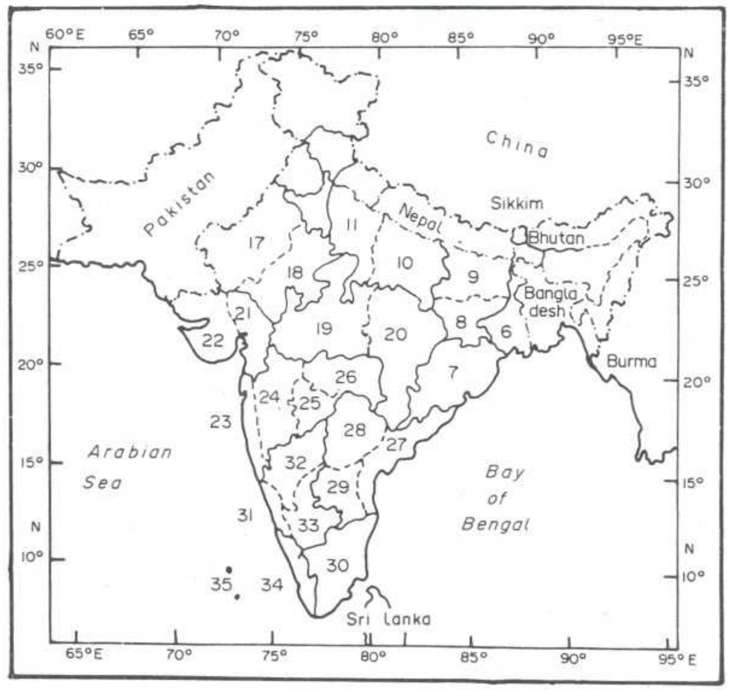

Fig. 1. A map of India showing different sub-divisions. Pune is in sub-division No. 24 and 19 and 20 correspond to Madhya Pradesh.

2. VARIATIONS IN THERMODYNAMIC PARAMETERS IN ABL DURING CONTRASTING WEATHER CONDITIONS

Pune is situated on the lee side of the Western Ghats. Winds are mostly west to southwest in the lower troposphere. Synoptic situations which are more favourable for prominent weather development over Pune are: (i) when a depression from the east coast takes a more southerly course; (ii) when the axis of the monsoon trough in the mid-troposphere (2.5–3.5 km) is situated along a more southerly latitude (19–20°N) and (iii) the presence of a trough of low pressure off the westcoast.

The two periods considered in this paper are 12–17 July 1980 and 1–6 August 1980. The first period represents the break monsoon conditions and during the later period the monsoon was active. During the break monsoon conditions (12–17 July 1980) the axis of the monsoon trough was located at the foothills of Himalayas. The period of active monsoon conditions (1–6 August 1980) was associated with the southward shift of the monsoon trough to its normal position. There was a cyclonic circulation over the central part of Madhya Pradesh in the lower troposphere in the first half of this period. In the later half it moved west in south Madhya Pradesh and adjoining north Maharashtra. The trough off the west coast also persisted. The representative synoptic situations during the two periods are shown in Figs 2a and 2b. Thermodynamic parameters such as virtual potential temperature (θ_v K), equivalent potential temperature (θ_e K) were computed from the aerological observations obtained during the two periods of active and break monsoon as mentioned above. The thermodynamical parameters were obtained at an interval of 50 mb starting from the surface up to 500 mb. Zonal and meridional transports of heat and moisture ($U\theta$, $U\theta_e$; $V\theta$, $V\theta_e$) in the lowest 340 m a.s.l. layer have been obtained using the Pilot Balloon observations at Pune.

Mean profiles of temperature (T), θ_v and θ_e during the two periods are shown in Fig. 3. The profiles during break monsoon period and active monsoon period are shown by dotted lines and solid lines, respectively. The dry adiabatic lapse rate curve is also shown for comparison. Profiles of zonal and meridional transports of heat and moisture (up to 340 m) are shown in Fig. 4. These transport values have been obtained by taking products like $U\theta$, $U\theta_e$, $V\theta$ and $V\theta_e$. Dotted lines represent transport profiles during break monsoon conditions and solid lines represent those for active monsoon conditions.

2.1. *Variations in* T *and* θ_v *profiles*

On the days of active monsoon conditions the temperature profiles showed adiabatic stratification up to 850 mb and then stable lapse rates aloft, whereas on the days of break monsoon adiabatic stratification was observed up to 780 mb (Fig. 3). A temperature inversion layer (2°C km^{-1}) was observed between 750 and 700 mb during break monsoon days. θ_v profiles during the two periods showed slightly more stability during active monsoon periods compared to that on break monsoon periods except between 750 and 700 mb layer which is marked by stable (inversion) region. This stable (inversion) layer was observed on all the 6 days of observations. It has been shown that if

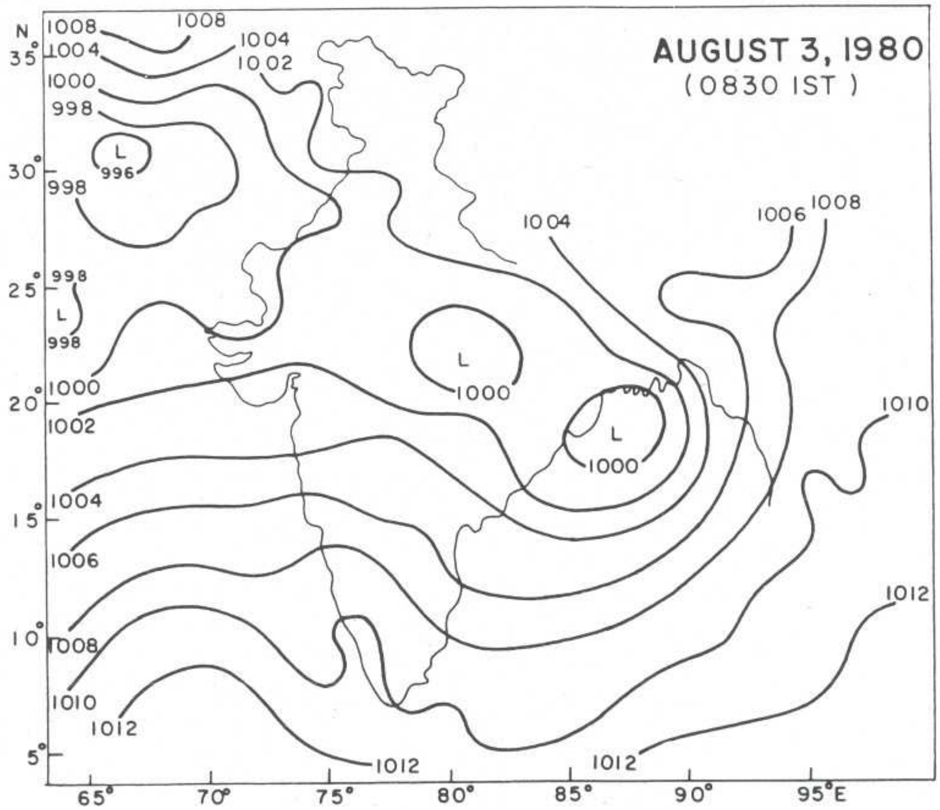

Fig. 2a. Representative synoptic situation for active monsoon period (1–6 August 1980).

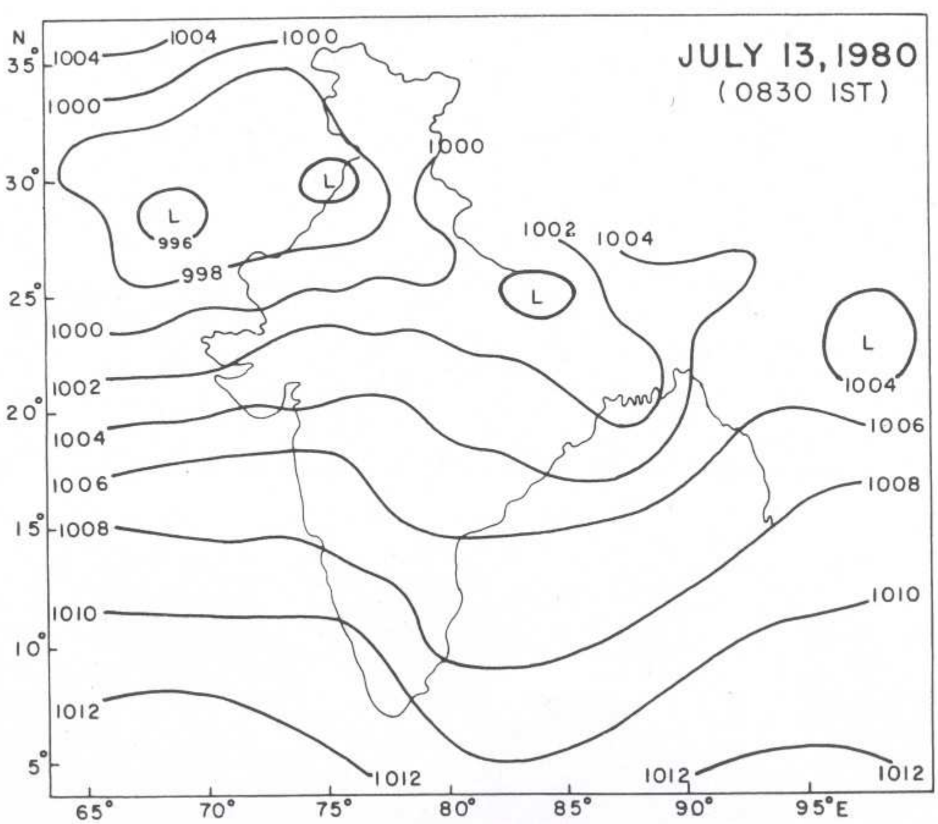

Fig. 2b. Representative synoptic situation for break monsoon period (12–17 July 1980).

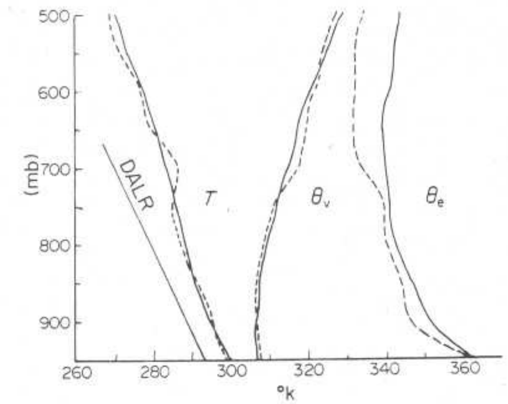

Fig. 3. Mean profiles of T, θ_v, θ_e on break (– – – –) and active (———) monsoon periods. DALR indicates dry adiabatic lapse rate.

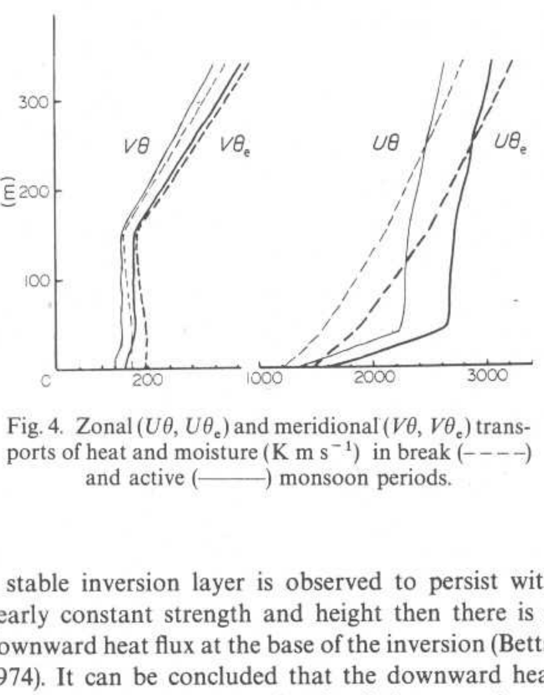

Fig. 4. Zonal ($U\theta$, $U\theta_e$) and meridional ($V\theta$, $V\theta_e$) transports of heat and moisture (K m s^{-1}) in break (– – – –) and active (———) monsoon periods.

a stable inversion layer is observed to persist with nearly constant strength and height then there is a downward heat flux at the base of the inversion (Betts, 1974). It can be concluded that the downward heat flux at the base of the inversion implied suppression of convective activity during the break monsoon conditions. Since convective clouds can play an important role in the vertical transport of pollutants, the pollutant dispersal could be similarly affected (Ching *et al.*, 1988). On active monsoon days the moisture from lower levels is pumped upwards by synoptic disturbances. The mid-tropospheric cyclonic circulation causes pumping of the moisture to higher levels (Srinivasan and Sadasivan, 1975). Thus the transport of moisture content to higher levels is attributed to the synoptic conditions prevailed on active monsoon days. On the days of break monsoon conditions, due to absence of favourable synoptic system the moisture did not reach beyond 750 mb.

2.2. *Variations in θ_e profiles*

θ_e profiles during the two periods of contrasting synoptic weather conditions showed differences. θ_e is a useful measure for the convective instability of the atmosphere. θ_e profiles during the break monsoon period showed more convective instability in the lower layer (up to 900 mb) than that on active monsoon days (Fig. 3). This has also been observed in an earlier study (Srinivasan *et al.*, 1975). In spite of the increased convective instability on the days of break monsoon period cloud development is inhibited because of the synoptic scale subsidence. There is a difference of about 8 K in the θ_e minimum values between the two periods. During periods of increased deep convection, energy primarily in the form of moisture is transported from lower layer into the layer of θ_e minimum, thus increasing the θ_e minimum in that layer.

2.3. *The variability and pattern of distributions of these thermodynamical parameters have been brought out and given in the Appendix*

2.4. *Zonal and meridional transports of heat and moisture*

The meridional transports of heat and moisture ($V\theta$, $V\theta_e$) did not show much difference during the two periods. There was a slight increase in meridional transport on break monsoon days. During the active monsoon period the zonal transports of heat and moisture showed larger values in the lower subcloud layer and slow increase upwards whereas during the break monsoon period increases occurred from the surface to 340 m (Fig. 4).

3. TEMPERATURE STRATIFICATION DURING DIFFERENT WEATHER CONDITIONS

The temperature measurements were made using a bimetallic thermometer. It consisted of bimetallic sensor with a suitable housing (Weston, U.S.A.). The accuracy of the thermometer was estimated to ± 0.5°C in the range 0–40°C. The housing of the thermometer was designed so as to prevent the sensor from becoming wet. A Dakota aircraft was used for these observations. The observations were carried out between 1300 and 1400 IST. The heights as obtained from the corrected altimeter reading were used to compute the potential temperature (θ) at an interval of 150 m from surface up to 1500 m.

3.1. *Categorization of temperature stratification*

The temperature stratification up to 5000 ft has been classified into four different categories depending on the extent of mixed layer and gradient of θ in overlying stable layer. The extent of the mixed layer has been determined by considering the gradient of θ (in adiabatic stratification the gradient of θ vanishes, however in Category I gradient of θ up to 2 K km^{-1} has been also considered as adiabatic stratification). These categories are shown in Figs 5–8 in which the X-axes are θ in K and Y-axes are the heights in feet (conversion factor 100 feet = 30.48 m). These categories are described below.

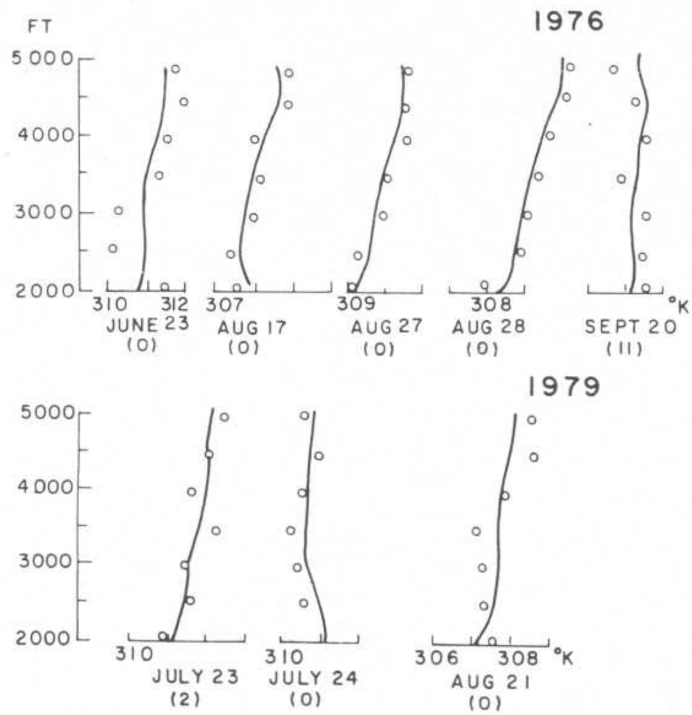

Fig. 5. Temperature stratification for Category I. The figure in parentheses at the bottom is rainfall (mm).

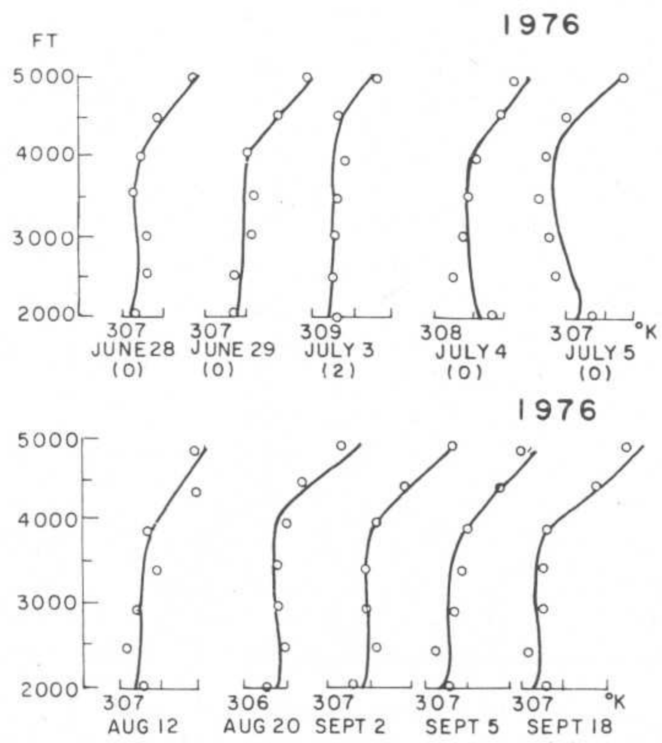

Fig. 6. Same as Fig. 5 for Category II.

Category I: The sub-cloud layer was adiabatically stratified.

Category II: The layer up to 4000–4500 ft was adiabatically stratified. The overlying stable layer was having gradient of θ 5–6 K km^{-1}.

Category III: There is adiabatic stratification up to 3000–3500 ft. The overlying layer was stably stratified with gradient of θ 4–5 K km^{-1}.

Category IV: The whole sub-cloud layer was stably stratified with gradient of θ 5–6 K km^{-1}.

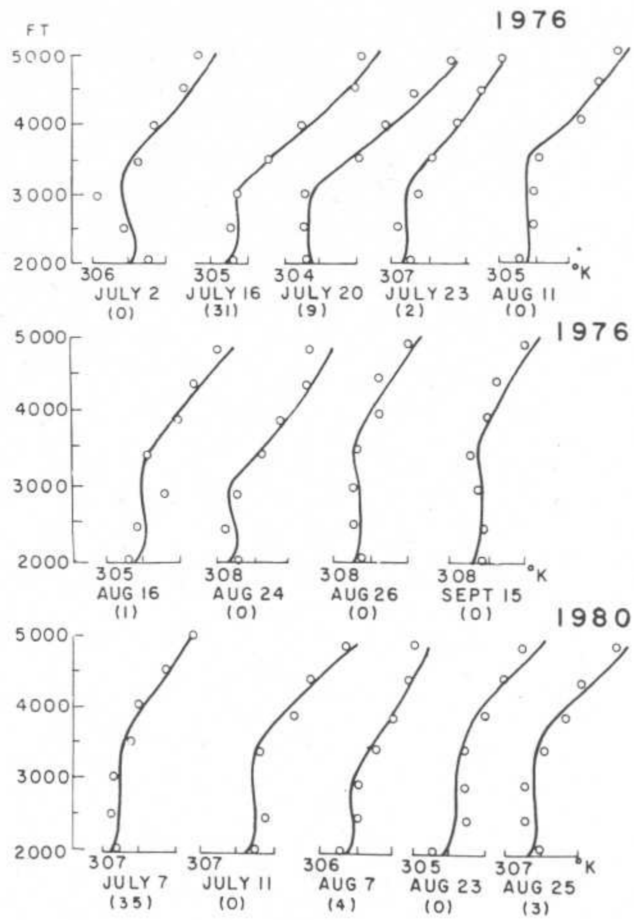

Fig. 7. Same as Fig. 5 for Category III.

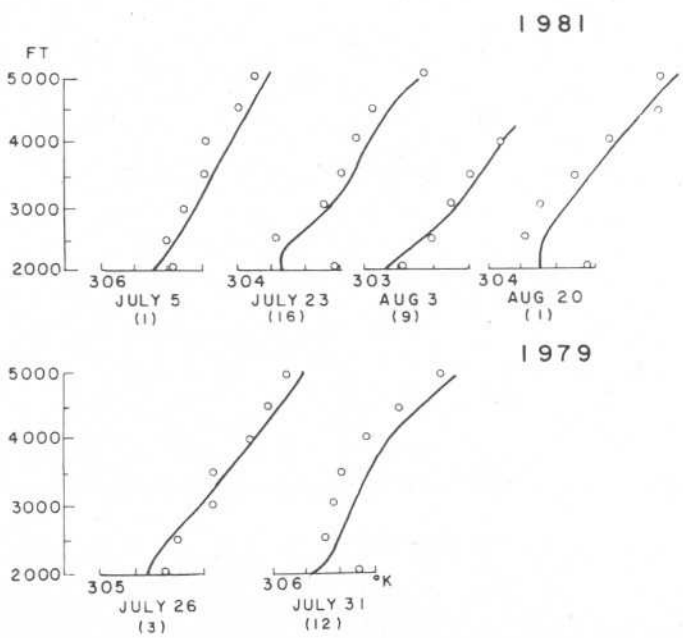

Fig. 8. Same as Fig. 5 for Category IV.

In the absence of any favourable synoptic weather conditions, the monsoon activity weakens. During the summer monsoon season, surface temperature rises by 4–10°C in a few hours from sunrise, generating dry convection. The convective mixing makes the air layer adiabatic (Category I). When the weather conditions change due to presence of a favourable synoptic system, the moisture in the atmospheric boundary layer (ABL) is pumped upwards. The moist convection reaches to higher levels and cloud increases. As the cloudiness increases, the cloud bases appear at lower height (Categories II and III). The increasing intensity of moist convection enhances the cloudiness and downdrafts. Also, if the process continues, it results in precipitation. During such situations, the sub-cloud layer becomes stably stratified (Category IV).

On the days Category I, mostly dry convective conditions prevailed. The adiabatic stratification up to 5000 ft is attributed to the penetration of convective currents to high levels. The above results are in agreement with those reported by others (Moores *et al.*, 1979; Garstang and Betts, 1974). On the days of Category II, weak to moderate moist convection prevailed. If Category I represents the undisturbed state of the ABL then Category II would represent a transition to a slightly disturbed state of ABL. Similar results have been obtained by Ruiz (1975) and Gaynor and Ropelwaski (1979). On the days of Category III, moderate to active moist convective conditions prevailed. The lowering of cloud base and hence the lifting condensation level limit the growth of the mixed layer. On the days of Category IV the mixed layer was absent. The lapse rate of the temperature up to 5000 ft was nearly saturated adiabatic. The absence of mixed layer is attributed to the suppression of turbulent activity by rain or downdraft (Seguin and Garstang, 1976).

Categories I–IV represent the modification of the sub-cloud layer due to atmospheric conditions, i.e.

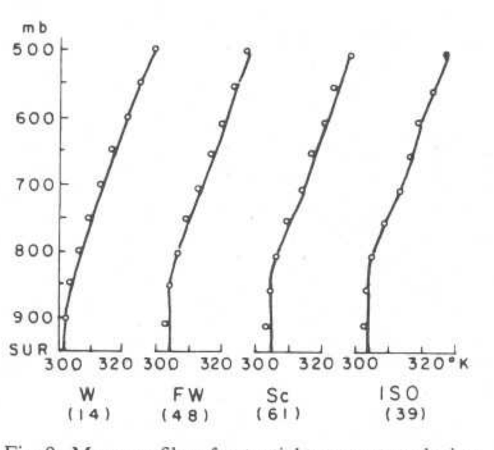

Fig. 9. Mean profiles of potential temperature during fairly widespread (FW), widespread (W), scattered (SC), and isolated (ISO) type of monsoon activity during 1980 and 1981. Numbers in parentheses indicate number of days.

clouds and precipitation. They depict the states of transformation of ABL from undisturbed to disturbed, which is in agreement with Houze (1971) and Zipser (1977). The four different categories observed in temperature stratification of the sub-cloud layer showed responses of the boundary layer to different weather conditions. The first and second categories represent break and weak monsoon conditions, respectively. The third and fourth categories are associated with moderate to active monsoon conditions. The rainfall amounts (given in Figs 5–8 at the bottom) also, in general, support the weather conditions prevailed on those days. These results are supported by the mean profiles of θ obtained using the aerological observations during 1980 and 1981 during different activities of monsoon (Fig. 9). These profiles indicate that the extent of the convectively mixed layer gets suppressed as the activity of the monsoon increases.

4. CONCLUDING REMARKS

The study of the variations in the thermodynamic characteristics of the ABL during the periods of contrasting synoptic weather conditions showed that the thermodynamic parameters were dominated by the deep moist convection/subsidence associated with the synoptic weather conditions. The profiles of T, θ_v, θ_e during the two periods of contrasting synoptic weather conditions showed differences. The active monsoon conditions were associated with lowering of mixed layer height, absence of inversion/stable layers and decreased convective instability in the lower layers of monsoon ABL. The reverse was observed on break monsoon days. Very little information is available on the activity of the boundary layer processes associated with deep moist/unsaturated and near dry processes within the span of monsoon trough. It can, however, be visualized that important interactions would occur under normal as well as under extreme conditions of active and break monsoon conditions. Observations during MONTBLEX 1989 (Monsoon Trough Boundary Layer Experiment) may hopefully prove useful for further investigations.

The study of the temperature stratification of sub-cloud layer using the temperature observations carried out in aircraft showed that these stratifications can be classified into four different categories depending on the extent of the mixed layer and gradient of potential temperature in the overlying stable layer and they represent different weather conditions during the summer monsoon season. The first and second categories can be associated with break to weak monsoon conditions. They appear to be consistent with the preponderance of subsidence and feeding in of dry air from aloft as observed on break/weak monsoon conditions as discussed in section 2. The third and fourth categories could be associated with moderate to active monsoon conditions in which the moisture reaches to higher levels due to synoptic scale convergence.

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REFERENCES

Betts A. K. (1974) Reply to comment on 'Non-precipitating cumulus convection and its parameterization'. *Q. Jl R. met. Soc.* **100,** 469–471.

Ching J. K. S., Shipley S. T. and Browell E. V. (1988) Evidence of cloud venting of mixed layer ozone and aerosols. *Atmospheric Environment* **22,** 225–242.

Echternacht K. L. and Garstang M. (1976) Change in the structure of the tropical sub-cloud layer from undisturbed to disturbed states. *Mon. Wea. Rev.* **104,** 407–417.

Emmitt G. D. (1978) Tropical cumulus interaction with and modification of the sub-cloud layer. *J. atmos. Sci.* **35,** 1485–1502.

Garstang M. and Betts A. K. (1974) A review of the tropical boundary layer and cumulus convection. *Bull. Amer. Met. Soc.* **55,** 1195–1205.

Gaynor J. E. and Ropelwaski C. F. (1979) Analysis of the convectively modified GATE boundary layer using insitu and acoustic sounder data. *Mon. Wea. Rev.* **107,** 985–993.

Holt T. and Sethuraman S. (1987) A comparison of the significant features of the marine boundary layer over the East Central Arabian Sea and the North Central Bay of Bengal during MONEX-79. *Mausam* **38,** 171–176.

Hong M. S. and Carmichael G. R. (1986) Examination of a Subgrid-scale parameterization for the transport of pollutant in a non-precipitating cumulus cloud ensemble. *Atmospheric Environment* **20,** 2205–2217.

Houze R. A. (1971) Structure and dynamics of a tropical squall-line system. *Mon. Wea. Rev.* **105,** 41–55.

Johnson R. H. (1981) Large effects of deep convection on the GATE tropical boundary layer. *J. atmos. Sci.* **38,** 2399–2413.

Mohanty U. C. and Dube S. K. (1981) Statistical structure of the meteorological parameters over the Bay of Bengal during Monsoon-77 experiment. *Mausam* **32,** 51–54.

Moores W. H., Caughy S. J., Readings C. J., Milford J. R., Mansfield D. A., Abdulla S., Guyner T. H. and Johnston W. B. (1979) Measurements of boundary layer structure and development over S. England using a aircraft and tethered balloon instrumentation. *Q. Jl R. met. Soc.* **105,** 397–421.

Parasnis S. S., Krishna K. and Mohan B. (1980) Temperature stratification of the atmospheric boundary layer over the Deccan Plateau, India during the summer monsoon. *Boundary-Layer Met.* **19,** 165–174.

Parasnis S. S., Selvam A. M. and Ramana Murty Bh. V. (1985) Variations of the thermodynamical parameters in the atmospheric boundary layer over the Deccan Plateau region, India. *Pure appl. Geophys.* **123,** 305–313.

Rao Y. P. (1976) Southwest monsoon. *Met. Monogr.* **1.** India Meteor. Dept.

Ruiz O. (1975) Meso-scale study of the tropical sub-cloud layer. Report No. 237, Dept. Atmos. Sci., Colorado State University.

Seguin W. R. and Garstang M. (1976) Some evidence of the effects of convection on the tropical sub-cloud layer. *J. atmos. Sci.* **33,** 660–666.

Selvam A. M., Murty A. S. R., Vijayakumar R., Paul S. K., Manohar G. K., Reddy R. S., Mukherjee B. K. and Ramana Murty Bh. V. (1980) Some thermodynamical and microphysical aspects of monsoon clouds. *Proc. Indian Acad. Sci.* (*Earth Planet Sci.*) **89,** 215–230.

Sikka D. R. (1978) Some aspects of life history, structure and movement of monsoon depressions. In *Monsoon Dynamics* (edited by T. N. Krishnamurty), pp. 1501–1529. Birkhauser, Basel, Switzerland.

Srinivasan V. and Sadasivan V. (1975) Thermodynamical structure of the atmosphere over India during southwest monsoon season. *Indian J. Met. hydrol. Geophys.* **26,** 169–180.

Srinivasan V., Raman S. and Sadasivan V. (1975) Some aspects of the thermodynamic structure of monsoon depressions. *Indian J. met. hydrol. Geophys.* **26,** 487–491.

Zipser E. J. (1977) Mesoscale and convective-scale downdrafts as district components of squall-line structure. *Mon. Wea. Rev.* **105,** 1568–1589.

APPENDIX: VARIABILITY AND PATTERN OF DISTRIBUTION OF ATMOSPHERIC BOUNDARY LAYER PARAMETERS

Aerological observations were carried out between 1100 and 1130 IST daily during the summer monsoon seasons of 1980 and 1981. The meteorological parameters considered in this study are: temperature (T), potential temperature (θ), equivalent potential temperature (θ_e) and relative humidity (r.h.). The values of these parameters were obtained at 50 mb interval from surface up to 500 mb. The standard deviation (σ), coefficient of variation (CV), skewness and kurtosis with their standard errors (σ_s and σ_k) have been computed using the standard formulae (Mohanty and Dube, 1981). Lower values of σ and CV correspond to high steadiness, space-homogeneity and time stationarity. The values of skewness and kurtosis reveal the pattern of distribution followed by the meteorological parameters as compared to normal distribution and their standard errors enable one to infer the extent to which they follow a normal distribution.

Vertical profiles of skewness and kurtosis for T, θ, θ_e and r.h. from surface up to 500 mb are shown in Figs A1 and A2 for the two years 1980 and 1981. The limits for skewness and kurtosis for the normal distribution are shown in the Figs A1 and A2 by vertical dotted lines. The values of standard errors for skewness and kurtosis are 0.3 and 0.5, respectively for the present study. The limiting values for skewness and kurtosis are given as $\pm 3\sigma_s$ and $\pm 5\sigma_k$ (Mohanty and Dube, 1981). Table A1 gives the values of σ and CV (%) for T, θ, θ_e and r.h. for 1980 and 1981. From this table it can be seen that although the variations in T and θ, by and large, showed small values at all levels, slightly higher values were observed in the higher levels (700–500 mb). The steadiness of T and θ also showed decreasing trend in the 700–500 mb layer. The values of σ and CV did not exceed 2 and 1%, respectively. The differences in the variations of the meteorological parameters in lower and higher layers are attributed to the variations in the monsoon activity. This has also been observed in the case of θ_e values. The values of σ and CV in case of θ_e are 4–6% and $< 2\%$, respectively (Table A1). The higher values of σ at 900 mb may be due to the variations in the convective instability in the lower layers. Convective instability in the lower layer of the monsoon ABL is related to the monsoon activity. When the monsoon is active due to a favourable synoptic weather system, the convective instability in the lower layer is weakened. Although the convective instability is initially good for promoting convection, later on convection destroys it. Thus it is less during active monsoon conditions and more during weak monsoon conditions (Srinivasan *et al.*, 1975). Although the variability in θ_e with altitude is uniform in the layer above 900 mb, in extreme weather conditions the difference in θ_e is considerably greater

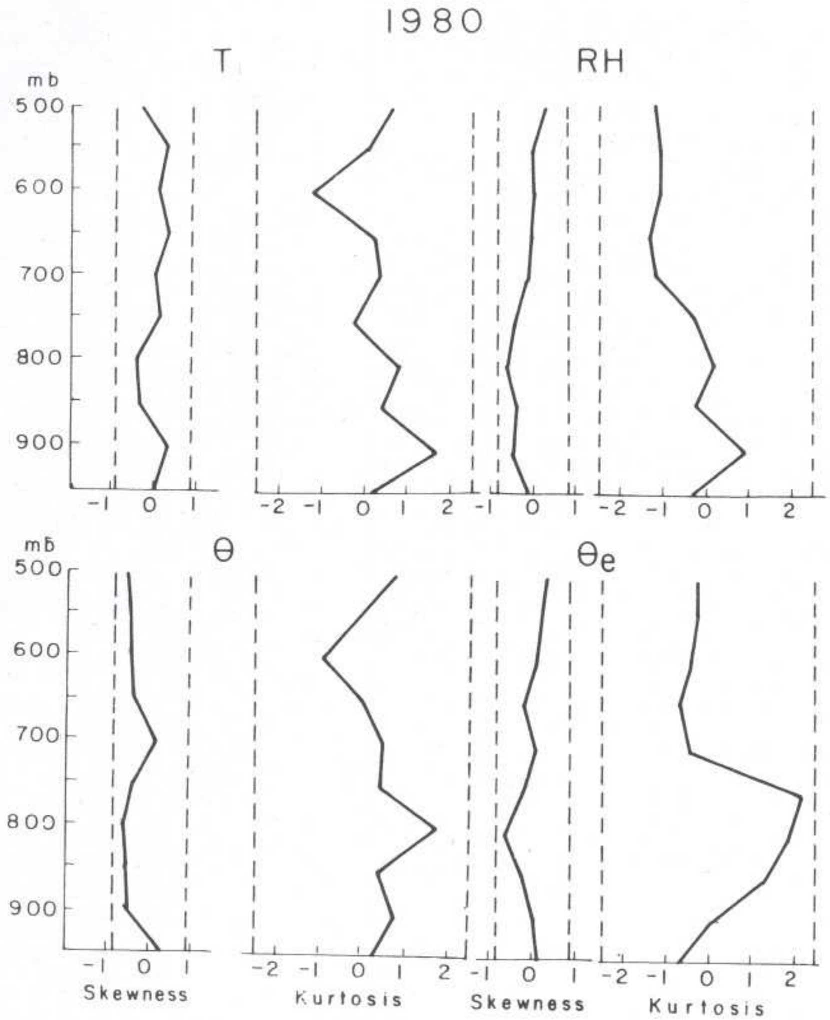

Fig. A1. Profiles of skewness and kurtosis for T, θ, θ_e and r.h. for 1980. Dotted lines indicate limits for normal distribution.

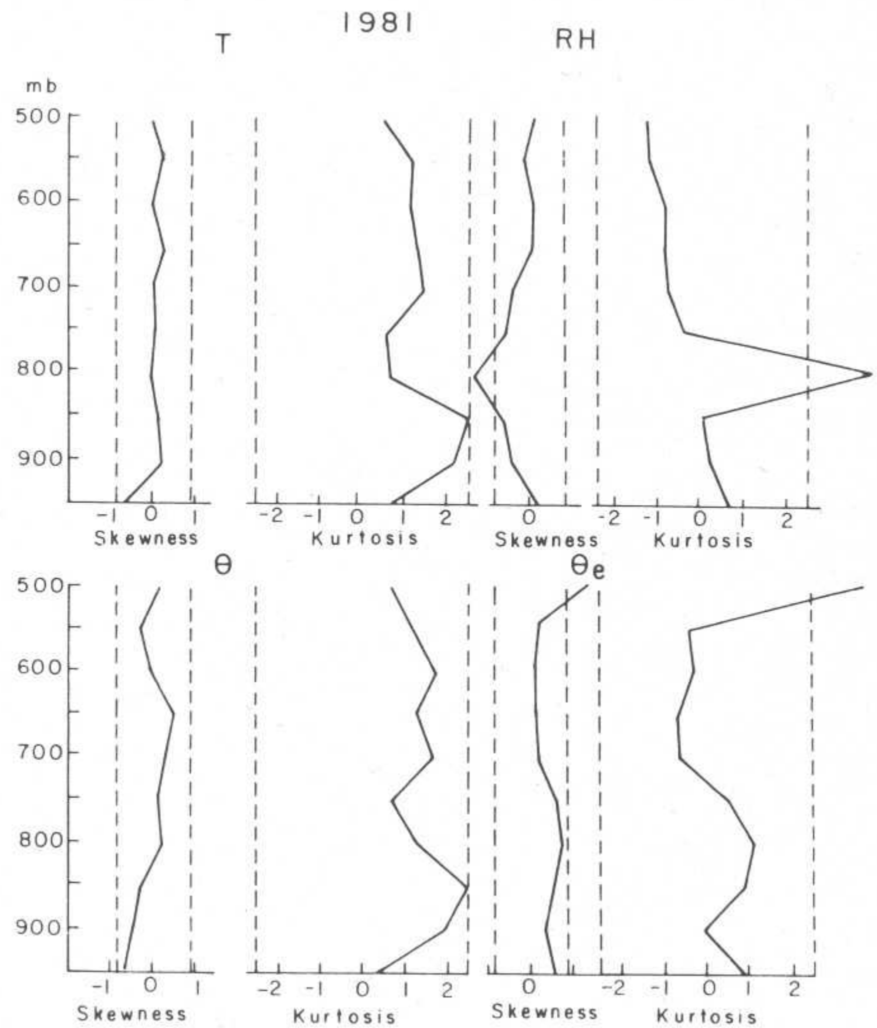

Fig. A2. Same as Fig. A1 for 1981.

Table A1. Values of standard deviation, coefficient of variation (%) for T, θ, θ_e and r.h. during 1980 and 1981

Level (mb)	T STD	T CV	θ STD	θ CV	θ_e STD	θ_e CV	r.h. STD	r.h. CV
Year 1980								
Surface	1.3	0.4	1.2	0.4	3.8	1.1	5.4	6.5
900	1.5	0.5	1.6	0.5	0.6	1.9	8.1	10.6
850	1.5	0.5	1.5	0.5	5.4	1.6	8.3	10.2
800	1.4	0.5	1.4	0.5	4.8	1.4	8.8	10.6
750	1.2	0.4	1.3	0.4	4.7	1.4	11.5	14.4
700	1.6	0.6	1.8	0.6	5.8	1.7	18.5	27.6
650	1.9	0.7	2.1	0.7	6.3	1.9	19.8	33.5
600	1.7	0.6	2.0	0.6	5.5	1.6	19.8	34.9
550	1.9	0.7	2.2	0.7	5.6	1.7	19.7	35.1
500	1.9	0.7	2.1	0.7	5.1	1.5	19.9	37.0
Year 1981								
Surface	0.9	0.3	0.9	0.3	4.0	1.1	6.2	7.8
900	1.6	0.5	1.6	0.5	6.5	1.9	8.2	10.2
850	1.6	0.5	1.7	0.6	6.1	1.8	8.9	10.6
800	1.6	0.6	1.7	0.5	6.0	1.8	10.1	11.8
750	1.7	0.6	1.9	0.6	6.1	1.8	13.8	17.4
700	1.9	0.7	2.1	0.7	6.2	1.9	18.5	27.5
650	1.8	0.7	2.0	0.7	6.0	1.8	17.6	28.8
600	1.7	0.6	2.0	0.6	5.3	1.6	18.0	31.0
550	1.6	0.6	1.9	0.6	5.1	1.5	21.7	36.9
500	1.6	0.6	2.0	0.6	4.4	1.3	20.7	36.5

(Fig. 3). This is attributed to the moisture content which reaches higher levels during active monsoon conditions. The values of σ and CV in the case of r.h. are between 6 and 21 and 6 and 37%, respectively (Table A1). In the lower layers (up to 700 mb) the variability of r.h. is less than that in the layers above 700 mb level. The steadiness of r.h. values in the lower layers of monsoon ABL is due to the fact that the moisture content of the lower atmosphere (up to 850 mb) remains unaltered irrespective of the activity of the monsoon (Srinivasan and Sadasivan, 1975). The large variability in r.h. in the higher layer may be due to the difference caused by removal of water vapour by precipitation in the convergent zone during active monsoon conditions.

The distribution of these meteorological parameters in the monsoon ABL can be deduced from the vertical profiles of skewness and kurtosis. From Figs A1 and A2, it is clear that, in general, the values of skewness and kurtosis did not exceed the limits of normal distribution (dotted lines). Thus the meteorological parameters follow normal distribution. This result is in agreement with earlier result obtained from the space–time variations of meteorological parameters over the Bay of Bengal (Mohanty and Dube, 1981). The variations in the meteorological parameters in the monsoon ABL is the result of the interactions of boundary layer processes and the large scale weather processes. In other words, the responses of the meteorological parameters to the large scale weather processes is such that the distribution do not deviate from normal. The activity of the monsoon during both the years 1980 and 1981 was normal.