Mausam, (1986), **37**, 1, 123-128

551.511.33 : 551.553.21

Study of thermodynamic parameters in strong and break monsoon

D. S. DESAI

Meteorological Office, Pune

(*Received 22 April 1983*)

सार — भारत पर दक्षिण-पश्चिमी मानसून वर्षा के आकाशीय वितरण तथा तीव्रता में उतार-चढ़ाव सर्वविदित हैं। भारत पर वर्षण गतिविधि में धक्का (उत्क्षेप) प्रबल मानसून का कारण बनता है तथा बाद में वर्षा रुक जाती हैं। इस प्रकार मानसून में बाधा आती है या वह कमजोर पड़ जाता है। ये स्थितियां विभिन्न सिनॉप्टिक स्थितियों से विशेष रूप से संबद्ध हैं। इन दो विशिष्ट अवस्थाओं में शुष्क बल्ब तापमान, ओसांक तापमान, विभव तापमान, समतुल्य विभव तापमान तथा संश्लिष्ट आर्द्र स्थैतिक ऊर्जा जैसे ऊष्मागतिकीय परिमापकों का अध्ययन किया जाता है तथा पूर्वानुमान में उनके सम्भावित उपयोग को उभारा जाता है।

ABSTRACT. Fluctuations in the intensity and spatial distribution of southwest monsoon rainfall over India are well known. Spurt in the rainfall activity over India leading to strong monsoon and cessation in the rainfall activity leading to break/weak monsoon are typically associated with different synoptic situations. In these two typical situations, the variations of thermodynamic parameters like dry bulb temperature, dew point temperature, potential temperature, equivalent potential temperature and saturated moist-static energy are studied and their possible use in forecasting are highlighted.

1. Introduction

The southwest monsoon rainfall over India shows characteristic fluctuations in its intensity and spatial distributions. In strong monsoon, there is increased and heavy rainfall over India outside sub-montane districts of Himalayas, northeast India and southeast Peninsular India. In the weak monsoon, there is a subdued rainfall activity over these areas. In contrast, in 'break monsoon', there is increased and heavy rainfall in the sub-montane districts of Himalayas, northeast India and southeast Peninsular India while other part of India has considerable decrease of rainfall activity. These phases of monsoon are found to be associated with the position and intensity of the monsoon trough which controls the monsoon rainfall distributions. The monsoon trough normally extends upto 500 mb level tilting southwards with height, is a warmer region with strong low level convergence giving rise to vertical velocity and strong convection. Apart from other synoptic situations, in strong monsoon, the monsoon trough is very active with embedded vortices and is south of the normal position. Whereas, in weak monsoon, the monsoon trough is very weak without any embedded vortices and its position is normal or south of it. In contrast, in break monsoon, the monsoon trough moves north to the foot hills of Himalayas and sometimes is not seen at all upto 850 mb level. Thus, oscillation of the axis of the monsoon trough over the *plains of north India*, causes variation of monsoon rainfall leading to strong or break/weak monsoon conditions. The region over which the monsoon trough lies and oscillates, will exhibit changes in the thermodynamic variables. Therefore, the study of the thermodynamic variables over the monsoon trough during the period of strong and break monsoon will help in understanding (a) structure of the atmosphere, (b) conditions of stability and instability, (c) moisture contents and its variations and (d) monsoon activity and its behaviour during next couple of days.

Another important reason which tempted this study is as follows : During break monsoon, *the axis of the monsoon trough* lies close to the foot hills of Himalayas or sometime not seen at all in surface chart. If this situation continues for two days or more, it is invariably observed that a secondary trough forms over Peninsular India roughly along 13 deg. N. And it is also seen that tropical easterly jet in the upper troposphere (say 150 mb/100 mb) over Peninsular India becomes weak and extends to 20 deg. N without much horizontal wind shear. This has a direct influence on the north-south temperature gradient over India which either reverses or gets modified and readjusted. This, in turn, influences the thermodynamic variables over India and in particular, over the region of the monsoon trough.

Seven stations, over which monsoon trough, sometimes lies or oscillates, have been selected for this study. The stations selected are : New Delhi (28°N, 77½° E), Lucknow (27°N, 81°E), Calcutta (23°N, 88°E), Jodhpur (20½° N, 73°E), Ahmedabad (23°N, 72½° E), Nagpur (21½° N, 79°E) and Bombay (19° N, 73°E). A break

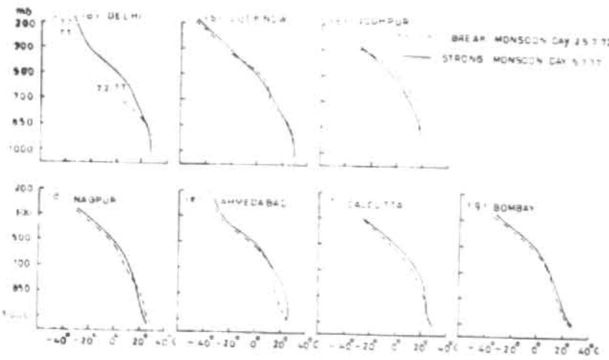

Fig. 1. Vertical dry bulb temperatures with height

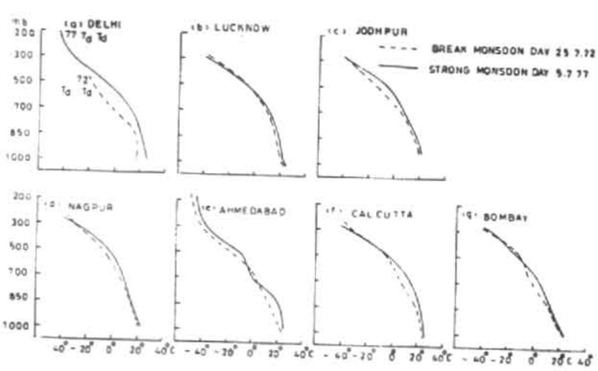

Fig. 2. Vertical profile of dew point temperatures with height

monsoon period 17 to 28 July 1972 and a strong monsoon period 1 to 12 July 1977 were selected on the basis of rainfall distribution and associated synoptic situations. The vertical profiles of the following thermodynamic parameters over the seven stations during the periods of strong and break monsoon were prepared and studied. The thermodynamic parameters are :

(1) Dry bulb temperature (*TT*),

(2) Dew point temperature (T_dT_d),

(3) Potential temperature (θ),

(4) Equivalent potential temperature (θ_e)

(5) Saturated moist static energy (MSE)

1.1. *Synoptic situation* 17 *to* 28 *July* 1972 (*Break monsoon*)

The eastern end of the monsoon trough moved north to the foot of Himalayas by the 17 July 1972 in association with the movement of a depression (which was cyclonic storm for two days) from Bay of Bengal to north Bihar, where it weakened later. While the western end of the monsoon trough moved north to the foot hills, in association with three western disturbances which moved away eastwards, across Jammu & Kashmir during the period. Thus, the axis of the monsoon trough lay very close to the foot hills of Himalayas from 17 to 28 July 1972. Two low pressure areas at 700 mb level moved westwards across Peninsular India, along the secondary trough near latitude 13 deg. N during this period. Moderate to severe heat wave conditions prevailed over many parts of Uttar Pradesh and Madhya Pradesh between 1 & 3 August 1972. The heavy rainfall was mainly confined to the sub-montane districts of Himalayas and northeast India and also over Tamil Nadu and neighbourhood. While, the remaining parts of India had practically no rainfall at all.

1.2. *Synoptic situation* 1 *to* 12 *July* 1977 (*Strong monsoon*)

The monsoon trough was south of the normal position in association with movement of depression across the monsoon trough on 1st. The monsoon trough was very active with embedded cyclonic circulation, one over Orissa and neighbourhood and other over northeast Arabian Sea off north Maharashtra-south Gujarat coast. Heavy and well distributed rainfall occurred over the country outside northeast India and southeast Peninsular India.

2. Data used

Daily weather charts from Weather Central, Pune and *Indian Daily Weather Reports* published by India Meteorological Department (I.M.D.) were consulted to select strong and break monsoon period. Upper air observations published by I.M.D. were also used in this study.

3. Discussion of the results

3.1. *Comparison of dry bulb temperature* (*TT*)

Fig. 1 shows the graph of vertical dry bulb temperature with height for seven stations on strong and break monsoon day. Mean *TT* graphs for strong and break monsoon periods are similar to the individual days. It is seen that, there is a significant change in *TT* profile between strong and break monsoon day/period and this is important in the heat budget study of the monsoon circulation. In particular, *TT* values in break monsoon over Delhi, Lucknow, Calcutta and Nagpur are higher by a degree or two upto 850 mb level and are lower above. Whereas, *TT* values in break monsoon over Ahmedabad, Bombay and Jodhpur are less by a degree or two upto 700 mb level.

3.2. *Comparison of dew point temperature* (T_dT_d)

Fig. 2 shows the vertical profile of T_dT_d with height for strong (5 July 1977) and break (25 July 1972) monsoon day. The most significant feature is that T_dT_d values on strong monsoon day are higher by 2° to 3°C. This should be, as during strong monsoon moisture content is more and its extension is upto 500 mb level sometimes. The difference in the moisture content between strong and break monsoon day is less over the eastern half of the monsoon trough (*viz.*, Calcutta and Lucknow) and more over the western half of the monsoon trough (*viz.*, Delhi).

Fig. 3 shows the vertical profile of T_dT_d with height for the period of strong (1-2 July 1977) and break (17-28 July 1972) monsoon. This also shows that the moisture contents and its vertical extension are very high in the strong & break monsoon and the difference in the moisture contents between strong and break monsoon period over the western half of the monsoon trough is more than the eastern half of the monsoon trough.

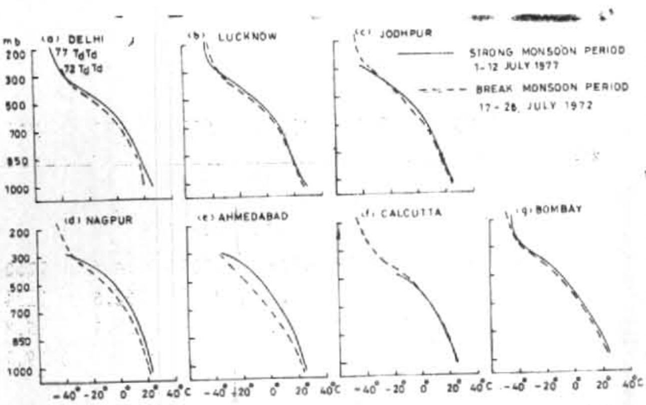

Fig. 3. Vertical profile of dew point temperature with height

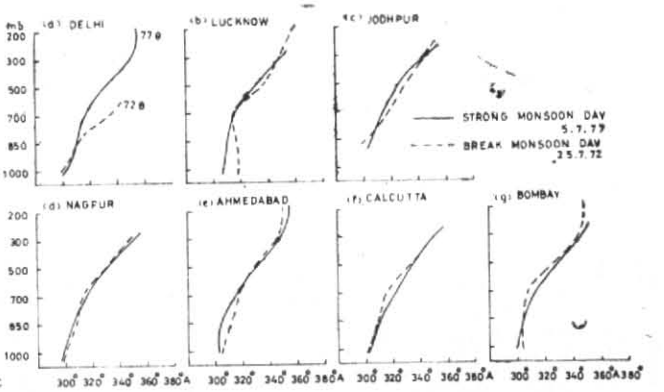

Fig. 4. Vertical profile of potential temperature with height

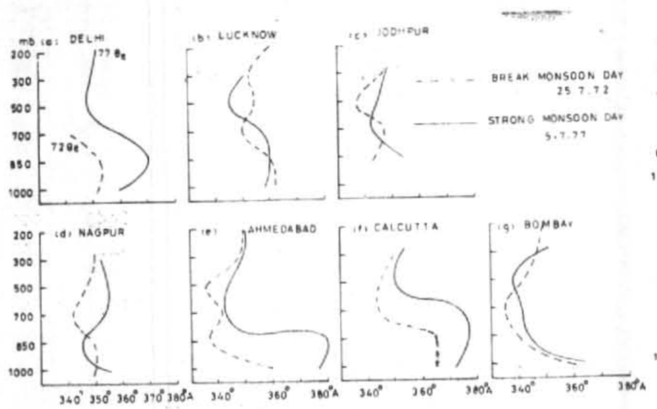

Fig. 5. Vertical profile of equivalent potential temperature with height for strong monsoon (5 July 1977)

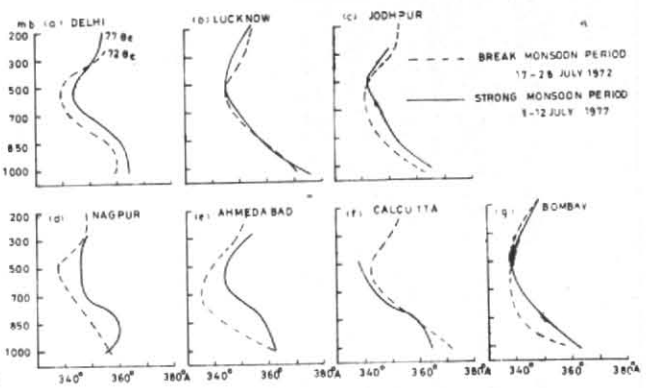

Fig. 6. Vertical profile of equivalent potential temperature with height for break monsoon (25 July 1972)

This property of T_dT_d can be explained as follows : During strong monsoon, the eastern end of the monsoon trough extends into north Bay across the plains of north India. The winds over north Orissa and West Bengal coasts are mainly southeasterlies which cause incursion of moisture from the north Bay there and hence the higher values of T_dT_d. During break monsoon, the eastern end of the monsoon trough lies along the foot hills of eastern Himalayas. The winds over coastal Orissa and West Bengal are predominantly southerlies which cause incursion of moisture over Bengal, Orissa and northeast India and hence the higher values of T_dT_d there. Further, during strong monsoon, the western end of the monsoon trough extends into northeast Arabian Sea off Saurashtra-Gujarat coast. The winds over Saurashtra-Gujarat coasts are mainly southwesterlies from the northeast Arabian Sea causing the incursion of moisture and higher values of T_dT_d. This is also supported by the satellite pictures in the strong monsoon conditions where intense, convective clouds are observed over northeast Arabian Sea and neighbourhood. During break monsoon, the western end of the monsoon trough lies close to the foot hills of western Himalayas and the winds over northwest India are dry westerlies causing less incursion of moisture and lower values of T_dT_d. Satellite pictures during break monsoon show shallow layered clouding over northwest Arabian Sea off 'Arabia' coast showing that westerly winds over northwest India are mainly dry with little moisture.

3.3. *Comparison of potential temperature* (θ)

Fig. 4 gives the vertical profile of θ with height on strong and break monsoon day. The values of 'θ' are less in break monsoon over Delhi and Calcutta and more over Lucknow, Nagpur, Ahmedabad and Bombay. Since θ increases with height over all the stations on both break and strong monsoon day, there is static stability. This static stability increases with height over all the stations. During break monsoon, atmosphere tends towards more static neutral.

3.4. *Comparison of equivalent potential temperature* (θ_e)

Figs. 5 and 6 give the vertical profile of θ_e with height, on strong (5 July 1977) and break (25 July 1972) monsoon day and strong (1-12 July 1977) and break (17-28 July 1972) monsoon period respectively. When we examine the profile for the period (Fig. 6), there is convective instability over all the stations in the lower levels as θ_e decreases with height. This has been pointed out long ago by Normand and Rao (1946). The height of convective instability is approximately

TABLE 1

Moist static energy (10^6 ergs)

	1000	850	700	500	300	200	1000	850	700	500	300	200
Delhi												
	25 *July* 1972						5 *July* 1977					
c_pT	3018	2958	2858	2249	2510	2291	2998	2958	2858	2719	2480	2250
gZ	0	137.6	301.2	571.9	957.4	1239	—5.5	134.6	299.2	570.9	956.5	1234
Lq	331	338.5	112.8	37.6	—	—	544.1	476.4	326.0	105.3	18.1	5.8
Total	3349	3434.1	3272	3358.5	3467.4	3530	3536.6	3569	3483.2	3395.2	3454.6	3489.9
Calcutta												
	25 *July* 1972						5 *July* 1977					
c_pT	2997	2948	2838	2709	2470	2271	2997	2948	2884	2719	2460	2231
gZ	0	138.4	301	571.9	955.5	1234	—8.1	132.8	299.2	571.9	957.5	1233.1
Lq	476.4	426.3	213.1	117.8	20.1	—	526.6	501.1	351.0	137.9	11.0	—
Total	3473.4	3512.7	3352.1	3398.7	3445.6	3505	3515.5	3582.3	3534.2	3428.8	3432.5	3464
Jodhpur												
	25 *July* 1972						5 *July* 1977					
c_pT		2884	2878	2709	2450	2221		2908	2828	2679	2440	2211
gZ		139.8	303.1	574.8	957.5	1231		133.3	295.3	564.1	942.7	1215.5
Lq		326	213.1	55.2	13.3	7.5		351	225.7	117.8	13.3	5.0
Total		3349.8	3394.2	3339.0	3420.8	3459.5		3392	3349.0	3360.9	3396.0	3431.5
Ahmedabad												
	25 *July* 1972						5 *July* 1977					
c_pT	2978	2884	2858	2689	2450	2231	2988	2958	2858	2699	2460	2270
gZ	—	139.5	299.2	570	949.6	1223.3	0	138.5	300.2	571.9	949.6	1226
Lq	451.3	311.4	163	47.6	9.8	4.3	501.5	501.5	150.4	75.2	12.2	6.5
Total	3420.3	3331.9	3320.4	3305.6	3400.4	3458.6	3489.5	3598	3308.6	3346.1	3421.6	3502.5
Bombay												
	25 *July* 1972						5 *July* 1977					
c_pT	2998	2884	2826	2679	2430	2211	3007.9	2898	2818.7	2699.2	2440	2221
gZ	0	143	302.1	570.9	949.6	1221	— .7	137.8	298.2	566	947.6	1222
Lq	476.4	288.4	137.9	82.7	16.3	0.8	501.3	326	175.5	75.2	19.8	—
Total	3451.4	3315.4	3268.0	3332.6	3395.9	3432.8	3508.5	3361.8	3292.4	3340.4	3407.4	3443
Nagpur												
	5 *July* 1977						25 *July* 1972					
c_pT	2958	2908	2838	2709	2470	2241	2998	2918	2808	2699.2	2460	2221
gZ	—5.9	135.6	297.2	576	950.6	1231	0	143	305.1	573.9	955.5	1231
Lq	451.3	326	268.3	175.5	24.1	7.5	376.1	326	175.5	122.9	24.1	5
Total	3403.4	3369.6	3403.6	3451.5	3444.7	3479.5	3374.1	3387	3288.6	3396	3439.6	3457
Lucknow												
	5 *July* 1977						25 *July* 1972					
c_pT		2968	2828	2749	2470	2251		2958	2848	2709	2709	2480
gZ		136.8	299.2	570	954.5	1231		133.2	295.3	566	949.6	1227.2
Lq		338.5	288.4	112.8	14.8			376.1	300.9	105.3	12.0	
Total		3443.3	3415.6	3431.8	3439.3	—		3467.3	3444.2	3380.3	3670.0	—

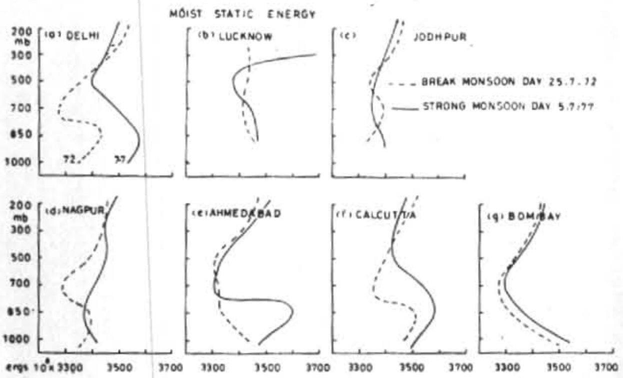

Fig. 7. Vertical profile of saturated moist static energy with height for strong & break monsoon

upto 500 mb over all the stations and the atmosphere becomes stable above 500 mb level. The values of θ_e are higher in strong monsoon period over all the stations except Calcutta and Lucknow. On individual break and strong monsoon day (*see* Fig. 3), the presence of convective instability depends mainly upon the incursion of moisture as in the case of Bombay. However, the values of θ_e in strong monsoon are significantly higher than the break monsoon day.

3.5. *Comparison of saturated moist static energy (MSE)*

The saturated moist static energy (MSE) was calculated for all the seven stations for strong (5 July 1977) and break (25 July 1972) monsoon day and its vertical profile given in Fig. 7 and values are given in Table 1.

The MSE is defined as :

$$\text{MSE} = c_pT + gZ + Lq,$$

where, c_p = Specfic heat of dry air for constant pressure,

T = temperature in absolute,

g = gravity

Z = height

L = latent heat of condensation

q = specific humidity at saturation.

The term c_pT measures enthalpy and depends on T. The second term gZ measures potential energy and is function of Z. The third term Lq measures latent heat and is function of q. At standard levels, *i.e.*, 1000, 850, 700, 500, 300, 200 mb, these three quantities have been calculated for the strong and break monsoon day and compared.

There is no significant change in the enthalpy term between strong and break monsoon day as the profile of dry bulb temperature on both days are almost same as seen under 3.1. Similarly, the 'potential energy' which is a function of height (Z) does not show any change between strong and break monsoon cases over all the stations. There is a significant change in the last term Lq, *i.e.*, latent heat, which is function of moisture. As content of moisture is more in strong monsoon over all the stations (*vide* 3.2), the Lq term has higher values over all the stations level by level. We find, on strong monsoon day; (i) The value of MSE is more in low level upto 700 mb level over Delhi, Calcutta, Lucknow, Ahmedabad and Bombay mainly due to the increase of moisture, (ii) MSE increases with height upto 850 mb level and decreases upto 500 mb level over Delhi, Ahmedabad and Calcutta, (iii) Maximum value of MSE is at 500 mb over Delhi, Lucknow and Calcutta and is at 700 mb level over Jodhpur, Ahmedabad and Nagpur. We also find, on break monsoon day MSE has minimum value at 700 mb level over Delhi, Lucknow, Nagpur and Calcutta and at 500 mb level over Jodhpur and Ahmedabad. Over Bombay, MSE and its profile are similar on both strong and break monsoon period though MSE values are higher on strong monsoon period. This is mainly due to the more moisture in strong monsoon period.

4. Similar studies by others

Harris and Ho (1969) studied the vertical profile dry bulb temperature over Saigon and concluded that there is no significant change, similar to that of strong and break monsoon situations. Gray *et al.* (1970) postulated that this property has greater significance in the circulation and radiation budget of the monsoon. Normand and Rao (1946) pointed out that there is always convective instability in the lower level during the monsoon period. However, this holds good only when there is good moisture content as it is in monsoon period, particularly during strong monsoon period. Riehl and Malkus (1958) have studied the total energy between pressure level P_0 and P given by $E = \int_{P_0}^{P} Q\,dP$, where, $Q = c_pT + gZ + Lq$ = saturated moist static energy, over the equatorial trough zone over ocean and land. From the values of Q, Srinivasan and Sadasivan (1975) obtained θ_e values over India in active and weak monsoon periods. They find that θ_e values over India are much higher than those calculated by Riehl and Malkus. In the present study θ_e values calculated for break and strong monsoon over the monsoon trough region are the highest, though in break monsoon they are relatively smaller. Anjaneyulu (1969) found that the energy content in monsoon trough is much more than the mean equatorial trough. Young (1972) found that $\partial\theta_e/\partial Z$ decreases by increase of θ_e in the mid-tropospheric levels over the oceanic stations and by decrease of θ_e in lower troposphere over the land stations. In the present study, $\partial\theta_e/\partial Z$ decreases due to the increase in θ_e near mid-troposphere values. Srinivasan and Sadasivan (1975) found similar results during active and weak monsoon period over India.

5. Conclusions

In view of constrasting features of synoptic situation and rainfall during the break and strong monsoon period, the study was undertaken to examine the vertical profile of thermodynamic parameters and their properties, which can be of great help in day to day forecasting. The stations selected are situated over the monsoon trough region which is the region of low level convergence and positive vorticity field. It is observed that :

(*i*) There is no significant difference in the dry bulb temperature profile with height, in both the days, (*ii*) There is a marked and significant difference in T_dT_d profile on both days, where during strong monsoon day, T_dT_d values are much higher (as much as 6 to 8°C) than the break monsoon day, (*iii*) Over Calcutta and Delhi, values of θ are less in break monsoon than in strong monsoon and reverse is the case over other stations. There is static stability over all the stations on both the days as θ increases with height, (*iv*) It is generally known that, there is convective instability over the monsoon area as monsoon region contains plenty of moisture. This holds good for the break and strong monsoon period though the values of θ_e are higher in the strong monsoon period. On individual days, there can be convective stability in the lower levels (*i.e.*, θ_e decreases with height) when there is no moisture incursion over the stations and (*v*) Moist static energy in strong monsoon is much higher than the break monsoon. Profiles of MSE and θ_e are similar.

Acknowledgements

The author is grateful to Dr. G.C. Asnani for useful discussion and his constant encouragement. He is also thankful to Shri N.B. Thade for his help in collecting data and preparation of diagrams and to Mr. R.K. Nair for typing the manuscript.

References

Anjaneyulu, T.S.S., 1969, *Tellus*, **21**, 1, pp. 64-74.

Harris, B.E. and Ho, F.P., 1969, 'Structures of the tropopause over southeast Asia during the summer monsoon month of July, Sci. Rep. 3, Hawaii Inst. of Geophys.

Gray *et al.*, 1970, Symp. Tropical Met., Honolulu, Am. Met. Soc. & WMO, p. Dv-1.

Normand, C.W.B. and Rao, K.N., 1946, *Nature*, **158**, 4004, p. 128.

Riehl, H. and Malkus, J. B., 1958, *Geophysics*, **6**, 3-4, pp. 504-538,

Srinivasan, V. and Sadasivan, V., 1975, *Indian J. Met. Hpdrol Geophys.*, **26**, 2, pp., 169-180.

Young, J. A., 1972, *Dynamics of the Tropical Atmosphere*, N. C. A. R., Boulder, Colorado, pp. 463-468.