STABILITY OF THE SUB-CLOUD LAYER DURING THE SUMMER MONSOON

SURENDRA S. PARASNIS
Indian Institute of Tropical Meteorology, Pashan Road, Pune 411008, India

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Abstract. Stability of the sub-cloud layer has been studied by examining the difference between the temperature of the lifting condensation level (LCL) and that of a meteorological sounding at the LCL. The difference in these temperatures was used as an indicator of the stability of the sub-cloud layer. When the temperature at LCL was warmer/cooler than its surroundings, it indicated the unstable/adiabatic/stable conditions of the sub-cloud layer. It was observed that when conditions were unstable or adiabatic, there was less monsoon activity. Stable conditions were associated with active monsoon periods. The results are discussed with the enhancement/decrease of convective activity on days of weak/active monsoon conditions.

1. Introduction

Stability of the sub-cloud layer plays an important role in the transports of heat and moisture from the surface. Stability of the sub-cloud layer is mainly dependent on the heating of the surface, which may produce strong upward heat and moisture fluxes. Also, the updrafts and downdrafts from the cloud layer which extend into the sub-cloud layer can change the stability to a great extent. In a review paper (Garstang and Betts, 1974) it was mentioned that during disturbed weather conditions, the thermodynamic structure of the sub-cloud layer changed from unstable to stable. Seguin and Garstang (1976) attributed the modification of the sub-cloud layer to strong coupling between the cloud and the sub-cloud layers. Evidence of such interactions has been presented by Echternacht and Garstang (1976), Betts (1976), Esbensen (1977) and Johnson (1981).

In this paper, aerological observations carried out at Pune (18°32′ N, 73°51′ E, 559 m ASL) during the summer monsoon seasons of 1980 and 1981 have been used to study the stability of the sub-cloud layer. The difference between the temperature at the lifting condensation level (LCL) and the temperature at the same level in the environment has been used as an indicator of stability of the sub-cloud layer. The purpose of this paper is to bring out and discuss the relationship between the stability conditions of the sub-cloud layer and the weak and active monsoon periods during the summer monsoons of 1980 and 1981.

2. Location of Observations and Meteorological Conditions

Pune is situated on the lee side of the Western Ghats. Westerly airflow in the lower troposphere during the summer monsoon (June–September) brings a large influx of moisture inland from the Arabian Sea. Synoptic and meso-scale disturbances leading to low-level convergence and vertical motions of the moist air give rise to continuous to intermittent rain from stratiform/cumulus clouds. The annual rainfall varies from 60 to 75 cm of which 75% falls during the summer monsoon season.

3. Method of Analysis

Aerological observations were carried out at Pune during the summer monsoon seasons of 1980–1981 during 1100–1200 IST daily. Since the rainfall during July and August contributes maximally to the seasonal rain, observations during July and August only are considered in this study. Profiles of temperature in the environment have been obtained. Computations of the height (H, km) and temperature (T_L, °C) at the LCL have been made using the daily values of temperature (T, °C) and dew point temperature (T_d, °C) at the surface with the help of the following formulae (Dugan, 1973):

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

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

$$T_c = T_d + 273.2 - 0.62(T - T_d) ,$$

$$T_L = T - 9.76H ,$$

where T and T_d are values of temperature and dew point temperature at the surface; G and T_c are intermediate parameters involved in the computations of H.

The T_L values have been obtained for the two months (July–August) for 1980 and 1981. It is clear that the T_L values are related to the values of LCL height and T. The temperature at the LCL level in the environment (T_E) has been obtained from the temperature profiles (Figure 1). The differences between the two temperatures, viz., T_L and T_E, have been examined. If the difference ($T_L - T_E$) is positive, the sub-cloud layer is unstable at the surface and adiabatic in the upper part. If the difference is negative, the sub-cloud layer is stable. The equality of the two temperatures implies neutral stability of the sub-cloud layer. This follows from the fact that a dry adiabatic lapse rate has been assumed in the computations of the LCL height.

4. Variations in the Difference ($T_L - T_E$)

The daily values of ($T_L - T_E$) are shown in Figure 2 (solid lines). It is seen that on most of the days, ($T_L - T_E$) values are positive showing that the air in the surface layer is unstable and the upper part of the sub-cloud layer is adiabatic. On a few days, when ($T_L - T_E$) values are negative, the sub-cloud layers are stably stratified.

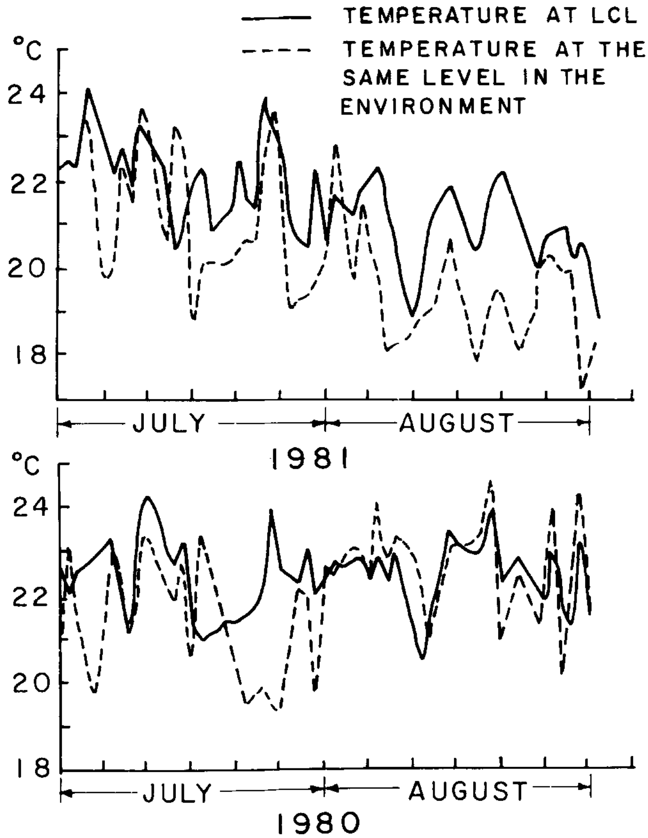

Fig. 1. Daily values of T_L (———) and T_E (----) during 1980 and 1981.

In the absence of any favourable synoptic weather system, the monsoon activity weakens. During the summer monsoon season, surface temperature rises by 4–10 °C within a few hours after sunrise. This rise in surface temperature generates a strong lapse rate (super-adiabatic) in the surface layer. The convective mixing in the sub-cloud layer makes the upper part of the layer adiabatic. In such cases, the difference $(T_L - T_E)$ is positive because of the deviation of the profile from adiabatic in the surface layer. When the weather conditions change due to the presence of a favourable synoptic weather system, the moisture in the atmospheric boundary layer is pumped upwards. The moist convection reaches higher levels and the cloud layer increases. As the cloudiness increases, the cloud bases appear at a lower height. The increasing intensity of moist convection leads to downdrafts with the enhancement of cloudiness. Also, if the process continues, it results in precipitation. During such cases, the sub-cloud layer becomes stably stratified. In such situations, the difference $(T_L - T_E)$ is negative because of the stabilisation of the sub-cloud layer.

5. Temperature Difference ($T_L - T_E$) and the Monsoon Activity

The difference ($T_L - T_E$), considered as an indicator of the stability of the sub-cloud layer, has been examined with respect to the monsoon activity over the region. Pune is situated in the Madhya Maharashtra region. Pune is the only station for which aerological observations are available representing thermodynamic conditions that prevail over the Madhya Maharashtra region during the different monsoon conditions. The day-to-day observations of the monsoon activity over the Madhya Maharashtra region have been obtained from publications of the India Meteorological Department, India. The activities of the monsoon have been reported as Widespread (W), Fairly widespread (FW), Scattered (Sc) and Isolated (Iso) in descending order of monsoon activity (areal rainfall). The classification of monsoon activity as W, FW, Sc and Iso, respectively, correspond to more than 75%, 51–75%, 26–50% and 1–25% of the area receiving rainfall.

In Figure 2, the differences ($T_L - T_E$) have been shown against monsoon ac-

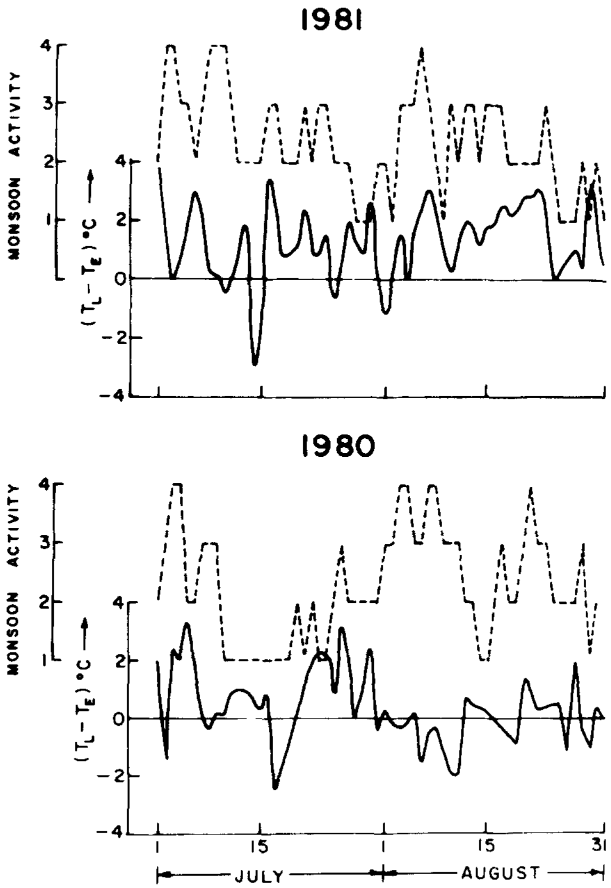

Fig. 2. Daily values of ($T_L - T_E$) °C and the monsoon activity (----) during 1980 and 1981.

tivity, assigning numerical values to the different categories as W-4, FW-3, Sc-2 and Iso-1. It is observed that as the difference in the two temperatures approaches zero (negative in a few cases), the monsoon activity increases. When the difference increases (positive), the monsoon activity decreases. One or two large negative values may not correspond to equally strong monsoons, but the overall tendency of the curve shows that on days when $(T_L - T_E)$ is small, there is an increase in monsoon activity and vice versa. The slight disagreement noticed is due to selection of one station as representative of the whole region.

The consideration of LCL temperature is useful for convective types of cloud and not for higher level stratiform clouds. The qualitative assessment of monsoon activity does not differentiate between stratiform and convective types of clouds, nor does it convey how much rain is falling. But as far as the stability of the sub-cloud layer is concerned, the stabilisation takes place due to increased cloudiness and lowering of cloud bases, irrespective of cloud types.

Stability of the sub-cloud layer in a convectively unstable atmosphere has not been proved to be a particularly useful indicator of the convective activity or convective rainfall except when the latter acts to stabilize and inhibit convection. In earlier studies (Srinivasan *et al.*, 1975; Parasnis *et al.*, 1985), it was observed that the convective instability (which is responsible for convective activity) was lower in the lower layers of the atmosphere on the days of active monsoon conditions as compared to that on days of weak monsoon conditions. Although convective instability initially promotes convection, later on convection destroys it. The difference $(T_L - T_E)$ may be considered as an indicator of convective activity. On days of active monsoon conditions, this difference was lower than that on days of weak monsoon conditions. This is in agreement with the earlier studies mentioned above.

It is generally observed that the instability builds up prior to a monsoon burst and decays during the monsoon season. Thus the maxima in the instability is expected to occur at the monsoon onset. In this paper, the period considered was July–August which is about 2–3 weeks after the usual monsoon onset at Pune (the usual date of monsoon onset at Pune is 10 June). The monsoon season consists of alternating periods of weak and active monsoon periods which affect the instability of the sub-cloud layer.

6. Conclusions

This paper addresses the stability of the sub-cloud layer of a monsoon atmosphere and the relationship of the stability to moist convection.

The behaviour of the stability indicator defined as the difference between the temperature of a parcel lifted adiabatically to its LCL (T_L) and the environmental temperature at the same level (T_E) showed the following:

(a) when the difference is positive, there is unstable and adiabatic stratification of the lower and upper sub-cloud layer. These days are generally associated with weak monsoon activity,

(b) when this difference is negative, there is stabilization of the sub-cloud layer due to increasing cloudiness and a lowering of cloud bases. These days are generally associated with active monsoon conditions.

The relationship between monsoon activity and boundary-layer stability, estimated by the effective temperature at the LCL shown in this note is based on only four months of observations. The results are thus tentative. Confirmation of the hypothesis needs further investigation.

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