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Some aspects of the thermodynamic structure of monsoon depressions*

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ABSTRACT. Using equivalent potential temperatures (θ_E), the thermodynamic structure of monsoon depressions (in the north-south section) has been studied. During the mid-monsoon months of July and August 1970 and 1971, eight depressions moved inland from the Bay of Bengal. Vertical profiles of θ_E across the section Lhasa, Gauhati, Calcutta, Bhubaneshwar, Visakhapatnam and Madras were constructed and discussed. The variations in convective instability in relation to the clouding and weather associated with a monsoon depression are pointed out. Vertical sections of moisture and virtual temperature distributions across a monsoon depression are also presented.

The study brings out the existence of (*i*) a region of neutral convective instability and high moisture content upto the mid-troposphere just south of the centre of the depression where heavy overcast skies, *Cb* clouds and heavy rain occur and (*ii*) a layer of minimum θ_E and low moisture content centred about 3·0 km asl, 4° to 5° south of the depression suggesting a possible region of subsidence. In this region though convective instability is high in the lower troposphere, it is not realised presumbably because of the synoptic scale subsidence. The moist ascending air close to the centre and the descending (subsiding) air further south form a circulation in the vertical plane and the distribution of virtual temperatures shows that this vertical circulation is energy-producing.

1. Introduction

The two variables that describe the thermodynamic structure of the atmosphere are temperature and humidity at the various levels. It is possible to represent them by a single parameter, such as the equivalent potential temperature (θ_E). An analysis of a single parameter (θ_E) to study the thermodynamic structure is easier than to analyse two (temperature and humidity). Even a casual examination of the distribution of equivalent potential temperatures with height in the monsoon season over India shows a well defined minimum near the mid-tropospheric level; below this level, equivalent potential temperature decreases with height and the atmosphere is convectively unstable, whereas above this level the atmosphere is convectively stable. Rao (1960) has pointed out that 'convective instability is a normal feature of the monsoon months and extends upto 4 to 6 km.' However, the degree of convective stability/instability in the atmosphere undergoes changes with synoptic situations and also varies from place to place. In this paper we shall present the distribution of convective instability of the atmosphere in the field of monsoon depression and deduce certain results therefrom regarding the thermodynamic structure and certain other features of the depression.

During recent years, the radiosonde network over the country has been strengthened and the quality of radiosonde data has also improved, with humidity values available to greater heights than before. The establishment of a vital radiosonde station at Bhubaneshwar (in July 1971) close to the normal track of monsoon depressions, has filled in a longfelt need in the data gap. It may, therefore, be expected that a fairly reasonable idea of the thermodynamical structure of the monsoon depression could be obtained with these improved and increased data when the depression comes close to West Bengal-Orissa coasts. With this view, two monsoon depresssions that crossed West Bengal coast in July-August 1971, just after the establishment of the radiosonde station at Bhubaneshwar, were taken up for study. The results are presented in this paper.

2. Methods of analysis

One of the methods to study the vertical structure of any atmospheric system is to construct vertical space or time sections across the system and analyse the distribution of a set of meteorological variables in the section. In the present case, a NE-SW oriented vertical section extending from Lhasa to Madras was prepared, when the depression centre was close to West

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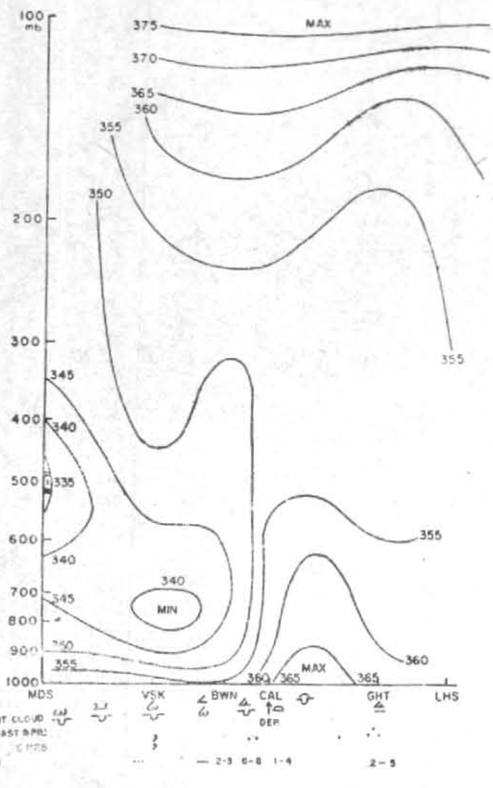


Fig. 1. 12 GMT of 8 August 1971

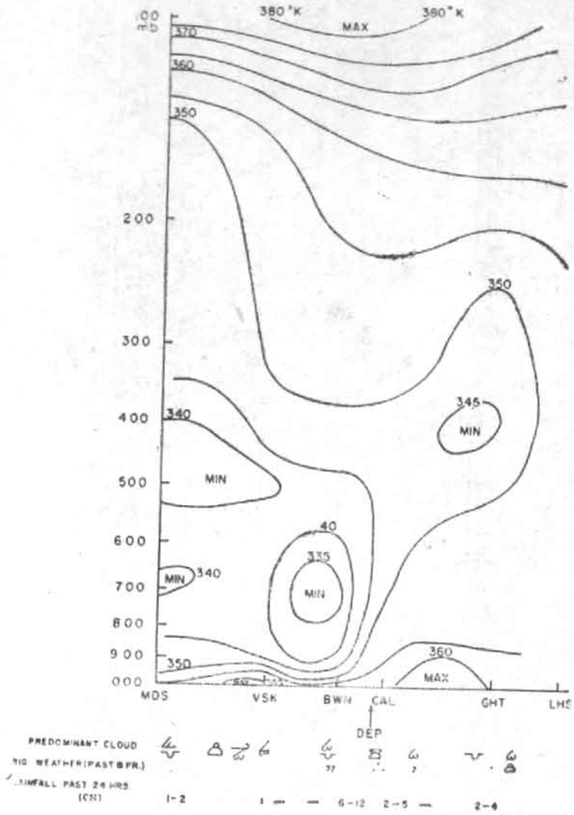


Fig. 2. 00 GMT of 26 July 1971

Vertical cross sections of θ_E along Madras— Gauhati— Lhasa

Bengal coast. This section which passes close to the centre of the depression, includes the radiosonde stations at Lhasa, Gauhati, Calcutta, Bhubaneshwar, Visakhapatnam and Madras. The equivalent potential temperatures at all the available levels from the radiosonde ascents at these stations at the synoptic hour when the depression was close to West Bengal coast were calculated using the tables prepared by Rao (1953), and vertical sections were constructed and they formed the basic material for the present study.

3. Case studies

On the evening of 8 August, a depression was centred near 23°N, 87·5°E and another depression was centred near 22°N, 88·5°E on the morning of 26 July. The vertical section depicting the distribution of θ_E with height for 1200 GMT of 8 August 1971 and 0000 GMT of 26 July 1971 are shown in Figs. 1 and 2. Isolines of equivalent potential temperatures have been drawn at 5° intervals on the vertical sections.

The main features noticed in these two cross-sections are :

(*i*) A pronounced minimum in θ_E at a distance of about 3-4° of latitude to the south of the depression centre between 800 and 600 mb levels.

(*ii*) Immediately to the north of it and extending over an area about 200 km south of the depression centre, θ_E is almost constant with height in the lower and mid-troposphere.

(*iii*) Two other minimum in θ_E are present near about 500-mb level away from the depression centre to the north and the south. These minima are at heights usually noticed on a normal day during the monsoon season.

(*iv*) The minimum in θ_E to the south of the depression is more pronounced than the minimum in the normal distribution and is also seen at a lower altitude than in the normal; this means that associated with the monsoon depression, there is a more rapid decrease of θ_E with height over these areas, leading to more pronounced convective instability in the lower tropospheric levels.

(*v*) By reference to the clouds, weather and rainfall amounts plotted in Figs. 1 and 2,

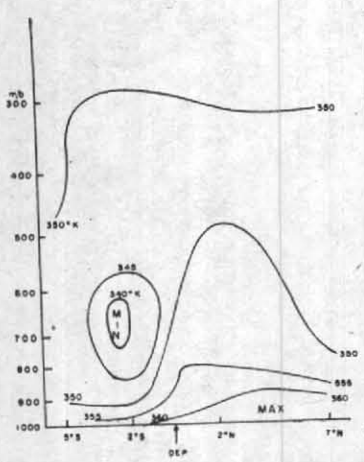
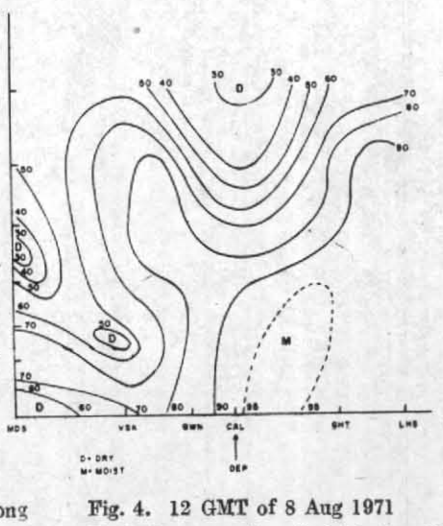


Fig. 3· Vertical profile of mean θ_E along a north-south section across the centre of monsoon depression (Composite of 8 cases)



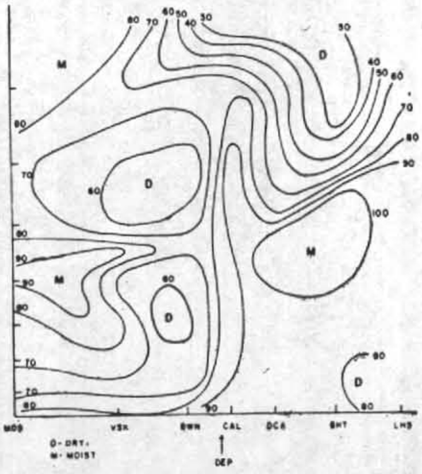


Fig. 4. 12 GMT of 8 Aug 1971 Fig. 5. 00 GMT of 26 Jul 1971

Vertical cross section of relative humidity(%) along Madras-Gauhati-Lhasa

it may be seen that heavy rain and heavy clouding have occurred over areas where θ_E lines are nearly vertical (*i. e.*, within two degrees to the south of the depression centre). Further south over the area of pronounced θ_E min., rainfall rapidly decreases and clouding is also much less mainly of *As* and *Ac* type.

(*vi*) To the north of the depression centre, convective instability is very much less pronounced in contrast to south of the depression centre at corresponding distances.

In order to establish that the distribution of θ_E noticed in Figs. 1 and 2 are not isolated instances, a composite vertical section incorporating the data for eight cases of monsoon depression during 1970-71 (Fig. 3), reveals the same characteristics of distribution of θ_E as discussed above, confirming that such a distribution of θ_E is a general feature of all monsoon depressions.

As already mentioned in the introduction, θ_E is a function of both temperature and humidity. Experience with radiosonde data over India during the monsoon season has been that the day-to-day changes in dry bulb temperature are much smaller compared to the changes in the dew point temperature, particularly between 850 and 500 mb levels. Thus the predominant contribution to changes in θ_E is due to moisture. To study the distribution of moisture in the present case, space cross-sections of relative humidity corresponding to Figs. 1 and 2, were prepared (Figs. 4 and 5). They bring out that the air is highly humid upto the mid-troponspheric levels in the region where θ_E values are constant with height. To the south of the depressions, there is a relatively dry area corresponding to the region of pronounced θ_E min.

The tephigrams of Calcutta (near the centre of the depression) and Visakhapatnam (about 5° of latitude to the south of the centre of the depression) for 1200 GMT of 8 August 1971 are given as typical examples (Fig. 6). The nearly saturated adiabatic lapse rate and high moisture content at levels upto 600 mb in the tephigram of Calcutta and the dry relatively stable layers particularly between 850 and 700 mb in the Visakhapatnam tephigram are noteworthy.

4. Interpretation

(*i*) The constancy of θ_E from surface upto the mid-tropospheric levels near and just to the south of the depression centre implies that over this area air from the surface is ascending moist adiabatically upto the mid-troposphere. In the upper troposphere, however, the convective stability persists on the days of monsoon depressions also as on a normal day.

(*ii*) Further south, while there is considerable increase in the convective instability in the lower levels (below 700 mb), no significant change from the normal is seen above 500 mb level. Inspite of the increased instability, no weather occurs and this can be only if some powerful influence is present to inhibit cloud

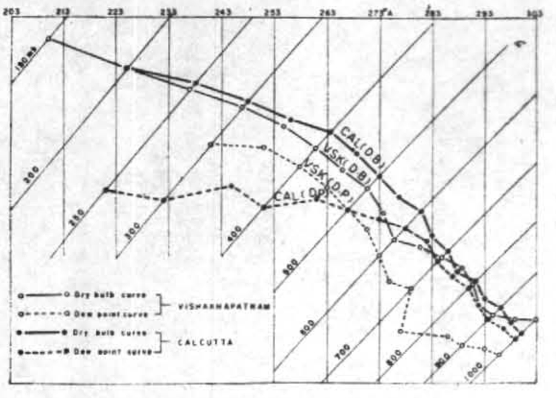


Fig. 6. Typical tephigrams of Calcutta and Visakhapatnam at 1200 GMT on 8 August 1971

growth. We have seen from Figs. 4 and 5 that the region of pronounced θ_E min. to the south of the depression is also an area of relatively dry air. This dry air could have come either by advection or by subsidence. Upper air trajectories were constructed on these days and they do not indicate advection of dry air. Therefore, the only other possibility is subsidence. The tephigrams of the stations in this area also lend support to this conclusion. This synoptic scale subsidence at the intermediate levels is perhaps the cause of the absence of weather.

(*iii*) The ascending air motion near the centre of the depression and the descending air (as evidenced by subsidence) to the south of it, form a vertical circulation associated with the monsoon depression, although it may not be the same parcel of air ascending near the depression centre that is descending to the south.

(*iv*) In areas where rainfall and weather is caused by the monsoon depression convective instability is less than on an undisturbed day, while in the region of subdued weather further south, convective instability is more. This apparent inconsistancy is resolved to some extent, when we take into consideration the synoptic scale circulation features, particularly in the vertical plane, as discussed above. Besides, though convective instability is initially good for promoting convection, later convection destroys the instability and thus it is less when the weather is disturbed.

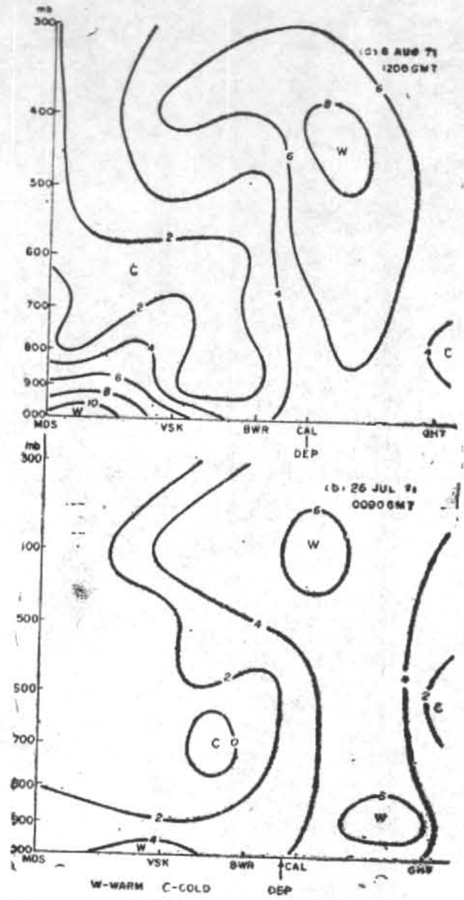


Fig. 7. Isopleths of departures of virtual temperatures (°C) from standard atmosphere

(*v*) In order to probe further into the implications of such a vertical circulation in the field of a monsoon depression, vertical sections of virtual temperatures for 26 July and 8 August 1971 corresponding to Figs. 1 and 2 were prepared (Figs. 7 a and 7 b). It will be seen from these figures that the ascending column of air is relatively lighter (warmer) and the descending column denser (colder). Thus the vertical circulation, associated with a monsoon depression has lighter air ascending and denser air descending, *i.e.*, it is a self-sustaining or energy-producing type of circulation similar to extra-tropical depressions. Koteswaram and George (1960) have postulated that the monsoon depression they studied was of a baroclinic type, though they guardedly qualified their conclusion "that the data at disposal are not quite adequate for arriving at definite conclusions regarding the thermal structure of this depression". The present study provides

*The analysis is given in the form of isopleths of departures from Standard Atmosphere for Asian Tropics (Pisharoty 1959).

a definite basis to confirm the earlier postulate of Koteswaram and George (1960).

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