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Some synoptic aspects of the low level inversion over Arabian Sea during MONEX'79

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सार — 1979 के ग्रीष्म कालीन मानसून प्रयोग के दौरान अरब सागर के ऊपर वायुमण्डलीय प्रेक्षणों से दक्षिण-पश्चिमी मानसून के शुरू होने के पहले, शुरू होने के समय और मानसून के पूर्ण रूप से सक्रिय होने के समय महासागरीय क्षेत्र में निम्न स्तरीय तापीय व्युत्क्रमण की उपस्थिति का पता चलता है। उष्मागतिक चार्टों के आधार पर उप-व्युत्क्रमण परत में तापीय तथा आर्द्रता स्तर विन्यासों को प्रस्तुत किया गया है। संयुक्त राज्य अमरीका के वायुयानों–कॉनवेयर 990, इलैक्ट्रा तथा पी-3 से संकलित अधःपाती सौंदे आंकड़ों से परिलक्षित व्युत्क्रमण परतों के आकाशीय तथा कालिक चरों को संचित्रों के रूप में प्रस्तुत किया गया है। व्युत्क्रमण के बनने का मुख्य कारण महासागर से उठने वाली ठण्डी और आर्द्र पवन तथा महाद्वीप से उठने वाली गर्म शुष्क पवन का संगम हो सकता है।

जब सिनॉप्टिक विक्षोभ क्षेत्र में पहुँचा, उप-व्युत्क्रमण परत में एक आर्द्र-जिव्हा को बनते हुए देखा गया है। इस तीक्ष्ण आर्द्रता प्रवणता का निर्माण व्युत्क्रमण से नीचे ऊर्ध्वाधर ऊर्ध्वमुखी गति से संबंधित हो सकता है। इस अवधि में स्थैतिक स्थायित्व की परिछेच्छिकाओं से पता चलता है कि उप-व्युत्क्रमण परत में स्थैतिक स्थायित्व परिमापक में वृद्धि होने से व्युत्क्रमण के आधार की ऊंचाई और ऊंची हो जाती है।

अधःपाती-सौंदे आंकड़ों का उपयोग करके विभिन्न स्थानों के ऊर्ध्वाधर पी-वेग अभिकलित किए गए हैं। मानसून के विभिन्न चरणों में व्युत्क्रमण परत पर ऊर्ध्वाधर पी-वेग के प्रभाव का अध्ययन किया गया है।

ABSTRACT. Aerological observations over the Arabian Sea during the Summer Monsoon Experiment in 1979 show the presence of low level thermal inversion over the oceanic region prior to the onset, at the time of onset and at the established phase of the southwest monsoon. The thermal and moisture stratifications in the sub-inversion layer have been presented on the basis of thermodynamic chart. The spatial and temporal variations of the inversion layers as found from the dropsonde data collected from the United States aircraft *Convair* 990, *Electra* and *P-3*, have been presented in the form of charts. The formation of inversion may be attributed mainly to the confluence of the cool moist air of oceanic origin and the dry warm air of continental origin.

When a synoptic disturbance approached the area, a moist tongue was seen to form in the sub-inversion layer. The formation of this sharp moisture gradient may be related to the vertical upward motion below the inversion. The profiles of static stability during this period show that the height of the base of inversion becomes higher with the increase of static stability parameter in the sub-inversion layer.

Vertical *p*-velocities have been calculated at different locations using the dropsonde data. The impact of the vertical *p*-velocity on the inversion layer at different phases of monsoon has been discussed.

1. Introduction

One of the characteristic phenomena over the Arabian Sea during the Summer Monsoon Experiment in 1979 is a low level inversion layer (Sen and Das 1980). Ghosh *et al.* (1978) also observed the inversion during ISMEX (1973). Saito (1975) has extensively studied the inversions during AMTEX-1974.

The purpose of this paper is to analyse the spatial and temporal variation of the inversion layer including thermal and moisture stratification in the sub-inversion layer, over the Arabian Sea during pre-onset, onset and established phase of monsoon and some characteristic features in the sub-inversion layer associated with the approach of a synoptic disturbance.

2. Data and procedure

The data used in this study consist of extensive dropsonde data obtained by three research aircraft of U.S.A. These research flights were undertaken between 05 and 10 GMT. As we are concerned with the description of large scale features of low level inversion layers over the area under consideration, we can assume that this small variation in the time of data coverage may not seriously affect our result. Seven days including a day when a synoptic disturbance was approaching towards the area were selected depending on the availability of maximum data. Tephigram analysis and cross-section analysis have been performed to study the wind, temperature and the humidity structure of the sub-inversion layer in the area under consideration.

3. Synoptic consideration

Summary of the synoptic outlook during the month of June 1979 is as follows : After the passage of a low pressure area over the Arabian Sea high pressure persisted on 1 and 2 June 1979. After this, the ridge of high pressure over the Arabian Sea remained dominant till 12 June, except on 6 and 7 June, when a trough of low became the significant synoptic feature over the Arabian Sea. This period has been referred to as the pre-onset period. During the period 13-16 June, the trough of low remained active and concentrated into a depression over east Arabian Sea with lowest central pressure near 15 deg. N, 70.5 deg. E on 16 June. Moving in a northwesterly direction it further intensified into a severe cyclonic storm and struck the Arabia coast on 20 June. With the movement of this system, the monsoon progressively advanced northwards and covered the entire west coast of India by 21 June. This period is called the onset period. Active monsoon prevailed afterwards over the Arabian Sea for the rest of the month. This period is referred to as the established phase in the following discussion.

4. The thermal and moisture stratification of the inversion layer

During the pre-onset, onset and established phase of the monsoon the inversion and the thermal structure of the sub-inversion layer show manifold variation. For example, there is a partial disappearance of inversion layer through large scale upward motion of air and local concentration of vapour (moist tongue) during the onset period.

The sub-inversion layer may be divided into two or three layers from the consideration of temperature and moisture. Some typical examples are shown in Fig. 1.

In case (A) the sub-inversion layer consists of two layers, the convection layer in which the temperature lapse rate is almost adiabatic and specific humidity is nearly constant with height and a moist stable layer with a sharp lapse rate of dew point temperature above it. The state below 949 mb seems to result from quasi-stationary convective mixing. In case (B) the sub-inversion layer consists of moist layer upto 950 mb in which temperature lapse rate is almost adiabatic, a moist stable layer upto 850 mb and finally a moist adiabatic layer upto 800 mb. In case (C) the sub-inversion layer consists of a convection layer from surface to 958 mb in which temperature lapse rate is adiabatic and specific humidity is nearly constant with height and a moist stable layer from 935 mb to 920 mb with sharp lapse rate of dew point temperature and these levels are separated by a transition layer from 968 to 935 mb.

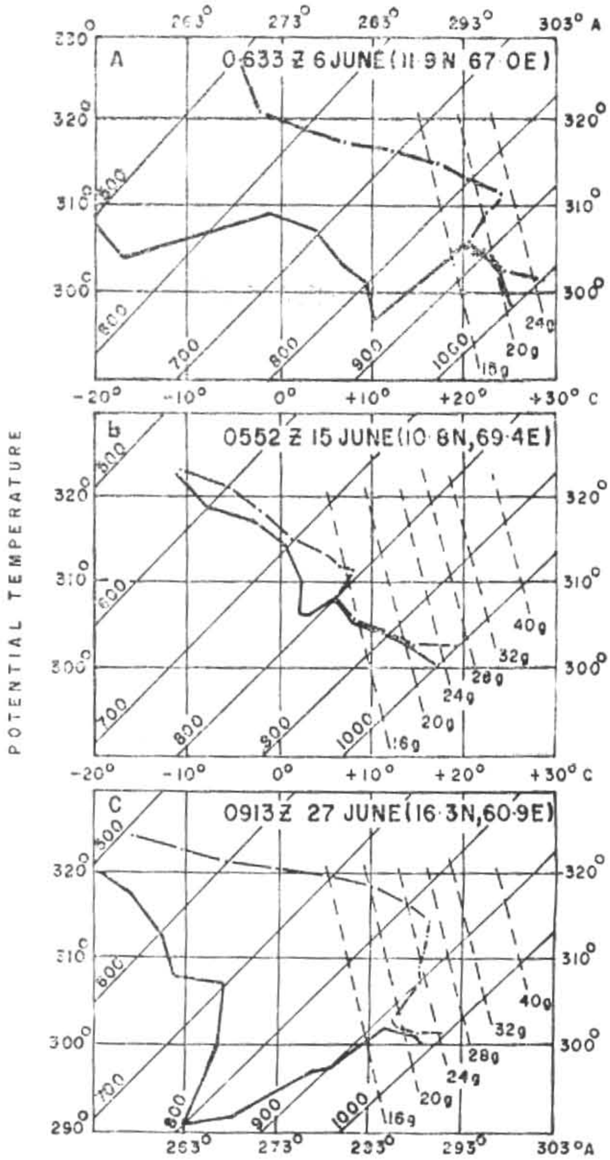

Fig. 1. Examples of profiles of temperature and dew point temperature. Full lines represent temp. and dew point temp. Thin horizontal lines are dry adiabats and broken lines sp. humidity (g/kg)

Now in order to analyse the multiple structure of a sub-inversion layer, the categories and criteria used by Saito (1975) for the study of inversion during AMTEX 1974 have been used in our study also. By using the above classification the spatial variation of stratification of the sub-inversion layer over the Arabian Sea for the representative dates during pre-onset, onset and established phase of monsoon are shown in Figs. 2 to 4.

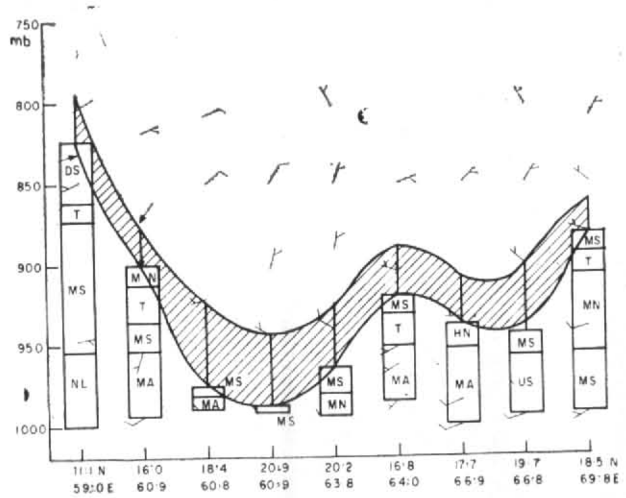

Fig. 2. Spatial distribution of the inversion and structure of sub-inversion layer for 7 June 1979 (pre-onset phase)

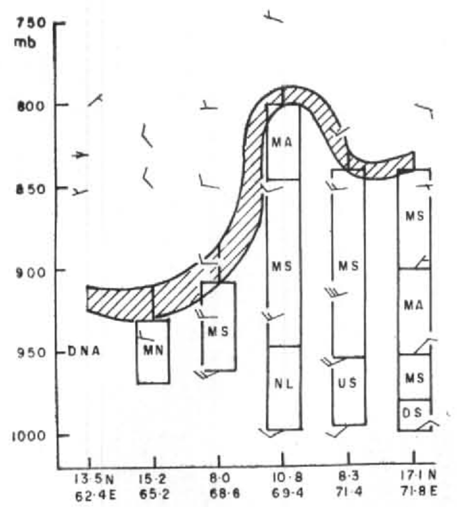

Fig. 3. Spatial distribution of the inversion and structure of sub-inversion layer for 15 June 1979 (onset phase)

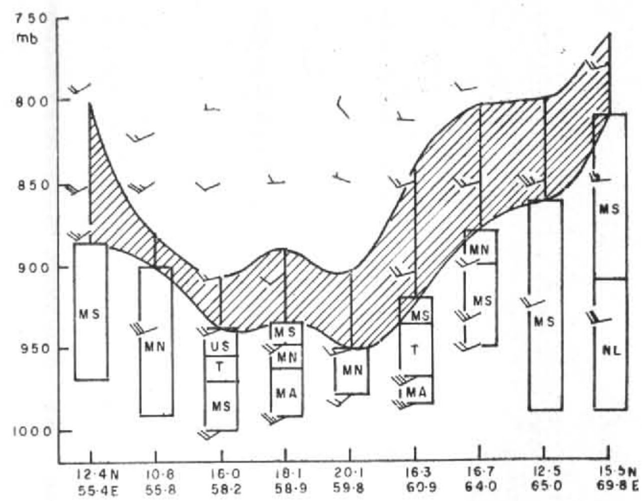

Fig. 4. Spatial distribution of the inversion and structure of the sub-inversion layer for 27 June 1979 (established phase)

The hatched area denotes the depth of the inversion (mb) in Figs. 2-4

5. The spatial and temporal variations of the inversion layers

Corresponding to this thermal and moisture stratification and its spatial variation, the behaviour of the height and base of the inversion have been looked into.

It has been observed that during the pre-onset period on 7 June, the base of the inversion was at about 975 mb near the Arabia coast and went up gradually toward the western coast of India and south Arabian Sea (900 to 850 mb). There is a tendency for lifting and weakening of the inversion and increase in depth of the surface moist layer, as the Indian Peninsula is approached. The potential temperature at the base of the inversion also shows similar characteristics. This suggests the effect of heating from the sea is on the increase as we approach west coast of India and south Arabian Sea.

The tops of the inversion over the region show the same characteristic, *i.e.,* the tops of the inversion are higher eastwards and southwards. Generally, moist stable southwesterly to westerly wind prevailed at the base of the inversion and dry westerly to northwesterly wind at the top of the inversion. During the onset phase on 15 June it has been observed that a deep moist layer existed in the vicinity of the well marked low and nearer to this zone the inversion layer came up in between 800 mb and 750 mb. The variations of the base and height of the inversion are manifested by the location of the system, *i.e.,* nearer to the system, higher the inversion base. Inversion layer either became shallow or practically disappeared at some places nearer to the system due to instability in the lower layer leading to vertical mixing across the inversion.

During the established phase of monsoon on 27 June the inversion layer showed the same characteristic phenomena as the one during the pre-onset period. There

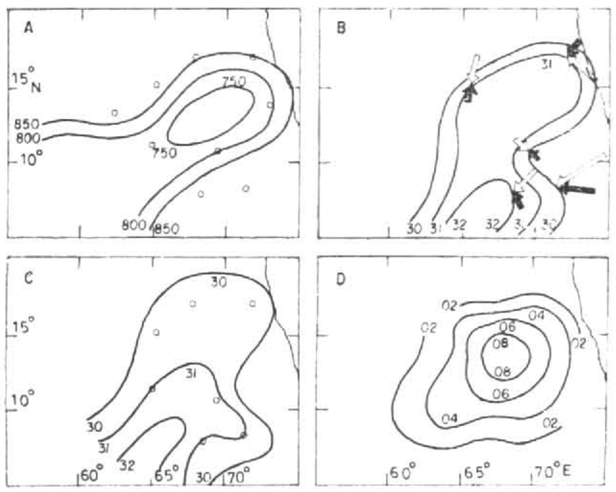

Fig. 5. Analysis for a synoptic disturbance in the sub-inversion layer for 15 June 1979 : (A) Pressure in mb at the top of the moist layer; (B) Distribution of wet bulb potential temperature at 900 mb (in °C) and relative winds at 900 mb (solid arrows) and 850 mb (hollow arrows); (C) Distribution of wet bulb potential temperature at 850 mb and (D) Distribution of relative cloud thickness within the disturbances.

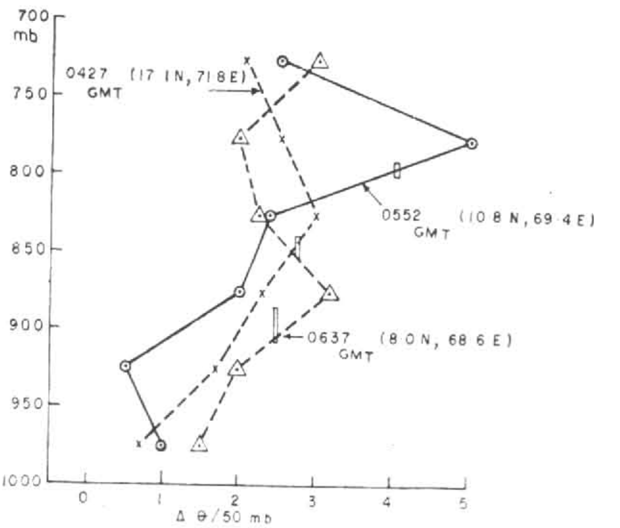

Fig. 6. The profiles of static stability at three locations over the Arabian Sea for 15 June 1979 Double lines indicate the depth of inversions in the mb corresponding to three profiles.

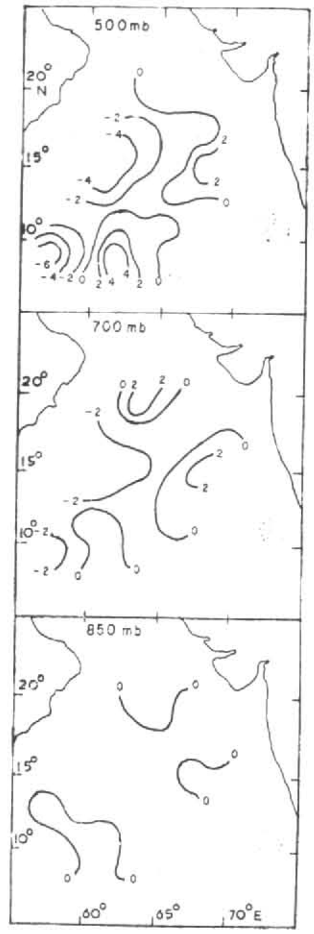

Fig. 7

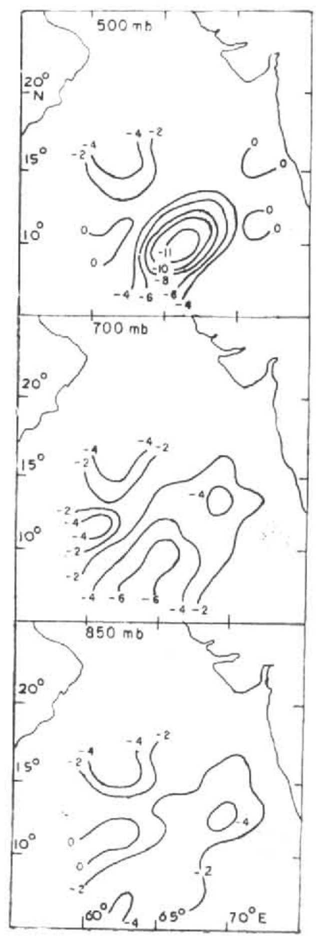

Fig. 8

Figs. 7 & 8. Distribution of vertical velocity (10^{-3} mb/sec) for 7 June 1979 (Fig. 7) and 15 June 1979 (Fig. 8)

is a tendancy for lifting the inversion as the west coast of India is approached. The one notable difference in this case is that the average depth of moisture below the inversion towards the east of 60 deg. E is higher than that during the pre-onset period. The base of the inversion has gone up due to rapid release of moisture upwards from the lower layer of deflected trades.

Considering wind and temperature observations over all the locations it would appear that there was moist air in the surface layers and continental air above with an inversion between the two air masses. Also there was no anticyclone or any other condition over the area between 900 and 800 mb levels which could cause subsidence giving rise to any inversion.

6. Effect of warm air advection on the inversion layer

The vertical profiles of potential temperature over the central Arabian Sea at the time when the synoptic disturbance was approaching the region indicates that the base of the inversion became higher with increase in potential temperature due to the advection of warm air mass.

7. Synoptic disturbances in the sub-inversion layer during the onset period

It has already been mentioned that a deep moist layer was found in the vicinity of the synoptic disturbance at the time of onset of the southwest monsoon. As the disturbance approached the central part of the east Arabian Sea the moist layer further concentrated and appeared like a moist tongue as shown in Fig. 5(A). The deep moist layer was found to extend from 11 deg. N, 68 deg. E to 15 deg. N, 72 deg. E and the thickness of the moist layer steeply decreased on both sides. The wet bulb potential temperature θ_W in °C

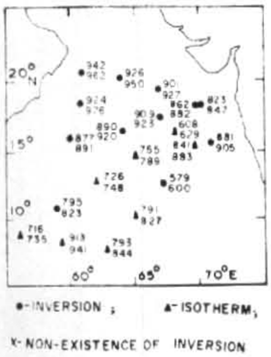

Fig. 9

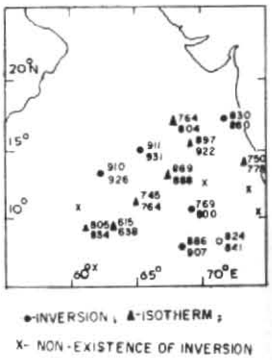

Fig. 10

Figs. 9 & 10. Distribution of inversion layer with top and base pressure values (mb) for 7 June 1979 (Fig. 9) and 15 June 1979 (Fig. 10)

at the 900 mb surface at the same time is represented in Fig. 5(B). The convective cumulus over the zone has been reported by the aircraft flights. Fig. 5(C) shows θ_W at the 850 mb surface. It should be noted that the area enclosed by the line 31 deg. C is smaller at 850 mb level than over 900 mb level. This three dimensional distribution of θ_W suggests a vertical upward motion around the thick moist layer. The vertical p-velocity distribution presented in Fig. 8 confirms this. The distribution of relative cloud thickness which is referred to as ratio of the real cloud thickness to the height of 500 mb in the disturbance is illustrated in Fig. 5(D) (Chen-Rui-rong 1980).

For additional evidence of this upward motion let us see the relative wind fields with reference to the winds at the 900 mb surface following Saito (1975). The reason for selecting 900 mb as a reference level is that the pattern of θ_W at 900 mb level is similar to that of the moisture and the base of cumulus cloud almost at this level.

The relative winds at the 950 and 850 mb surfaces are shown by thick lines with arrow heads and double lines with arrow heads respectively in Fig. 5(D). It is seen that the relative winds converge at 950 mb and diverge at 850 mb and so the upward motion relative to the flows at 900 mb is expected.

8. Variation of static stability as an index of inversion

The static stability between two levels p_1 amd p_2 can be defined as $S = -\dfrac{\partial\theta}{\partial p} = \left(\theta_{p2} - \theta_{p1}\right) \Big/ \triangle p$

where, θ = potential temperature, $p_1 > p_2$;

$\triangle p$ = pressure increment

and $\triangle\theta = \theta_{p2} - \theta_{p1}$

By the use of this lapse rate of potential temperature with 50 mb depth, the profiles of static stability at three locations for 15 June 1979 have been analysed. The results are shown in Fig. 6. It is clear from the illustrations that the height of the base of the inversion increases and depth decreases with the increase of static stability parameter in the sub-inversion layer.

9. The impact of vertical velocity on the inversion layer

In order to see the impact of vertical velocity on the inversion layer during pre-onset, onset and established phases of monsoon, vertical p-velocities at different locations at 850, 700 and 500 mb alongwith the distribution of inversion layers have been looked into and some of these have been presented in Figs. 7 to 10.

During the pre-onset period on 7 June the low level inversion is higher by about 50 mb in the region of maximum upward velocity (4×10^{-3} mb/sec at 500 mb and 2×10^{-3} mb/sec at 700 mb). Similar is the situation at the established phase of monsoon on 27 June (2×10^{-3} mb/sec at 500 and 700 mb). At the time of onset of monsoon (15 and 17 June), when there was a synoptic disturbance over the the Arabian Sea, the upward velocity was considerably higher compared to that during the pre-onset phase. In the regions of maximum upward motion either the inversion layers were higher or missing. Maximum upward motions of 14×10^{-3} mb/sec at 500 mb and 12×10^{-3} mb/sec at 700 mb have been observed on 17 June. The downward motion at lower and middle levels to the west and southwest of the disturbance is associated with the intrusion of dry and cold air into the disturbance.

10. Conclusion

(*i*) There is a large concentration of moisture and nearly dry adiabatic lapse rate in a shallow layer below the inversion. Above the inversion there was a dry and rather unstable layer with nearly dry adiabatic lapse rate upto about 600 mb.

(*ii*) During the pre-onset period and the established phase of monsoon, there is a tendency for lifting and weakening of the inversion and the increase in depth of the surface moist layer eastwards, as the Indian Peninsula is approached. However, during the onset period the variation of the base and top of the inversion is closely related with the location of the synoptic disturbance. Inversion layer either becomes shallow or practically disappears during the onset phase and the depth of moisture increases nearer to the system.

(*iii*) The low level inversion is probably of airmass type, warmer drier continental air spreading over the cool moist air of oceanic origin. Colon (1964) and Desai (1966, 1968 & 1970) also arrived at the same conclusion.

(*iv*) Accompanying the warm air advection the sub-inversion layer becomes less stable and the layer of inversion is raised.

(*v*) When a synoptic disturbance approached the area a moist tongue was formed in the sub-inversion layer, the scale of which was a few hundred kilometres. The formation of this sharp gradient of water vapour was related to the vertical upward motion below the inversion associated with an ensemble of cumulus convection.

(*vi*) The profiles of static stability during the period of synoptic disturbance show that the height of the inversion layer is raised, as the static stability parameter increases in the sub-inversion layer.

(*vii*) During the pre-onset period and established phases of monsoon, low level inversion layer is lifted upward by about 50 mb to 100 mb in the region of maximum upward motion (2 to 4×10^{-3} mb/sec) at 500 mb and 700 mb.

During the onset phase when a synoptic disturbance was passing through the region, inversions were either diffused or lifted and weakened considerably in the region of strong upward motion (10 to 12 $\times$ 10^{-3} mb/sec) at 500 mb and 700 mb.

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