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Radiatively driven subsidence over the Eastern Arabian Sea from MONSOON-77 data*

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// Aerological observations by Russian ships during MONSOON-77 have been used to explore the subsidence over the Eastern Arabian Sea which is marked by low level inversions. The technique of conserved variable analysis has been used to estimate the rate of subsidence of air at the top of convective boundary layer (CBL). It has been observed that the CBL top air subsides at the rate of 30 hPa per day. //

1 Introduction

The convective boundary Layer (CBL) plays an important role in regulating the transport of heat and moisture from the surface to the layers above. The saturation point (SP) representation of moist thermodynamics was introduced by Betts[1]. This remains unchanged during an adiabatic ascent/descent, so it is a thermodynamic tracer for an air parcel. Air parcels are characterized by their SP properties such as saturation pressure, potential temperature, and equivalent potential temperature, which are conserved under dry or moist adiabatic motion. The thermodynamic structure of CBL over the oceanic tropical regions has been investigated with the assumption that thermodynamic variables remain invariant during adiabatic ascent or descent[2,3]. The characteristic CBL structures observed over the Deccan Plateau have been documented by the present authors[4]. Parasnis[5] has investigated the variation in CBL structure during a break and active monsoon. In these studies the subsidence of CBL top air has been estimated by using the conservation of mixing ratio (q).

The purpose of this paper is to show how the above analysis could be used to estimte the rate of radiatively driven subsidence. A small sample of aerological observations (of about 45 observations) over the Arabian Sea during MONSOON-77 has been studied with the help of above method of analysis to find out the CBL structure. An attempt has been made to estimate the rate of subsidence of the CBL top air using the characteristic CBL structure.

2 Sites of observations and meteorological conditions

Aerological observations were carried out during MONSOON-77 by stationary erstwhile USSR research vessels in the eastern region (10-14°N, 64-68°E) of the Arabian Sea (Fig. 1). Six-hourly observations were taken during 13-16 July 1977 from three ships, namely, Priboy (12°N, 64°E), Okean (14°N, 66°E), and Shirshov (12°N, 68°E). As far as the synoptic conditions for the period 13-16 July 1977 are concerned, the representative surface pressure distributions on 15 July 1977 are shown in the figure. The position of trough line has a bearing on monsoon activity. The monsoon trough was aligned with the Gangetic plains (on 15th and 16th July) and protruded over the head of the Bay of Bengal. The trough off the west coast of India also persisted during this period with a well-marked embedded vortex near the coast (15°N). We see from Fig. 1 that the synoptic conditions were favourable for an active monsoon during this period.

3 Method of analysis

The aerological observations during 13-16 July 1977 for Priboy and Okean (region A) and Shirshov (region B) from the surface up to 500 hPa were averaged at every 25-hPa intervals. The averaged values of T and T_d (temperature and dew point) for the two regions were used to compute the virtual potential temperature (θ_v), equivalent potential temperature (θ_e), saturated equivalent potential temperature (θ_{es}), and mixing ratio (q). The saturation point (SP) is defined as the intersection of the dry adiabat through the parcel temperature and the constant q line through the dew point. The corresponding pressure is the saturation level

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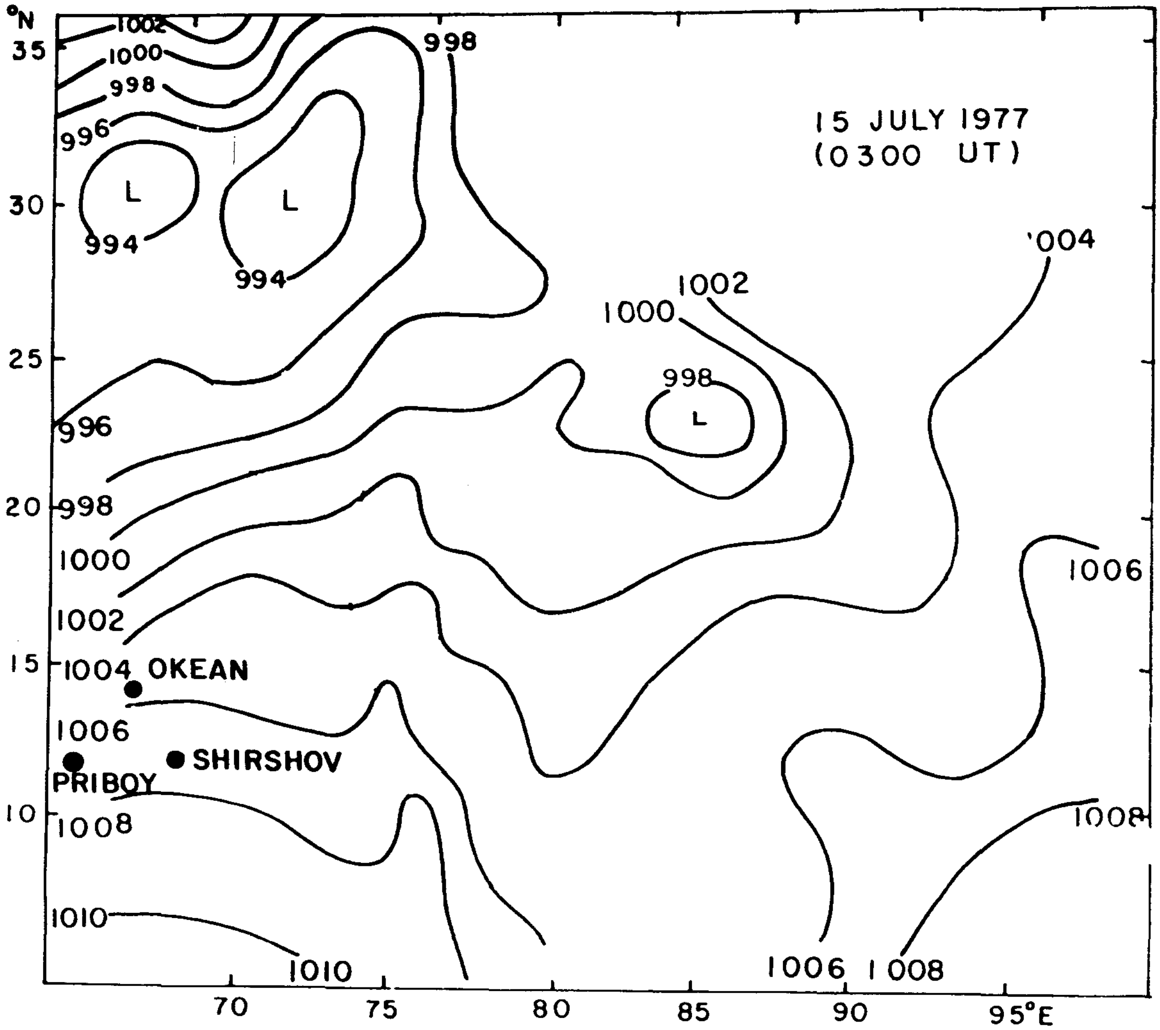

Fig. 1—Surface pressure distributions on 15 July 1977. Locations of the three ships, namely, Priboy, Okean and Shirshov, are also shown.

pressure (p_{SL}). The pressure difference $\mathcal{P}$ at the saturation point is given as

$$\mathcal{P} = p_{SL} - p \qquad \text{... (1)}$$

where p is the pressure of the parcel of air. The thermodynamic state of an air parcel is specified by the properties of its SP and $\mathcal{P}$. Since the environment considered is unsaturated, SP means the lifting condensation level (LCL) for all practical purposes. $\mathcal{P}$ is the LCL pressure difference from the pressure of air parcel.

4 Results and discussion

4.1 Low-level inversions over region A

In one of the recent studies[6], it has been observed that, during 13-16 July 1977, in 80% of the soundings inversion layers were present over region A, but only a single sounding with an inversion was found over region B. The details of inversion over region A are given in Table 1. In region A inversion layers were observed between 900 and 680 hPa in individual soundings. These inversion layers over the region A could inhibit the convective activity. Low level inversion layers play a significant role in maintaining the organization of convective systems by suppressing deep covection. The deep moist convection comprises the ascending limb of the Hadley circulation. Also, in the absence of inversion the moisture is reaching up to higher levels. In case of shallow convection, the inversion (stable layer) limits moisture reaching up to higher levels. As far as the prevailing meteorological conditions are concerned, the trough off the west coast was well defined during this period. Consequently over region B the weather conditions were favourable for deep convection. The vertical velocity profiles indicated upward motion in region B and downward motion over region A (Ref. 7). This supports the difference in prevailing weather conditions in regions A and B.

Table 1—Details of inversion layers over region A

Date	Time UT	Inversion Base hPa	Inversion Depth hPa	Inversion Strength K/100 hPa
	Ship: Priboy (12°N, 64°E)			
13.7.77	0610	860	30	4.7
	0980	830	30	5.3
	1710	900	30	1.0
	2180	900	40	0.8
14.7.77	0580	880	20	7.0
	0980	880	20	1.5
	1180	890	50	1.8
15.7.77	0450	890	40	3.8
	1000	860	40	1.5
	1580	880	40	0.8
16.7.77	0650	850	20	7.5
	Ship: Okean (14°N, 66°E)			
13.7.77	0390	800	20	0.5
	0900	830	20	10.0
	2190	840	30	2.0
14.7.77	0440	680	30	5.3
	1590	820	20	7.0
	2190	830	30	1.3
15.7.77	0560	810	30	8.0
	1020	850	40	4.3
	1590	810	20	10.5
	2290	820	30	7.7
16.7.77	0540	800	20	2.0
	1080	860	20	4.0
	1590	850	20	1.0
Mean		842.5	28.7	4.14

4.2 CBL Structure

The parameter $\mathcal{P}$ is a very useful variable to distinguish between layers that are in and above CBL. Negative values of $\mathcal{P}$ are related to layer subsaturation. Subsaturation value is indicative of deficiency of saturation. The $\mathcal{P}$ averages for regions A and B are shown in Fig. 2. From this figure we find that in region A (Priboy and Okean) shallow cloud layers are observed between 950 and 870 hPa with constant subsaturation (value of $\mathcal{P} \sim -40$ hPa). The $\mathcal{P}$ averages in region B show a cloud layer between 950 and 720 hPa. Figure 2 also shows the q, θ_v, θ_e and θ_{es} averages for both regions A and B. From the q profiles, we observe that the moisture is, in general, more in region B than in region A. The θ_v profiles indicate an increase in the stability over region B as compared to that over region A, except in the layer 850-600 hPa which is due to the presence of inversion layers in this layer. In earlier studies of CBL, the top of CBL was associated with the minimum values of $\mathcal{P}$ and θ_e and maximum value of θ_{es} (Refs 1 and 3). Over region A, top of the CBL has been taken to be 730 hPa, where the minimum values of $\mathcal{P}$ and θ_e and maximum value of θ_{es} coincide ($\sim$20 hPa).

The vertical profiles of θ_e and θ_{es} can be used to assess low level stability[8]. Consider the adiabatic rise of an air parcel from 980 hPa (straight line) (Ref. 2). Over region A, it is observed that θ_e is warmer than θ_{es} between 920 and 780 hPa, which indicates positive buoyancy of air parcel. In region B, the parcel shows positive buoyancy from 900 hPa up to more than 600 hPa. According to the classification[8] based on the vertical profiles of θ_e and θ_{es}, region A is associated with suppressed convection and region B with deep convection.

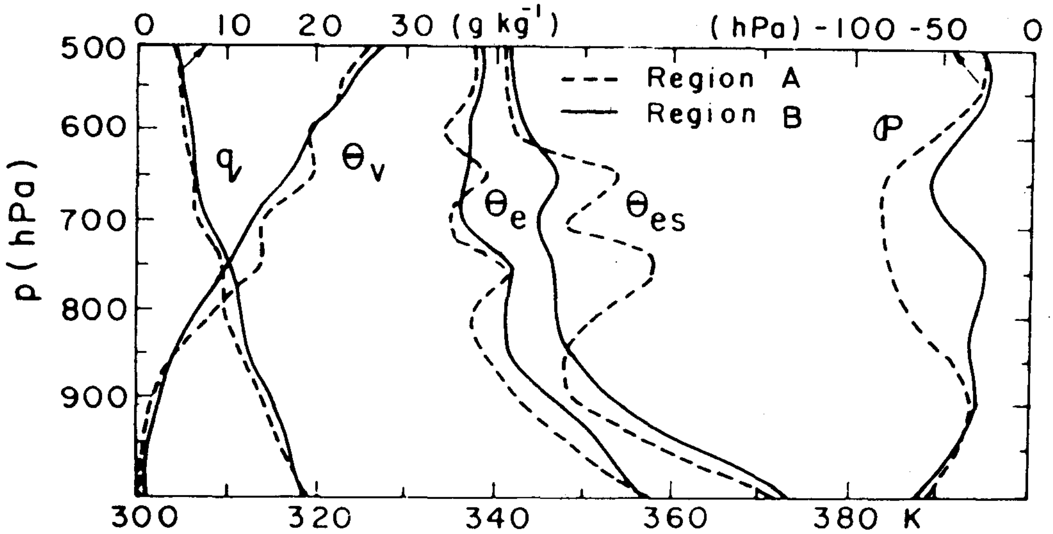

Fig. 2—Mean profiles of q, θ_v, θ_e, θ_{es} and $\mathcal{P}$ for the regions A (----) and B (——).

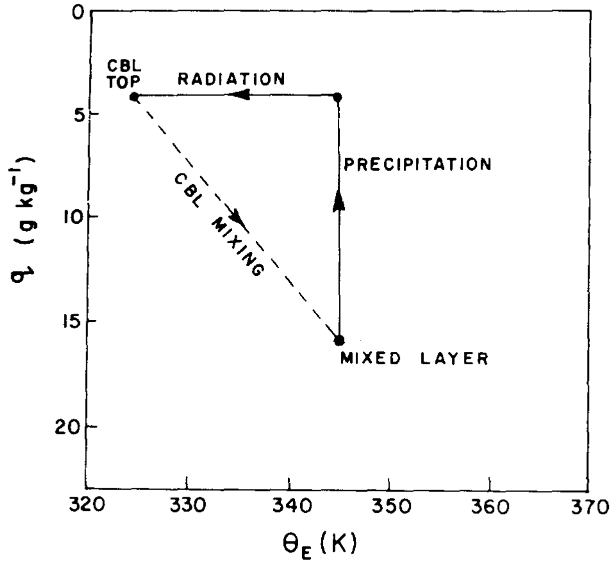

Fig. 3—Schematic θ_e-q diagram showing the effect of precipitation and radiative cooling on an air parcel saturation point.

4.3 Estimation of radiatively driven subsidence of CBL top air

A schematic θ_e - q diagram showing the effect of precipitation and radiative cooling on an air parcel saturation point is given in Fig. 3. Precipitation in deep convective branch of tropical circulation moves parcels from subcloud layer to lower q at constant θ_e. Radiative cooling in the subsiding branch lowers θ_e at constant q. We have considered the conservation of q. If we assume that the air above the CBL top has sunk with radiative cooling without mixing, the estimation of the level of origin of the CBL top air can be made by using conservation of q provided the vertical structure of q of the atmosphere is known. In Table 2, the SP parameters are given at CBL top (at the level of θ_e minimum) averaged for Priboy and Okean (region A). A set of parameters at Shirshov (region B) for 660 hPa, where the average value of q was observed to be 7.15 g kg^{-1}, is also given. The differences in θ and p for the two sets indicate that the CBL top air over region A has subsided 81 hPa (741-660 = 81 hPa). The air has cooled by 4.7 K in potential temperature. If the radiative cooling rate is assumed to be − 1.75 K per day (Ref. 2), it enables us to estimate the rate of subsidence as 30 hPa per day in 2-3 days.

Table 2—SP parameters at the CBL top

Data set	p hPa	p_{SL} hPa	$\mathcal{P}$ hPa	q g kg^{-1}	θ K
Priboy	771	670.0	−101.0	7.70	309.9
Okean	711	619.0	−92.0	6.60	313.5
Mean	741	644.5	−96.5	7.15	311.7
Shirshov	660	606.9	−53.1	7.15	316.4
Difference	Δp	Δp_{SL}	$\Delta\mathcal{P}$	Δq	$\Delta\theta$
	81	37.6	−43.4	0.0	−4.7

5 Conclusions

This case study, carried out using the aerological observations over the Arabian Sea region, has shown that the rate of subsidence of CBL top air can be estimated using the conserved variable analysis. Over the Eastern Arabian Sea the rate of radiatively driven subsidence was found to be 30 hPa per day.

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