Atmospheric boundary layer during ARMEX-2002 at stationary positions - comparative study

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सार – इस शोध–पत्र में वर्ष 2002 की ग्रीष्मकालीन मानसून वर्षा ऋतु के दौरान अरब सागर के पूर्वी क्षेत्रों में वायुमंडलीय परिसीमा स्तर (ए. बी. एल.) की प्रमुख विशेषताओं का अंवेषण करने के लिए अध्ययन किया गया है। इस कार्य हेतु दो स्थिर अवस्थाओं (30 जून–10 जुलाई तथा 22 जुलाई – 5 अगस्त 2002) के लिए आरमेक्स 2002 के पहले चरण के दौरान ओ. आर. वी. सागरकन्या पर एकत्रित किए गए वायु विज्ञान संबंधी प्रेक्षणों और धरातलीय मौसम विज्ञान से संबंधित प्रेक्षणों पर विचार किया गया है। इन प्रेक्षणों का उपयोग करते हुए वायुमंडलीय परिसीमा स्तर और विभिन्न धरातलीय प्राचलों के स्थानिक परिवर्तनों की उर्ध्वाधर संरचना की जांच की गई। इस जांच से प्राप्त हुए परिणामों से विभिन्न धरातलीय मौसम वैज्ञानिक प्राचलों में महत्वपूर्ण दैनिक भिन्नताओं का पता चला है। इस अध्ययन से यह भी ज्ञात हुआ है कि वायुमंडलीय परिसीमा स्तर की उर्ध्वाधर संरचना पर अपतटीय द्रोणी का कोई प्रभाव नहीं पड़ता है। वायुमंडलीय परिसीमा स्तर में हल्के उपमेघ स्तर, गहन मेघ स्तर, कमजोर स्थिर स्तर के साथ बहुस्तरीय संरचना का पता चला है और चक्रवातीय परिसंचरण के समय 2–4 अगस्त 2002 में वायुमंडलीय परिसीमा स्तर तक बढ़ जाते हैं। चूंकि वायुमंडलीय परिसीमा स्तर गहन उपमेघ के स्तर, हल्के मेघ के स्तर, तीव्र स्थिर स्तर प्रतिलोमी सतह के साथ संबद्ध होता है अतः भारत के पश्चिमी तट के साथ–साथ देखी गई अपतटीय कमजोर द्रोणी के प्रभावस्वरूप वायुमंडलीय परिसीमा स्तर की गहराई कम हो जाती है।

ABSTRACT. A study has been carried out to explore the salient features of the Atmospheric Boundary Layer (ABL) over the eastern Arabian Sea regions during the summer monsoon season of 2002. For this purpose the aerological observations and surface meteorological observations collected onboard ORV Sagar Kanya during the Phase-I of ARMEX-2002 for the two stationary positions (30 June-10 July and 22 July – 5 August 2002) have been considered. Utilizing these observations the vertical structure of the Atmospheric Boundary Layer and the temporal variation of different surface parameters has been investigated. The results showed prominent diurnal variation in different surface meteorological parameters. The study also revealed that there is no influence of the offshore trough on the vertical structure of the Atmospheric Boundary Layer. The ABL showed multilayered structure with shallow sub cloud layer, deep cloud layer, weak stable layer and the ABL extending up to higher levels in the presence of the cyclonic circulation (2-4 August 2002). Whereas the ABL is associated with deep sub cloud layer, shallow cloud layer, strong stable layer (inversion layer) and shallow ABL depth under the influence of weak offshore trough observed along the west coast of India.

Key words − ARMEX, Vertical structure of the ABL, ARMEX-2002, Temporal variation, Marine ABL.

1. Introduction

Knowledge of the thermodynamic structure of the Atmospheric Boundary Layer (ABL) over the Arabian Sea during summer monsoon are invaluable for understanding the monsoonal flow. Radiosondes from ships and dropsondes from aircraft during the International Indian Ocean Expedition (IIOE, 1963-65) provided for the first time some insight into the temperature and moisture stratification in the lower troposphere (Colon, 1964) over the Arabian Sea particularly in the region north of 10° N.

Useful datasets are also provided through the experiments like Indo-Soviet Monsoon Experiment (ISMEX-73), MONSOON-77, MONEX-79, MONTBLEX-90, BOBMEX-99 and more recently INDOEX-2000. Utilization of these dataset has helped in exploring the detailed structure of the Atmospheric Boundary Layer (ABL) over the oceanic as well as land regions (Pant, 1977, 1978 1982; Ghosh *et al*., 1978; Mohanty *et al*., 1983; Parasnis and Morwal, 1991a; 1993a; Morwal, 2003; Sam *et al*., 2001; Holt and Sethuraman, 1987). In the present paper, observations collected during the recent experiment called Arabian Sea Monsoon Experiment
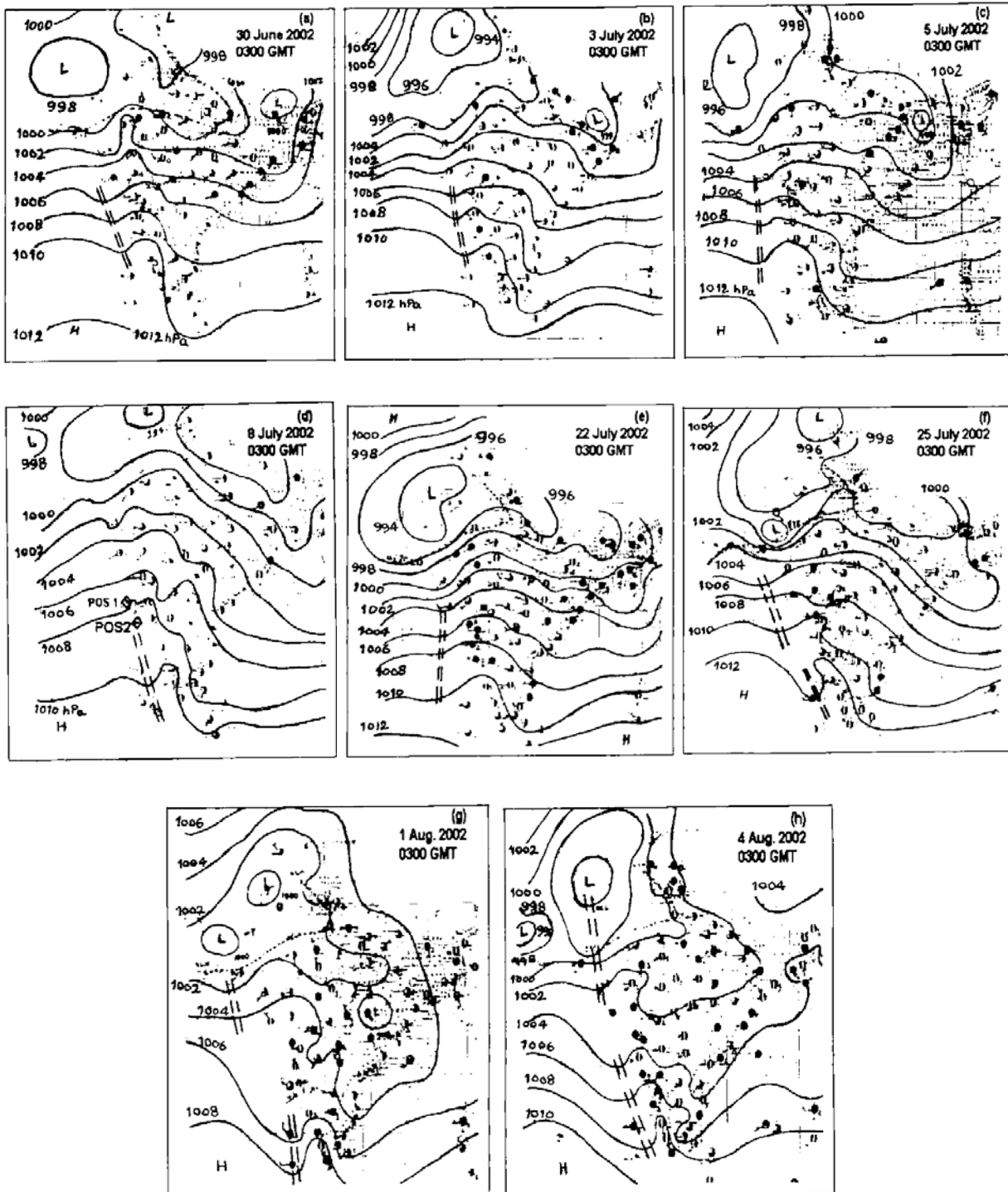
Figs. 1(a-h).   Position of the offshore trough (marked by double dashed line) along the west coast of India for some representative days during POS 1 (a-d) and POS 2(e-h). Also the position of the ship during stationary positions is marked in Fig. 1(d)

(ARMEX) have been utilized. In order to explore the vertical structure of the ABL over the Arabian Sea during the summer monsoon season, radiosonde observations and the Automatic Weather Station data have been utilized.

This study, in particular, provides the average features of the marine ABL for observations collected at two stationary positions during the Phase-I of ARMEX *i.e.*, during 24 June to 15 August, 2002.
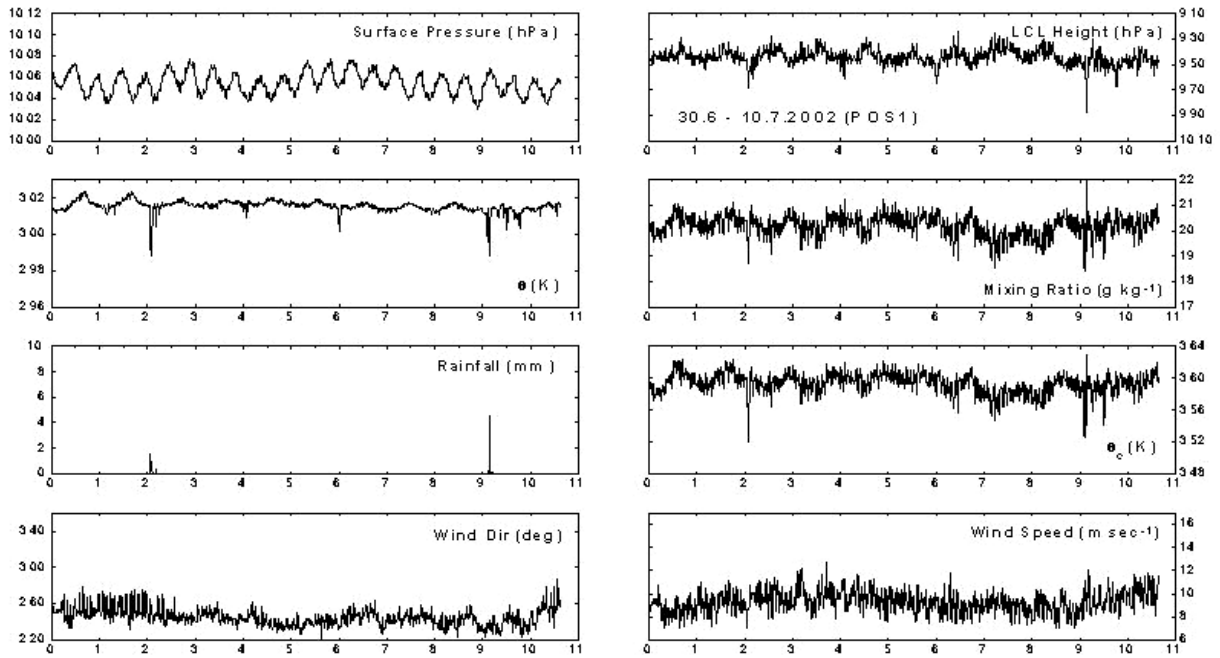
Fig. 2. Temporal variation of different thermo dynamical parameters at the surface at POS1 (30 June – 10 July 2002)

2. Location of observations and meteorological conditions

High resolution aerological observations are collected during Phase-I of ARMEX onboard ORV Sagar Kanya during 24 June to 15 August 2002. Also, surface meteorological observations (at deck level, 12 m) are collected using the Automatic Weather Station at an interval of 10 minutes. During Phase-I of ARMEX the ship is stationary at two positions *viz.* POS1 (16° 94′ N, 7l° 20′ E) and POS2 (15° 38′ N, 72° 18′ E) and it is shown in Fig. 1(d). The periods associated with these two stationary positions are 30 June (0000 UTC) to 10 July (1111 UTC) and 22 July (0021 UTC) to 5 August (0536 UTC). The dataset contains 23 and 37 radiosonde ascents respectively at POS1 and POS2. As far as synoptic conditions are concerned, the off shore trough along the west coast persisted on most of the days from 20 May to 17 September along different parts of west coast except during 25-31 July 2002. The exact position of the offshore trough (as described in the Weather Summary, Mausam, 2003) during the observational period of ARMEX Phase-I Experiment is given in Table 1. The position of the offshore trough for some days during POS1 and POS2 is shown in Figs. 1(a-h). In general, the offshore trough is very weak. There was a cyclonic circulation between 2.1 and 4 km asl off coasts of Karnataka and Goa during the first week of August 2002. It remained stationary during 2-3 August and became less marked on 4 August 2002. The surface winds over the Arabian Sea were nearly

normal (7.5-10 m sec^{-1}) in June whereas during July they were less than normal (10 - 12 m sec^{-1}) by 2.5 m sec^{-1} to the north of 15° N.

3. Method of analysis

For better understanding of the monsoon activity in association with the ABL thermodynamic structure over the Arabian Sea regions, the Saturation Point (SP) concept introduced by Betts (1982) is used. When an unsaturated air parcel is lifted dry adiabatically along the constant mixing ratio line till saturation is attained, that level is termed as Saturation Level (SL). Thus, the point of intersection of dry adiabat through T and constant mixing ratio line through T_d is known as SP and is specified by parameters such as θ_{SL}, q_{SL} and p_{SL}. In the present study SP for all practical purposes means LCL at different levels since the environment considered here is unsaturated. SP is unchanged during dry/moist adiabatic ascent/descent. However, under the influence of some physical processes SP can change. These processes are radiative cooling/warming and precipitation/evaporation of falling precipitation (Betts, 1982). Further, P^* *i.e.*, saturation pressure deficit is defined as

$$P^* = p_{SL} - p$$

Where p is the air parcel pressure and p_{SL} is pressure at saturation level. P^* indicates the lack of saturation in the layer p to p_{SL}. It is positive in the cloudy region (or
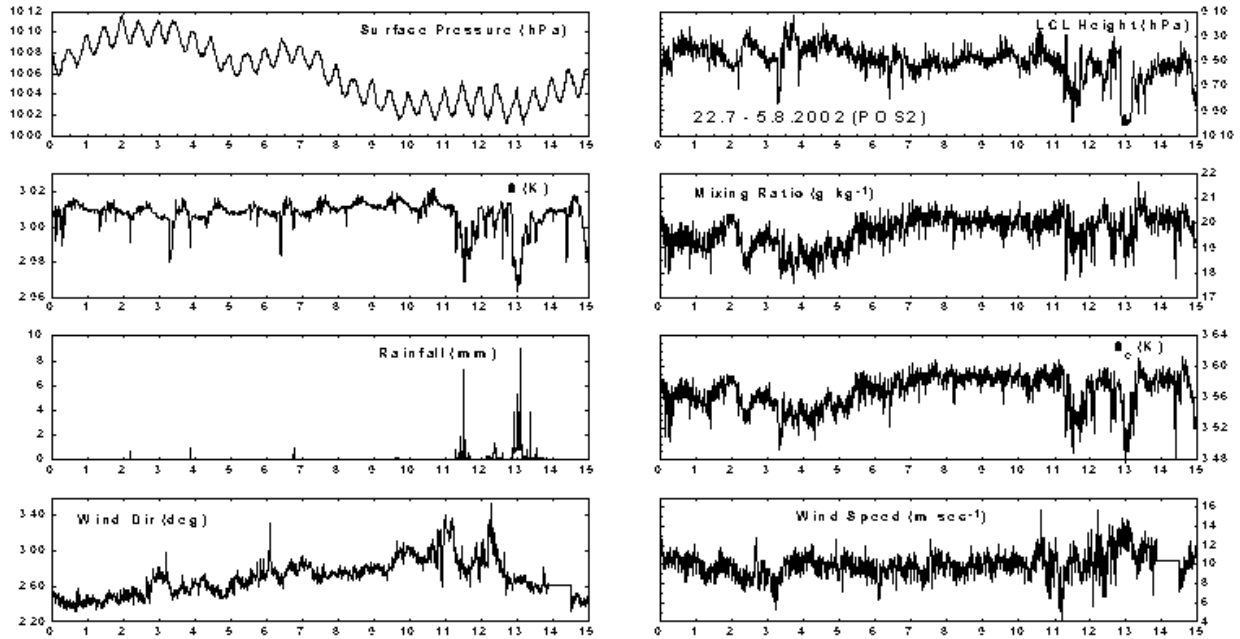
Fig. 3. Same as Fig. 1 at POS2 (22 July – 5 August 2002)

negative values with small magnitude) and negative in the unsaturated region (high negative values). The vertical profiles of P^* resemble the vertical profiles of relative humidity.

Conserved variable diagrams (θ_e - q) are very useful to understand the influence of different physical processes and convective mixing on the vertical structure of the ABL. The mixing line is straight line on these diagrams. Both the axes, *i.e.*, θ_e on X and q on Y, represent conserved variables. A single mixing line structure is produced under the influence of convective mixing processes and when it is modified by the different physical processes, as described above, a double mixing line structure is produced (Betts and Albrecht, 1987). The top of the ABL is represented by a kink *i.e.*, change in slope of the mixing line. These diagrams have been used in many studies to understand the thermo dynamical structure of the ABL (Betts and Albrecht, 1987; Parasnis and Morwal, 1991b; 1993a, b; Parasnis *et al.*, 1991; Sam *et al.*, 2001; Emanuel, 1994). To examine the type of convection, Kloesel and Albrecht (1989) have classified the radiosonde soundings into three types of idealized profiles depending on the vertical profiles of θ_e and θ_{es} and the path of the non entraining air parcel rising from the mean sub cloud layer. These classes are: (*i*) Inversion

sounding (*ii*) High θ_e sounding and (*iii*) Low θ_e sounding. Inversion sounding represents shallow convection, High θ_e sounding represents deep convection and the Low θ_e sounding is associated with the suppressed convection. More details of this technique are discussed by Morwal and Seetaramayya (2003). The above methods can be applied over land as well as over oceanic regions to characterize the differences in the thermodynamic structure of the atmospheric boundary layer.

The 12-hourly high resolution radiosonde observations collected onboard ORV Sagar Kanya have been used to investigate the characteristic features of the thermodynamic structure of the marine ABL. Different thermodynamical parameters such as potential temperature (θ in K), virtual potential temperature (θ_v in K), humidity mixing ratio (q in g kg^{-1}), equivalent potential temperature (θ_e in K), saturated equivalent potential temperature (θ_{es} in K), pressure at saturation level (p_{SL} in hPa) and saturation pressure deficit (P^* in hPa) have been computed from surface up to 400 hPa level for each individual ascent and also for the average datasets at both the stationary positions utilizing the vertical profiles of p, T and RH. Also, for AWS data the parameters such as Lifting Condensation Level (LCL in hPa), q, θ and θ_e have been computed for the period

associated with stationary positions. The different formulae used in computation are described in Morwal (1998).

4.   Results and discussion

4.1. *Distribution of surface meteorological parameters*

The daily march of surface meteorological parameters *viz*., surface pressure, potential temperature, LCL height, mixing ratio, θ_e, wind direction, wind speed and rainfall for POS1 and POS2 is given in Figs. 2&3 respectively. For both the stationary positions surface pressure showed prominent semi diurnal variation. From these figures it is clearly evident that the variation in surface pressure is more at POS2 (1001 - 1011 hPa) as compared to that at POS1 (1003 - 1008 hPa) which is in support of the prevailing weather conditions during the two stationary periods. At POS1 the temporal variation in pressure is subtle in nature whereas at POS2 they showed increasing trend during 22-24 July, decreasing trend during 25 July - 31 July and nearly constant values from 1 - 4 August and increasing trend thereafter. The pressure values are high during 23-29 July as compared to other days at POS2. This is in support of the fact that there is no offshore trough along the west coast during 25-31 July as reported in the weather summary. The thermo dynamical parameters *viz*., θ, q, θ_e and LCL showed diurnal variations. The temporal variation in these parameters is less at POS1 as compared to that at POS2. This may possibly be due to the fact that during first stationary period the weak offshore trough prevailed and as such the synoptic conditions are found to be more or less same throughout the observational period. All the thermodynamic parameters showed large temporal variations, specifically during 2-4 August as the second stationary period is associated with continuously changing weather conditions *i.e*., presence of offshore trough (22-24 July) to absence of offshore trough (25 - 31 July) and then existence of cyclonic circulation associated with offshore trough (2-4 August). The position of the offshore trough along the west coast of India during the observational period is described in Table 1.

The parameters θ, q and θ_e, in general, showed higher values at POS1 compared to POS2 indicating warm, moist and more convective surface layer at POS1. At POS2 the surface layer is cool and dry, specifically more pronounced during 2 - 4 August. The rainfall data showed precipitation during 2-4 August. The cooling and drying may possibly be associated with the precipitation and downdrafts as seen from the rainfall distribution. Similar features were observed by Betts (1976) and Parasnis and Morwal (1993a) while studying the

TABLE 1

Position of the offshore trough along the west coast of India during 2002

Period	Position of the offshore trough
20 Jun – 24 Jun	Gujarat coast to Kerala coast
25 Jun – 26 Jun	North Arabian Sea to Karnataka coast
27 Jun – 8 Jul	South Gujarat coast to Kerala coast
9 Jul – 13 Jul	Maharashtra coast to Kerala coast
14 Jul – 17 Jul	Maharashtra coast to Karnataka coast
18 Jul – 24 Jul	Maharashtra coast to Kerala coast
1 Aug – 2 Aug	Karnataka coast to Kerala coast
3 Aug – 21 Aug	Maharashtra coast to Kerala coast

modification of the boundary layer due to the rainfall events. The daily march of θ_e at the surface indicated more moist convective activity at POS1 as compared to POS2. The moist convective activity depends on both parameters *i.e*., surface temperature and humidity. As mentioned earlier, at POS1 the surface layer is warm and moist indicating more convective activity. The maximum diurnal variation is observed during the period 2-5 August. The LCL varied between 960 - 930 hPa at POS1 whereas at POS2 the variation is from 1000 - 930 hPa which is mainly during 2 - 4 August. At POS1 the winds are southwesterly and wind speed varied between 8 - 11 msec^{-1}. The winds are southwesterly to northwesterly at POS2 and wind speed showed large variations (6 - 14 msec^{-1}). During both the stationary periods the surface layer was found to be becoming cool and dry after the rainfall events.

Thus the temporal distribution of different thermo dynamical parameters at the surface showed more or less similar variations when there is no convective activity and large variations are observed during the periods associated with active monsoon conditions/ convective events.

4.2. *Vertical structure of the ABL*

In order to bring out the differences in the vertical structure of the ABL, three different cases based on the prevalent synoptic weather conditions have been considered. In Case I with the view to emphasize the influence of the presence of the offshore trough along the west coast of India two soundings collected in the
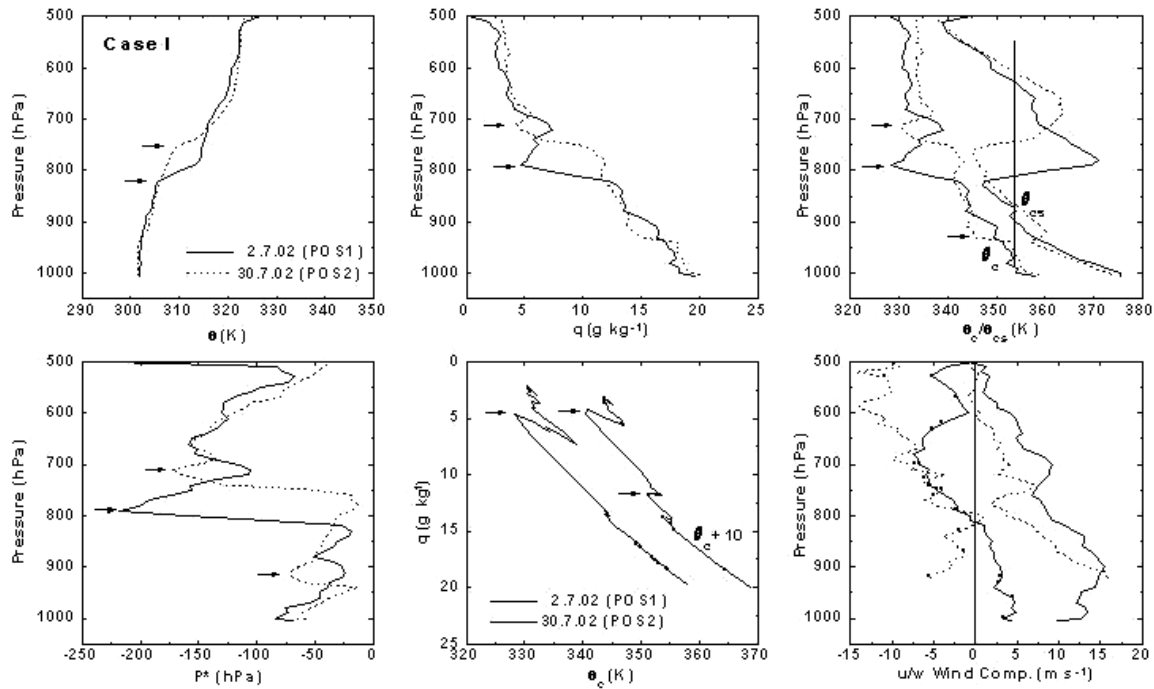
Fig. 4. Vertical profiles of different thermo dynamical parameters *viz*., potential temperature (θ), mixing ratio (q), equivalent potential temperature (θ_e), saturated equivalent potential temperature (θ_{es}), saturation pressure deficit (P^*), u and v components of winds and conserved variable diagrams (θ_e-q) on 2 July 2002 and 30 July 2002 at 1200 UTC

presence (2 July 2002 at 1200 UTC) and absence (30 July 2002 at 1200 UTC) of the offshore trough have been considered. On 2 July the position of the offshore trough was from south Gujarat coast to Karnataka coast (Table 1) and on 30 July there was no trough along the west coast. In Case II in order to explore the influence of cyclonic circulation associated with offshore trough off the west coast of India two soundings collected in the presence (2 August 2002 at 1200 UTC) and absence (5 July 2002 at 1200 UTC) of cyclonic circulation have been used. On 5 July the trough off the west coast was running from south Gujarat coast to Karnataka coast and on 2 August its position was from Karnataka coast to Kerala coast (Table 1). Also, there was a cyclonic circulation near Karnataka coast during 2 - 4 August 2002. In Case III the average of 23 (30 June – 10 July) and 37 (22 July – 5 August) radiosonde ascents respectively at POS1 and POS2 have been utilized to characterize the averaged vertical thermodynamic structure of the ABL.

The vertical profiles of the thermodynamic parameters *viz*., θ, q, θ_e, θ_{es}, P^* and u and v components of winds from surface up to 400 hPa level and conserved variable diagrams (θ_e - q) for the above mentioned three cases are shown in Figs. 4-6 (Fig. 4: Case I, Fig. 5: Case II

and Fig. 6: Case III). The onset of southwest monsoon over Kerala commenced on 29 May 2002, and it covered the entire country by 15 August 2002. In Fig. 4, the days 2 July and 30 July belong to POS1 and POS2 respectively. In Fig. 5 one day each at POS1 (5 July) and POS2 (2 August) is considered. Fig. 6 depicts the average vertical profiles at POS1 and POS2.

From Fig. 4 it is seen that the vertical profiles of θ and q on 2 July (solid line) do not differ much from that of 30 July (dashed line) except in the layer 820-730 hPa. The mixed layer which is associated with nearly constant values of θ is from surface - 920 hPa and surface - 940 hPa on 2 and 30 July respectively. The layer 820-790 hPa which is associated with sharp increase of θ and sharp decrease of q is representative of an inversion layer (or very high stable layer). This inversion layer is observed almost on all the days at POS1. This stable layer is observed between 760 to 710 hPa on 30 July 2002 and it is associated with less increase of θ and less decrease of q as compared to that on 2 July 2002. From θ_e, θ_{es} and P^* profiles it is clearly seen that the moist convective activity is more or less same on both the days up to 820 hPa level. The extent of the cloud layer is more on 30 July (up to 760 hPa) as compared to that on 2 July (up to 820 hPa).
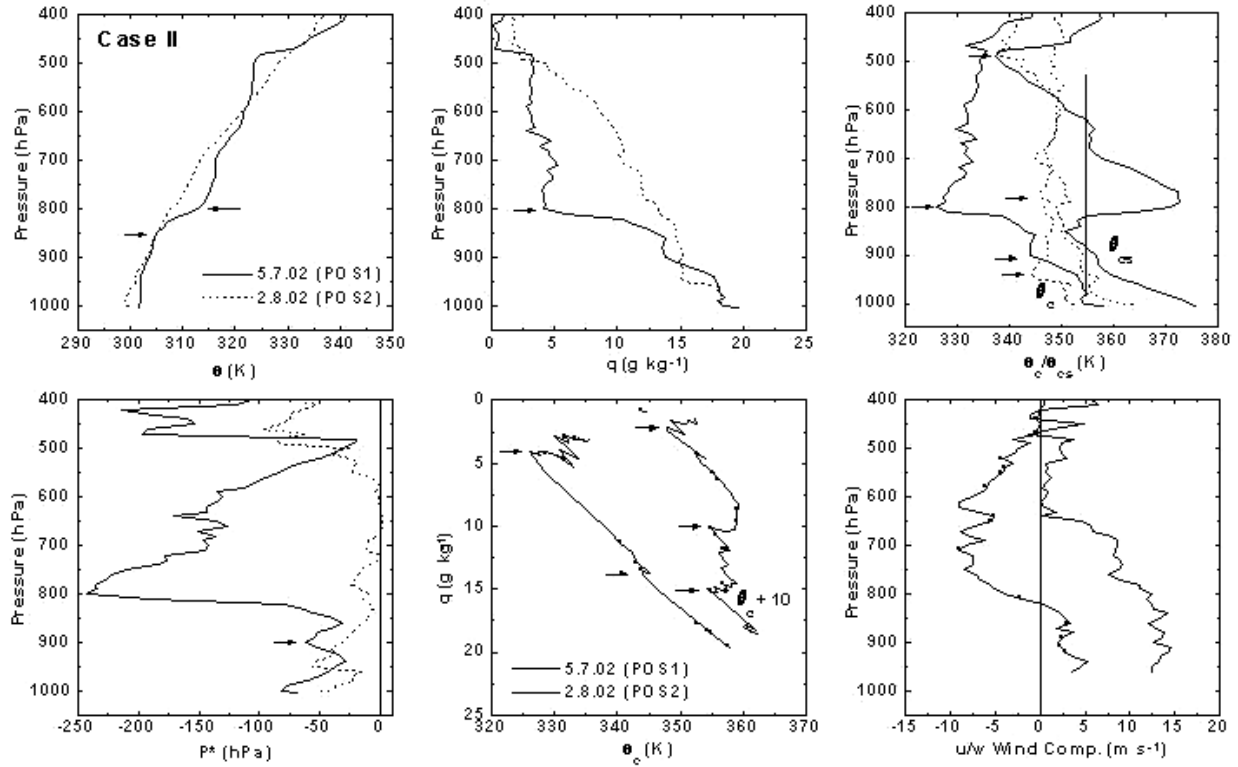
Fig. 5. Same as Fig. 3 on 5 July 2002 and 2 August 2002 at 1200 UTC

TABLE 2

Pressure (hPa) at the top of different sub layers in the ABL along with surface pressure

Cases	Surface pressure	Layer		Stable/inversion layer		
		Sub cloud layer	Cloud layer	Top	θ_e	P^*
Case I						
2 Jul 2002	1004.6	920	820	790	328.2	-217.9
30 Jul 2002	1002.5	940	760	710	330.7	-174.5
Case II						
5 Jul 2002	1004.7	940	840	800	326.0	-242.4
2 Aug 2002	1001.6	960	540	480	338.0	-84.3
Case III						
POS1	1004.1	940	830	730	332.3	-155.2
POS2	1003.9	960	760	670	337.8	-74.0

However, on 30 July the cloud layer is slightly less saturated in the lower layers (as seen from θ_e, θ_{es} and P^* values) as compared to that on 2 July. The stable layer (identified by sharp decrease of θ_e and sharp increase of θ_{es}) overlying the cloud layer is very strong on 2 July in comparison to 30 July. The ABL (marked by arrows and determined at the level associated with minimum values

of θ_e and P^* and maximum value of θ_{es} in the vertical profiles) extended up to higher levels on 30 July (710 hPa) as compared to that on 2 July (790 hPa).

The θ_e - q profiles in Fig. 4 showed single mixing line structure on 2 July (solid line solid circle) whereas double mixing line structure is observed on 30 July (solid
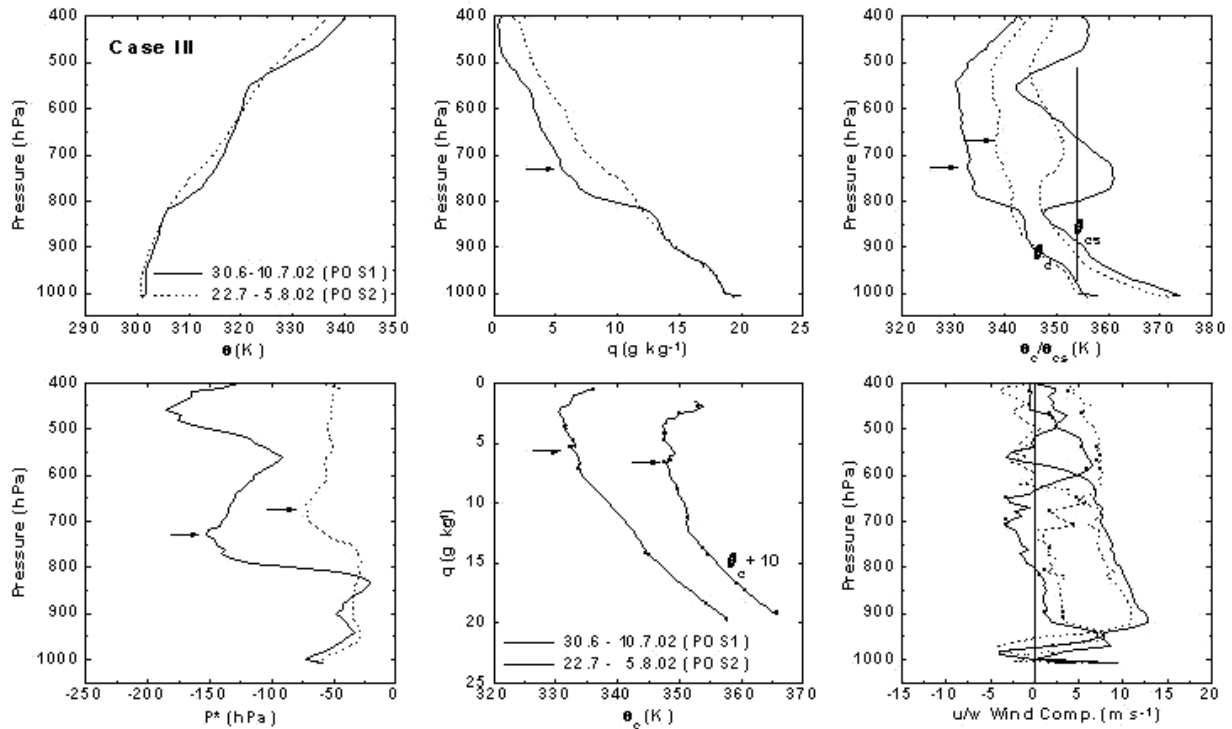
Fig. 6. Same as Fig. 3 for averaged dataset at POS1 and POS2

line open circle and shifted by 10 K). The top of the ABL is marked by a kink associated with the change in slope of both θ_e and q as observed by Betts and Albrecht (1987). On 2 July only one kink is observed at the ABL top whereas two distinct kinks (890 hPa and 710 hPa, marked by arrows in Fig. 4) are seen in the mixing line on 30 July 2002. The low level stability analysis showed that both the soundings are associated with inversion. The convective activity is inhibited by the inversion layer. The strength of the inversion is more on 2 July as compared to 30 July. Also the inversion layer is observed at higher levels on 30 July as compared to 2 July. Table 2 gives the top of different sub layers and surface pressure along with values of θ_e and P^* at the top of the ABL. The vertical profiles of u and v components of winds showed that on 2 July winds are southwesterly in the ABL (790 hPa) and became northwesterly above. On 30 July winds are northwesterly from 910 hPa up to higher levels. Thus from this comparison it is clearly evident that in the eastern Arabian Sea the vertical structure of the ABL showed some changes in the mid levels (800-700 hPa). The mid levels which were warm and dry in the presence of the offshore trough became cool and moist in its absence. The extent of the mixed layer increased (890 hPa), the depth of the cloud layer decreased and the ABL is limited to lower levels (790 hPa) when the offshore trough is present. It is

therefore noticed that in the eastern Arabian Sea the presence or absence of the offshore trough (synoptic scale feature) have no direct influence on the structure of the ABL but it is the position of the observational platform which makes the difference. Ghosh *et al.* (1978) have reported the upward shift of the inversion with longitudinal variation. Also, Parasnis and Morwal (1993a) have confirmed that the inversion layer shifts upward with longitude and it becomes very weak in the eastern Arabian Sea. The present study also confirms the earlier reported results. The inversion layer is strong and at lower levels at POS1 (16° 94′ N, 71° 20′ E) which is observed northwest of POS2 (15° 38′ N, 72° 18′ E) and it is found to be shifting upward at POS2.

From Fig. 5 it is seen that on 5 July the atmosphere is in general warm and dry at all levels as compared to that on 2 August (from θ and q profiles). There is a very stable layer between 840 to 800 hPa on 5 July. In this layer the q profile of 5 July also shows a sharp decreasing trend. In general, the moisture content (q profiles) is more on 2 August at all levels except in the layer 950 to 900 hPa as compared to 5 July. The difference in moisture content between the two profiles is 1-10 g kg^{-1}. The whole ABL is more saturated on 2 August as compared to that on 5 July as seen from the vertical profiles of θ_e, θ_{es} and P^*.
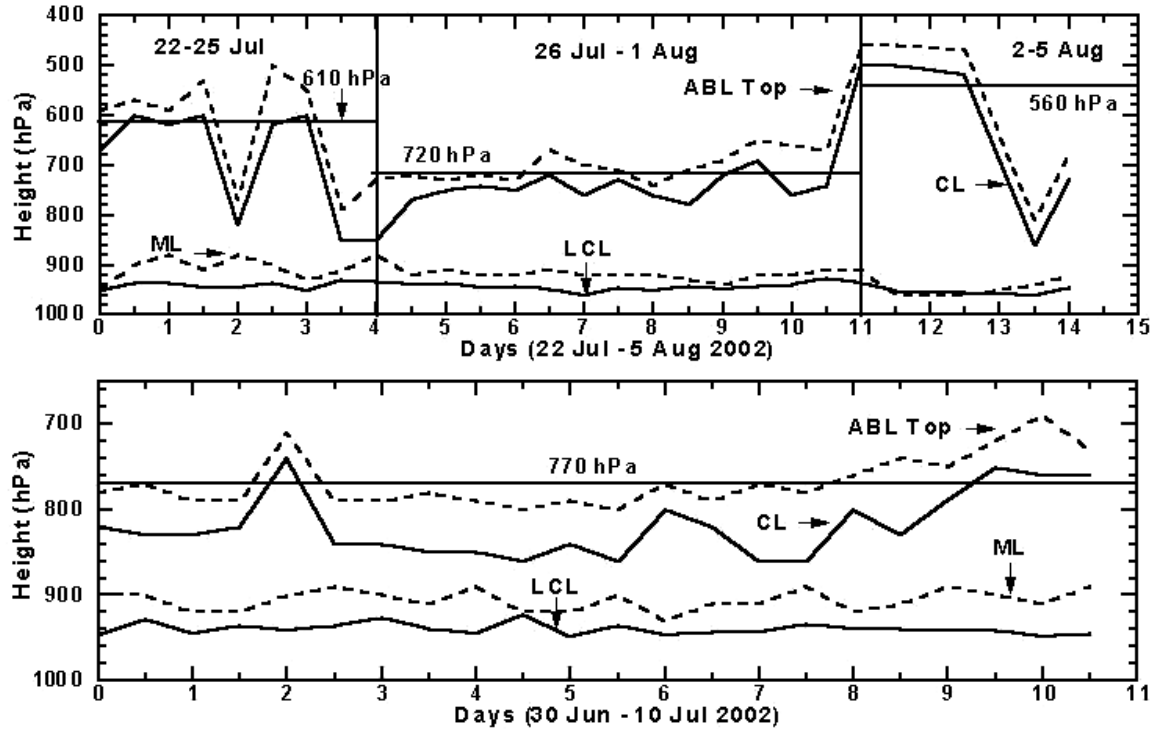
Fig. 7. Height of different sub layers *viz*., LCL (Lifting condensation level), ML (Mixed layer or sub cloud layer), CL (Cloud layer) and top of the ABL in the Atmospheric Boundary Layer

This may be due to the prevailing cyclonic circulation on 2nd August which is responsible for the pumping of moisture up to higher levels (Srinivasan and Sadasivan, 1975). Even though the moisture content at the surface is same for both the days, moisture is not transported to higher levels on 5th July as suitable weather conditions were not observed. Srinivasan and Sadasivan (1975) have also reported higher values of θ_e during active monsoon conditions as compared to weak monsoon conditions at levels between 750 hPa & 400 hPa which are in support of the above results. On 5 July the sub cloud layer is deep (940 hPa), cloud layer is shallow (940-840 hPa) and the ABL extended up to lower levels (800 hPa) as compared to that on 2 August. The top of the different sub layers in all the three cases mentioned above is given in Table 2. The P^* profiles indicated that the stable layer overlying the cloud layer is very strong on 5 July (very sharp decrease of P^*) and it is weak on 2 August. The cloud layer is deep and saturated on 2 August (960-540 hPa).

The mixing lines on θ_e - q diagrams on 5 July (solid line with solid circle) and 2 August (solid line with open circle and shifted by 10 K) are also shown in Fig. 5. The mixing lines showed double mixing line structure on

5 July and multiple mixing lines are observed on 2 August (marked by arrows). The top of the each mixing line is shown by a kink *i.e.*, change in slope of θ_e and q. The double (or multiple) mixing line structure observed on 5 July and 2 August may be associated with the redistribution of θ and q patterns due to falling precipitation and also existence of multiple cloud layers. The low level stability analysis indicated that the sounding on 5 July is representative of inversion sounding and the ABL is limited up to 800 hPa *i.e.*, the influence of the convective mixing is seen up to the base of the inversion. On 2 August the deep convection is indicated by the low level stability analysis. The wind data is not available on 2 August. The vertical profiles of u and v components of wind on 5 July showed southwesterly winds in the ABL and northwesterly winds above. Thus the comparative investigation of the vertical structure of the ABL showed that the convection which was inhibited by the presence of inversion layer before the formation of the cyclonic circulation reached up to higher levels under the influence of the cyclonic circulations and the whole atmosphere became cool and moist.

From the averaged vertical profiles of θ (Fig. 6) it is seen that at POS1 (solid line) θ is more at all levels from

surface up to 400 hPa level except between 620-520 hPa as compared to that at POS2 (dashed line). An inversion layer is present almost on all days from 30 June to 10 July near about 800 hPa level (Figure not given) which is also evident in the averaged profile between 810 & 780 hPa. This layer acts as a barrier and inhibits the transport of heat and moisture and momentum from the lower layers to the higher levels (McBean, 1979). Srinivasan and Sadasivan (1975) reported that the moisture content is same up to 850 hPa level irrespective of the prevailing weather conditions over land as well as oceanic regions (Arabian sea regions). In this case it is observed that the humidity mixing ratio is more or less same from surface up to 820 hPa at both the stationary positions. However, above this level it is more at POS2 by ~2-3 g kg^{-1} in comparison to that at POS1. Even though the moisture content is same below 820 hPa level, it is not transported to higher levels at POS1 due to the presence of the inversion layer at that level. Also, this may be due to the absence of favourable synoptic scale disturbances which are responsible for the transport of moisture from surface to the higher levels.

The vertical profiles of θ_e and θ_{es} showed that the moist convective instability in the lower layers (up to 820 hPa) at both the positions is more or less same. Above 820 hPa there is more moist convective activity at POS2 (Srinivasan and Sadasivan, 1975). The mixed layer or sub cloud layer extends up to 940 hPa and 960 hPa respectively at POS1 and POS2. The depth of cloud layer is less (110 hPa) at POS1 as compared to POS2 (180 hPa). The stable layer above the cloud layer is strong at POS1 and the ABL extends up to 730 hPa and marked by a sharp maximum in θ_{es} and minimum in P^*. The θ_e minimum is not well pronounced and a flat θ_e minimum is observed. The ABL extends up to higher level at POS2 (670 hPa) marked by minimum in θ_e and P^* and maximum in θ_{es}. Thus the influence of the surface layer is visible up to higher levels at POS2. The low level stability criteria utilizing the θ_e and θ_{es} curves at POS1 and POS2 showed that the soundings at POS1 are associated with the inversion soundings (shallow convection) whereas those at POS2 are representative of the deep convection.

The conserved variable diagrams showed a single mixing line structure in the ABL at both the stationary positions and ABL top is marked by a kink (shown by arrows) in the curve. The double mixing line structure observed on individual days (as seen from the Case I and Case II) is not noticed in the averaged profiles. This may be probably due to the fact that the cloud layers of different depths occur at different levels and in the averaged profiles the effect becomes mild. The vertical profiles of P^* indicated that the ABL is more saturated at POS2 as compared to that at POS1. The cloud layer

(indicated by nearly constant and high P^* values) is found to be deeper at POS2 as compared to POS1. Also the inversion layer is clearly evident from these profiles at POS1. The vertical profiles of u and v components of winds at POS1 and POS2 showed existence of wind maxima around 910 hPa. At POS1 southwesterly winds are observed at all levels except between 800-610 hPa where they are northwesterly. The winds are northwesterly up to 610 hPa and northeasterly aloft at POS2.

Thus the ABL at POS1 and POS2 is represented by layered vertical structure. The ABL at POS2 is associated with more moist convective activity reaching up to higher levels, shallow mixed layers, thick cloud layers (180 hPa) and ABL extending up to higher levels (670 hPa) and a single mixing line structure.

Fig. 7 shows the temporal variation of the height of the different sub layers in the ABL (in hPa) *viz.*, LCL, mixed layer (or sub cloud layer), cloud layer and top of the ABL at POS1 and POS2 for all the days considered in this study. During both the periods it is observed that the LCL is below the mixed layer indicating the saturation of the upper part of the mixed layers. Similar feature was observed by Parasnis *et al*. (1991) over a coastal station during MONTBLEX-1990 and also by Parasnis and Morwal (1993a) over the Arabian Sea region. In general, the LCL is observed at higher levels at POS1 as compared to POS2. The mixed layers are shallow at POS2 as compared to those at POS1. The cloud layer depth is more during the period 22-25 July and 2-4 August 2002. The ABL extends up to higher levels during 9-10 July and 2-4 August. This may be due to the presence of disturbance along the west coast of India which resulted in a more moist convective activity.

5.   **Concluding remarks**

A study has been carried out over the eastern Arabian Sea utilizing the aerological observations and surface meteorological observations collected through Arabian Sea Monsoon Experiment-2002. The data pertains to two stationary positions in the Arabian Sea at POS1 (16° 94′ N, 71° 20′ E) and POS2 (15° 38′ N, 72° 18′ E) during the period 30 June – 10 July and 22 July – 5 August 2002 respectively. The results of the study showed that :

(*i*) Surface meteorological parameters at both the stationary positions indicated prominent diurnal variations in the different thermo dynamical parameters. Also, the variations in different thermo dynamical parameters are of subtle nature. Under the influence of the synoptic scale disturbance [Cyclonic circulation (CC) associated with

offshore trough] all the thermodynamical parameters showed large variations. Further, the surface layer which was warm, moist and convective became cool, dry and less convective (*i.e.*, decrease in θ_e) after the convective events.

(*ii*) Vertical structure of the ABL showed that an inversion layer persisted in all the ascents around 800 hPa at POS1. This inversion layer showed upward shift at POS2 with weakening of the inversion strength. The inversion layers were not observed during the disturbed conditions.

(*iii*) The structure of the ABL showed multilayered structure with variation in the thickness of different sub layers due to presence/absence of the weak offshore trough and the cyclonic circulation embedded in it. In general up to 820 hPa the atmosphere is more or less same at both the stationary positions. However, above this level the atmosphere is cool and moist at POS2 as compared to POS1. At POS1 the ABL showed deep mixed layers, shallow cloud layers and strong inversion layers whereas the mixed layers become shallow, cloud layers deepened and the inversion layer becomes weak at POS2. Under the influence of the cyclonic circulation the whole ABL becomes homogeneous. The extent of the ABL at POS1 (30 June – 10 July), POS2 under three different conditions *viz.* (*i*) in the presence of offshore trough (22-25 July) (*ii*) in the absence offshore trough (26 July - 1 August) and (*iii*) under the influence of the CC (2-4 August) is found to be up to 770, 610, 720 and 560 hPa respectively (indicated by horizontal line in Fig. 7).

(*iv*) Conserved variable diagrams (θ_e-q) revealed the existence of double mixing lines except on the occasions when the inversion layer is observed below 750 hPa (at POS1). This may possibly be due to the existence of multiple cloud layers.

(*v*) Low level stability analysis, utilizing the vertical profiles of θ_e and θ_{es} and the constant θ_e line from 980 hPa level, showed that all the soundings at POS1 and POS2 (except sounding obtained during 2-4 August) are classified as inversion soundings and they are associated with shallow convection. However, the soundings collected during the period of cyclonic circulation along the west coast of India are classified as high θ_e soundings and they showed deep moist convection.

Acknowledgements

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