

Comparison of PBL structure between pre-monsoon and monsoon season at Anand during 1997

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ABSTRACT

Planetary boundary layer (PBL) structure during two contrasting months of May and July at Anand (Gujarat, India) representing dry and hot pre-monsoon and humid-cool monsoon season respectively based on LASPEX 97 data is discussed. In May, the growth of boundary layer is primarily governed by surface insolation whereas in July surface insolation as well as cloud processes contribute to its growth.

Key words : PBL structure, LASPEX-, Conserved variable analysis

Climatologically, the month of May is characterised by a dry air mass and clear sky conditions, whereas, the month of July is characterised by southwest monsoon, humid air mass and cloudy skies. During such extreme typical weather conditions, having different land properties, one may expect substantial changes in the height of the atmospheric boundary layer (ABL) and the associated mixing processes on time scales of an hour, day (diurnal), month and season. In a recent study Nagar *et al.* (2000), have reported salient features of the ABL during May 1997 at Anand (22°35'N, 72°55'E, 45.1 m asl). They concluded that its evolution is governed mainly by the surface insolation. In the afternoon, in response to intense surface heating, convective mixed layer develops up to a height of 3200 m. They have also reported that unlike sharp gradients of virtual potential temperature (θ_v) and mixing ratio (q) above the mixed layer observed in the mid-latitudes, the tropical atmosphere over Anand shows a gradual change over to the free atmosphere from the mixed layer under clear sky conditions. This study has paved a way for further investigations in the ABL properties of a semi-arid station,

Anand (marked by A in Fig.1) in other months also. In the present study the changes in ABL structure in the month of July due to addition of moisture from the neighbouring Arabian sea (Fig. 1) is investigated keeping the soundings of the month May as a benchmark.

MATERIALS AND METHODS

A brief discussion about the experimental site is given by Nagar *et al.* (2000). In this study three hourly radiosonde data from 00 to 12 UTC in a day taken during Intensive Observational Period (13th to 17th) in the months of May (summer) and July (monsoon) 1997 have been analysed. The thermodynamic parameters such as virtual potential temperature (θ_v), equivalent potential temperature (θ_e), saturation equivalent potential temperature (θ_{es}) and mixing ratio (q) are computed following Bolton (1980). The ABL heights are deduced from the vertical profiles of the above parameters following Betts (1985) and Betts and Albrecht (1987).

Synoptic situation

During the observational period, the

mean meteorological conditions were very dry and hot during the month of May whereas in July the weather was humid, cloudy and relatively cooler. Synoptic conditions during two days on 16th May and 17th July 97 (Fig. 1a, 1b) are representative of the respective months. A strong high-pressure ridge with light variable winds lay over the study area during May while in July a trough of low off Saurashtra and Gujarat coast and a ridge along west coast in Fig. 1b are evident. Surface and low-level winds in July were southwesterly.

RESULTS AND DISCUSSION

It has been known that the thermodynamic parameters θ , θ_v , θ_c , θ_{cs} and q play an important role in understanding the properties of the ABL such as the atmospheric stability, mixing processes, air mass characteristics of local/distinct origin, lifting condensation level (LCL), level of free convection (LFC), convective boundary layer (CBL) height, diabatic and adiabatic processes near the earth's surface etc. Betts (1985), Betts and Albrecht (1987) have extensively used the theory of thermodynamics in evaluating the above processes in depth. Nagar *et al.* (2000) have further stressed the usefulness of studying θ_v , θ_c , θ_{cs} and q profiles over the Indian region. Indeed θ_v can be used to identify the extent of mixed layer height. The low level stability can be identified with θ_c and θ_{cs} profiles. θ_{cs} can be used to identify stable layer. The maximum and minimum values of θ_c coincide with the base and top of the clouds respectively under certain circumstances. Betts and Albrecht (1987) emphasised the usefulness of conserved diagrams and showed that the variables θ_c and q are useful co-ordinates and the saturation points (SPs) can be plotted in

the diagram to identify thermodynamic processes. The condensation process does not change θ_c or q , but during the precipitation process the specific humidity q of the parcel point lowers at constant θ_c (and the reverse for evaporation of falling precipitation). The radiative process does not change q , but radiative cooling lowers θ_c at constant q . Mixing line is straight line on this θ_c - q diagram. During advective process parcel point does not move at all. Generally a mixing-line structure is observed where the vertical convective mixing dominates over the processes that do not conserve air parcel SP, such as radiative cooling, precipitation and evaporation of falling precipitation. The θ_v conserves during dry-adiabatic process but it does not conserve during moist-adiabatic conditions.

Some contrasting features of the characteristic variations of parameters θ_v , θ_c , θ_{cs} and q for two different months, viz. May and July, (Figs. 2 to 4), at Anand are discussed here.

Mean thermodynamic structure of the ABL

Five day mean vertical profiles of θ_v , θ_c and θ_{cs} at three hourly interval (from 00 to 12 UTC) during 13 to 17th of May and July 1997 are shown in Fig. 2 and Fig. 3 respectively. The mean sunrise time at Anand during May and July was 0557 IST (0027 UTC) and 0530 IST (00 UTC) respectively. Nagar *et al.* (2000) have summarised (Figs. 2 a-e) the mean vertical profiles of θ_v , θ_c and θ_{cs} for May from 00 to 12 UTC. The 00 UTC profiles are representative of the nighttime conditions. The boundary layer is characterised by a well-defined inversion up to 940 hPa, which persists till 03 UTC (Fig. 2b). The top of inversion is marked by θ_{cs} maximum and θ_c minimum. It is capped by

a stable layer between 940 and 890 hPa. A residual layer is seen from 890 to 690 hPa (3250 m). It is the remnant part of previous day's mixed layer which starts eroding near the surface just before the sunset as the thermals cease to form. Insolation during forenoon causes temperature in surface layer to rise sharply. At the surface, θ_{es} varies from 348 °K to 450 °K from 00 UTC to 09 UTC. Sensible heat flux and thermals attain their peak value between 06 and 09 UTC primarily by the energy drawn from the underlying surface. Figure 2d shows the growth of convective boundary layer at 09 UTC up to a height of 3280 m. Towards late afternoon and evening, the incoming solar radiation reduces to its minimum value. Consequently, the ground-based convection weakens and ceases the growth of the CBL height. The θ_v profile at 1200 UTC (Fig. 2e) shows a well mixed layer up to a height of 3280 m and this height is nearly the same as observed CBL height at 09 UTC.

From the mean vertical profiles of θ_v , θ_e and θ_{es} of 13-17 July 1997 (Figs. 3 a-f) a typical three layer structure (sub-cloud, cloud and inversion) of the CBL is quite apparent. Mean cloud base is around 950 hPa and the profiles of θ_v and θ_e show nearly constant values in the sub-cloud layer. There is a distinct moist layer (cloud layer) from 950 to 790 hPa. This is capped by an inversion where θ_{es} increases and θ_e decreases with height. The inversion top near 700 hPa is marked by a maximum in θ_{es} and minimum θ_e . The contrasting feature of July mean profile is marked by an increase in the moisture content in the lower levels of the atmosphere up to 800 hPa as compared to May. The θ_e profile shows relatively higher values in July than in May due to an incursion of moisture (Fig. 1b) into the lower atmosphere by the southwest

monsoon current, which flows from the Arabian Sea. It is noticed that the θ_e in the layer 1000-800 hPa varies from 340 to 320°K in May while it varies from 370 to 340°K in July (Fig. 3f). The increase of moisture in July results in the formation of cloud coupled boundary layer comprising of sub-cloud, cloud and cloud-topped inversion layers as against dry CBL found in May.

Another important difference between the two months is in respect of diurnal range of temperature in the surface layer. The difference between maximum and minimum value of θ_{es} at 1000 hPa recorded at 09 UTC and 00 UTC respectively is 50 °K in July as against 100°K in May. Under cloudy conditions, relatively lesser degree of nocturnal cooling in the surface layer takes place in July. As a result, surface inversion (1000-970 hPa) is shallow in July (Fig 3a) and gets completely wiped out by 03 UTC (Fig. 3b). Cloud layer is seen between 950 and 800 hPa topped by an inversion between 800 and 760 hPa supported by sharp increase in θ_e and θ_{es} and decrease in θ_v . Thermodynamic profiles of 03, 06, 09 and 12 UTC (Figs. 3b-e) show gradual growth of convective boundary layer during the course of the day. It reaches up to 700 hPa by 12 UTC and consists of sub-cloud layer up to 900 hPa, cloud layer between 900 and 730 hPa and cloud top inversion between 730 and 700 hPa. It is to be noted here that while in the month of May, due to lack of moisture the growth of CBL is entirely driven by surface insolation, in July, it is governed due to a combined effect of surface heating and cloud processes. The difference in the degree of convective mixing due to surface insolation between May and July is seen in the height of LCL in respective months. The mean LCL at 09 UTC was 3.5 km in May whereas it was 1.5 km in July.

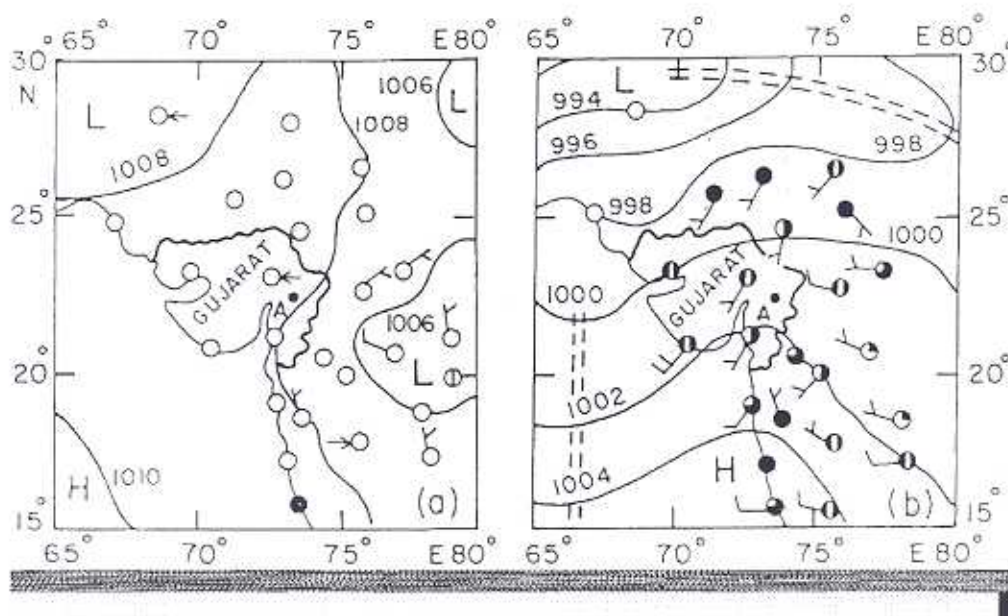


Fig. 1 : Surface charts at 03 UTC on (a) 16 May 1997 and (b) 17 July 1997.

Conserved variable analysis (CVA)

Betts and Albrecht (1987) postulated that the method of CVA has a great advantage to understand certain processes in the ABL. Seetaramayya *et al.* (1993) adopted this method to study the precipitation, evaporation and advection processes in the field of a depression over the head Bay of Bengal using the MONTBLEX-90 radiosonde observations. The CVA envisages the relationship between any two conserved thermodynamic parameters like θ_e and q .

It is inferred from the foregoing discussion that the ABL over Anand is mainly controlled by the daytime solar insolation and nighttime radiative cooling. These processes are reflected in the sounding taken at 09 UTC

(daytime) and 00 UTC (nighttime). Fig. 4 depicts the (θ_e, q) plots for May (Figs. 4a,b) and July 1997 (Figs. 4c,d) for 00 and 09 UTC. In the 00 UTC profile of May (Fig. 4a), saturation points (SPs) in the lower levels are separated widely up to 950 hPa indicating poor mixing in the inversion layer. Kink in the mixing line between 930 and 900 hPa represents a transition layer above which, a close packing of SPs is an indicator of well mixed residual layer. Sharp change in the slope of mixing line above the top of boundary layer (700 hPa) can be attributed to different thermodynamic characteristics of free atmosphere above the top of the ABL. In the afternoon surface heating leads to the formation of a well mixed boundary layer (low values of q) right from the surface to 700 hPa (Fig. 4 b). In July, a stable layer is seen at 00 UTC close to the

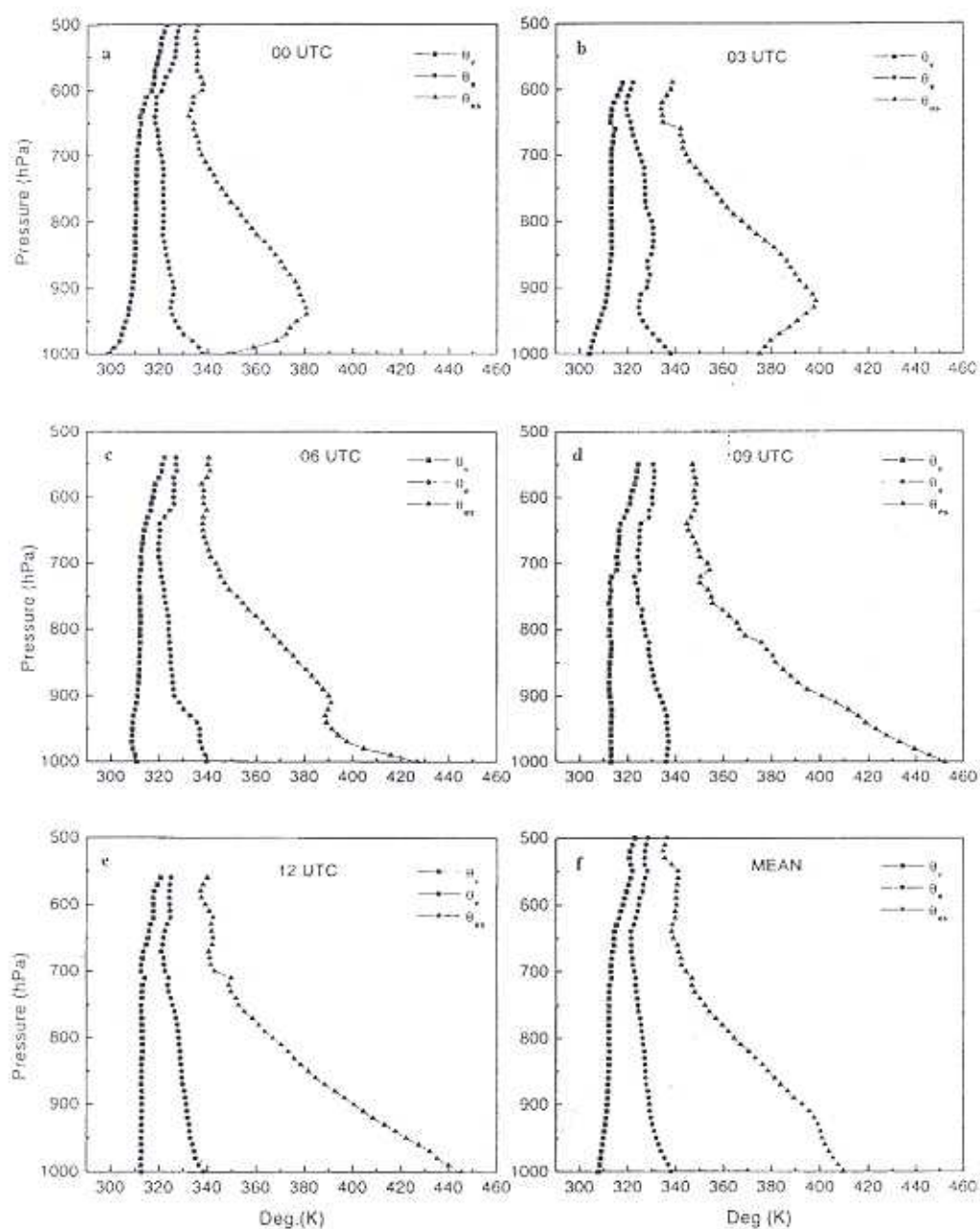


Fig. 2 : Daytime mean variation from 13-17 May 1997 at Anand.

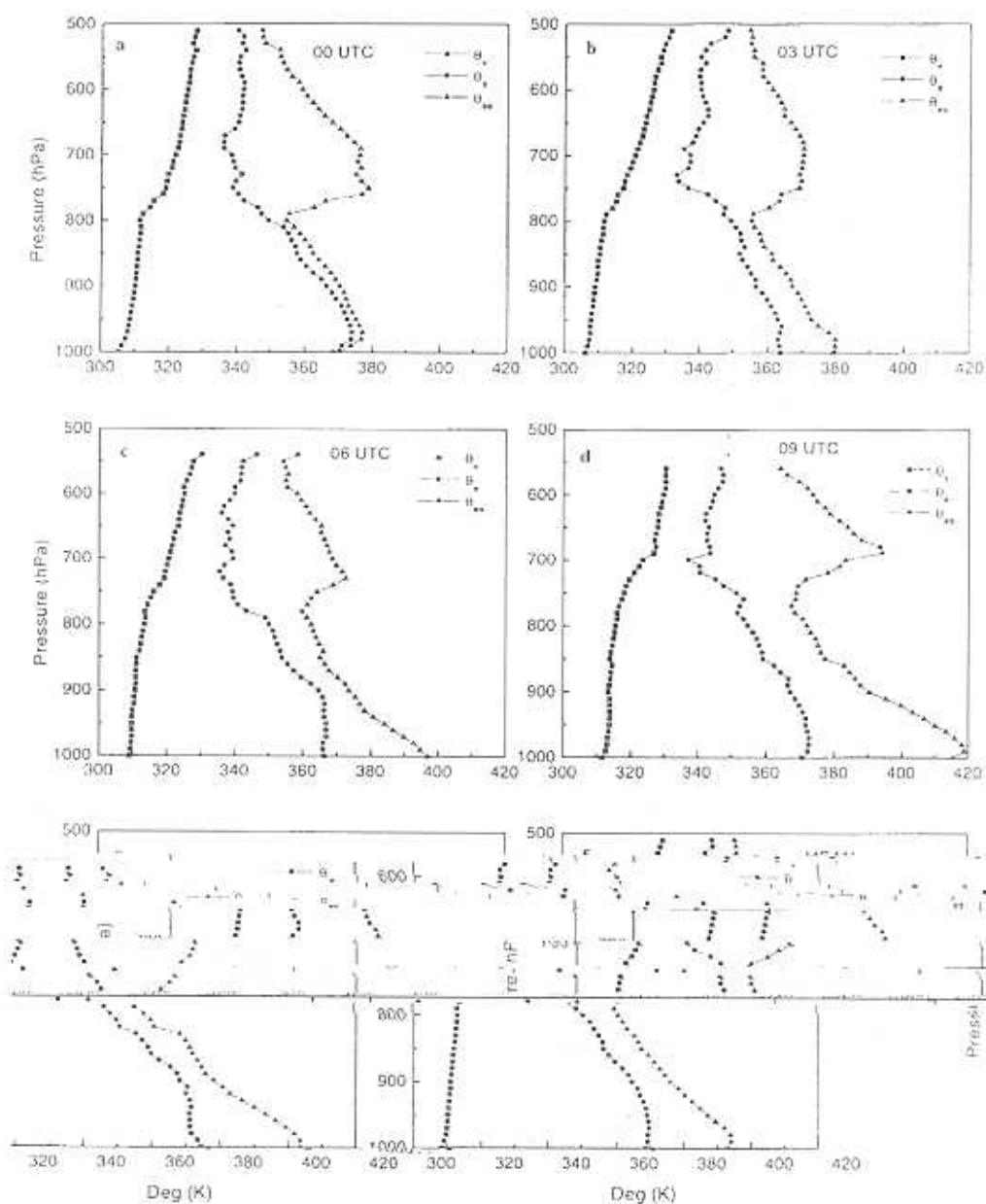


Fig. 3 : Daytime mean variation from 13-17 July 1997 and (c,d) 13 to 17 July 1997.

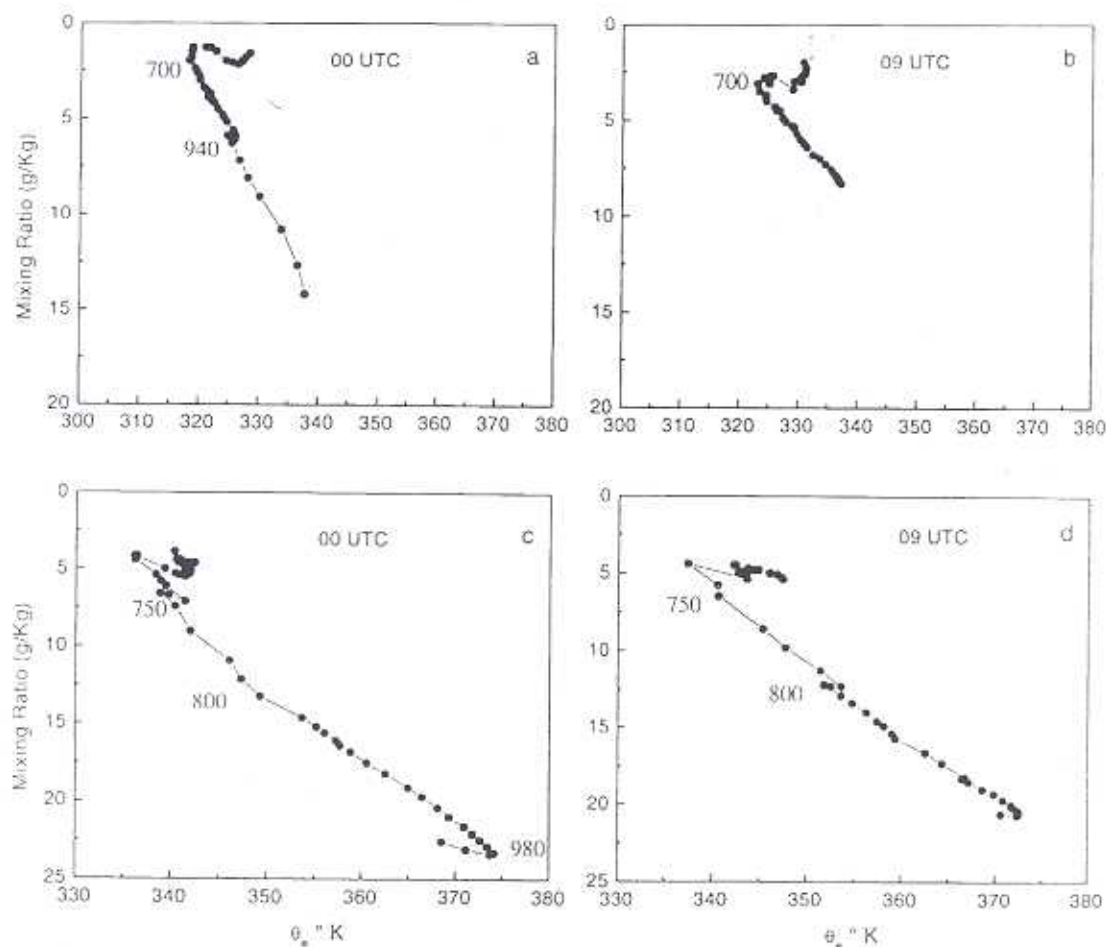


Fig. 4 : Mean plots (a,b) 13 to 17 July 1997 and (c,d) 17 July 1997.

surface up to 980 hPa in which slight increase of moisture (q) is observed (Fig. 4c). A fairly well mixed layer is seen up to 800 hPa above which poorly mixed inversion layer lies up to 750 hPa. At 09 UTC a single mixing line is seen (Fig. 4d) up to 780 hPa indicating that thermodynamically sub-cloud and cloud layers are well connected. It brings out that

in July, surface insolation and cloud processes together contribute to the growth of the CBL. Complex mixing line structure above the CBL is attributed to entrainment and cloud-topped radiative warming (Betts and Albrecht, 1987). The mixing line for July seldom show any precipitation (rainfall) process during the period of observation.

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