Diurnal Structure of Monsoon Boundary Layer

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Abstract

The characteristics of the monsoon boundary layer are imperative to understand in the perception of the tropical regions. The southwest monsoon is associated with a strong wind in the lower troposphere near 1.5 km and is referred to as Low Level Jet stream (LLJ). The boundary layer structure associated with the LLJ during monsoon can be studied using L-band Ultra High Frequency (UHF) radar. This L-band wind profiler-commonly referred as lower atmospheric wind profiler (LAWP), was installed at NARL, Gadanki. Zonal, meridional and vertical wind components are used to understand the diurnal variation of the wind in the Atmospheric Boundary Layer (ABL) and associated features. From the analysis during non rainy days of the southwest monsoon, it is found that the LLJ has maximum strength during the early morning hours at lower level and the height increases as day progresses. The vertical wind shows the transfer of momentum from the LLJ towards the surface, indicating the sinking motion during the daytime. Vertical gradient of the wind shear shows the intensity of clear air turbulence is moderate and no severe clear air turbulence is noticed during the monsoon period.

Key words: Monsoon boundary layer, Low Level Jet stream, boundary layer height, clear air turbulence

1 Introduction

The Atmospheric Boundary Layer (ABL) is the lowest layer of the atmosphere in which surface forcing plays dominant role (Stull, 1988). The ABL over a tropical station in the Indian region during the monsoon season is strongly influenced by the Low Level Jet stream (LLJ) and associated dynamics. Study of the ABL features during southwest monsoon is imperative to understand the underlying physics of the various monsoon processes (eg. convection triggering, turbulent transport of various quantities, the development of LLJ, etc). One of the important features of the ABL is its diurnal variation. This diurnal variation controls the transport process. This kind of variation is strong over the tropical region because the tropics is the hottest region of the globe, which in turn helps the formation of large organised convective clouds of all dimensions as part of the inter tropical convergence zone. Strong solar fluxes, land-sea-atmosphere contrasts and Hadley cell circulation of tropical regions cause ABL to become more dynamic. Hence, the surface boundary layer properties over this region have maximum diurnal and seasonal variations, especially in the southwest monsoon season. Hamza and Babu (2007) studied boundary layer characteristics associated with sea breeze circulation and brought out diurnal variation of boundary layer structure over a tropical coastal station. Indian southwest monsoon is characterized by the LLJ with a core wind at around 850 hPa (Joseph and Raman, 1966; Findlater, 1966 & 1967 and Desai et al., 1976). Madhu (2004) reported that this LLJ core is located around the ABL top.

The LAWP is an L-band Ultra High Frequency (UHF) wind profiler and was installed at Gadanki (13.5°N, 79.2°E), Andhra Pradesh in collaboration with the Ministry of Posts and Telecommunications/ Communication Laboratory, Japan for investigating ABL dynamics and precipitation cloud systems. The location of Gadanki in the Indian Peninsula is given in Figure 1. The LAWP is coherent, phased array, doppler radar operating at 1357.5 MHz with a peak power aperture product of 10^4 Wm^2 (Reddy et al., 2001) capable of providing continuous high-resolution wind measurements in the first few kilometers of the troposphere. Figure 2 shows the antenna and transmitter assembly unit of the LAWP. The development of wind profilers revolutionized the boundary layer studies with their excellent height and temporal resolutions (Gage and Balsley, 1978 and Balsley and Gage, 1982). During the past 10 to 15 years, relatively inexpensive, low-powered wind profilers have been developed to operate near 915 MHz. These small profilers are quite adequate for observing winds in the lower troposphere typically through the height of the atmospheric boundary layer (Ecklund et al., 1990). The UHF wind profilers are suitable for boundary layer observations (Ecklund et al., 1988; Rogers et al., 1993; Gage et al., 1994 and Gossard et al., 1998). The phased antenna array of LAWP consists of 576 circular micro strip patch antenna elements arranged in a 24 x 24 matrix over an area of 3.8 m x 3.8 m. The LAWP technical and processing details are given in Table 1. Details about the operating system and technical information can be seen in Reddy et al., (2001), Anandan et al., (1996, 2005).

A thorough knowledge of ABL characteristics during the southwest monsoon season is still lacking. In this background, an examination of boundary layer characteristics is carried out using high resolution wind data obtained from LAWP during the southwest monsoon season. Here, our study is focused mainly to understand the diurnal variation of LLJ speed, level of LLJ maximum wind core, ABL height and its structure during the southwest monsoon season.

2 Data and computational procedure

The data used for the present study is the zonal, meridional and vertical wind components retrieved from LAWP for the non rainy days of the southwest monsoon season to study the diurnal structure of the southwest monsoon. The LAWP data during non rainy days over the station was collected from the National Atmospheric Research Laboratory (NARL), Gadanki. The analysis was carried out for many days and the results for representative day of each month are presented. The representative days considered are 23 June, 25 July and 14 August for the year 1999. Since the LLJ strength came down considerably during September, no representative case was considered in September. Vertical gradient of the wind shear is evaluated to understand the characteristics of the turbulent features of the lower atmosphere during the southwest monsoon season. The diurnal variation of the ABL height during the southwest monsoon season is also studied using signal to noise ratio (SNR) of LAWP. The enhancement in radar reflectivity or SNR shows maximum refractive index structure constant in the inversion layer or in the regions where temperature and humidity gradients are large (Angevine et al., 1994 and Hashiguchi et al., 1995). Processing of the raw data, retrieval of the wind components and analysis of SNR were discussed by Anandan et al., (1996, 2005). The data set was taken from the L-band UHF radar (LAWP). The LAWP data set was compared with radiosonde and MST data sets and found that they are in good agreement (Reddy et al., 2001 and Praveena et al., 2003). A good example of the simultaneous observations of the LAWP, MST and Radiosonde are given in Figure 3 (Praveena et al., 2003).

3 Results and Discussion

Diurnal features of the ABL during different months of the southwest monsoon season are studied. Southwest monsoon is characterized by the presence of the LLJ. It is found that by the development of the monsoon surge, the wind in the lower troposphere shows high variability in both vertical and temporal domains. The height time intensity contour of the hourly averaged zonal wind is presented in Figure 4 a-c (representing one day each from June, July and August). Structure of the boundary layer is modified by the influence of the monsoon. The representative days belong to weak, active and normal monsoon situations on the basis of LLJ strength derived from the NCEP/NCAR reanalysis wind data set over the study area. The height-time intensity diagram gives us a close look to understand how the variations take place in the ABL in a day with respect to height. During the month of June, the zonal wind is strong (by the influence of LLJ) with a magnitude of more than 15 ms^{-1}. The zonal wind attained its maximum speed during the early morning hours. This maximum wind core is found at about 1.3 km height. As day progresses, insolation and consequent thermal activity modifies the ABL.

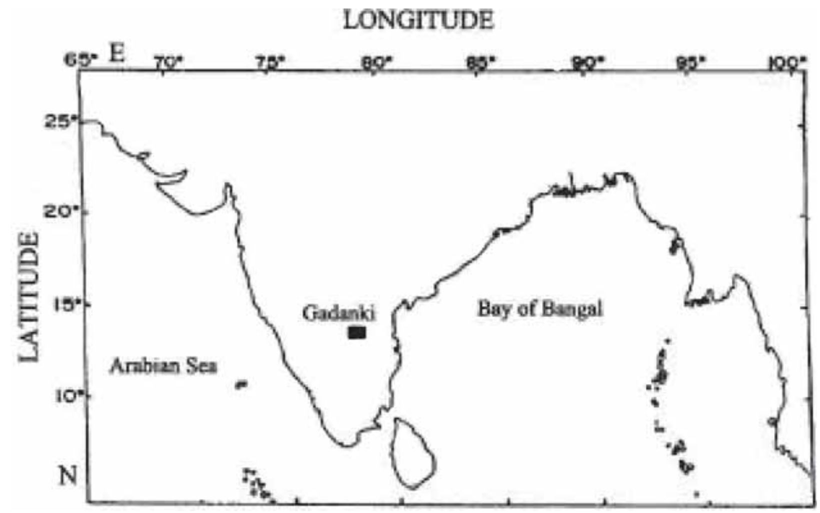

Figure 1 Location map of Gadanki

Figure.2 Antenna and transmitter assembly unit of the LAWP

PARAMETER SPECIFICATIONS (LAWP)	
Location	Gadanki (13.5°N, 79.2°E)
Antenna (Phased Array)	3.8m X 3.8m
Operating Frequency (f)	1357.5 MHz
Radar wave length (λ_R)	0.22 m
Transmitted peak power (P_t)	1000 Watts
Effective aperture (A_e)	10 m^2
Beam width	4°
No. of beams*	3(E15, Zenith and N15)
Gain (G)	33 dB
Receiver band width (B_N)	1.58 x 10^6
Receiver path loss α_r)	4 dB
Transmitter path loss α_t)	0.5 dB
Cosmic temperature (T_c)	10 K
Receiver temperature (T_r)	107 K
Maximum duty ratio	5%
Pulse width	1 – 2 μsec
Inter Pulse Period (IPP)	programmable
Range resolution (Δr)	150/300 m
Coherent Integration (N_C)	100
No. of FFT points	64 – 1024 (programmable)
Observational window:	
Lowest range bin (km)	0.3
Highest range bin (km)	9.25
Incoherent integration	100
Beam Dwell time (sec.)	93

* The number after letter E and N is in degree which indicates the oblique angle from zenith.

Table 1 System specification for LAWP unit

This results in the decrease of zonal wind strength and in the upward shifting of the LLJ core height. The core height is found at 2.8 km and this maximum height is found generally during evening hours. The elevation of the core height can be interpreted as due to the development of the Convective Boundary Layer (CBL). This convective activity made the ABL unstable. Generally, the LLJ is treated as the geostrophic wind, which deepens by the growth of the Convective Boundary Layer. The diurnal variation of the ABL structure during the monsoon season has peculiar characteristics associated with the monsoon system or more specifically due to the LLJ associated with the monsoon. It may be noted that the intensity of the LLJ during July and August are higher than that of June. The maximum core strength of the LLJ is found during the early morning hours in July and the speed is more than 22 ms^{-1}. The deepening of the LLJ by the development of the CBL is prominent in all the cases and the speed is always more than 15 ms^{-1}, indicating the active monsoon situation. The decrease of the wind strength as the day progresses can be attributed to the widening of the LLJ core caused by the development of CBL. During the study period it was found that the maximum wind speed is around 25 ms^{-1} at 08:00 IST around 1.4 km during the months of July and August, but the maximum wind strength during June is only 18 ms^{-1} in the early morning hours around 06:00 IST at about 1.2 km. In certain occasions, the LLJ core height during day time exceeds 3 km and hence the CBL approaches to the LLJ core. Figure 5 a-c represents the height-time intensity plot of the Signal to Noise Ratio (SNR) for the representative days of the southwest monsoon season. SNR gives the diurnal evolution of the atmospheric boundary layer height. ABL height is one of the fundamental parameters in many meteorological applications. Lack of reliable meteorological data to parameterize the CBL height especially in the tropical region made importance for the LAWP observations. LAWP data set is useful to delineate the diurnal evolution of the ABL structure (Angevine et al., 1994; Haghiguchi et al., 1995).

The vertical extent of the ABL can be defined in terms of enhanced radar reflectivity due to the sharp variation of the temperature and humidity (White and Fairall, 1991). The SNR is determined by the reflectivity turbulence seen by the LAWP, which depends on the strength of the mechanical turbulence and the background refractive index gradient (Gage, 1990). The positive values of SNR are due to the high gradient of the turbulent parameters in the ABL. The CBL height starts to grow from around 08:00 IST and dissipate after sun set. The maximum reflectivity is seen just below the LLJ core during the southwest monsoon months (June, July and August). During early morning hours, reflectivity maximum is found around 1.5 km and the CBL deepens as the progress of the day. During early morning hours the CBL height is shallow and the CBL height is found maximum during the evening hours due to the influence of the incoming solar radiation and consequent generation of thermal eddies. These eddies determine the height of the CBL during day time.

Figure 6 a-c represents the wind shear, a measure of turbulence during the representative days of the southwest monsoon period. It is obvious that the high wind shear is at the top of the boundary layer. It can exist in a horizontal or vertical direction and produces churning motions and consequent turbulence. Wind shear, encountered near the ground, is more serious and potentially very dangerous. Vertical shear is most common near the ground and can pose a serious hazard to aircrafts during take off and landing.

The Clear Air Turbulence (CAT) is often observed in the vicinity of jet streaks, where the vertical wind shear is large. Depending on wind shear, the intensity of CAT is divided into three main categories: light (L), medium (M), strong and severe (S) following Stull (1993). The figure (6 a-c) gives diurnal variation of the wind shear for representative days during the southwest monsoon season, especially in the vicinity of the ABL top. Even though the vertical interval (dz = 150 m) is somewhat large for the computation of vertical wind shear, the shear values obtained are reasonably well and hence the probability of CAT. One can present better results by decreasing the vertical interval. The wind as well as wind shear during June to August is

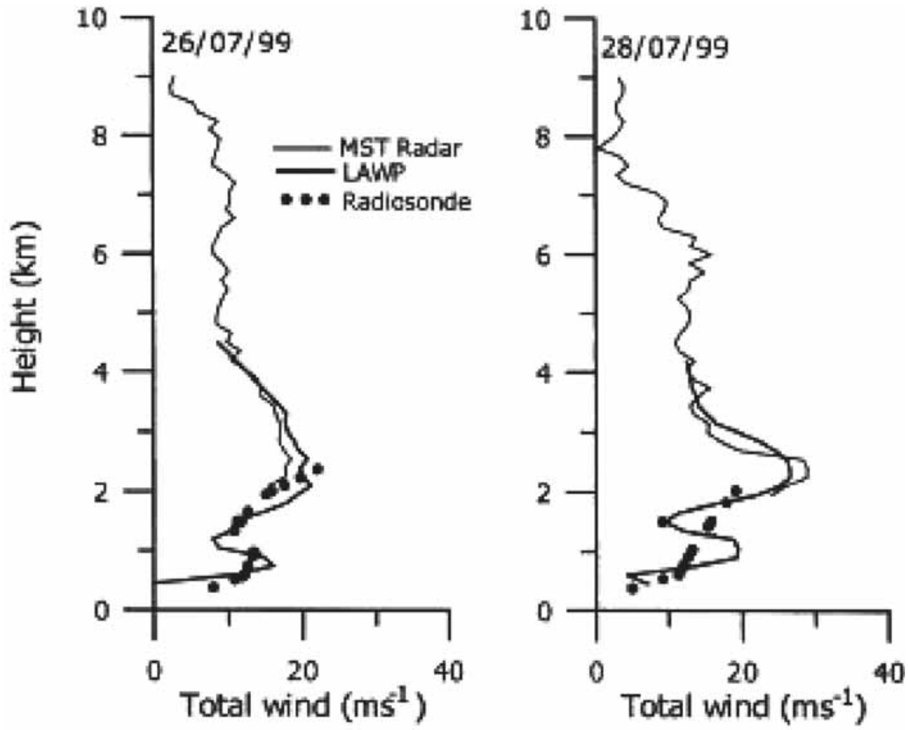

Figure 3 Comparison of wind speed measured by LAWP, MST radar and radiosonde on 26 July 1999 (10:30 IST) and 28 July 1999 (16:15 IST). (from Praveena et al 2003)

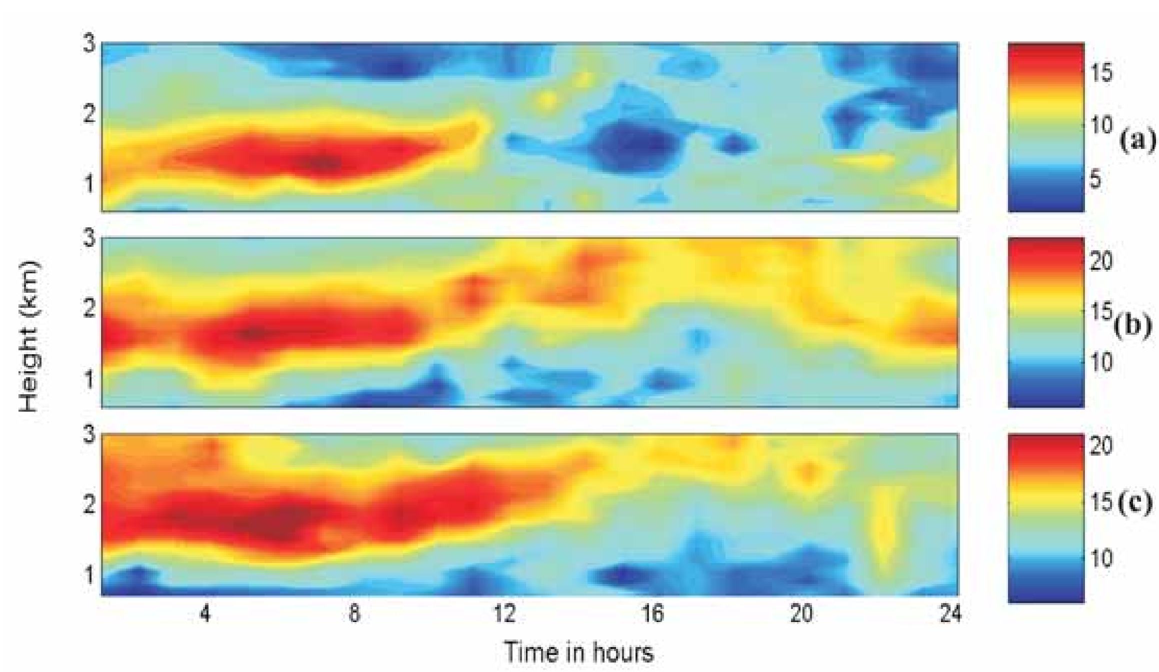

Figure 4 Time-height intensity plot of the hourly averaged zonal wind for (a) 23 June, (b) 25 July and (c) 14 August for the year 1999

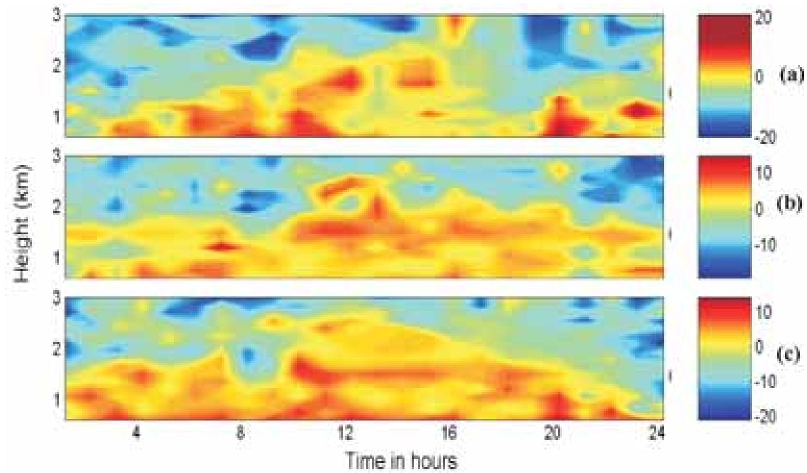

Figure 5 Time-height intensity plot of the hourly averaged Signal to Noise Ratio (SNR) for (a) 23 June, (b) 25 July and (c) 14 August for the year 1999

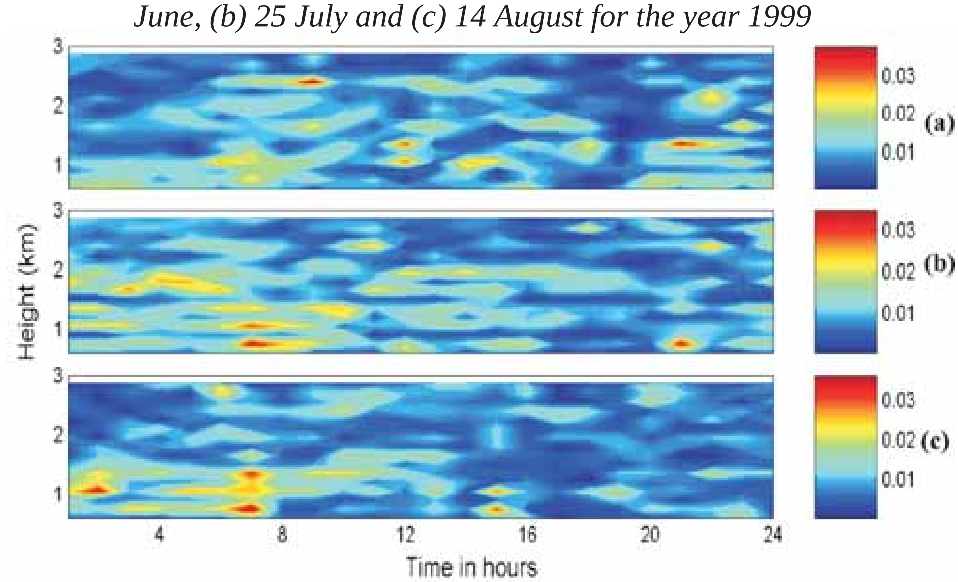

Figure 6. Time-height intensity plot of the hourly averaged vertical wind shear for (a) 23 June, (b) 25 July and (c) 14 August for the year 1999.

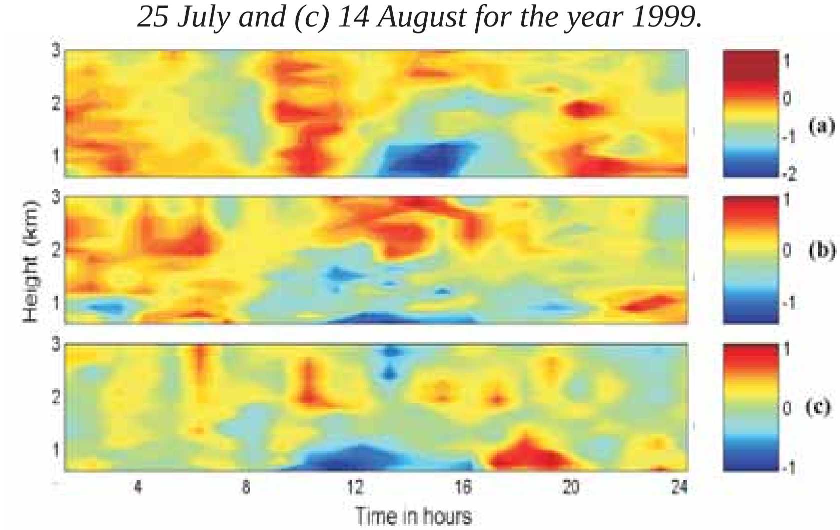

Figure 7. Time-height intensity plot of the hourly averaged vertical wind for (a) 23 June, (b) 25 July and (c) 14 August for the year 1999.

higher than in the other months. Although September belongs to monsoon season, the wind weakens rapidly by the withdrawal of monsoon. During monsoon season, due to the influence of the LLJ the wind direction is almost constant throughout the day. Even though the intensity of the wind shear is generally low, a layer of high wind shear is found in the Entrainment Zone (EZ). The maximum shear zone is found in the ABL during morning hours and it is due to the development of the CBL. The high values of shear zone in the EZ is found in almost all the cases. During evening (around 19:00 IST), the vertical wind shear values are almost zero, indicating a sudden breakup of the boundary layer turbulence due to the dissipation of the CBL. On certain days, high intensity of CAT is seen during mid night hours and it may due to the increase of the wind strength. This increase in wind strength might be attributed to the nocturnal low level jet.

Generally, the intense CAT is found just below the LLJ core and it can be noticed from the figures of zonal wind and vertical wind shear (figure 6 a-c). The CAT values observed during the study period are $0.039s^{-1}$, $0.036s^{-1}$ and $0.037s^{-1}$ on 23 June, 25 July and 8 August respectively. The maximum intensity of CAT is in a range of medium level and hence less hazardous to aircrafts but is capable of generating turbulence for triggering various convective activities.

Due to the development of the CBL, thermals are intensified and they transport surface properties upward and upper air properties to surface. Figure 7 shows the time-height plot of the vertical wind from the LAWP during the monsoon season. It is interesting to note that in the entire CBL the vertical wind shows sinking motion during most of the days, indicating transport of momentum from the LLJ to surface. The intensity of the downward component is high in the lower layer from noon to around 16:00 hours. Slight variation in boundary layer structure is observed in all the days.

4 Conclusion

The analysis of the wind and reflectivity of the lower atmospheric wind profiler during the non rainy days of the southwest monsoon season revealed that the LLJ and associated boundary layer activities vary diurnally in the vertical and temporal domains. During the monsoon season, LLJ is found to exist with the maximum speed in the early morning hours around 1.3 km and core height is elevated to about 2.8 km in the after noon hours. The ABL height shows similar variation as that of the LLJ wind core height over the temporal domain. The LLJ core height increases from morning as the progress of day. This increase in the LLJ core height is attributed to the development of the thermal eddies and these eddies grow with the LLJ core at its top due to the development of the convective boundary layer. During day time the wind core height increases and the momentum is transferred to lower level. This is caused by the influence of vertical wind shear, which is found to be negative during most of the day time. Intensity of CAT is found to be moderate and no severe CAT is noticed during the monsoon season. The high values of the vertical wind shear are found over the zone of residual layers of the ABL, just below the LLJ core.

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