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Study of Atmospheric Boundary Layer Height from radiosonde data over a flat terrain at VBIT – Hyderabad (17.4° N – 78.5° E)

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Abstract

Atmospheric Boundary Layer (ABL) processes control energy, water and pollutant exchanges between the surface and free atmosphere. Study of ABL structure and dynamics is very important since it greatly influences the local weather and air quality over a region. In this study, ABL characteristics were presented using observations of a high vertical resolution radiosonde over a tropical station situated at Vignana Bharathi Institute of Technology (VBIT), Hyderabad (17.4° N – 78.5° E) a rural area and a comparison is made with an urban area of Begumpet, Hyderabad. An attempt is made to observe the seasonal variation of ABL depth using vertical profiles of virtual potential temperature. The variation of Ventilation coefficient (VC), a factor determining the air pollution potential is also studied using the observed variations in wind speed and ABL depth. ABL height is found to be higher during pre-monsoon followed by monsoon and post- monsoon. Weak convection activity made it to be shallow during winter and Ventilation coefficient is found to be higher during monsoon due to high mean wind speeds.

Keywords: ABL, Ventilation coefficient, convection.

1. INTRODUCTION

The Atmospheric Boundary Layer (ABL) is defined as the lowest part of the atmosphere directly influenced by the Earth's surface on a time period of 1 day or less (Stull 1988). The depth of this layer is dependent on surface heating by the Sun leading to convection. ABL characterization is very important for climate, weather and air quality models because of its strong spatial and temporal variability (Garratt 1992). The ABL studies are sparse in the tropical region due to the non availability of sufficient data, especially over the Indian Region where monsoon plays a vital role.

ABL depth over a region depends on several factors like incoming solar radiation, topography, surface roughness of the region as well as other surface forcing and thus the ABL depth exhibits high spatial and temporal variability. Furthermore, the vertical extent and concentration of atmospheric pollutants over a region are decided by the depth of the boundary layer, the degree of vertical mixing and the strength of advection. Hence a combined effect of weak vertical mixing and low winds can cause the building up of pollutant concentration in the ABL. The variations in the ABL depth as well as in the mean wind have significant ramifications in terms of the air quality over a particular region. Over the Indian subcontinent, it is observed that ABL height is low during monsoon period and winter (Praveena and Kunhikrishnan 2004; Devara and Raj 1993). However during monsoon, due to the strong prevailing winds, pollutants get dispersed quickly and washed out by precipitation. In contrast to this, during winter, both winds and ABL depth are low and hence over Indian subcontinent, most of the pollution hazards occur during winter.

This study is mainly focused to report the observations of ABL features and its dynamics over a flat terrain at VBIT – Hyderabad (17.4° N – 78.5° E) and also the variability of ventilation coefficient (VC), which is a measure of the ability of the ABL to disperse pollutants.

2. EXPERIMENTAL METHODS AND DATA

High resolution GPS radiosonde flights were carried out with iMet (USA) radiosondes from Hyderabad at 11:30 LST or 06Z UT between April 2012 and February 2013. During the same period four times a day in every season radiosonde flights were launched from a nearby location of Begumpet which is an urban area (5 days in each season). The accuracies of wind and temperature as provided by the manufacturers are (± 1m/s, ± 0.2 K) for the iMet radiosonde. Outliers, GPS radiosonde data of winds and temperature, if any were removed by visual inspection. The experimental data is further divided into four seasons as pre-monsoon (April-May), monsoon (July-August) post-monsoon (October-November) and winter (December-January).

The altitude variation of pressure, temperature, humidity, wind speed and wind direction are obtained using the radiosonde data. The virtual potential temperature (Θ_v) is estimated as follows (Stull 1988);

$$\Theta_v = \Theta\ (1+0.61r) \qquad \text{------ (1)}$$

Where Θ is the potential temperature (K) and r is the water vapour mixing ratio (kg kg^{-1}). Within the mixed layer, Θ_v is constant due to turbulent mixing of heat as well as moisture and hence does not vary more than 2K km^{-1}(Parasnis and Morwal 1993). Unlike this Θ_v shows an abrupt change in magnitude above the boundary layer (Stull 1988; Satyanarayana et al., 2001). The altitude where this sharp gradient occurs in Θ_v is generally considered as the boundary layer height. Hence the top of the boundary layer is often identified from the virtual potential temperature (Θ_v) profiles (Garratt 1992). In the present work, ABL height is derived from inversions of virtual potential temperature. Gradient of the parameter Θ_v is used for obtaining ABL height, which can be useful for easy identification from the sharp changes taking place near ABL (Basha and Ratnam 2009).

Ventilation coefficient (VC) is one of the parameters used to assess the air pollution potential over a region. It represents the rate at which the air within the convective boundary layer is transported. VC is given by

$$VC = z_i \cdot U \qquad \text{--------} \ (2)$$

Where z_i is the boundary layer height and U is the mean wind. VC is a direct measure of the ability of ABL to disperse pollutants, and a higher value of VC indicates a more effective dispersion.

3. RESULTS AND DISCUSSION

3.1 Variation of ABL height

The ABL depth is detected by using vertical profiles of virtual potential temperature. The day to day variation of ABL height for 9 days of different seasons is shown in Figure1, during the period from 2012-2013 at VBIT, Hyderabad. The day to day ABL height variation showed a minimum during January - February 2013 (winter) and maximum during April-may 2012 (pre monsoon). While the other two seasons of July-August 2012 (monsoon) and October -November 2012 (post monsoon) showed values that lie between the pre monsoon and winter seasons. The ABL height showed a minimum value of 1911 meters during winter and a maximum value of 2962 meters during pre monsoon season. These results are in good agreement with the trends reported in earlier studies (Hanson 1984a; Devara and Raj 1993 and Mahalakshmi et al., 2011). It was noticed that high values of ABL height in pre monsoon as a result of high thermal convection and low during winter due to low thermal convection.

The seasonal variation of ABL height at VBIT is shown in Figure2. The average ABL height showed a maximum during pre monsoon (April & May) and minimum during winter (January & February). The average ABL height variations showed similar results to the studies conducted by other researchers (Mahalakshmi et al., 2011).

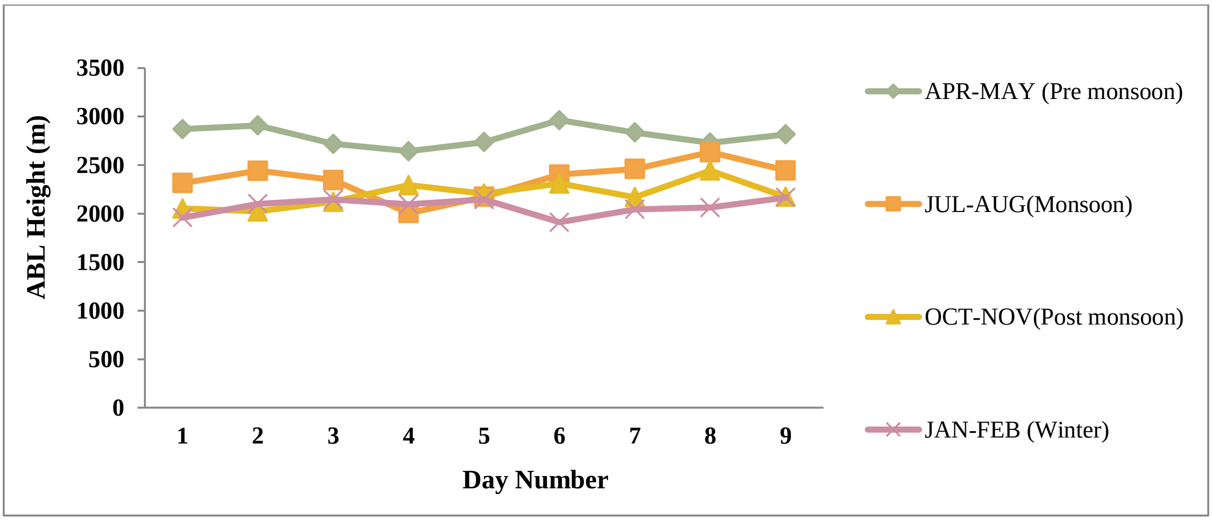

Figure 1: Day to day variations of ABL height at VBIT for different seasons (9 days data is used for each season)

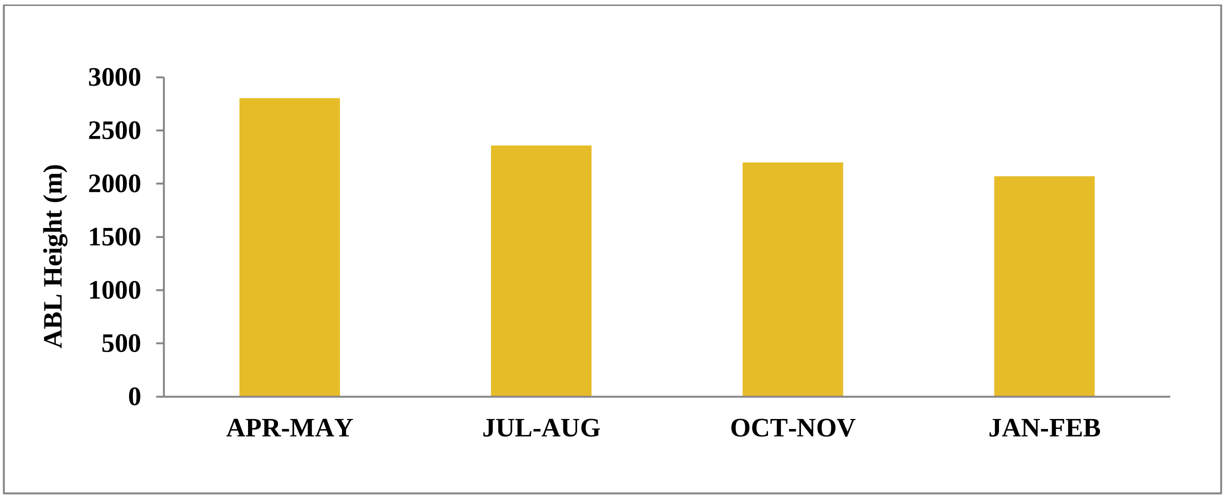

Figure 2: Seasonal variation of ABL height at VBIT

The radiosonde flights launched during four times of a day for all seasons at a nearby location Begumpet is used to study the diurnal variation of ABL height. Observed values of ABL height for different times during a day are explained below.

Diurnal variation of ABL height for different times of a day starting from 0000 UT (0530 LT) to 1800 UT (2330 LT) have been plotted in the Figure 3(a-d) for different seasons. The diurnal variation showed a higher value of ABL height during 1200 UT (1730 LT) and a lower value during 0000 UT/1800 UT (0530 / 2330 LT) which can be clearly observed in all the seasons. The large diurnal variation shows that the ABL height is more during 1200 UT (1730 LT) for pre monsoon followed by monsoon and post monsoon. Low values of ABL height is observed during winter season for different times of the day. The ABL height is observed low at 0000 UT (0530 LT) and 1800 UT (2330 LT) during night time for all seasons. These values are ranging approximately from a minimum of 0.8 km during winter to a maximum of 1.3 km during pre-monsoon. The night time and winter season ABL height is lower in thickness. During the day time and pre monsoon season ABL height is higher in thickness. Strong wind speeds allow for more convective mixing which causes the layer to expand. At night time the boundary layer contracts due to a reduction of rising thermals from the surface. As cold air is denser than warm air, the ABL height will tend to be shallower in the winter season. The diurnal variations study here showed the similar trends as reported by Basha and Ratnam 2009.

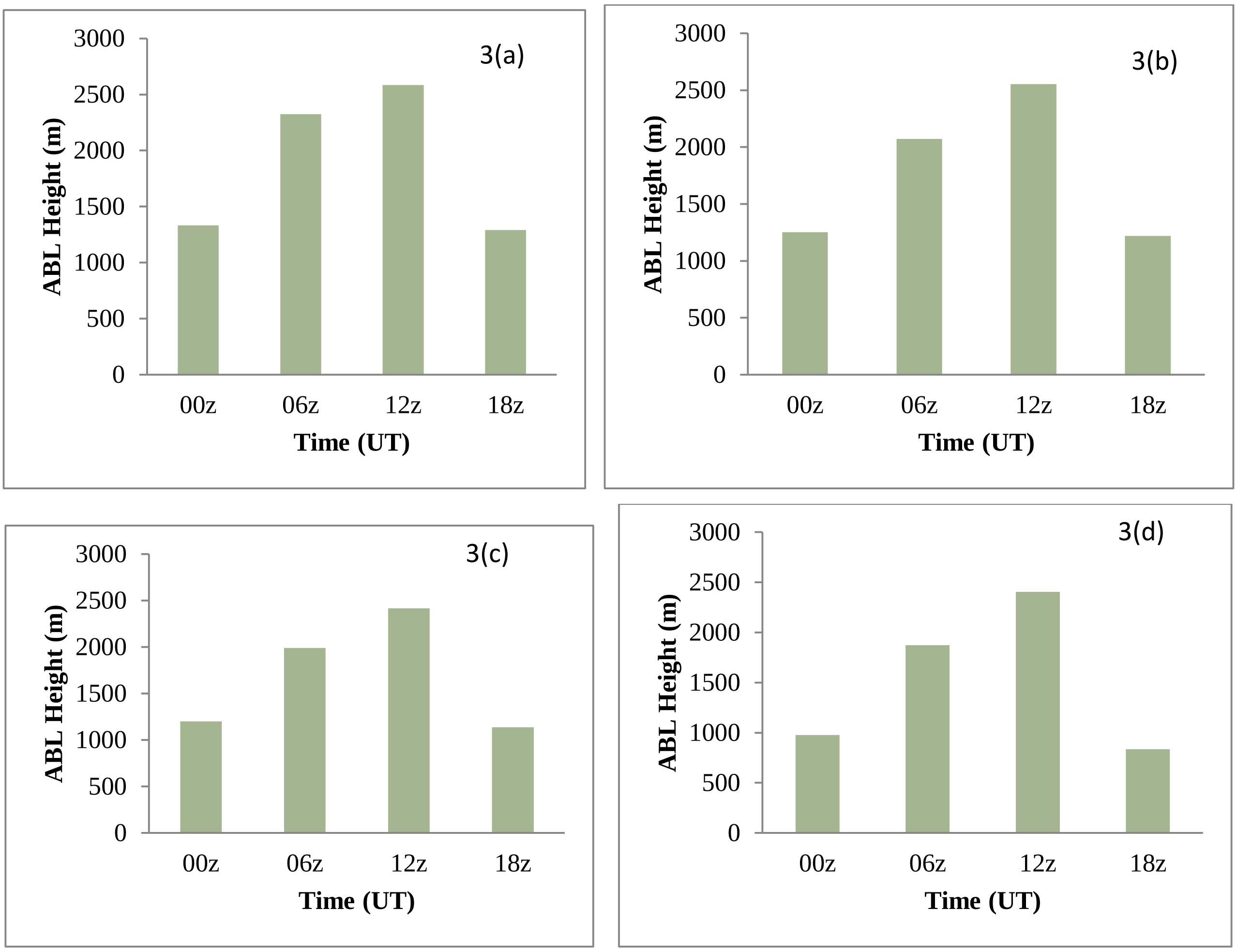

Figure 3 (a-d): Diurnal variation of ABL height at Begumpet

3.2 Variation of Ventilation coefficient

Ventilation coefficient (VC) is another important factor which gives good estimate for pollutant dispersion in atmosphere. As discussed in the methodology (VC = z_i .U), it is greatly influenced by wind speed along with ABL height. Hence we focused our discussion on the variation of wind speed and VC in this section.

The day to day variations of mean wind speed for 9 days of different seasons is shown in Figure 4, during the period from 2012-2013 at VBIT, Hyderabad. The day to day variation of mean wind speed showed a minimum during April-May 2012 (pre monsoon) and January -February 2013 (winter). It is observed with maximum values during July-August (monsoon) where the wind speeds are high as it is a highly convective period (Mahalakshmi et al., 2011; Sujatha et al., 2016). The mean wind speed showed a higher value of 17.8 m/s during monsoon season.

The seasonal variation of mean wind speed at VBIT is shown in Figure 5. The average wind speed showed a maximum during monsoon (July-August) due to high convective and minimum during pre monsoon (April-May) and winter (January-February) due to non convective conditions.

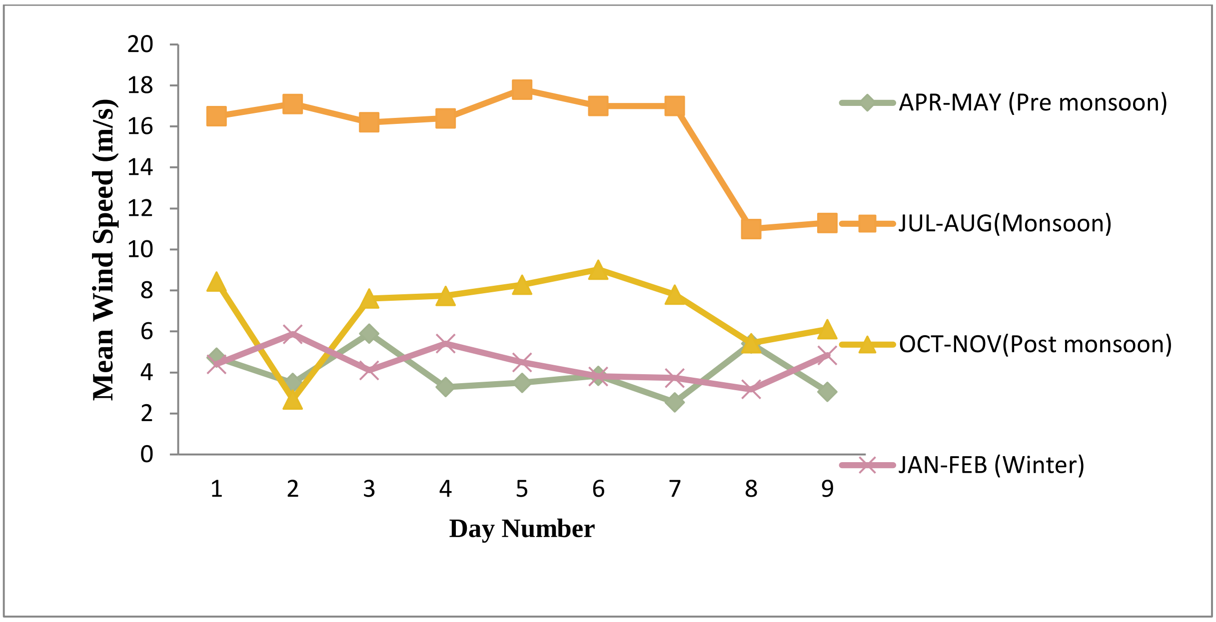

Figure 4: Day to day variations of Mean wind speed at VBIT for different seasons (9 days data is used for each season)

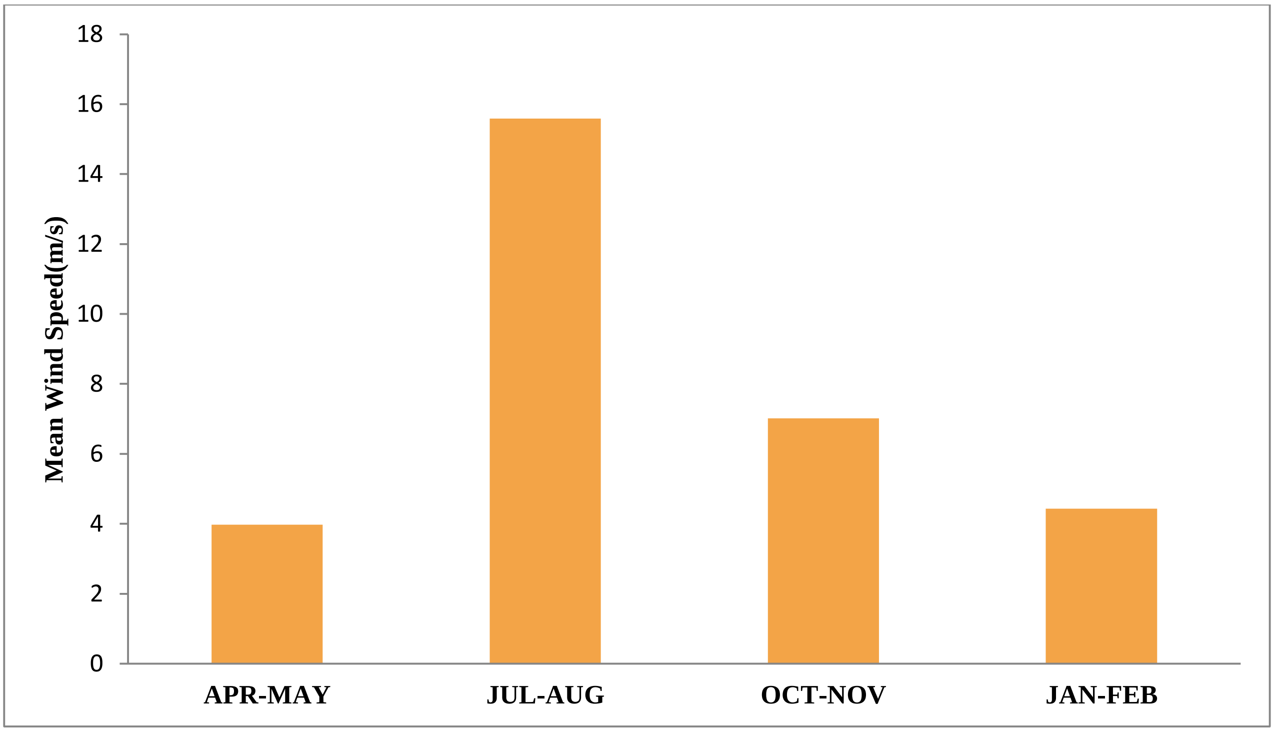

Figure 5: Seasonal variation of Mean wind speed at VBIT

The mean wind speed variation for different seasons at different times of a day starting from 0000 UT (0530 LT) to 1800 UT (2330 LT) have been plotted in the Figure 6(a-d). A higher value of mean wind speed is observed during 0000 UT (0530 LT) and a lower during 0600 UT (1130 LT) during pre monsoon season as shown in Figure 6(a). In the monsoon season during the timings 1800 UT (2330 LT) and 0000 UT (0530LT), the mean wind speed showed higher value. Low value of mean wind speed is observed during 1200 UT (1730 LT) as shown in Figure 6(b). The mean wind speed observations during post monsoon showed a higher value during 1800 UT (2330 LT) and a low value during 1200 UT (1730 LT) as shown in Figure 6(c). During winter the mean speed shows a higher value at 1800 UT (2330 LT) and a lower value at 0600 UT (1130 LT) as shown in Figure 6(d). From the above results it is clear that the diurnal wind speed variations showed higher values during 1800 UT (2330 LT) for all the seasons except for pre monsoon. During monsoon season the mean wind speeds are more as they are highly convective period when compared to all other seasons which are non-convective period. The mean wind speed showed a higher value of 17.34 m/s during monsoon. During night time 1800 UT (2330 LT) the mean wind speeds are higher for all seasons except for pre monsoon.

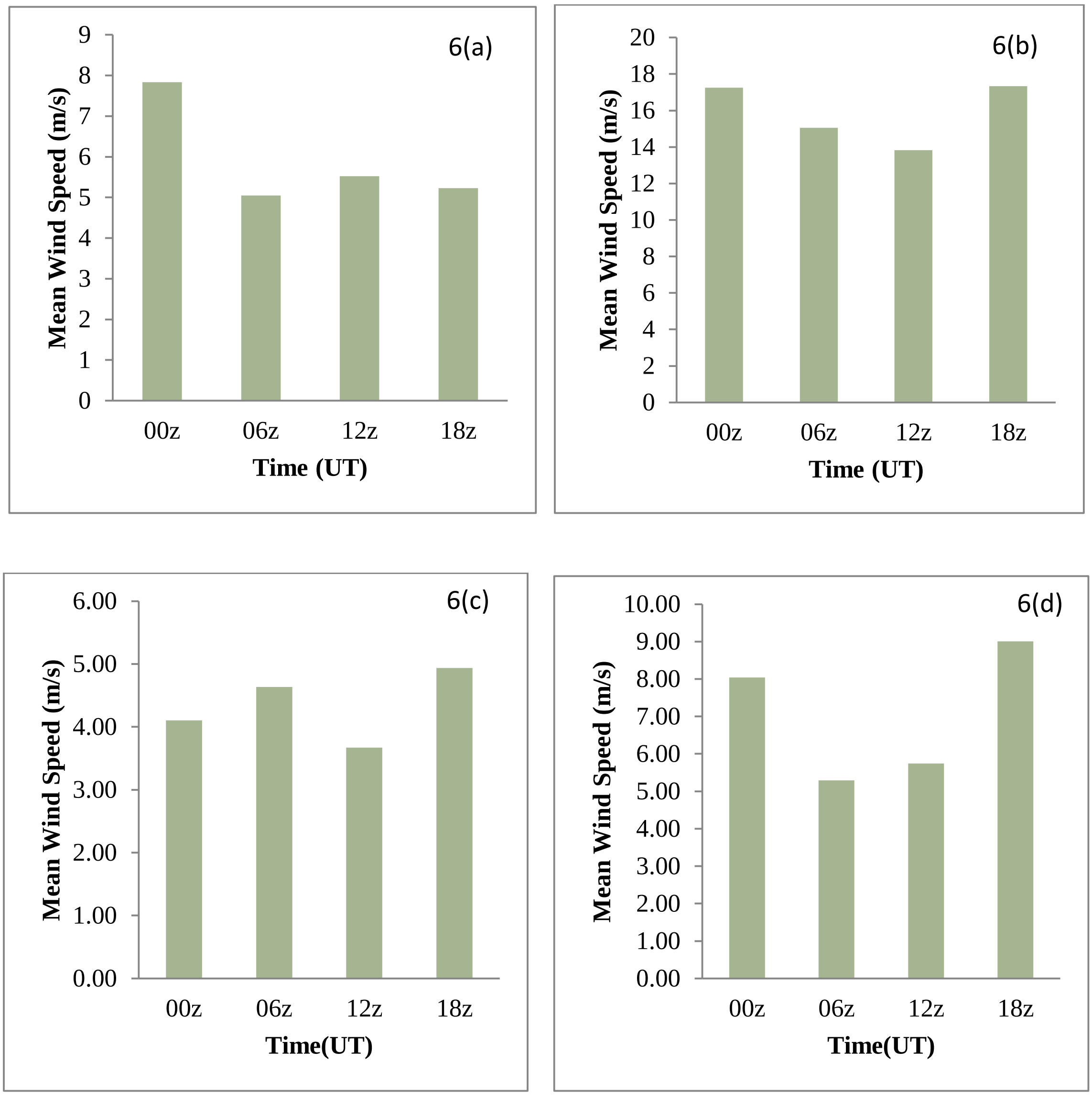

Figure 6(a-d): Diurnal variation of Mean wind speed at Begumpet

The day to day variations of Ventilation coefficient for 9 days during different seasons at VBIT, Hyderabad for the period 2012- 2013 is shown in Figure7. The day to day Ventilation coefficient variation showed a minimum during January-February 2013 (winter) and maximum during July-August 2012 (monsoon). The Ventilation coefficient showed a higher value of 41820 m^2/s during monsoon and these results are showing similar trends as reported in earlier studies conducted by Mahalakshmi et al., 2011 and Sujatha et al., 2016. It was noticed that the Ventilation coefficient is high during monsoon due to average ABL height and high wind speeds as it is a highly convective period when compared to other seasons. It is observed low during winter as it is associated with lower values of both ABL height and mean wind speed.

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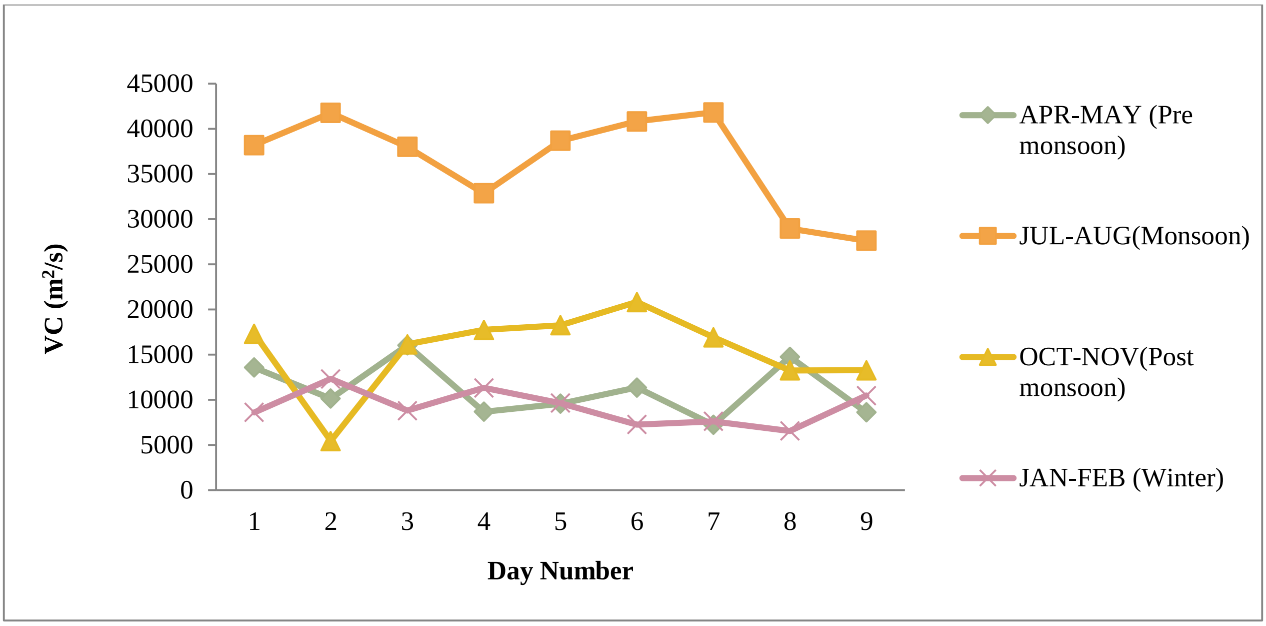

Figure 7: Day to day variations of Ventilation coefficient at VBIT for different seasons (9 days data is used for each season)

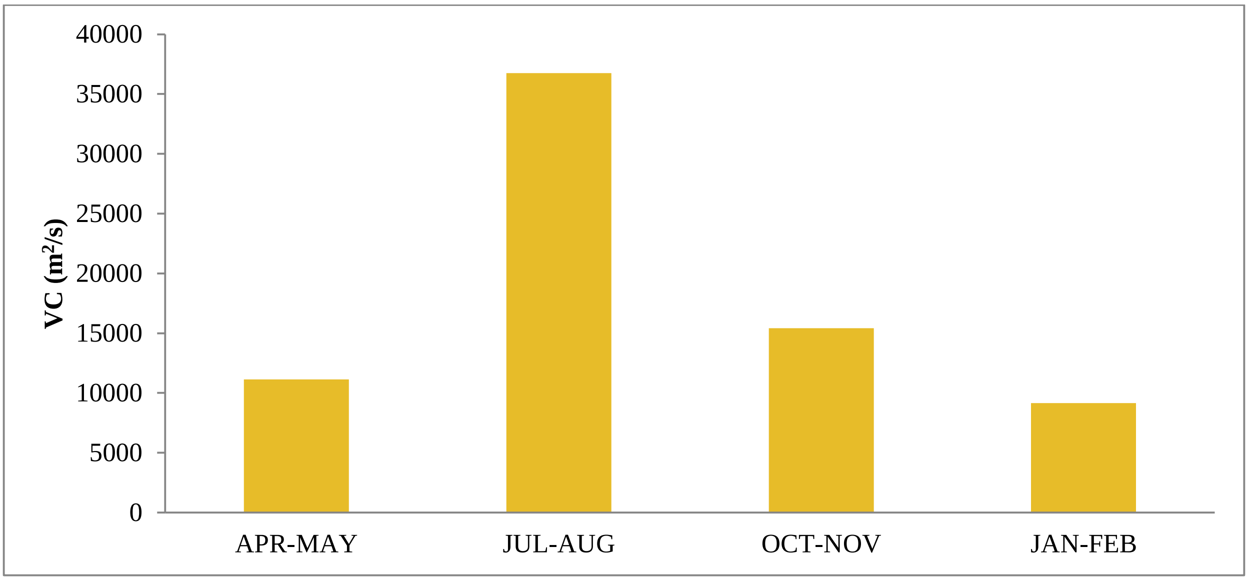

Figure 8: Seasonal variation of Ventilation coefficient at VBIT

The seasonal variation of Ventilation coefficient at VBIT is shown in Figure 8. The average ventilation coefficient showed a maximum during monsoon (July & August) and minimum during winter (January & February). The average Ventilation coefficient variations showed similar results to the studies conducted by other researchers (Mahalakshmi et al., 2011 and Sujatha et al., 2016).

Diurnal variation of Ventilation coefficient at different times of a day starting from 0000 UT (0530 LT) to 1800 UT (2330 LT) for different seasons have been plotted in Figure 9 (a-d). The diurnal variation showed a higher value of ventilation coefficient during 1200 UT (1730 LT) and lower value during 1800 UT (2330 LT) which can be seen in all the seasons except for post monsoon. The lower values of Ventilation coefficient is observed during 1800 UT (2330 LT) and 0000 UT (0530 LT) at night time and early morning for different seasons. The Ventilation coefficient showed a higher value of 34152 m^2/s during monsoon due to high mean wind speed. At night time the ABL height is less due to a reduction of rising thermals from the surface resulting in a lower Ventilation coefficient for all seasons. In the lower atmosphere the dispersion of pollutants is due to convection and mixing. Thus, low VC values which represent more pollution are observed during winter season and high values indicating low pollution dispersion are observed during monsoon as per the results reported in this work.

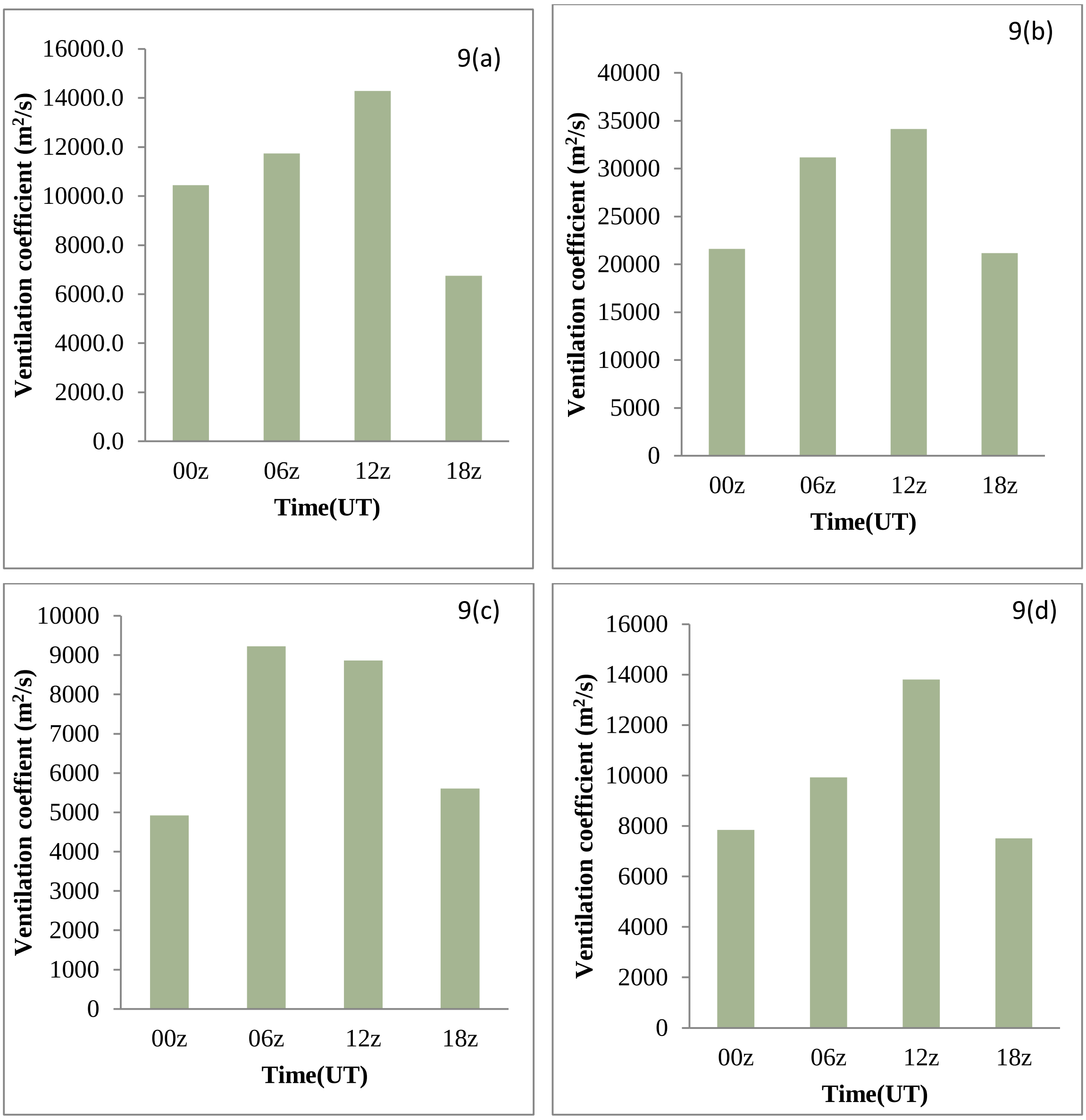

Figure 9(a-d): Diurnal variation of Ventilation coefficient at Begumpet

4. CONCLUSIONS

ABL height values were estimated on daily basis (using 9 days data for each season) from radiosonde data were studied, for a flat terrain study location of VBIT, Hyderabad along with seasonal variations. The study is also focused on mean wind speeds and ventilation coefficient. The diurnal variations of ABL heights, mean wind speeds and ventilation coefficient were studied for the study location of Begumpet. ABL height showed strong seasonal variability with highest values during pre-monsoon. During winter, ABL height is observed shallow because of weak convection activity. In response to heavy rainfall and associated changes in atmospheric and surface characteristics, decrease in ABL height is observed during monsoon when compared to pre monsoon. But the mean wind speeds are high resulting in a higher Ventilation coefficient during monsoon when compared to other seasons.

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