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Adoptation of atmospheric structure constant (Cn^2) for identification of boundary layer height: relevant to hazard monitoring

Alaka Medhi[1]*, M Devi[1], A K Barbara[1], Anna Depueva[2]
[1]*Department of Physics, Gauhati University, India*
**alaka.medhi05@gmail.com*
[2] *IZMIRAN, Troisk, Moscow, Russia*

Abstract

The Planetary Boundary Layer (PBL) or the boundary layer is the lowest part of the atmosphere ranging up to 2-4 km height and is largely influenced by the ground surface in contact with it. Above the PBL, the atmosphere is relatively free from the ground influences but the boundary layer dynamics has a role to play on it. Therefore the contributions of turbuances generated by heat exchange processes between ground and the atmosphere up to the PBL cannot be neglegted even at the free mixing tropospheric environment up to the tropopause altitude of 15-16 km. It is important thus to identify the PBL height, the responsible region of earth /atmosphere interacting zone, so that the effct of turbulence at the free mixing status can be identified. In this paper a new approach is taken in identifying PBL height by adopting the irregular structure, the structure constant parameter (Cn^2) that involves variabilities like humidity, potential & ambient temperature and presuure. The exercise is done over Guwahati (26.2°N, 91.75°E), an earthquke prone zone so that the observed result may be examined in identifying earthquke realted modification in structure constant parameter within the PBL height. Finally the focuss is made on the importance of such study in formulating predictive features in climate modification through understanding coupling processes within PBL and free mixing zone.

Key words*: 1. Planetary Boundary Layer, PBL 2.Turbulence parameter 3. Hazard*

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1. Introduction

The lowermost part of the atmosphere, the PBL being in touch with the surface is affected by the solar energy input and consequent regular temperature variations of day and night and season and due to other factors as cloud, aerosols etc. [Stull 33 1988, Arya 2009]. Therefore the consequent thermodynamic activities of the earth surface are reflected most prominently in this layer. There are a number of approaches in deriving PBL heights like from atmospheric temperature, pressure, and relative humidity (RH). Also there are reports demonstrating presence of fairly low PBL height to 3 km and above depending on suface roughness, atmospheric stability and others. Above the boundary layer the part of the atmosphere is isolated from the surface layer and normally remains relatively isolated from the layer below PBL.

Therefore the troposphere may be divided into two parts, the planetary boundary layer (PBL or ABL, atmospheric boundary layer) and the free troposphere above it. In the free troposphere the rapid and relatively sharp temperature variations are not very significant. However on special cases such as presence of jet streams, heat/cold fronts etc. the free atmospheric fluctuations may be significant.

Turbulence is one of the important transport processes in the PBL and it is used to define the boundary layer definition. The PBL plays a very important role in the transport of momentum, moisture and energy through processes that are inherently turbulent. The turbulent flow in PBL can effectively transport moisture, momentum and energy through turbulent eddies. During recent years, there has been emphasis on understanding the boundary layer height dynamics through meteorological parameters and by remote sensing devices as Radio sonde (RS), Sound detection And Ranging(SODAR), Light Detection And Ranging (LIDAR) GPS-occultation analyses etc. [Hoper & Eloranta, Basha and Ratnam 2009; Xie et al. 2012]. Radio wind profilers (RWP) have become indispensable tools to probe the atmosphere the first few kilometers above the ground.

With the above background, the paper aims to characterize and understand the turbulent structure parameter characteristics in the atmosphere specially over Guwahati (26.2°N, 91.75°E) in the boundary layer & and free conditions in view of utilising these features in the design of remote sensing wind profiler. For this purpose the main turbulent parameter studied here is the refractive structure constant parameter (Cn^2) and analysis will be done from the data available from Regional Meteorological Centre

Guwahati and Wyoming University (weather.uwyo.edu/upper air/sounding.html) by taking five years of data.

2. Methodology

For this study, the daily variation of the Cn^2 parameter is determined and then by averaging these profiles we have determined the monthly variations of this parameter from surface up to 10 km height with 100 m resolution. Characteristic features of Cn^2 at different altitudes are to be evaluated and then used to identify PBL and free atmosphere. For this purpose the Cn^2 parameter is determined by using five years of RS data. The RS contains a radio transmitter with sensors to measure pressure, temperature, humidity as well as wind speed and direction at different heights of the atmosphere starting from the surface to around 30 km. The entire package of transmitter and sensors is carried aloft by a spherically shaped free flying balloon released from surface, generally two times a day i.e., at 0000 and 1200 UTC. The data received from the balloons launched at different meteorological stations around the world are available to public users, provided by the University of Wyoming (http://weather.uwyo.edu/upperair/sounding.html). For achieving the aims as defined, Cn^2 values are calculated by using the equation (1) and (2) with the data from the above website.

The expression for Cn^2 is defined by equation (1) as [Tatarskii V I 1971]

$$Cn^2 \equiv a^2 \infty' l_0^{\frac{4}{3}} M^2 \qquad \text{-----------------------------------} (1)$$

Where, a^2 is a dimensionless constant within 1.5 and 3.5, but most commonly taken as 2.8 [Monin et al. 971], ∞' is a numerical constant generally taken as unity, l_o is the buoyancy/outer scale length of the turbulence spectrum and M is the vertical gradient of potential refractive index fluctuations. This gradient is expressed as [Warnock et al. 1985]

$$M = -77.6\times10^{-6}\left(\frac{P}{T}\right)\left(\frac{\partial \ln\theta_T}{\partial Z}\right)\left[1+\frac{15500}{T}\left(1-\frac{1}{2}\frac{\partial \ln q/\partial Z}{\partial \ln\theta_T/\partial Z}\right)\right] \qquad \text{-----------------------------------} (2)$$

Where, T is the ambient temperature in K, P is the pressure; q is the specific humidity (SH) and θ_T the potential temperature (PT), given as:

$$\theta_T = T \times \left(\frac{P_0}{P}\right)^{0.3} \qquad \text{-----------------------------------} \ (3)$$

where P_0 is the standard atmospheric pressure and Z is the height in meters.

The total turbulent energy density spectrum consists of a production region, the inertial sub range and the dissipation region. Most of the turbulence production energy input occurs at scale sizes between $6l_0$ and $l_0/6$, where $l_0/6$ is defined as the onset of the inertial sub range. The outer scale l_0 is presumed to be around 10m 1_0, although no direct evidence is available on the thickness of a turbulent layer [Singh et al. 2008]

Taking RS data at an interval of 100 m height, the gradients of potential temperature ($\partial\theta/\partial z$) and specific humidity ($\partial q/\partial z$) are computed up to the height of 10km. From the gradients so obtained, M values are calculated by using equation (2) and Cn^2 profile is then drawn (equation 1) for daytime (00Z) hours of each day taking l_0 to be 10m with values of constants 'a' & ∞' as 2.8 and 1 respectively [Singh et al. 2008, Belu 2012, Monin et al. 1971]. From these profiles, the day to day variation of Cn^2 with height is plotted for each day of each month. From this monthly average Cn^2 value is calculated.

3. Result and analysis: Seasonal variation of Cn^2:

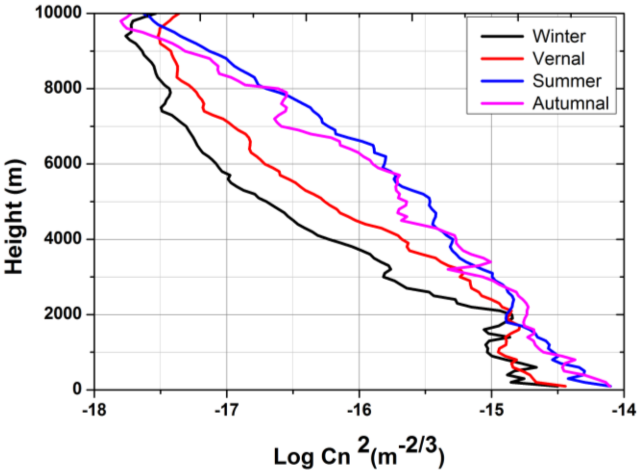
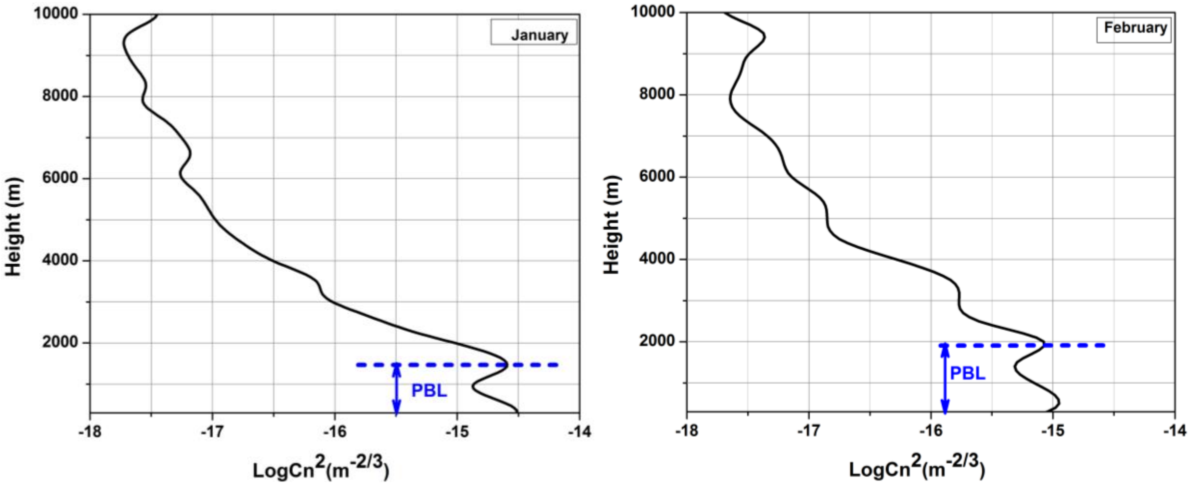


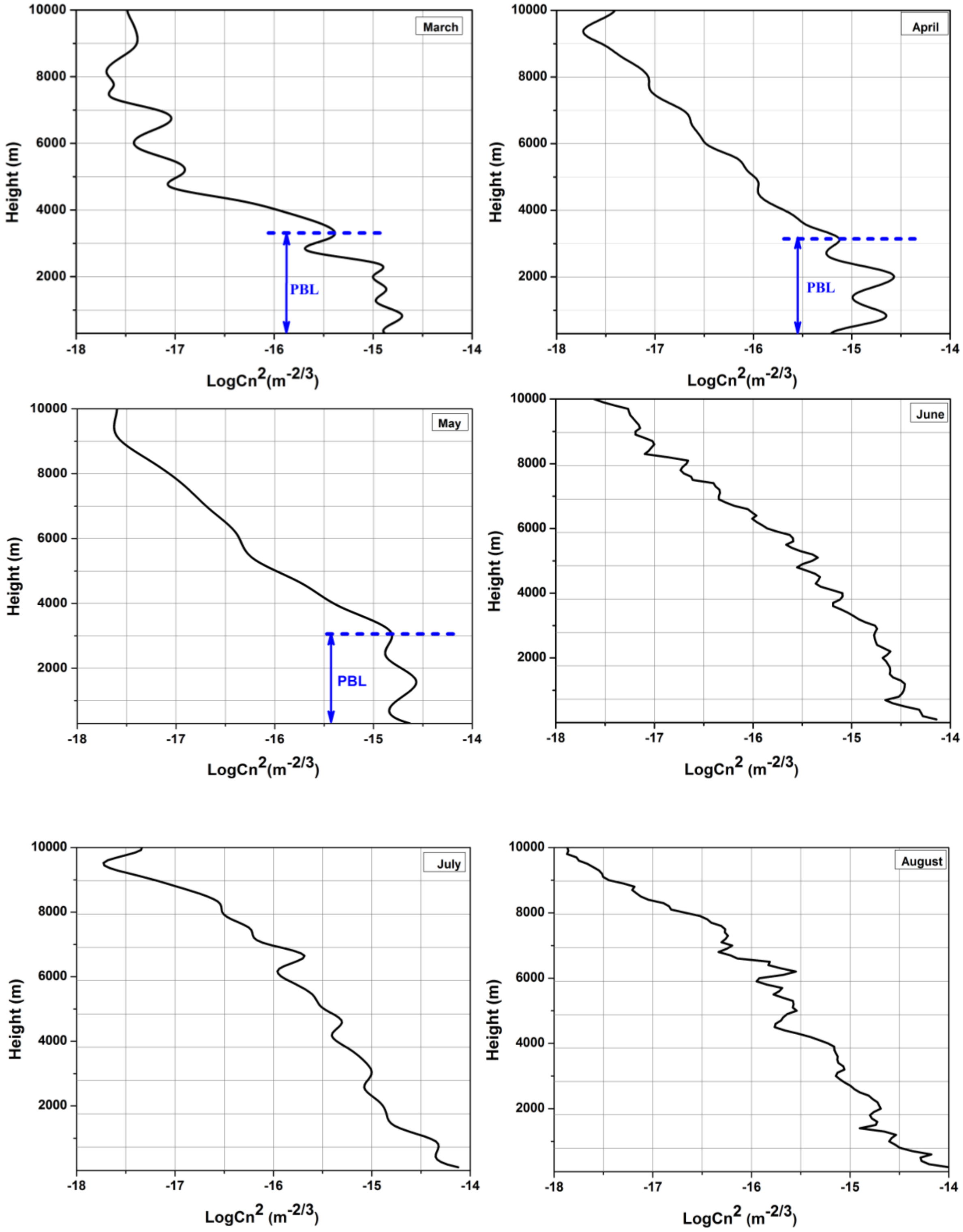
Figure 1: Seasonal variation of Cn^2, accumulated average of 5 years

Figure 1 shows the seasonal variation pattern of Cn^2 up to 10km height. While presenting these seasonal patterns, five years of structure constant values are averaged and then taking June-August as summer months, September-November as autumnal equinox and December-February as winter season while months from March-May cover vernal equinoxial period. It is seen that Cn^2 has a large value of $-14.2m^{-2/3}$ in near the surface in the summer and autumnal season compared to the vernal and winter season. Also the profiles show that up to the height of 10km, Cn^2 attains higher value during summer and autumnal equinox and lowest value during winter and vernal equinox season [Medhi et al 2015]. One can note a transition in Cn^2 variation pattern from positive slope to negative and vice versa at a height around 2-3km during vernal and winter. But during summer and autumnal season such transition are not well defined. We mark this altitude as PBL.

The detailed variation of Cn^2 in each month is discussed in the following section.

The PBL height is marked in every figure while defining the boundary layer, special care is taken so that small fluctuations does not litter the definition of boundary layer. Boundary layer height is taken where the slope goes positive to negative. From Figure 2 it is seen that in case of monthly variation the PBL is well defined in vernal and winter months compared to the autumnal and summer months.




March
April
May
June
July
August
Height (m)
10000
8000
6000
4000
2000
PBL
-18
-17
-16
-15
-14
LogCn2(m-2/3)

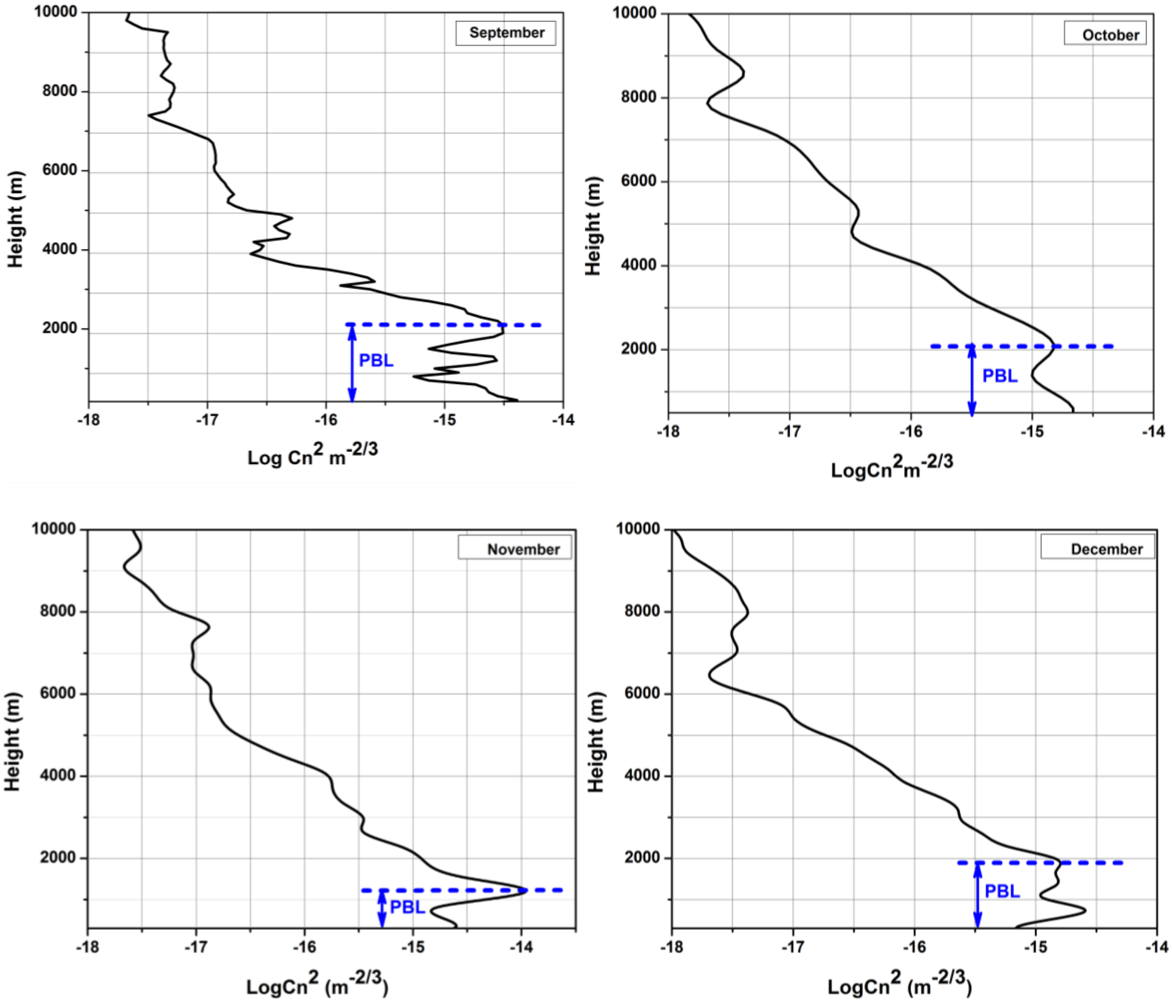
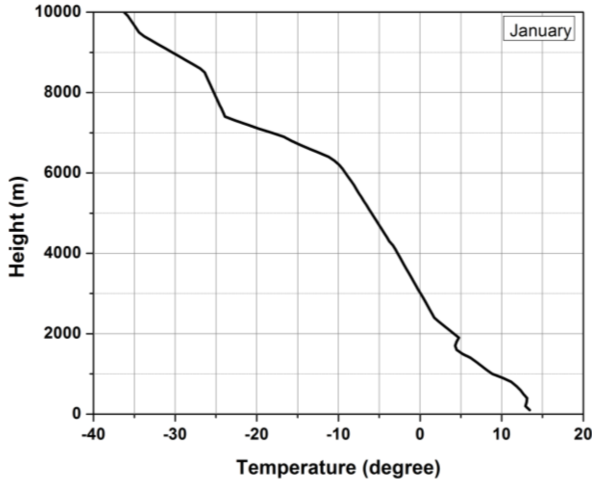
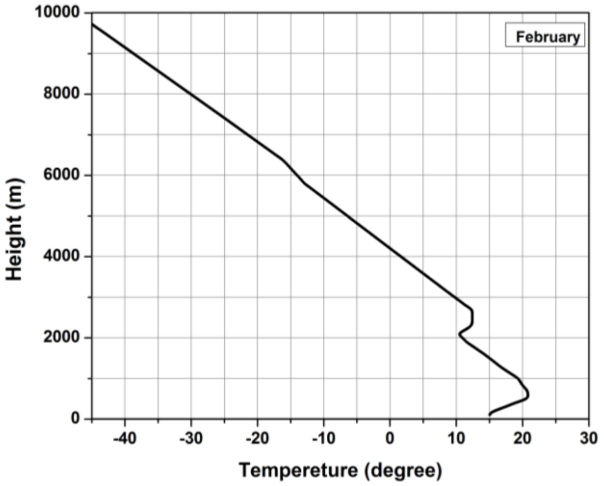
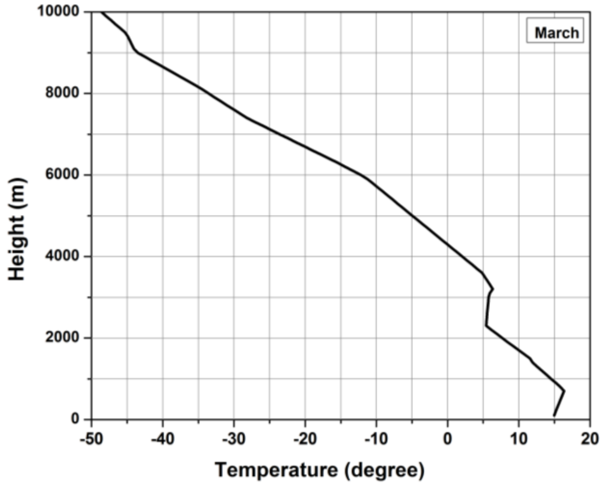


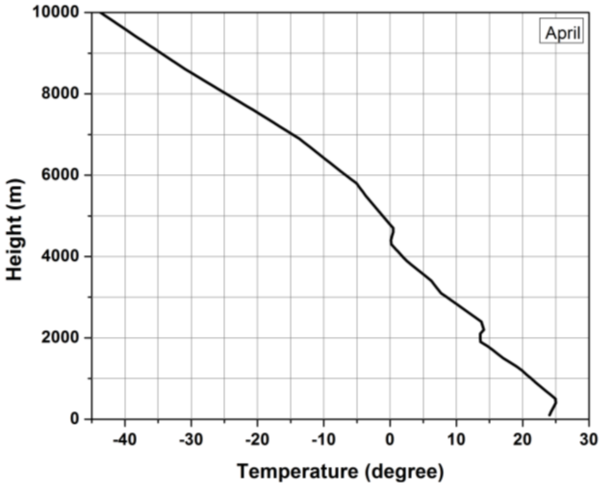
Figure 2: Climatological variation of Log Cn^2 for different months (January–December) over Guwahati, the blue line shows the estimated PBL height

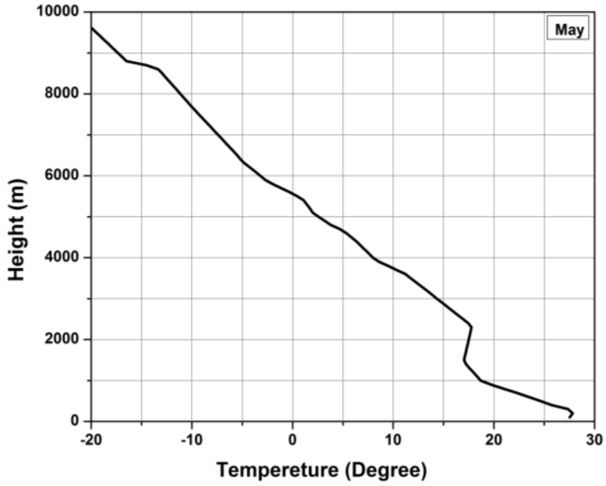
Boundary layer heights observed from Cn^2 profiles are compared with the temperature profile for each month. Figure 3 shows the temperature variation for the month of January to December over Guwahati.

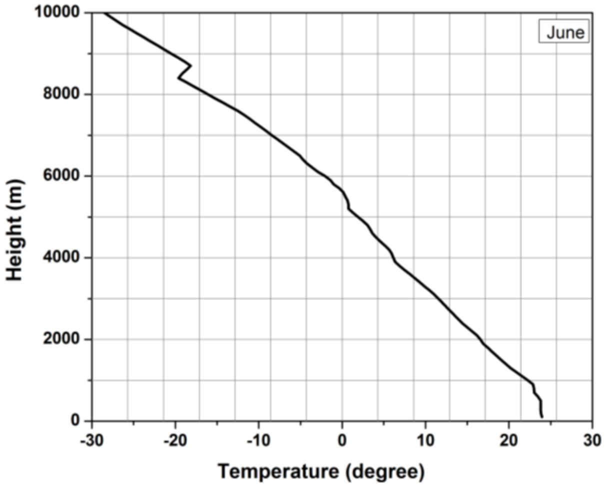

January
Height (m)
10000
8000
6000
4000
2000
0
-40
-30
-20
-10
0
10
20
Temperature (degree)


February
Height (m)
10000
8000
6000
4000
2000
0
-40
-30
-20
-10
0
10
20
30
Tempereture (degree)


March
Height (m)
10000
8000
6000
4000
2000
0
-50
-40
-30
-20
-10
0
10
20
Temperature (degree)


April
Height (m)
10000
8000
6000
4000
2000
0
-40
-30
-20
-10
0
10
20
30
Temperature (degree)


May
Height (m)
10000
8000
6000
4000
2000
0
-20
-10
0
10
20
30
Tempereture (Degree)


June
Height (m)
10000
8000
6000
4000
2000
0
-30
-20
-10
0
10
20
30
Temperature (degree)

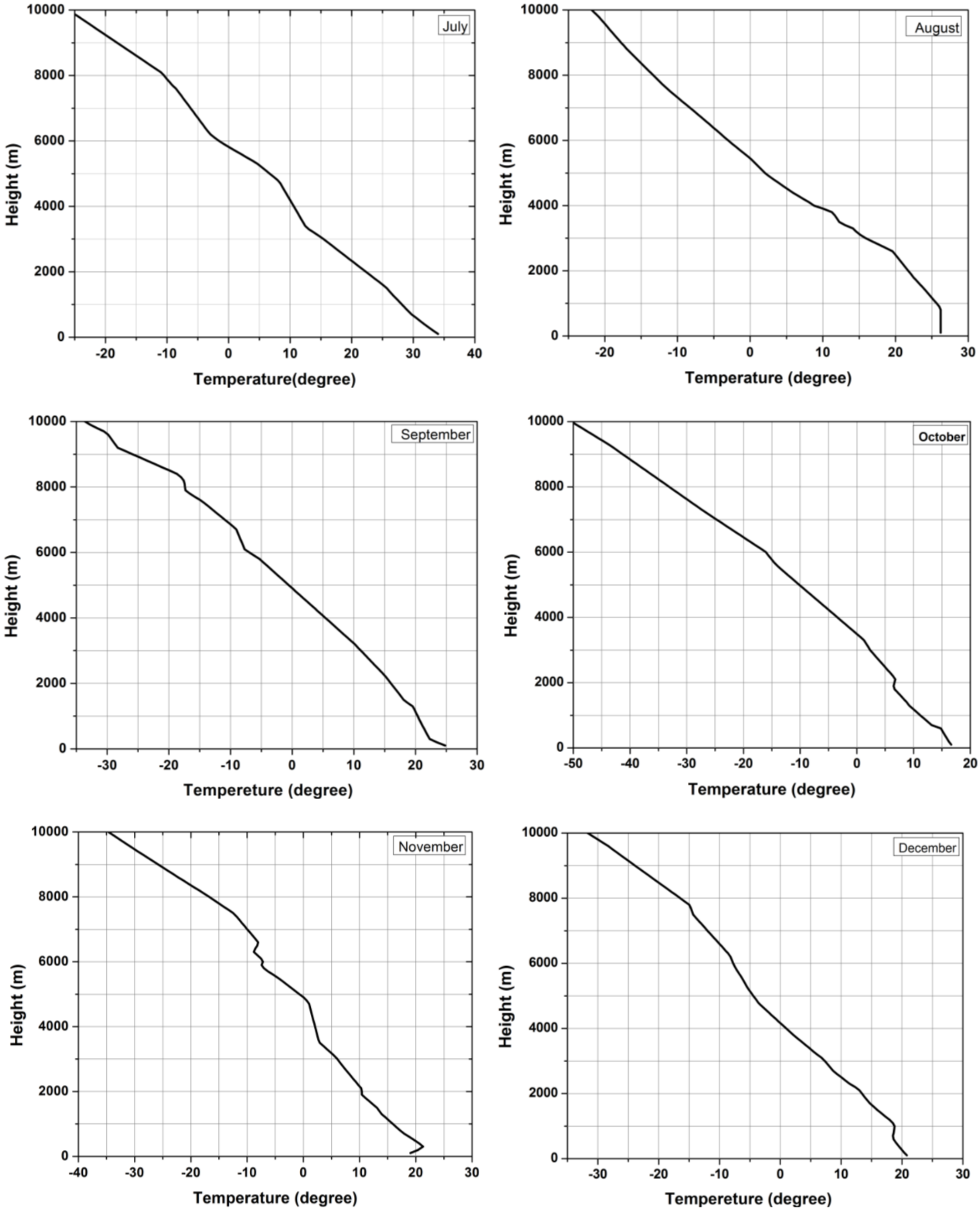


Figure 3: Representative plot of variation of temperature with altitudes at different months (January–December) over Guwahati. Note: PBL height is not visible in these profiles unlike in the Cn^2 profiles of Figure 2

From Figures 2 and 3, the PBL height obtained from both the Cn^2 and temperature profiles are shown in table I. From the table one can note that Cn^2 is better index to identifying the PBL height.

Table I: Comparision of PBL height from Cn^2 and temperature profile

Month	PBL (Cn^2 profile) Km	PBL (temp profile) km
January	1.6	1.8
February	1.9	2.1
March	3.1	2.8
April	3.1	2.2
May	3	2.2
June	Not well defined	Not well defined
July	Not well defined	Not well defined
August	Not well defined	Not well defined
September	2	Not well defined
October	2.1	Not well defined
November	1.4	Not well defined
December	1.9	Not well defined

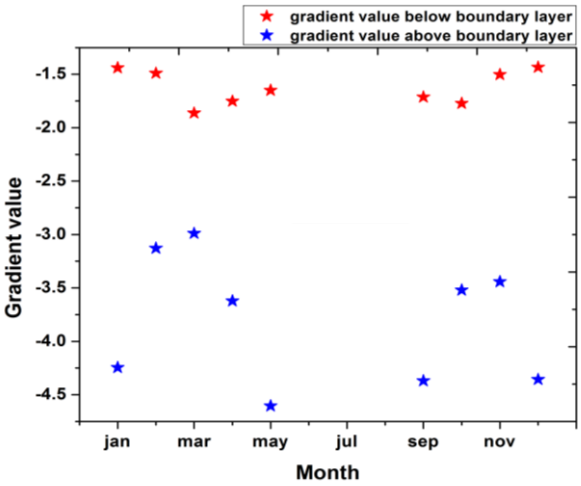
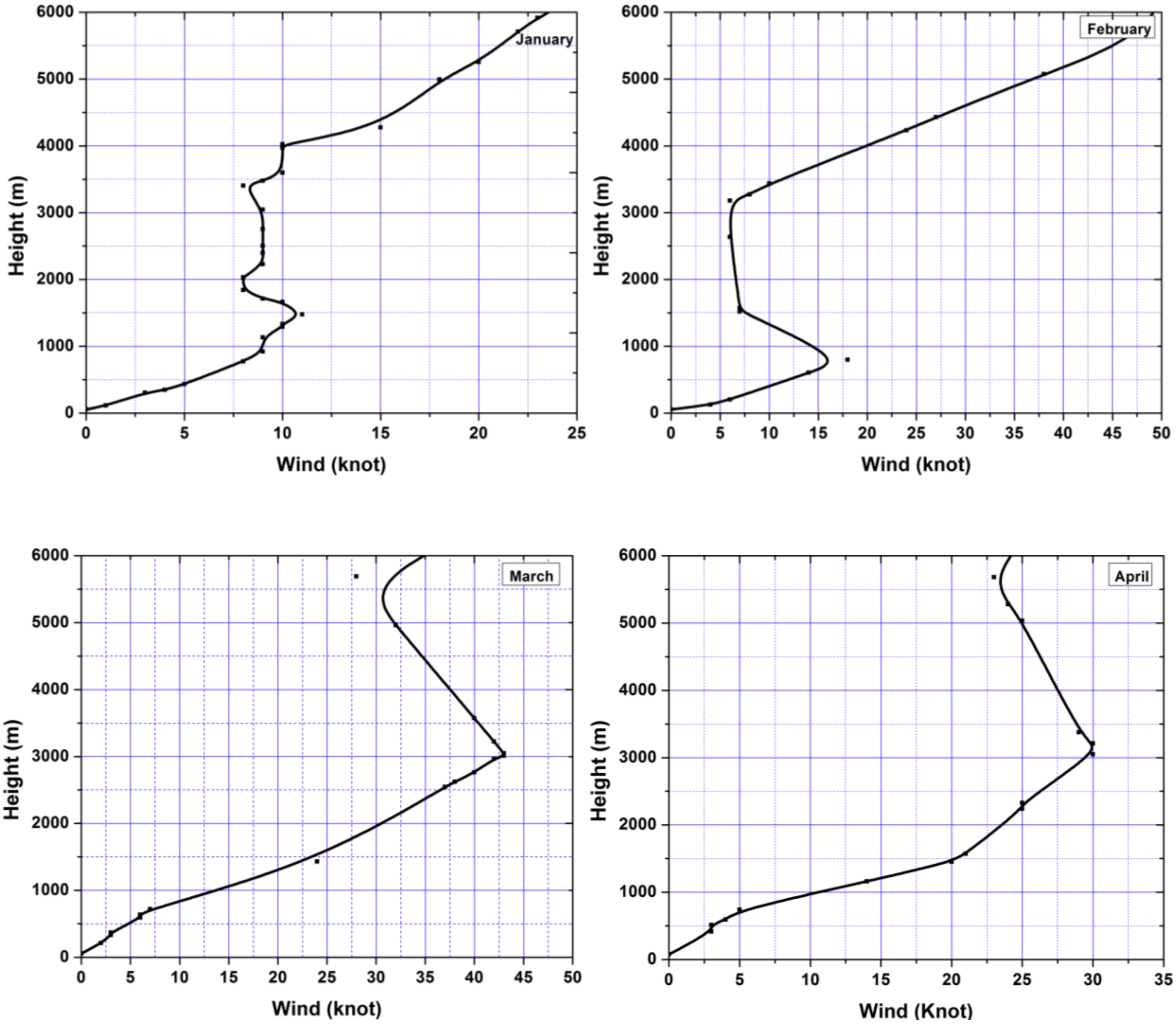


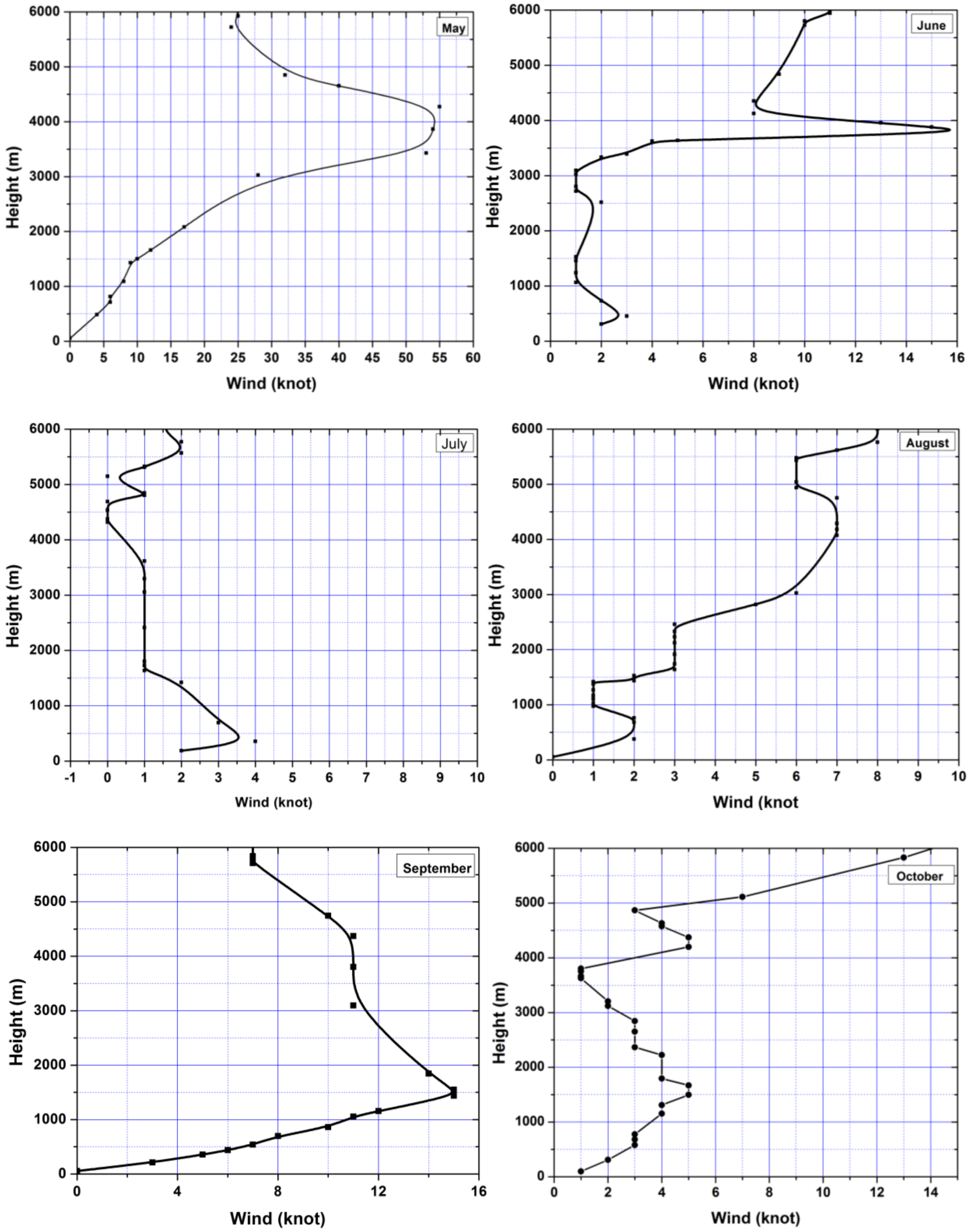
Figure 4: Gradient variation of Cn^2. Red marks are for values below PBL height and blue indicates the gradient value of Cn^2 above PBL height

To identify the Cn^2 varitions pattern with altitude within PBL and free mixing zone, the rate of change of Cn^2 with height are calculated and are presented in Figure 4. The presence of strong gradient within

PBL is clearly seen in all the months except in the monsoon season where there is no well defined height isolating PBL & the free mixing situations.

As a next parameter of this analysis, the wind speed variations below and above PBL zone are analysed and Figure 5 shows the wind speed variation for the month of January to December. From the figure it is clear that wind speed is higher within PBL bounded zone but decrease as wind enters the free mixing height. The rate of change of wind speed with height is also well observed to be higher within PBL compared to the free mixing zone as shown in Figure 6.




May
Height (m)
Wind (knot)
0
1000
2000
3000
4000
5000
6000
0 5 10 15 20 25 30 35 40 45 50 55 60
June
0 2 4 6 8 10 12 14 16
July
-1 0 1 2 3 4 5 6 7 8 9 10
August
Wind (knot
0 1 2 3 4 5 6 7 8 9 10
September
0 4 8 12 16
October
0 2 4 6 8 10 12 14

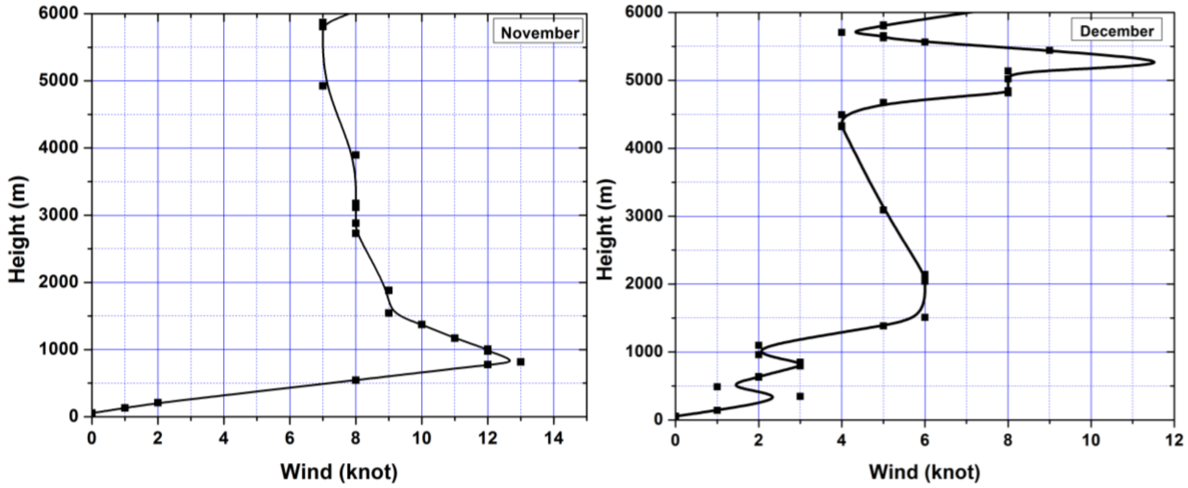


Figure 5: Wind speed variation for different months (January–December) over Guwahati covering PBL and free mixing zone

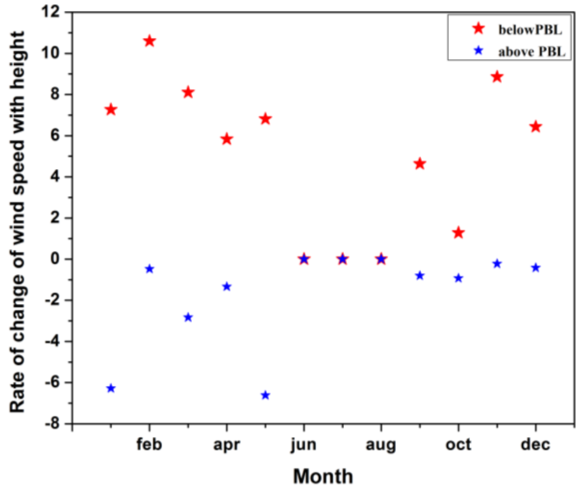


Figure 6: Rate of change of wind speed below PBL height (red mark) and blue mark show the gradient value of wind above PBL height

4. Disscussion:

The analysis of the work finally results that PBL height over Guwahati has a seasonal cahracter reaching maximum diuring April-May and minimum during winter. The hight is not well developed in rainy days specially in June and July with the onset of Monsson. However unlike the Cn^2, the temperature profiles fail to show signature of the PBL at this latitude zone. The observations that the temperature-based methods more applicable to capture the PBL at higher latitudes [Axel von and João 2013], suggest that at the latitude of Guwahti one is expected not to receive clear PBL structure in temperature profiles. There is however other parametes utilised in identifying PBL height. A few other available methods using different thermodynamic aspects are vertical gradient of potential temperature, relative humidty, though there is no single way of identifying a correct height of PBL. Such determination is made complex by the fact that the boundary layer often experiences stronger mixing even more than that of free troposphere, mainly due to increase levels of turbulence. Our approach of utlising Cn^2 parameter is to take care of almost all the variabilities associated with determination of PBL height, like potential temperature, humdty and irregularities.

Further, the Cn^2 evaluated height when examined in association with wind speed variation pattern within PBL and free mixing zone, the results are well comparable. The increase in speed at the PBL height and the simultaneous decrese of the same as it centeres the free mixing zone as observed by us are also reported by earlier worker. Therefore the speed braking height as taken as an index of PBL top seems to justify our approach. Such results finally show that there is well detected PBL height at this zone in all the seasons except in monsoon period and Cn^2 approch can be well adopted for such study.

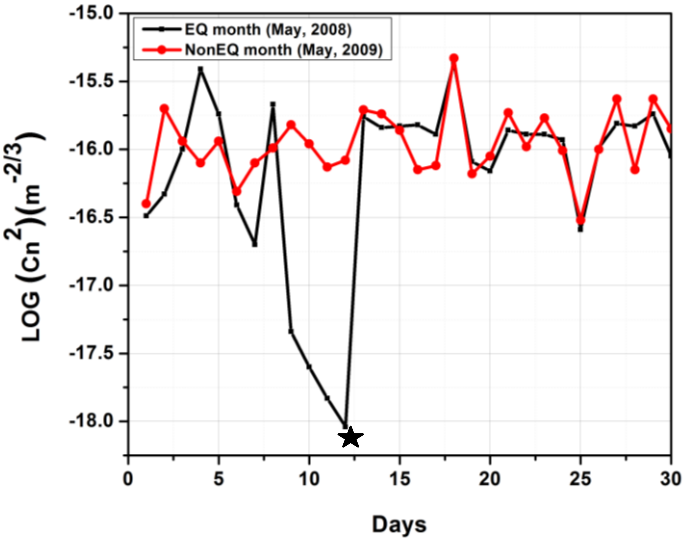


Figure 7: Earthquake time Cn^2 Variation (within PBL range).Note: Decrease of Cn^2 value prior to China earthquake May, 2008. Star mark indicate the EQ day

Further, structure constant parameter as changes with hazardous situation, there is a positive aspect too of utilising PBL bounded or free mixing Cn^2 data in identifying onset of hazard situation with different thermodynamic approaches, which will be the future aspect of the work. In this connection we bring our observation on variation of the PBL bounded Cn^2 profile features prior to the strong China earthquake (Fgure 7). One can note decrease in Cn^2 value just prior to the earthquake event. More case studies will be conducted using this approach to identify predictor features through Cn^2 profiles in bounded and free mixing zone for thunder, worst weather situations and earthquake events.

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