Turbulence Studies using UHF radar observations over Gadanki (13.5^0N, 79.2^0E)

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Abstract

Wind information and Doppler moments obtained from UHF radar observations for a period of one year (April 1999-March 2000) are used to study diurnal, monthly and seasonal variation of turbulence. Turbulence studies are made using Turbulent Kinetic Energy (TKE), spectral widths, Signal to Noise Ratio (SNR) and refractivity structure constant (Cn^2). From the diurnal observations TKE is found to be maximum around noon time and minimum in the night time indicating maximum turbulence in the day time. Spectral widths and SNR observations indicate the intensity of turbulence and mixing depth (height of the boundary layer) in different seasons. Peak SNR indicates the evolution of boundary layer representing mixing level depth or turbulent region. Spectral widths and refractivity structure constant show maximum in summer which show the intensity of turbulence.

Introduction

Boundary Layer is that part of the troposphere that is directly influenced by the presence of earth's surface and responds to surface forcings with a time scale of about an hour or less. These forcings include frictional drag, evaporation and transpiration, heat transfer, pollutant emission and terrain induced flow modification (Stull, 1988). It is also referred to as Atmospheric Boundary Layer (ABL). Atmospheric flows in the PBL are considered to be highly turbulent, mainly generated by buoyant convection or vertical shear in the horizontal fields.

Turbulent Kinetic Energy (TKE) is one of the most important quantities to study the turbulent boundary layer. Kallistratova et al., (2001) have compared turbulent momentum fluxes derived from Sodar and sonic anemometer measurements and determined turbulent kinetic energy (TKE) from measurements of three wind components by Doppler radar, momentum flux from the density of turbulent kinetic energy. They showed a good comparison of the results. Hadi et al., (2000) studied Boundary Layer structure over Gadanki during pre-monsoon period and concluded that PBL height varies with time and local factors, which do not seem to depend on coriolis factor. PBL mixing height is deduced from SNR by Angevine et al., (1998) and from reflectivity by Krishna Reddy et al., (2000) and concluded that strong SNR is induced mainly by the temperature and humidity gradients at the top of PBL rather than by turbulence.

2. Data base

One year Lower Atmospheric Wind Profiler (LAWP) observations at Gadanki from April 1999 to March 2000 are utilized for the present study. These studies are related to ten clear air echo days in each month for the observation period of one year. LAWP gives continuous measurement of wind over the entire diurnal cycle (24 hours).The available data in an hour is averaged to represent hourly data. So 24-hourly averages are available on all the days. Seasons are classified as Summer (March, April and May), Monsoon (June, July, August and September), Post- monsoon (October, November and December) and Winter (January and February). Diurnal variation of studies are represented choosing a typical day in each season. They are 19^{th} April 1999 (summer), 11^{th} July 1999 (Monsoon), 24^{th} November 1999 (Post- monsoon) and 25^{th} January 2000 (Winter). This paper is organized as follows. Database and analysis are presented in section 2. Results and discussion are presented in section 3. Diurnal variation of turbulent kinetic energy, spectral widths, signal to noise ratio and refractivity structure constant in different seasons are presented in section 3.1. Monthly variations of spectral widths, refractivity structure constant are presented in section.3.2. Summary and results are presented in section 4.

3. Results and discussion

3.1.1 Diurnal variation of Turbulent Kinetic energy

Turbulent Kinetic Energy (TKE) per unit mass is defined as

$$\frac{TKE}{m} = \frac{1}{2}(\overline{u'^2} + \overline{v'^2} + \overline{w'^2})$$

where *u' ,v' and w'* are turbulent portion of the wind in zonal, meridional and vertical directions respectively (Stull,1988)

Figure.1 shows diurnal variation of turbulent kinetic energy per unit mass in different seasons at four different altitudes. During summer season, a large diurnal variation is observed from the early morning hours towards noon time and then decreasing towards night time. Maximum TKE of 60 m 2 s -2 is observed at around 1100 hours LT at an altitude of 0.6 km. Above that altitude TKE is decreasing with altitude, indicating maximum turbulence at lower altitude regions around noon time. During monsoon season, TKE is increasing with altitude and is maximum of 100 m 2 s -2 around 0600 hours LT at an altitude of 1.5 km, 95 m 2 s -2 at 0.90 km around 1500 hours LT , 90 m 2 s -2 at 1.2 km around 1300 hours LT. During post- monsoon season, TKE is increasing with altitude up to 1.2 km and then decreasing slowly with altitude. Maximum TKE of 60 m 2 s -2 is found around 1300 hours LT. In general TKE is maximum around noon time and minimum in the night time indicating maximum turbulence occurrence during the day time.

3.1. 2.Diurnal variation of Spectral widths and Signal to Noise ratio

Figure 2 (a) shows diurnal variation of spectral widths observed on typical days in different seasons. During summer season, spectral widths are low before sunrise and increasing towards noon time and then decreasing till evening and then increase in the night time and remain stable for some time. During monsoon spectral width is maximum in the early morning hours and is decreasing towards night time. During post- monsoon, it is minimum in day time, but maximum in night time. During winter season, spectral widths are minimum compared to all other seasons. Spectral width is maximum in day and night times. From the figure it is observed that spectral widths are maximum around noon time in summer and winter, morning time in monsoon and night time in post-monsoon seasons, indicating maximum turbulence at those timings.

Figure 2(b) shows diurnal variation of SNR observed on typical days. The growth of convective boundary layer, can be identified as strong echo layer rising up quickly in the morning until it reached maximum height around noon. The peak of SNR in summer season reveals boundary layer structure. It also indicates the evolution of boundary layer representing mixing level depth or turbulent region. The peak of SNR is low during early hours after sunrise and goes on increasing with time and attains maximum around noon time and a sudden fall due to dissipation and again increasing due to inversion. A clear diurnal variation of boundary layer structure indicated by the peak SNR in summer season with a maximum height of ~ 2 km around noon time is observed. In general the height of peak SNR, indicating the convective boundary layer height is about 2 km, and low in other seasons i.e. post- monsoon, monsoon and winter. around noon time is observed. Kunhi Krishnan et al., (2001) have observed boundary layer structure as a case study (March 19, 1998) over Gadanki. They reported that ABL depth indicated by the reflectivity goes up to 1.5 km by 12.30 hrs associated with trade wind inversion prevailing over Gadanki and clear evolution of ABL is not observed during August due to intermittency of convective activity.

3.1.3 Diurnal variation of Refractivity Structure constant

A clear air radar such as the boundary- layer profiler receives its return signal primarily from inhomogeneities of the radio refractive index. These inhomogeneities are characterized by the refractivity structure constant Cn^2 . The profiler SNR at a given range is proportional to Cn^2 (Wyngard and LeMone, 1980) and Fairall, (1991) showed that Cn^2 peaks at the inversion atop CBL. Therefore a peak in the range corrected SNR indicates the CBL top and volume reflectivity is given by the relationship

$$SNR = \frac{P_t \alpha_t \alpha_t \tau_e A_e \cos\chi}{8\Pi(\alpha_r T_c + T_r) K B_n r^2 \Delta r} \eta$$

The refractivity structure constant $C_n^2 \approx \frac{\lambda^{1/3}}{0.38} \eta$ indicates the strength of turbulence. Figure 3 shows diurnal variation of refractivity structure constant on typical days. During summer season, turbulence is minimum during early hours. The height up to which turbulent mixing is increasing up to noon time is indicated by an increased structure constant value of -14.2 m -2/3 at 2.2 km at around 1200 hours LT, then it suddenly drops at an hour of 1800 hours LT. This value suddenly attains maximum and remains stable. From the figure it is seen that turbulence is patchy and intermittent. Vigorous mixing is observed during noon time. During monsoon season, Cn^2 is maximum of ~ 15 m-2/3 during early hours of the day i.e. from 0400 hours LT to 1000 hours LT and a sudden drop is observed intermittently. Maximum turbulence is observed at around 2.0 km at 0600 hours LT. After that hour it tends to decrease, indicating less mixing during day time. During post- monsoon season turbulent regions are observed during night time. Low value of Cn^2 of ~ 15.2 m -2/3 are observed during day time. Maximum value of Cn^2 of ~ 13.2 m -2/3 is observed during night time.

3.2 Monthly variation of spectral width and Refractivity Structure Constant

Figures 4(a) and 4(b) show monthly variation of spectral widths and refractivity structure constant averaged over ten days from afternoon hours (1200-1400LT) in a month for a period of one year. From figure (a), it can be seen that the spectral width is maximum in the month of May at an altitude of 0.6 km, indicating strong turbulence. Spectral widths are decreasing from the summer months towards winter. Maximum value of 0.55 ms^{-1} is observed in summer and minimum of 0.2 ms^{-1} in winter season. A similar feature is also evident from the figure (b) of logarithm of refractivity structure constant. It shows a maximum of -14.8 $m^{-2/3}$ in summer at an altitude of 0.6 km and then slightly decreasing in the subsequent seasons and shows a low value of ~-16.25 $m^{-2/3}$ in winter. It is observed that Log Cn^2 value is varying in between the values -14.25 $m^{-2/3}$ and -16.25 $m^{-2/3}$ in the mid afternoon hours over the above period.

4. Summary and conclusions

Diurnal and seasonal variations of refractivity structure constant are studied in different seasons using typical clear air days. Seasonal variation is studied using ten day clear air day averages in each month for a period of one year. Peak SNR represents boundary layer height. A well defined diurnal variation of boundary layer height is observed in summer season. It is maximum around 2 km in summer and minimum in winter season, may not be well defined in monsoon and post- monsoon seasons. From the Turbulent kinetic energy observations, TKE is found to be maximum around noon time in summer and winter seasons, indicating maximum turbulence. Spectral widths and SNR observations indicate the intensity of turbulence and mixing depth in different seasons. Mixing depth indicated by peak SNR is found to be maximum around noon time in summer season. Spectral widths and Refractivity structure constant show maximum in summer and minimum in winter seasons around noon time. Seasonal variation shows similar features of diurnal variations in all the measurements.

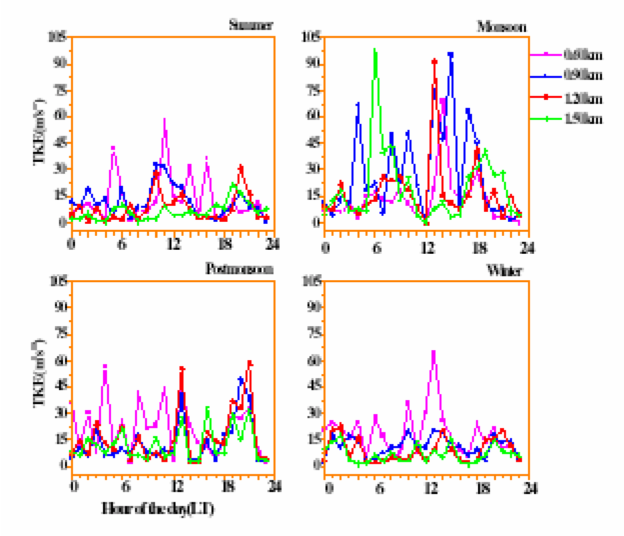

Figure 1. Diurnal variation of Turbulent Kinetic Energy at four different altitudes in four different seasons.

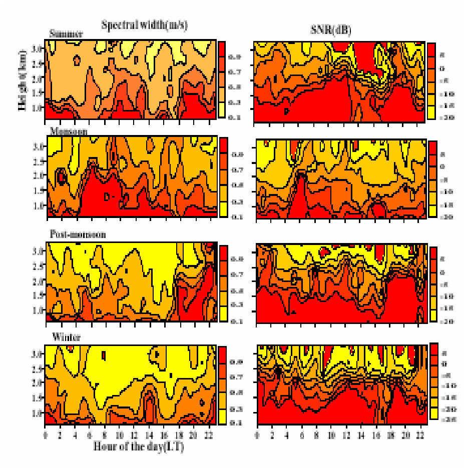

Figure 2. Height –time contour diagram of (a) spectral width (m/s) b) SNR (dB) observed on typical days 19 April 1999 (summer), 11 July 1999 (monsoon), 24 November 1999 (post-monsoon),and 25 January 2000 (winter) in different seasons.

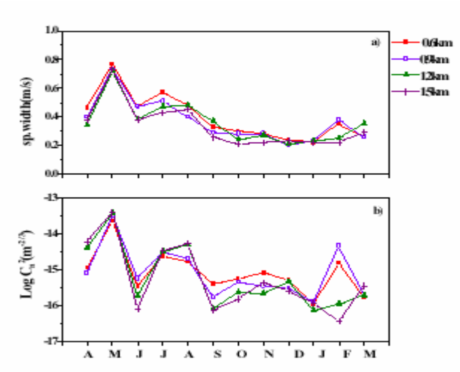

Figure 3. Diurnal variation of refractivity structure constant in four different seasons.

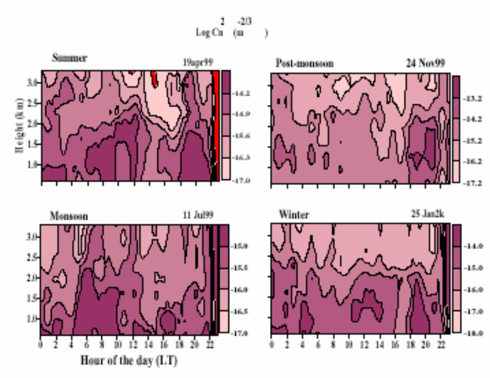

Figure 4. Monthly variation of a) spectral width (m/s) and b) Log Cn2 averaged over 1200-1400 LT of ten clear air days in a month of the year (April 1999-March 2000)