# Temporal variations of ventilation coefficient at a tropical Indian station using UHF wind profiler

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**Extensive observations of the atmospheric boundary layer height and wind speed using an L-band UHF wind profiler were utilized to estimate ventilation coefficient (VC), an index of air pollution potential over Gadanki (13.5°N, 79.2°E), a tropical Indian station during the period from March 1999 to April 2000. On an average, maximum boundary-layer height was observed during pre-monsoon period with the highest value (~ 2.3 km) in April and minimum during winter (~ 1.4 km), with the lowest value in January. The daily, monthly and seasonal variations of VC were studied during this period. It was found that VC is high during noon hours, leading to less pollution potential during noon hours. VC is found to be low during winter period and high during monsoon period.**

THE atmospheric boundary layer (ABL) height variation over a region has theoretical, experimental and practical implications. The ABL height controls the vertical extent, concentration and transformation of atmospheric pollution to some extent and has importance on the study of trace gases and ozone in the lower troposphere. The vertical mixing of the atmospheric pollutants are strongly influenced by the height of the ABL, which acts as an interface between the more polluted regions near the earth's surface and the relatively cleaner free atmosphere above. Thus air-quality measurements are directly related to the ABL parameters. It is therefore important to obtain estimates of the boundary layer height and also the wind fields for air pollution monitoring and assessment. Both direct/conventional as well as remote sensing methods have been in use for studying air quality. Recent developments in radars such as the development of UHF wind profilers, made it possible to monitor the ABL growth and wind fields with good spatial and temporal resolution. In this communication we report a study on the temporal variations of ventilation coefficient (VC), a parameter that depends on the ABL height and mean wind within the mixed layer, and its possible implications on the dispersion of air pollutants using UHF wind profiler observations over an inland tropical station, Gadanki, India.

Measurements were made over a tropical inland station Gadanki (13.5°N, 72.9°E), a rural area situated near the east coast of the southern Indian peninsula (Figure 1) and about 361 m a msl. The terrain features are rather complex, with a number of hills (average height ~ 750 m) within 10 km radius and an irregular mixture of agricultural and population centres. The wind profiler located at Gadanki is a low-power, L-band (1357.5 MHz) UHF pulsed coherent, phased array radar having an effective peak power aperture product of $1.2 \times 10^4$ $Wm^2$, capable of providing continuous high-resolution wind measurements in the first few kilometres of the atmosphere. This system is commonly referred to as Lower Atmospheric Wind Profiler (LAWP). The peak-transmitted power is 1 kW, which is fed to the micro stripped antenna array consisting of 24 × 24 elements occupying an area of 3.8 × 3.8 $m^2$, generating a radiation pattern with a gain of 29 dB and one-way beam-width of 4°. The antenna beam can be positioned through electrical phase switching at any one of the three fixed orientations, 15°N, 15°E and zenith. The pulse width can be set as 0.33, 1 and 2 µs corresponding to a range resolution of 50, 150 and 300 m respectively. Detailed description of the system, data analysis and validity of the measurements and observations are given elsewhere[1–3]. For the present study, observations using the UHF wind profiler during the period from March 1999 to April 2000 and few days during March 1998 are used.

VC represents the rate at which the air within the convective boundary layer is transported[4]. This parameter plays an important role in the dispersion of aerosols and is one of the factors that determine the pollution potential over a region of interest. The VC is given by

$$VC = ZiU \tag{1}$$

where $Zi$ is the ABL height and $U$ the average wind velocity

$$(U = \sum_{i=1}^{i=z_i} u_i)$$

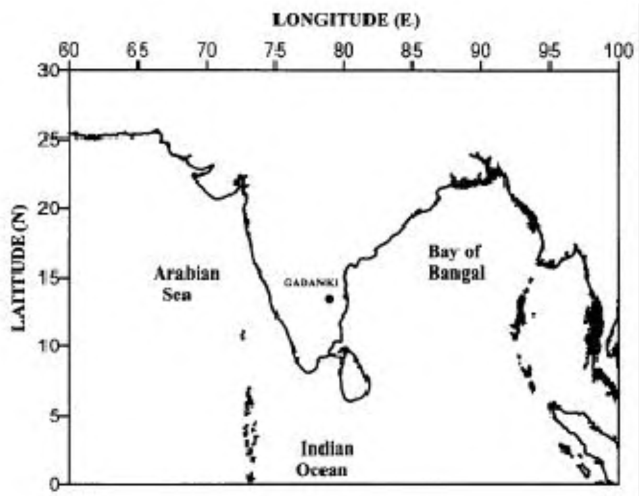


**Figure 1.** Location map showing Gadanki.

*For correspondence. (e-mail: pkkrishnan_spl@yahoo.co.in) in the mixed layer. Low values of VC indicate less efficient dispersion of pollutants. The higher the coefficient the greater is the ability of the atmosphere to disperse the pollutants and hence less pollution hazard or good air quality. In this estimation wind speed from the first two range gates was eliminated because of contamination due to ground clutter. But this will not affect the estimates of VC, as turbulence mixing within the daytime convective boundary layer makes the wind profile nearly steady with respect to height. In this study the ABL height ($Z_i$) is obtained from the wind profiler, as it can monitor ABL height from an enhancement in the radar reflectivity at the inversion layer capping the ABL due to the strong humidity gradients and turbulence[5]. The subjective and objective method proposed by Angevine *et al.*[6] is used here. It utilizes the median of reflectivity as a tracer for detecting the ABL height. The ABL height estimated using this method is checked again with the reflectivity pattern for each day to avoid errors that can arise due to the presence of other reflected layers in the lower levels. Using the maximum boundary layer height for each day, monthly average is also found. In the present study only precipitation-free periods are used.

Diurnal evolution of ABL is shown in Figure 2 *a*, where the solid curve represents the hourly values of ABL height estimated using the reflectivity method discussed earlier. It can be seen that the ABL depth (Figure 2 *a*) is low during morning hours and it gradually increases and reaches a higher value at noon hours and starts decreasing in the evening. This is the general behaviour of daytime convective boundary layer observed during clear air days. The evolution of the daytime boundary layer can influence the aerosol particle concentration, size distribution and gas-phase chemistry at the ground level. In the early morning hours when the ABL depth is shallow, there can be accumulation/concentration of pollutants near the surface. So the pollutants trapped in the ground-based stable layers during the previous night are dispersed and transported to other regions of the lower atmosphere by turbulent mixing as the boundary layer starts evolving with time after sunrise. Moreover, the increased boundary layer height and extensive mixing together with the entrainment at the top of the inversion layer can dilute the pollutant concentration. During evening hours, the pollutants emitted or transported from other regions can be constrained at the lower heights in the boundary layer and can remain until early morning hours due to the formation of nocturnal stable boundary layer.

Thus the diurnal behaviour of the boundary layer plays an important role in aerosols particle concentration at the ground level. This is further evident from the variation of VC. Figure 2 *b* and *c* represents the temporal variation of wind speed and ventilation coefficient respectively. The diurnal variation of VC shows low values during early morning hours; it gradually rises and reaches maximum value during the noon hours and decreases in the evening. This indicates the high dispersive capacity of ABL during afternoon hours.

The variations in the prevailing conditions can influence ABL height, wind speed and hence the VC. To study the monthly variation of VC, the maximum ABL height for each day and the corresponding wind speed within the

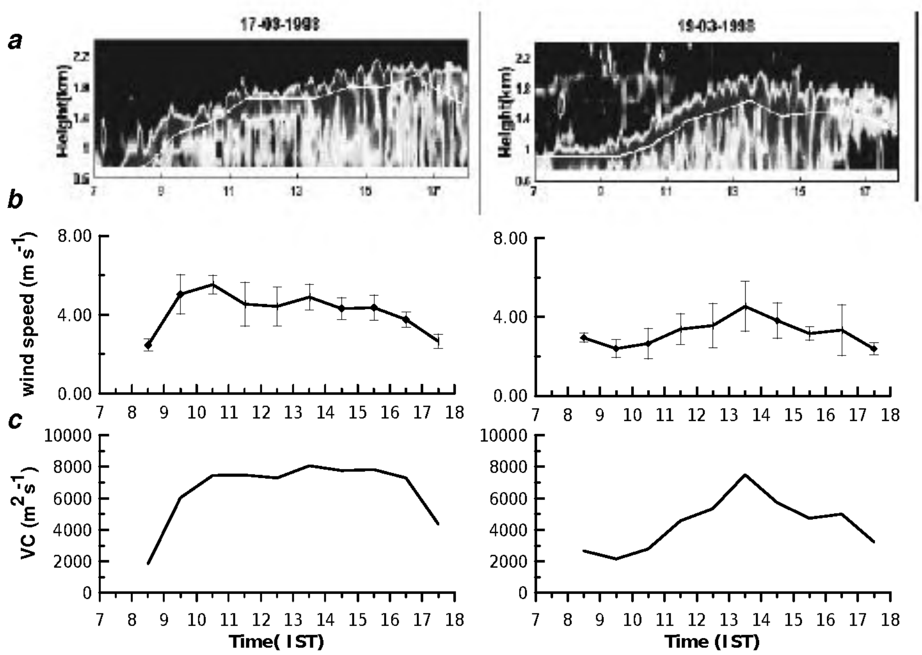


**Figure 2.** (***a***) Time evolution of radar reflectivity. Solid curve represents ABL height estimated using (***b***) wind speed and (***c***) ventilation coefficient.

boundary layer are found. This is used to estimate the monthly average of VC (Figure 3). The vertical bars in Figure 3 represent the standard deviation from the mean value. It is apparent that VC has the highest value during July (~ 13723 $m^2s^{-1}$) and lowest during January (6928 $m^2s^{-1}$). The ABL height is high during April and this reaches an average of ~ 2.3 km, whereas lower values are observed in January (~ 1.4 km). During the other months the ABL height varies in the range ~ 1.4 to 2.3 km. It can be noted that the monthly variation for the period from March to April 2000 is similar to that during March to April 1999. Maximum wind speed is observed during June, July and August. It can be seen that the variation of VC during the period from November to April is influenced both by the ABL height and wind speed within the ABL, whereas during May to October, it closely follows the same type of variation as that of the wind speed. Note that the ABL height does not vary much from July ($Zi$ = 1.6 km) to January ($Zi$ ~ 1.4 km). It can be noted from Figure 3 that (i) the annual variation of ABL height is not so drastic as that of wind speed, and (ii) it is the larger increase in wind speed rather than ABL height that results in high VC during the monsoon months. This implies a cleaner environment during monsoon. It is apparent that VC has the maximum value in July and minimum in January. Variation in VC during the monsoon period is controlled mainly by variations in wind speed rather than the ABL height.

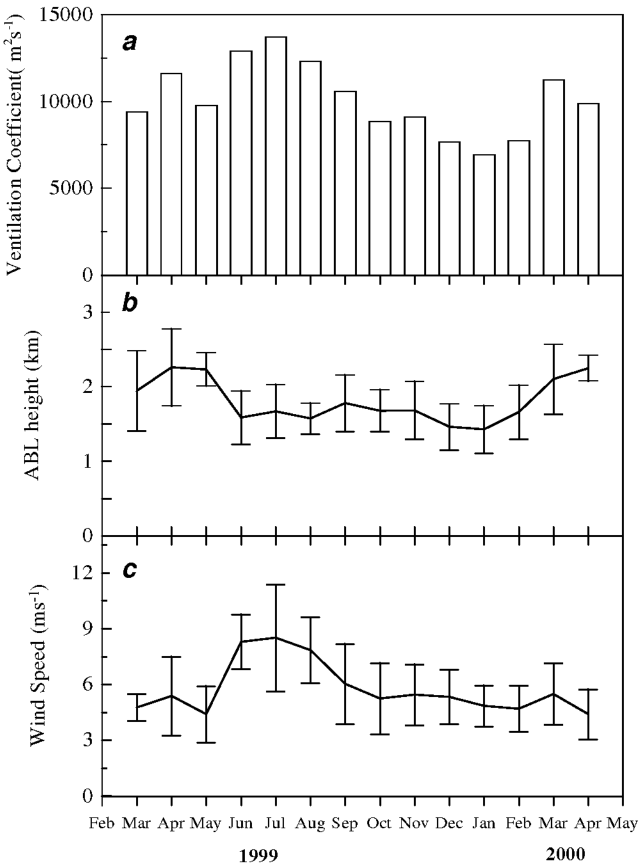


**Figure 3.** Monthly variation of (***a***) VC, (***b***) ABL height and (***c***) wind speed.

With the objective of checking the wind direction during the period of study, the weekly average is considered, as shown in Figure 4. The wind pattern shows the prevalence of northerly or northeasterly flow during the period from November to March. Therefore, superimposed on the changes in VC, winter and pre-monsoon experience relatively polluted air transported from the north and northeast regions of the Indian subcontinent. The change in wind pattern occurs during May and continues until September/October. During this period wind becomes westerly or southwesterly, carrying pristine air from the Arabian Sea and the Indian Ocean.

In general, four seasons occur over the Indian subcontinent, i.e. the hot summer (pre-monsoon) season from March to May, the southwest monsoon season from June

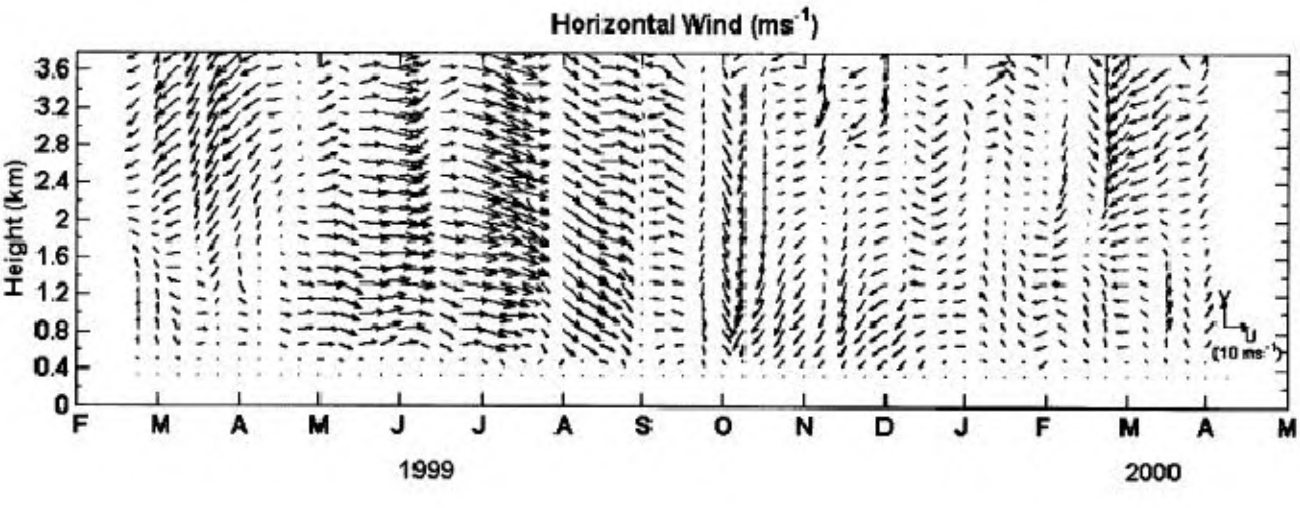


**Figure 4.** Variation of horizontal wind during the period from March 1999 to April 2000.

**Table 1.** Seasonal variation of mean noontime ABL height and VC

| Season | No. of days taken | Mean noontime ABL height (km) | VC ($m^2s^{-1}$) |
|---|---|---|---|
| Summer (March–May) | 76 | 2.20 ± 0.42 | 10565 |
| Monsoon (June–September) | 80 | 1.65 ± 0.33 | 12491 |
| Post-monsoon (October, November) | 29 | 1.68 ± 0.35 | 9012 |
| Winter (December–February) | 51 | 1.50 ± 0.34 | 7405 |

to September, the warm dry (post-monsoon) season from October to November, and the winter (northeast monsoon) season from December to February[7]. In order to study the variation of VC during the different seasons that are characteristic of the Indian subcontinent, the data are grouped into four seasons. The average values of VC along with the mean noontime ABL heights are given in Table 1. It can be seen that VC is high during monsoon (12491 $m^2s^{-1}$), and low during winter (7405 $m^2s^{-1}$.). During summer, VC is found to be 10565 $m^2s^{-1}$, whereas during post-monsoon period VC is found to be 9012 $m^2s^{-1}$. The high value of VC during summer compared with post-monsoon is mainly attributed to the high value of ABL height during this season. However, lower values of ABL height and wind speed result in lower values of VC during winter period. During the monsoon period, along with the high value of VC, washout processes by precipitation can result in a cleaner environment, whereas during winter season the low value of VC along with reduced wet removal process can result in high concentration of surface-emitted species in the lower atmosphere, resulting in high pollution potential. The low value of VC can lead to hazy conditions during winter season. Parameswaran[8], using post-sunset lidar measurements over Trivandrum (8.5°N, 77°E) reported higher values of VC during monsoon and lower values during winter months. Conversely, the ventilation coefficients estimated over Pune (18.5°N, 73.8°E) during post-sunset period using lidar[4,9] showed higher values during summer and lower values during monsoon and winter months. It should be noted that in the present study we report the daytime values of VC compared to the post-sunset values reported earlier[4,8,9].

Owing to the lack of simultaneous surface measurements, we attempted a comparison based on a few observations made at the surface level over the peninsular Indian region under the assumption that the synoptic conditions over the Indian region are not changing much. The only reported observations made over Gadanki are on surface ozone and precursor gases during the period 1993–96 (ref. 10), revealing maximum values during winter/summer periods and minimum during monsoon season. The diurnal variation in ozone and $NO_x$ concentration was attributed to the ABL process, even though a number of other factors such as the availability of solar radiation, abundance of precursor gases, etc. can influence ozone mixing ratios under varying synoptic conditions. But the diurnal and seasonal variations of surface-emitted aerosol concentration are strongly dependent on the ABL height and wind speed, i.e. on VC. The findings on the seasonal behaviour of VC have been corroborated by surface measurements of particulate matter using quartz crystal microbalance impactor by Pillai *et al.*[11], over Trivandrum during the period from October 1998 to December 2000. They observed highest value of particulate matter during winter and lowest during monsoon. This effect was most prominent for PM 2.5 observations, with the percentage share to total aerosol concentration having highest value in winter (~ 86%) and lowest during monsoon (~ 74%). The averaged diurnal variation in particulate matter was reported to be low during daytime, which is in accordance with the variation in VC discussed earlier.

Extensive observations of the ABL over Gadanki using UHF wind profiler during March 1999 to April 2000 revealed that the average ABL height over Gadanki is high in April (~ 2.3 km) and low in January (~ 1.4 km). The estimates of VC over Gadanki revealed the following:

(i) The diurnal evolution of VC shows higher values during noon hours.
(ii) The monthly variation of VC indicates highest value in July and lowest in January.
(iii) The seasonal variation of VC revealed low values during winter and high values during monsoon season.

The analysis showed that VC is strongly influenced by wind speed during monsoon season, whereas both ABL height and wind speed determine the value of VC during the other seasons over Gadanki.

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# Impact of diesel vehicular emissions on ambient black carbon concentration at an urban location in India

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**Vehicular emissions in the urban areas are known to contribute significantly to aerosol black carbon (BC) loading to the atmosphere. Quantification of BC emissions is important from the climate research point of view, as the BC aerosols strongly absorb solar radiation. A case study has been carried out in an urban area, Hyderabad, to assess the impact of emissions associated with truck transport on ambient BC concentration. The study was carried out during the recent nationwide truck strike of April 2003. The results indicate a significant reduction in the BC loading associated with withdrawal of the trucks. The decrease was gradual, while the recovery was almost immediate.**

ATMOSPHERIC aerosol black carbon (BC) is known to be a significant absorber of solar and terrestrial radiation and is recognized as a potent greenhouse species of atmospheric aerosols[1,2]. BC is emitted into the atmosphere as a by-product of all combustion processes (vegetation burning, industrial effluents and motor-vehicle exhausts). It is one of the important constituents of ambient particulate matter[3]. BC is chemically inert in the atmosphere and predominantly is in the submicron size; its main atmospheric sink is wet deposition[4]. While scattering aerosols increase the atmospheric albedo tending to cool the earth, BC absorbs radiation causing a warming. The darker grey particles are, the more solar energy they can absorb, thereby heating the atmosphere[5]. BC aerosols originating from fossil-fuel combustion and biomass burning, and carbonaceous aerosols contain BC directly emitted during the combustion process (primary aerosols) and organic matter vapour (secondary aerosols)[6]. In this communication we present the results of a case study conducted in an urban area, Hyderabad, Andhra Pradesh to assess the impact of emissions from diesel truck transport on aerosol BC concentration.

Continuous measurements of aerosol BC have been carried out using an Athelometer model AE-21, of Magee Scientific, USA. The aethalometer makes measurements of mass concentration of aerosol BC by measuring the attenuation of light transmitted through a quartz filter tape on which the ambient particles are made to impinge. The reduction in the transmission consequent to the collection of particles is calibrated in terms of the mass concentration of BC. More details are available elsewhere[7,8] (http://www.mageesci.com/Aethalometer_book_2009.pdf). The study area was located within the urban area of Hyderabad (17°10′–17°50′N and 78°10′–78°50′E), which is the fifth largest city in India (Figure 1). Measurements were

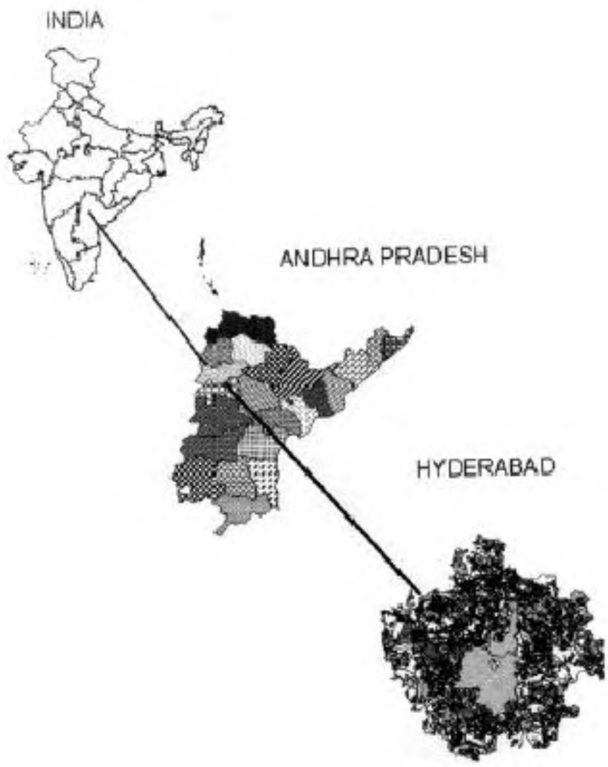


**Figure 1.** Location map showing the study area.

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