Influence of boundary layer dynamics on pollutant concentrations over urban region – A study using ground based measurements

D V Mahalakshmi1,#, K V S Badarinath1,5,* & C V Naidu2

1Atmospheric Science Section, National Remote Sensing Centre, Dept of Space, Govt of India, Balanagar, Hyderabad 500 625, India
2Department of Meteorology and Oceanography, Andhra University, Visakhapatnam 530 003

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Ventilation coefficient (VC) over urban area of Hyderabad, India during night-time in 2008 has been calculated using night-time mixed layer height with boundary layer lidar (BLL) and radiosonde data to investigate the influence of VC on pollutant concentration. Carbon monoxide (CO), ozone (O3) and black carbon (BC) aerosol mass concentrations in relation to mixed layer height and wind speed have been analysed for different seasons, viz. winter, pre-monsoon, monsoon and post-monsoon associated with boundary layer and ventilation coefficient (VC). The results of the study suggested that VC plays an important role in dispersing the pollutants.

Keywords: Ventilation coefficient, Atmospheric boundary layer (ABL) height, Pollutant concentration, Black carbon aerosol, Carbon monoxide aerosol, Ozone aerosol, Aerosol mass concentration

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1 Introduction

Atmospheric boundary layer (ABL), part of the troposphere, is directly influenced by the land surface processes. The transfer of energy between the surface and the air is partly accomplished by the turbulent eddies. Atmospheric turbulence in the ABL is produced primarily by wind shear and buoyancy. Diurnal variations in wind speed, static instability, turbulent exchange and convective activity in the ABL are significant over tropics. Generally, all kinds of energy exchange with surface atmospheric boundary layer plays important role in transporting heat, momentum, moisture besides pollutants such as friction, sensible and latent heat flux occurs in ABL. In general, ABL height varies both in time and space, from hundreds of meters to a few kilometers. The ABL height (h) is a crucial parameter in weather and climate models. This height controls the vertical extent, concentration and transformation of atmospheric pollution and has influence on the concentration of trace gases and ozone in the lower troposphere. The vertical mixing of 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. During daytime, the ground is heated by the sun and a convectively driven, vertically mixed layer grows and reaches its maximum during the afternoon. After sunset, turbulence decays in the mixed layer and a residual layer is formed. The initial mean state and concentration variables of this layer remain that of the daytime mixed layer and change slowly in the absence of advection. During nighttime, temperature decreases throughout the depth of the residual layer and causes neutral stratification.

VC plays an important role in dispersion aerosol and is one of the factors that determines the pollution potential. Carbon monoxide (CO), ozone and black carbon (BC) aerosols have a major impact not only on human health and visibility in urban regions, but also on global and regional climate. Burning of biomass and fossil fuels, automobile exhaust, forest fires are the major sources of BC. In urban areas, the increasing energy demands for industry and transport propels fossil fuel utilization, which are the major source of pollutants. The BC aerosol and fly ash are unquestionably human produced because its natural sources are negligible. BC is inert in the atmosphere as a result of its chemical structure and also due to its predominant submicron size. Its main atmospheric
sink is wet deposition. Ozone is also one of the major pollutants and its high concentration can be harmful to human health and plants. The present study focuses on the estimation of ventilation coefficient and its influence on pollutant concentrations within the mixed layer over urban areas of Hyderabad during 2008.

2 Study area

The measurements were made over a tropical station Hyderabad (17°10′ and 17° 50′N latitude and 78° 10′ and 78° 50′E longitude), an urban area situated near the east coast of the southern peninsular in India (Fig. 1) (ref. 13). It is a semi-arid region with a total rainfall of ~700 mm during monsoon season (June-September). Hyderabad, the fifth largest city of India, is highly urbanized with a population of 5,751,780 inhabitants (census 2001). The city is influenced not only by urban pollutants but also industrial as well as neighbouring biomass burning trace gases and aerosols. Measurements were made during January - December 2008 in the premises of the National Remote Sensing Center (NRSC) at Balanagar (17°28′N and 78°26′E), Hyderabad, located well within the urban center (Fig. 1). The minimum and maximum temperatures in the study area are in the range 10 - 43°C and the rainy season is during June - September.

3 Datasets and Methodology

India is a monsoonal country with four seasons, viz. winter (December – February); pre-monsoon (summer) (March – May); monsoon (rainy) (June - mid September); and post-monsoon (mid-September – November) (ref. 14). Nocturnal mixed layer height using boundary layer lidar (BLL) and the average wind speed up to the height of boundary layer were utilized to calculate the ventilation coefficient (VC). The VC is given by VC=Z_iU, where, Z_i is the mixed height; and U, is the average wind velocity in the mixed layer. Data from the lidar was used to calculate mixed layer height for winter, pre-monsoon and post-monsoon. For the monsoon season, when the lidar observations were sparse, University of Wyoming radiosonde data was used. Mixed layer height was determined from the radiosonde profiles of potential temperature by similar method to that of Driedonks. The lidar laser output pulse energy was set at 10 µJ with 2500 Hz pulse repetition rate. The laser bin width was set at 200 ns, corresponding to a height of 30 m. The raw data profile was integrated at 10 minutes interval. The design specifications of the portable lidar system have been already described. Measurements of BC, CO and O_3 have been carried out using Aethalometer AE-21 (Magee Scientific, USA) and CO11M, 41M ozone analyser (Environment S.A, France), respectively. Aethalometer aspires ambient air from an altitude of 3 m above the ground using inlet tube and its pump. The BC mass concentration has been estimated by measuring the change in the transmittance of quartz filter tape, on to which the particles impinge. The instrument was operated at a time base of 5 min round the clock with a flow rate of 2.6 LPM. The instrument has been factory calibrated and errors in measurements are ±2%.

4 Results and Discussion

Figures 2 and 3 show the monthly variation of: (a) ventilation coefficient; (b) atmospheric boundary layer height; (c) wind speed within the mixed layer; and (a) black carbon; (b) CO; (c) ozone concentration during 2008 over Hyderabad, respectively. The vertical bars in the figure show the standard deviation from the mean. The maximum mixed layer height was observed during the month of April (~3.2 km) and
minimum during winter in the month of December (~1.3 km). VC is found to be highest in the month of May and lowest in December. The pollution loading over this station has been maximum in the month of May and minimum in the monsoon month of July as seen in Fig. 3. There is a sudden drop in the pollutants loading from May to June in the study area. Pollutant concentrations remained low during southwest monsoon months of June, July, August and September and build up again in the post-monsoon (October-November) and winter (December-February) months. In winter months, calm or weak winds increase the concentration of pollutants at ground level where stronger winds carry the pollutants far away from the source and dilute them.

The scatter plots of BC, CO and Ozone with respect to VC shown in Fig. 4 suggest a decreasing trend. The annual average concentration of BC, CO

![Graphs](https://via.placeholder.com/150)

Fig. 2 — Monthly variation of: (a) VC; (b) ABL height; and (c) wind speed during 2008

Fig. 3 — Monthly variation of: (a) O₃; (b) CO; and (c) BC during 2008
and ozone during night time has been 30.6, 932 and 37 µgm⁻³, respectively at Hyderabad during 2008. Figure 5(a-c) shows the seasonal variation of: (a) BC aerosol mass concentration; (b) CO; and (c) ozone over study area. The vertical bars in the Fig. 5 represent the standard deviation from mean. During monsoon, CO, O₃ and BC concentrations decreased to 3.5, 38 and 14%, respectively from the annual mean as a result of the washout by precipitation and transport of clean air from the ocean. During winter, ozone and BC aerosol mass concentrations were

![Figure 4](image1.png)

![Figure 5](image2.png)
increased by 45 and 8.6% from the annual mean. This has been attributed to prevailing meteorological conditions like low wind speed and low ventilation coefficient. Increase in pollutant concentrations during pre-monsoon has been attributed to transport of air mass from the northwest regions even though ventilation coefficient values were high.21

The seasonal variation of VC, ABL and mean wind speed within the boundary layer over during 2008 has been shown in Fig. 6(a-c) with vertical bars showing standard deviation. From Fig. 6(a), it can be noticed that VC is as high as 18530 m$^2$s$^{-1}$ during pre-monsoon period (43% higher than annual mean) and as low as 9125 m$^2$s$^{-1}$ during winter (29% lesser than annual mean), whereas during post monsoon period the value is 10173 m$^2$s$^{-1}$. VC is high during pre-monsoon period due to the high mixed layer height (33% higher than annual mean) [Fig. 6(b)] as well as wind speed (11% higher than annual mean). Earlier studies suggested that ABL height is low over the Indian subcontinent during winter.3,4 Figure 6(c) shows that the wind speeds are high during monsoon and pre-monsoon periods. Mixed layer height, wind fields and ventilation coefficient showed good correlation during winter period.

5 Conclusions
In the present study, influence of boundary layer dynamics on pollutant concentrations over urban region of Hyderabad, India has been analysed. The analysis of results suggested that:

1. The mixed layer height over Hyderabad during 2008 varies between 1.3 and 3.2 km with a maximum during April and minimum during December.

2. The monthly variation of VC over study area during 2008 showed maximum during May and minimum during December whereas pollutant concentrations showed maximum values in the month of May and minimum in July.

3. The seasonal variation of VC at Hyderabad showed good relation with pollutant concentrations near the surface.

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