

Vertical Stratification of Ozone in Different Seasons in the Lower Troposphere of New Delhi

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ABSTRACT

Vertical ozone measurements were carried out in the urban environment of New Delhi, in three different seasons from 1989-1991. Air sampling was done synoptically at ground level, 23 m, 51 m, 57 m, 117 m and 153 m heights. A significant positive vertical gradient in the ozone concentration was observed at all sites. At any given time, ozone levels were lowest at the ground level and invariably increased with increasing distance from the ground. A distinct seasonal variation in the vertical ozone profile was also observed. Ozone concentration was highest in summer at all heights. The peak in ozone concentration during the day, appeared earlier at all heights in summers, in comparison to winter and spring. At the 51 m height in summers, the ozone concentration decreased rapidly during the late evening. Such vertical ozone stratification may have severe implications for trees and residents of high rise buildings particularly in urban and industrial conglomerations which serve as the prime foci in the release of ozone forming substances.

(Key words: Ozone pollution, Oxidant, Tropospheric ozone, Vertical variation, Air quality)

1. INTRODUCTION

Tropospheric ozone pollution is gaining increasing importance on account of its steady build-up particularly near the ground. Oxides of nitrogen, methane and a variety of non methyl hydrocarbons that serve as ozone forming precursors are released both from natural and anthropogenic sources. Major among them are the emission from automobiles, pleasure crafts (Yumulu, 1994), biomass burning, forests fires, bush fires, forests and vegetation in the form of monoterpenes. Ozone is a major air pollutant having serious implications on human beings, apart from being phytotoxic and causing enormous damage to agricultural crops and forests (Heck *et al.*, 1983; Heggsted & Bennett, 1984; Runeckles, 1992). The

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radiative properties of ozone are similar to those of CO₂; hence, the ozone build up in the troposphere is likely to influence the heat budget of the lower atmosphere.

In the troposphere, ozone is highly transient in nature, and its concentration varies widely in time and space, exhibiting diurnal and seasonal variation which are well documented in literature (Bohm, 1991; Seinfeld, 1989). Studies on the vertical ozone variation are limited but do show a significant positive vertical gradient. The vertical ozone measurements have been carried out using balloons, aircrafts, cable car (Reiter, 1991) and along the mountain gradients. Such studies appear restricted in scope on account of the following reason: the use of aircrafts enables ozone measurements between 1 and 13 km in altitude but provide little information about ozone levels in the first few hundred meters immediately above the ground surface, as it is practically impossible for aircrafts to sweep close to ground level (Fabian & Pruchniewicz, 1977; Fishman & Seiler, 1983; Joos & Maffiolo, 1989). Measurements carried out at different altitudes along a mountain gradient in England (Gay, 1991), Japan (Murao *et al.*, 1990), Austria (Puxbaum *et al.*, 1991) and Canada (Peake *et al.*, 1983) gave some indication of the vertical variation of ozone but failed to provide accurate information because such measurements at different altitudes were made at the ground level and, thus, were not completely free from diverse influences operative at ground level and may not have truly represented the vertical ozone gradient. To eliminate such shortcomings, in a recent study, synoptic measurements were carried out in New Delhi at different heights from high rise buildings to determine the true vertical ozone variation in an urban environment exhibiting a positive trend (Varshney & Aggarwal, 1993). The work highlighted in this paper is an extension of the above mentioned work and is aimed at evaluating the seasonal influence on the vertical stratification of ozone by carrying out synoptic measurements up to a height of 51 m.

2. STUDY AREA AND SAMPLING SITES

New Delhi, the capital city of India, is located between 76°50'E-77°23'E and 28°12'N-28°53'N on the west bank of river Yamuna. It lies within the subtropical belt and experiences a maximum temperature of 46°C in summer and a minimum of 1°C in winter. It has a monsoonal climate with a average yearly rainfall of 66.6 cm, 80% of which is received from June-August. Wind is mild for most of the year except during the month of June, when on a few occasions, the city is lashed by sever dust storms. Most of the time, the wind direction is from W to NW, and the yearly mean velocity varies from 0.9-2.0 m/s. Delhi is a cosmopolitan city spread over an area of 1483 km² with a sprawling population of 9.4 million (1991 census). A major center for industrial and economic activity, Delhi has attracted the staggering number of 73,000 small, medium and large scale industries (1987-88 census). The city has also witnessed a rapid growth in the number of automobiles from 0.93 million in 1985 to 1.57 million in 1990.

Three sampling sites were carefully selected for vertical ozone measurement and a remote site was selected for comparison (Figure 1). The sites were selected according to the following considerations: (1) location in different activity areas to represent varying traffic density (Table 1). (2) Access to high rise buildings to enable synoptic air sampling at different heights. (3) Need for synoptic measurements and availability of ten portable air samplers.

SITE 1: Vikas Minar, a 117 m tall, twenty-one story building of the Delhi Development Authority (DDA), lies in the eastern side of the city on the west bank of river Yamuna, in

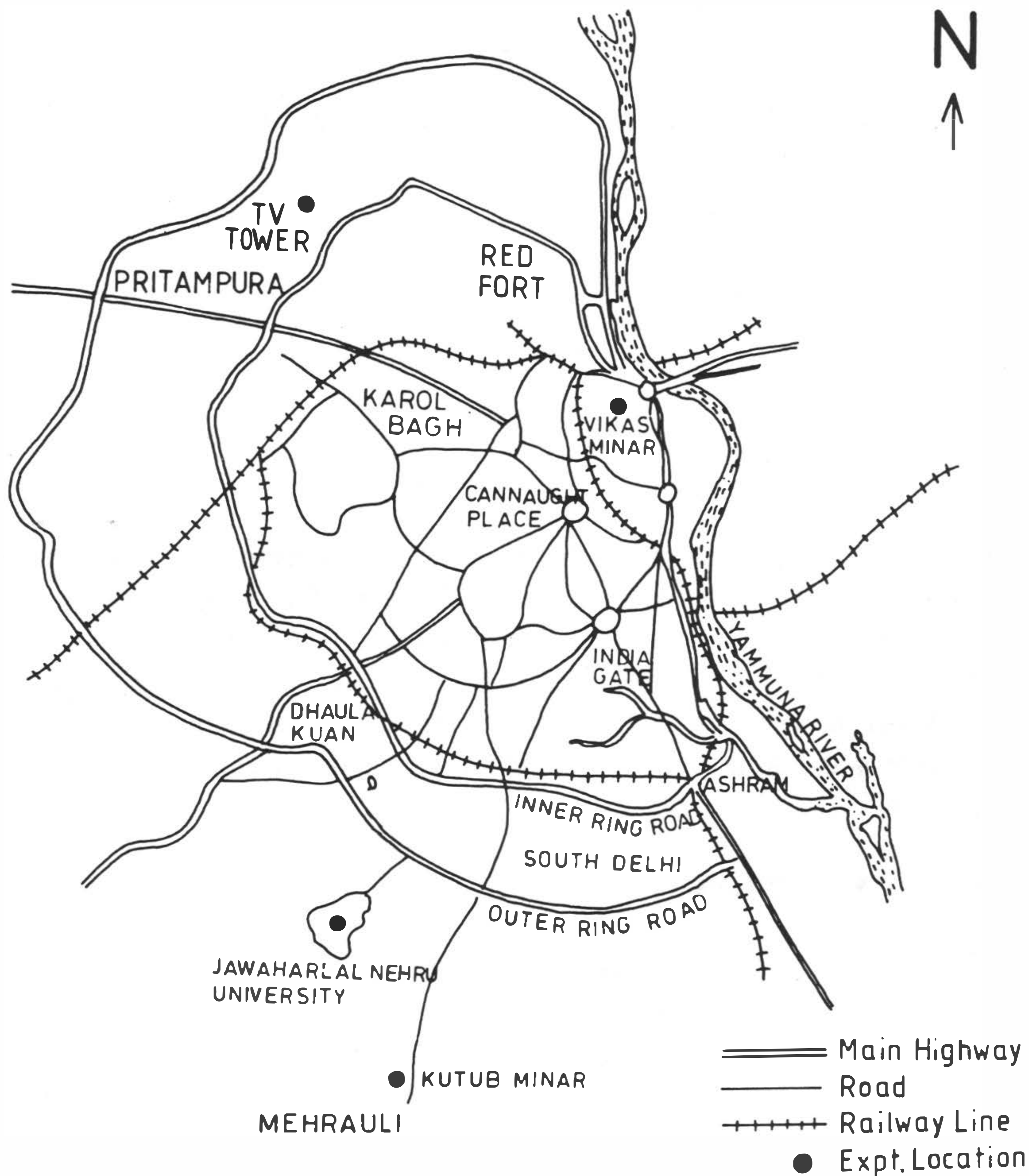


Fig. 1. Map of Delhi Showing sampling sites.

one of the densest traffic corridors of the city. Air samples were drawn at ground level, at an elevation of 57 m (eleventh floor window) and 117 m (terrace) from the ground.

SITE II: A 252 m tall, cement concrete TV tower, built in 1988, is situated in the western part of the city in the vicinity of newly developed residential colonies. The air samples were drawn at ground level, at the 102 m and at 153 m distance from ground.

SITE III: The 51 m tall, nine-story Jawaharlal Nehru University (JNU) library building is situated on an undulating terrain on the University campus in the south western part of the city. This site is relatively insulated from heavy traffic. The air samples were drawn at ground level, at a distance of 23 m (fourth floor window) and 51 m (terrace) from the ground. The seasonal influence on the vertical ozone stratification was only examined at this site.

SITE IV: Kutub Minar, a tall minaret of great historical importance, built in the 13th century AD, lies at the urban fringe on the southern periphery of the city. This site represents a pollution-free rural type of situation and was selected to serve as a reference site for comparison with other sites. Climbing on the Minaret is prohibited; hence, air sampling at this site was restricted to ground level only.

Table 1. Brief description of the sampling sites.

Site	Location	Activity area	Traffic density	Height of building
Vikas Minar	East	Urban	++++	117 m
TV Tower	North-west	Residential	+++	252 m
JNU	South-west	University campus	++	51 m
Kutub Minar	South	Remote	+	-

3. METHODOLOGY

Air samples were drawn with the help of KIMOTO portable handy samplers which were operated simultaneously at different heights. Air samplers were drawn in borosilicate glass impingers containing a 1% buffered KI solution with pH 7.0 (Byers & Saltzman, 1959), through a teflon tube mounted with a Whatman filter paper no: 1 to remove particulate matter. Air samples were drawn at a rate of 2 l/min for 1 hour each. Air samples were taken hourly from 11 AM, and care was taken to shield the impingers from direct sunlight. Ozone values are expressed in $\mu\text{g m}^{-3}$.

4. RESULTS AND DISCUSSION

Significantly high ozone levels were observed in the urban environment of New Delhi (Aggarwal, 1993). The ozone level at ground level at various sites in New Delhi fluctuated widely between $20 \mu\text{g m}^{-3}$ and $273 \mu\text{g m}^{-3}$. Ozone levels were maximum during the summer months (mean $79 \mu\text{g m}^{-3}$) and minimum during the winter (mean $53 \mu\text{g m}^{-3}$). The maximum concentration of $273 \mu\text{g m}^{-3}$ was observed during August 1990. During the day, ozone maxima were invariably reached during noon-hour (12-1 PM IST) at all sites. Subsequently, in the late afternoon the ozone levels started declining until late evening. Seasonal variations in ozone levels at all heights were significant. The monthly average from March to July ranged from $81.34-76.44 \mu\text{g m}^{-3}$, while lower were recorded from $58.8-54.88$ between Sept. to Jan. The maximum ozone concentrations were observed during the month of June (Varshney & Aggarwal, 1992, 1993).

Ozone exhibited a significant vertical variation at all sites, and the concentration increased with increasing heights. A comparison of ground level ozone at different sites revealed that ozone was maximum at Vikas Minar and minimum at JNU with the difference in concentration varying between 5.7 and 29%. Ozone levels at the TV tower were high in comparison to those at JNU. The difference ranged from 3.1-17.2%. However, the ozone levels at Vikas Minar and the TV tower were almost the same. Between the JNU and Kutub Minar sites, there was not much difference (3.83-11.07%). At JNU, on an average a 9.8% difference was observed in ozone concentration between ground level and the height of 51 m. The inter site differences observed in the ozone levels can be explained to be the results of the variation in the traffic densities at the four sites which fall in the following sequence:

Vikas Minar > TV Tower > Kutub Minar > JNU Library

The ozone levels also showed significant seasonal fluctuations in the vertical profile up to a height of 51 m at the JNU library site (Figure 2). Ozone concentration was highest in summer at all heights. The peak during the day appeared earlier in summers at all heights in comparison to winter and spring. At 51 m height in summers, the ozone concentration decreased rapidly during late evening (Figure 3). A similar trend was observed at 23 m and at ground level. The concentration of ozone in late evening remained almost the same at 23 m and at ground level irrespective of the season. At the height of 51 m, the ozone concentration in late evenings in summer was considerably less in contrast to the ozone level observed during the spring and winter indicating a rapid neutralization and scavenging of ozone. The vertical ozone stratification observed in New Delhi is not comparable to the measurements made elsewhere using air crafts, balloons and cable cars, on account of the inherent methodological bias and the entirely different altitudinal range from where air samples were drawn. All the vertical ozone profile studies, however, indicated a positive ozone trend.

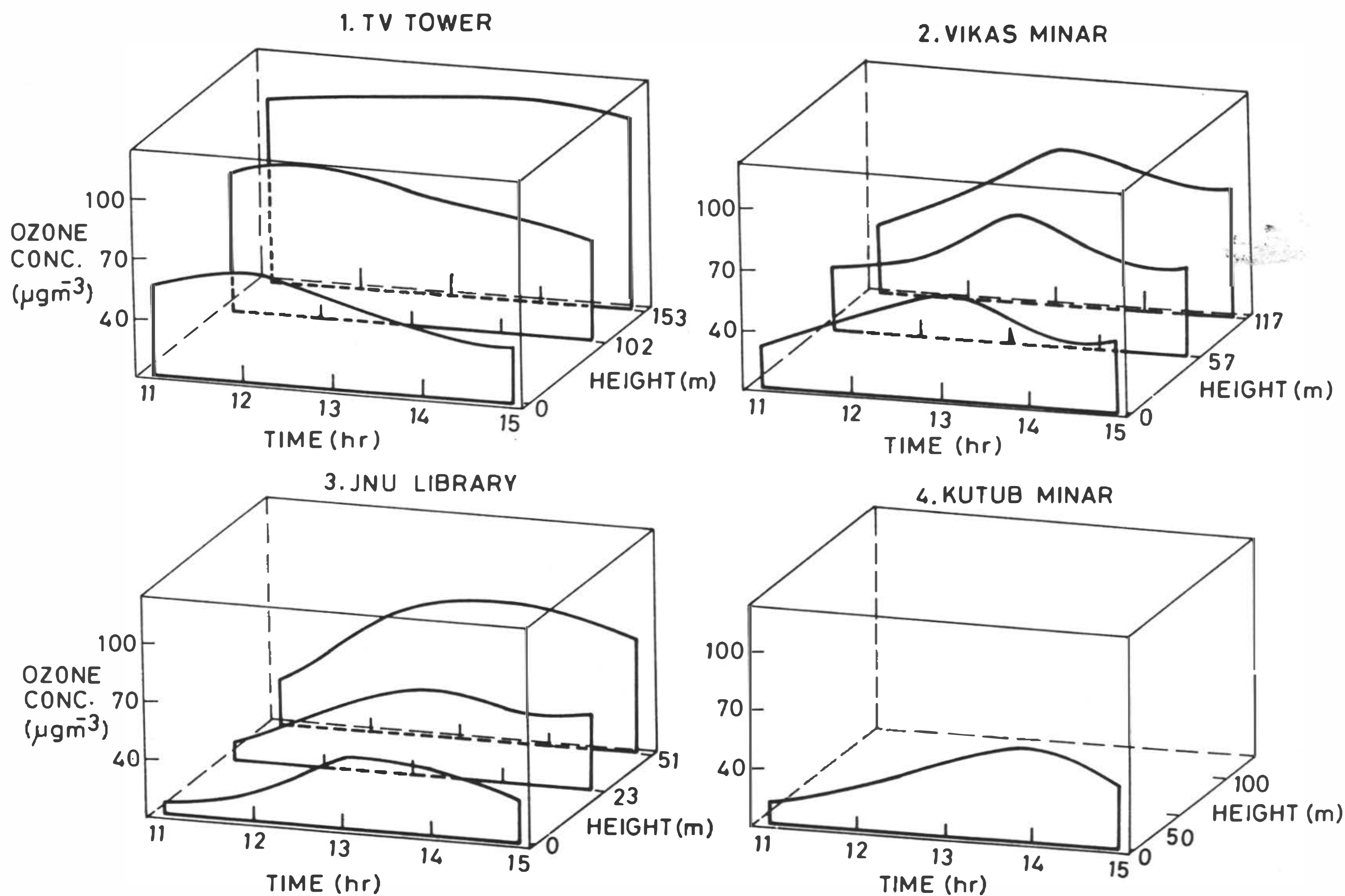


Fig. 2. Vertical ozone variation at 1. TV Tower, 2. Vikas Minar, 3. JNU and 4. Kutub Minar.

The ozone variation observed at various heights and in different seasons may be on account of the following reasons :

- (1) There exists a difference in relative rates of synthesis of the ozone at respective heights. Ozone concentration increases with increasing height from the ground showing a positive correlation with the incoming UV radiation required to initiate ozone synthesis.

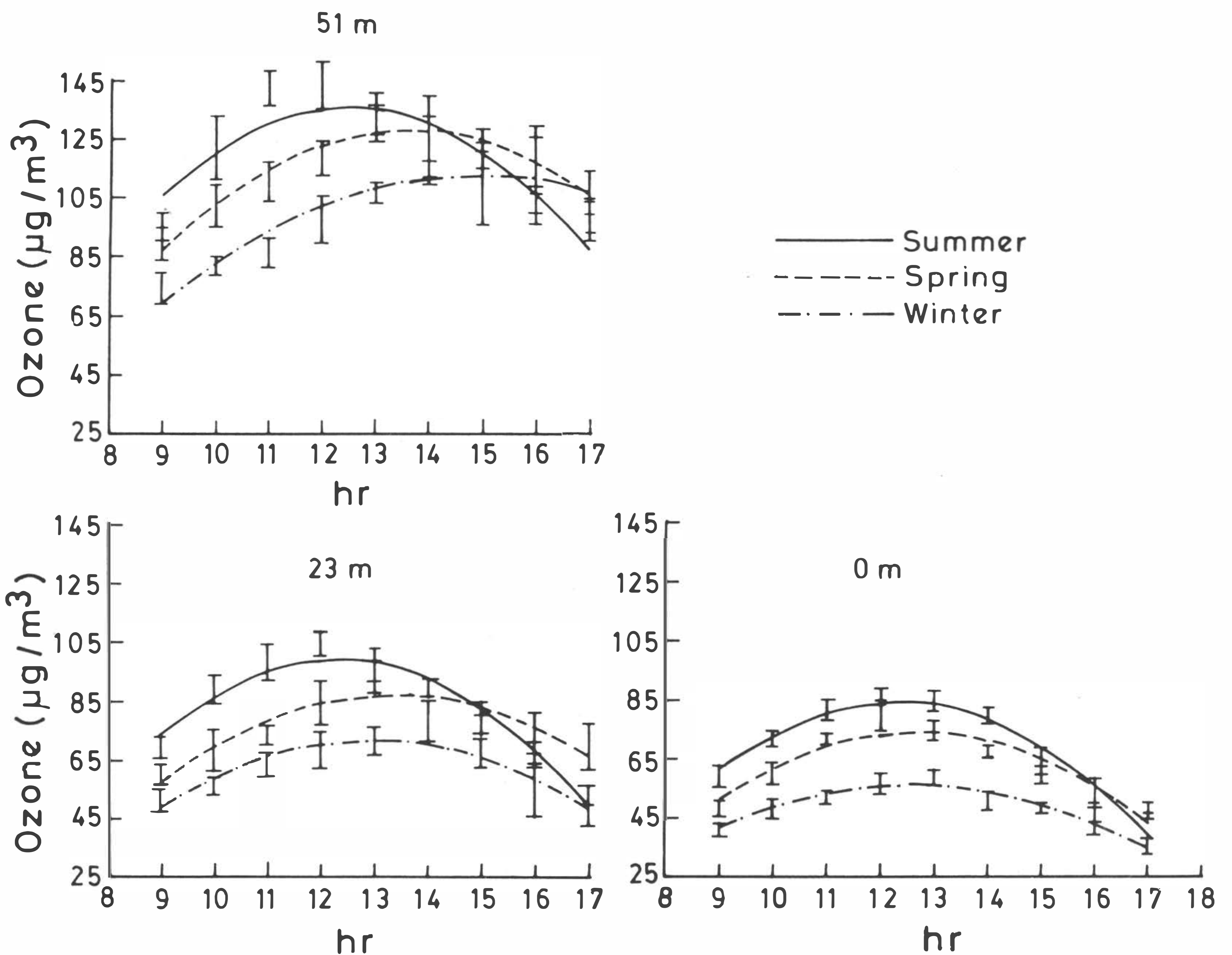
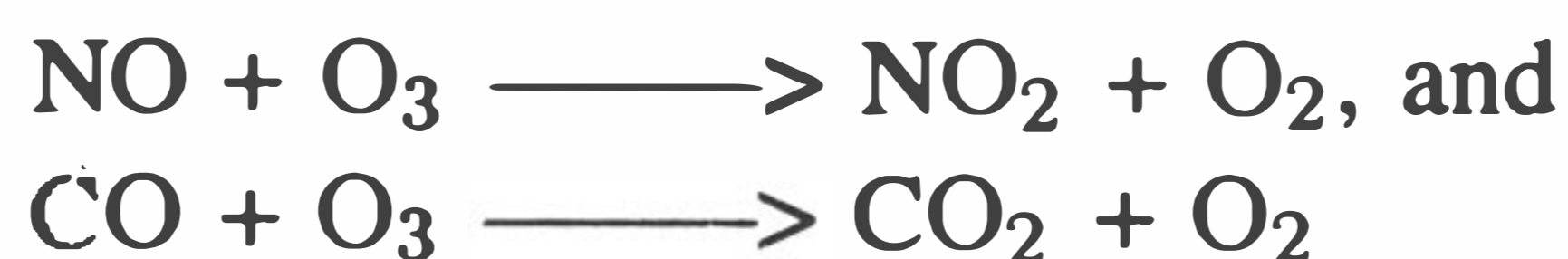


Fig. 3. Vertical stratification of ozone at JNU during summer, spring and winter.

The UV radiation progressively depletes as it passes through the air column on account of the particulate loading of the atmosphere (Bach, 1971). The suspended particulate loading of the atmosphere may be quite significant particularly in urban areas (Delhi: $140\text{-}540 \mu\text{g m}^{-3}$, GEMS, 1988). The UV radiation on account of its attenuation is lowest at ground level (Leeuw & Leyssisus, 1991). Along with attenuation, some amount of the UV radiation is likely to get utilized in atmospheric photochemical reactions while passing through the air column.

- (2) The difference in the rate of ozone neutralization and its scavenging by various ozone destroying substances (ODS) may significantly contribute to the vertical ozone stratification. Emission of NO_x and CO from automobile exhaust in the surface boundary layer are likely to scavenge ozone rapidly near the ground according to the following reactions :



- (3) Besides infusion of the ODS, ozone concentration may also be affected by micro-meteorological conditions which are vastly different at different heights particularly in an urban environment on account of the generation of local eddies caused by fast moving vehicles. Ozone destruction may be greater as a result of eddy mixing and the

accumulation of ozone destroying substances under temperature inversion near ground level. Miller and Ahrens (1970), however, are of the view that temperature inversion may not be responsible for the rapid ozone destruction at ground level. Vertical variation of ozone concentration in relation to the temperature profile was reported in France (Fontan *et al.*, 1992). The presence of soil, vegetation, building and other interactive objects may act as important neutralizing agents for tropospheric ozone, contributing to the vertical stratification in the troposphere (Mueller *et al.*, 1973; Levy *et al.*, 1985). The combined effect of the reduced synthesis of ozone and the increased ozone scavenging potential towards the ground contribute to the vertical stratification of ozone in the lower troposphere.

The vertical ozone stratification in the lower atmosphere may have serious implications on trees and vegetation, as has been widely reported from Europe and North America (Barnes & Davison, 1988; Kickert & Krupa, 1990; Spence *et al.*, 1990). Extensive damage to the canopies of avenue trees growing along dense traffic corridors in New Delhi has been observed by Varshney (1990). Occurrence of relatively high ozone concentration at canopy height may be directly responsible for the damage of the canopies of avenue trees in urban areas or may predispose avenue trees and other urban vegetation to additional environmental stresses.

In view of the growing impetus of urbanization and industrialization, the intensity and magnitude of ozone pollution is likely to intensify, and it is important to ascertain the vertical profile of ozone to evaluate the risk from tropospheric ozone pollution for trees and for the residents of high rise buildings in urban environments. Information of ozone level at tree height is an important consideration in formulating air quality standards. The measurements of ozone profiles in urban areas is important since metropolitan cities are plagued with the growth of high rise residential complexes. For urban and forested areas, it is important to specify the characteristics of the air quality in terms of pollutant concentration at different heights from the ground, at least up to the height of the tallest building or up to tree canopies for a pragmatic assessment of the air quality status of urban and forested areas.

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