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Impact Of Aerosols On SUV,UV-A And Ozone-A Study Based On Ground Measurements And Satellite Data Over Hyderabad

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Abstract: *Solar ultra violet radiation reaching the earth's surface has been largely discussed owing to its biological and photochemical activity. Great emphasis has been placed on the surface reaching particularly ultra–violet–B (UV-B) radiation. The shorter wavelengths that comprise UV–B are the most dangerous portion of UV radiation at surface. Exposure to UV–B radiation has adverse effects on human and other organisms. The most important factors influencing the UV–B radiation reaching earth's surface are atmospheric ozone, sun elevation (SZA), atmospheric altitude, clouds, haze and ground reflection.*

Ozone acts as a regulator of UV–B due to strong absorption characteristics over the ultraviolet region. Examination of the record of solar ultraviolet measurements showed substantial reduction of UV–B radiation on days with high level of air pollution. Tropospheric aerosol is the most important UV–B attenuating factor up to 40%. Changes in atmospheric aerosol loading strongly affect radiative properties of aerosol & spectral characteristics of UV radiation reaching the earth's surface.

Autocorrelation between total columnar ozone and the surface UV radiation is a complex function of many variables, including solar zenith angle, surface elevation, cloud cover, aerosol loading, surface albedo and vertical profile of ozone.Ground based measurements play an important role in improving the understanding of some of these effects.

In the present study ground reaching UV and its relationship with ozone and aerosols over a tropical urban city, Hyderabad, India during 2004 to 2006 were analysed.

Methodology*: Aerosol Optical depth (AOD) was measured at wavelengths 380, 440, 500, 675, 870 and 1020nm using MICROTOPS-II sunphotometer. During 2004 – 2006, a total of above 800 independent measurements of aerosol optical depth and UV measurements have been carried out. Total columnar ozone has been measured using MICROTOPS – Global distribution of the UV intensity was evaluated with archived data of the Earth Probe (EP)/Total Ozone Mapping Spectrometer (TOMS). II ozonometer. UV radiometer from Solar Light Co has been used to measure SUV in 280 – 315 nm.*

Keywords: *Ozone, Aerosol optical depth, SUV, UVA,TOMS satellite data*

I. Introduction

Solar ultra violet radiation reaching the earth's surface has been largely discussed owing to its biological and photochemical activity. The UV radiation is often sub-divided into three bands UV-C (100 – 280 nm) UV-B radiation (280-315 nm) and UV-A radiation (315-400 nm). UV radiation can be measured as irradiance – the power incident upon a surface unit area – in units of w/m^2 or as a radiant exposure or dose energy incident upon a unit surface area in a period of time (J/m2).

The UV–B region comprises only 1.25% of the total extra terrestrial irradiance and 0.5% of surface irradiance, which is small energetically, but its significant biological activity magnified its importance in the biosphere. Ozone acts as a regulator of UV–B due to strong absorption characteristics over the ultraviolet region. The majority of ozone absorption occurs in stratospheric ozone layer. Emissions from biomass burning and anthropogenic activities increase the concentration of aerosol particles in the atmosphere and surface ozone. The intensity of UV radiation received at ground is largely determined by the atmospheric aerosols. Examination of the record of solar ultraviolet measurements showed substantial reduction of UV–B radiation on days with high level of air pollution, which are associated with high concentration of particulate matter. Tropospheric aerosol is the most important UV–B attenuating factor up to 40%. The diffusion of UV – B irradiance increases with the increasing solar zenith angle and turbidity. Absorption and scattering characteristics are influenced by the variability of tropospheric pollutants and these characteristics are associated with the chemical composition of the aerosols.

The importance of influence of aerosols on surface UV radiation was introduced by Liu etal., (1991). Several investigations show that UV–B transmission through the atmosphere as well as the surface UV irradiance are negatively correlated with aerosol optical depth (Wenny et al., 1998). Based on long term sequences of aerosol optical depth (AOD), Krzyscin and Puchalski (1998) found that a 10% increase in AOD

manifests itself in about a 1.5% decrease in daily erythemal UV dose and extreme values of AOD were associated with changes in erythemal UV doses of 20-30% Krotkov etal., (1998) found that over certain parts of the earth with a high loading of absorbing particles the aerosols could reduce the UV flux at the surface by more than 50% . Kylling et al., (1998) estimated that changes in aerosol loading could give larger variations in the surface UV radiation than changes in the ozone column.

Reuder and Schwander (1999) concluded that potential day-to-day variability in atmospheric aerosols could produce changes in the spectral integrated UV radiation quantities up to 20-45%. Their calculations demonstrated that UV–B radiation changes due to typical variability could be equivalent to ozone amount variations in the range of 40-80 Du.

The global scale daily erythemal UV radiation data at the earth's surface are available from the Total Ozone Mapping Spectrometer (TOMS) employed by the NASA, Goddard Space Flight Centre. Ground based measurements show that sun measured UV irradiances in the Southern Hemisphere exceed those at comparable latitudes in Northern Hemisphere by up to 40% where as the corresponding satellite based estimation show only 10-15% differences (Madronich etal., 1998). As the short-term variation in aerosols is the source of uncertainties for deriving surface UV radiation from satellite data, the simultaneous measurement of aerosol and UV radiation are of great importance. Changes in atmospheric aerosol loading strongly affect radiative properties of aerosol & spectral characteristics of UV radiation reaching the earth' s surface.

Ozone levels directly influence the amount of UV radiation reaching the surface of the earth. Surface UV radiation levels are also strongly affected by clouds, aerosols, altitude, solar zenith angle, and surface albedo. These different factors contribute to high variability in UV radiation levels and make it difficult to identify the changes that result from ozone depletion. Ozone in the atmosphere prevents most harmful UV. 0.95% of the atmospheric ozone is found in the stratosphere, the remaining 5 to 10% is in the troposphere. Most of the stratospheric ozone is produced by photochemical reactions in equatorial regions. At high latitudes, there is less photochemical ozone production and much of the stratospheric ozone is imported from low latitudes by the Brewer-Dobson circulation.The atmospheric circulation varies seasonally and oscillations in the circulation patterns explain some of the natural spatial, seasonal, and annual variations in the global total ozone distribution. Solar activity also causes small fluctuations in total columnar ozone in phase with the solar cycle. In addition to natural ozone production and destruction processes (WMO, 1995, 1999, 2003), stratospheric ozone is destroyed by heterogeneous chemical reactions involving halogens, particularly chlorine and bromine, which are derived from chlorofluorocarbons (CFCs) and other ozone-depleting substances. In the presence of solar radiation, extremely low stratospheric temperatures facilitate ozone depletion chemistry differ. Low temperatures within the stable Antarctic vortex and the presence of ozone-depleting gases have led to an area of large-scale ozone depletion, the "ozone hole", which has been observed every spring since the 1980s. Ozone depletion can increase the level of UV radiation reaching the surface. These increased UV doses, particularly when combined with other environmental stressors are very likely to cause significant changes to the region's ecosystems.

Autocorrelation between total columnar ozone and the surface UV radiation is a complex function of many variables, including solar zenith angle, surface elevation, cloud cover, aerosol loading, surface albedo and vertical profile of ozone. Recent studies (Kylling. A. Bais et al., 1998) reported that high loading of absorbing particles could cause reduction of UV flux at surface by more than 50%. Ground based measurements play an important role in improving the understanding of some of these effects.In the present study ground reaching UVery and its relationship with ozone and aerosols over a tropical urban city, Hyderabad, India during 2004 to 2006 were analysed.

II. Methodology

Aerosol Optical depth (AOD) was measured at wavelengths 380, 440, 500, 675, 870 and 1020nm using MICROTOPS-II sunphotometer having measurement accuracy of ±2%. The detector consists of a silicon photodiode mounted behind a set of continuous variable interference filters. The field of view of the instrument is 1.8°.The AOD,$\tau_A(\lambda)$, was retrieved from the measuring data by accounting for Rayleigh scattering,$\tau_R(\lambda)$,and the contribution of gas absorbers is as follows:

$\tau_A(\lambda) = \tau(\lambda) - \tau_R(\lambda) - \tau_{O3}(\lambda) - \tau_{H2O}(\lambda)$

where $\tau_{O3}(\lambda)$ is the ozone optical depth and $\tau_{H2O}(\lambda)$ is the water vapour optical depth. The Rayleigh scattering has been calculated by the formula $\tau_R(\lambda) = (P/P_o)$ x0.008735 x $\lambda^{-4.08}$. In this formula P is the actual air pressure in hPa and P_o = 1013.25 hPa. During 2004 – 2006, a total of above 800 independent measurements of aerosol optical depth and UV_{ery} measurements have been carried out. Total columnar ozone has been measured using MICROTOPS – II ozonometer. UV radiometer from Solar Light Co has been used to measure SUV in 280 – 315 nm. The cosine response of the instrument is ± 5% with a resolution of 0.01 minimum erythemal dose per hour (MED/hr). The MED/hr is a measure of sunburning effect of solar radiation.

Global distribution of the UV intensity was evaluated with archived data of the Earth Probe (EP)/Total Ozone Mapping Spectrometer (TOMS). TOMS instrument is the second-generation backscatter ultraviolet ozone sounder. TOMS measures the total column density of ozone under all daytime observing and geophysical conditions by observing both incoming solar energy and backscattered UV radiation at six wavelengths. Backscattered radiation is solar radiation that has penetrated to the Earth's lower atmosphere and is then scattered by air molecules and clouds back through the stratosphere to the satellite sensors. Along that path, a fraction of the UV is absorbed by ozone. By comparing the amount of backscattered radiation to observations of incoming solar energy at identical wavelengths, one can calculate the Earth's albedo. Changes in albedo at the selected wavelengths can be used to derive the amount of ozone above the surface. TOMS makes 35 measurements every 8 seconds, each covering 50–200km wide on the ground, strung along a line perpendicular to the motion of the satellite. Due to the nature of the platform's orbits, the high northern latitudes were not completely covered during the Antarctic ozone hole season. Almost 200,000 daily measurements covered every single spot on the Earth except areas near poles, where the Sun remains close to or below the horizon during the entire 24 hr period. Near-real time total column ozone abundances were provided at a $1^{\circ} \times 1.25°$ latitude/longitude resolution. Due to the resolution discrepancy between the gridded elevation and ozone datasets, every fifth $1° \times 1°$ grid cell centroid fell on the boundary of two ozone grid cells. In this case the column ozone amount for that cell was taken as the simple average of the two adjoining cells. Effects of topography on the amount of radiation reaching the surface can be significant. Higher altitude regions will receive more direct beam radiation than lower altitude regions since the number of scattering events decrease with the density of the atmosphere, resulting in less radiation being scattered back to space. Rand's global elevation and depth dataset obtained from the National Center for Atmospheric Research (NCAR) Data Support Section was used to scale surface-level UV dose calculations at each grid cell. A nominal scaling factor of 6% increase per kilometer change in altitude was employed to estimate exposure levels for areas above sea level.

III. Results and Discussion

3.1. Diurnal and seasonal variation of AOD, SUV, UVA:

Aerosol optical depth (AOD) at 500nm was measured using sunphotometer on each experimental day. The diurnal and seasonal variations of AOD, SUV, and UVA on all the days during the period 2001 to 2005, and from January to May during 2006 were shown in Fig.3.1a, 3.1b, 3.1c. Since data points are limited during monsoon season there is a gap in the graph while depicting spatially in Fig.3.1. The winter season of December-February shows slightly increased AOD values compared to monsoon season of June-October in all the years. This indicates slow addition of aerosols into the atmosphere after wet removal processes during monsoon season. Maximum AOD during summer season(March-May) is due to experiences of high aerosol loading with abundance of coarse-mode particles of soil-dust origin due to the occurrence of dust storm, strong convection and wind blown dust. The minimum AOD values observed during monsoon season suggests decrease in tropospheric aerosol loading due to wet removal processes like washout and cloud scavenging. The observed minimum AODs during post monsoon could be due to weak production and strong wet removal processes that remove most of the aerosols from the atmosphere. High AOD during winter period has been attributed to lower wind speed and relative humidity, which offers the best condition for gas to particle conversion processes. Seasonal patterns of AOD during 2001-2006 remained same and are in agreement with other studies over Indian region (Devara P C S, Pandithurai et al., 1996) and (Niranjan etal.,1995).

Daily SUV and UVA variation during 2001-2006 at the study site is shown in Fig.3.1. The seasonal variation of SUV and UVA at noon time shows relatively low values during December and January (around (SUV= 1MED/hr and UVA =2MED/hr) except for the year 2003. The values are high compared to other years (SUV=2.6MED/hr, UVA=3.8MED/hr). The values reached maximum during summer period March to May (>3MED/hr).. Comparison of day to day variation of AOD, SUV and UVA in Fig.3.1.suggests that different levels of aerosol loading in the boundary layer results in significant modulation of solar UV radiation reaching the ground, especially during the days of high aerosol loading. The aerosol loading is observed to be high during 2002, and low SUV observed during 2002 also supports the impact of aerosols on the reduction of ground reaching SUV, especially during summer season. The observations in the present study are in confirmity with other studies reported in literature (Kylling et al., 1998) and (Krzyscin J W et al., 1998). The SUV varies markedly through the year and is more intense during summer season. Seasonal and diurnal cycles of solar radiation are responsible for observed variations in the SUV intensities.

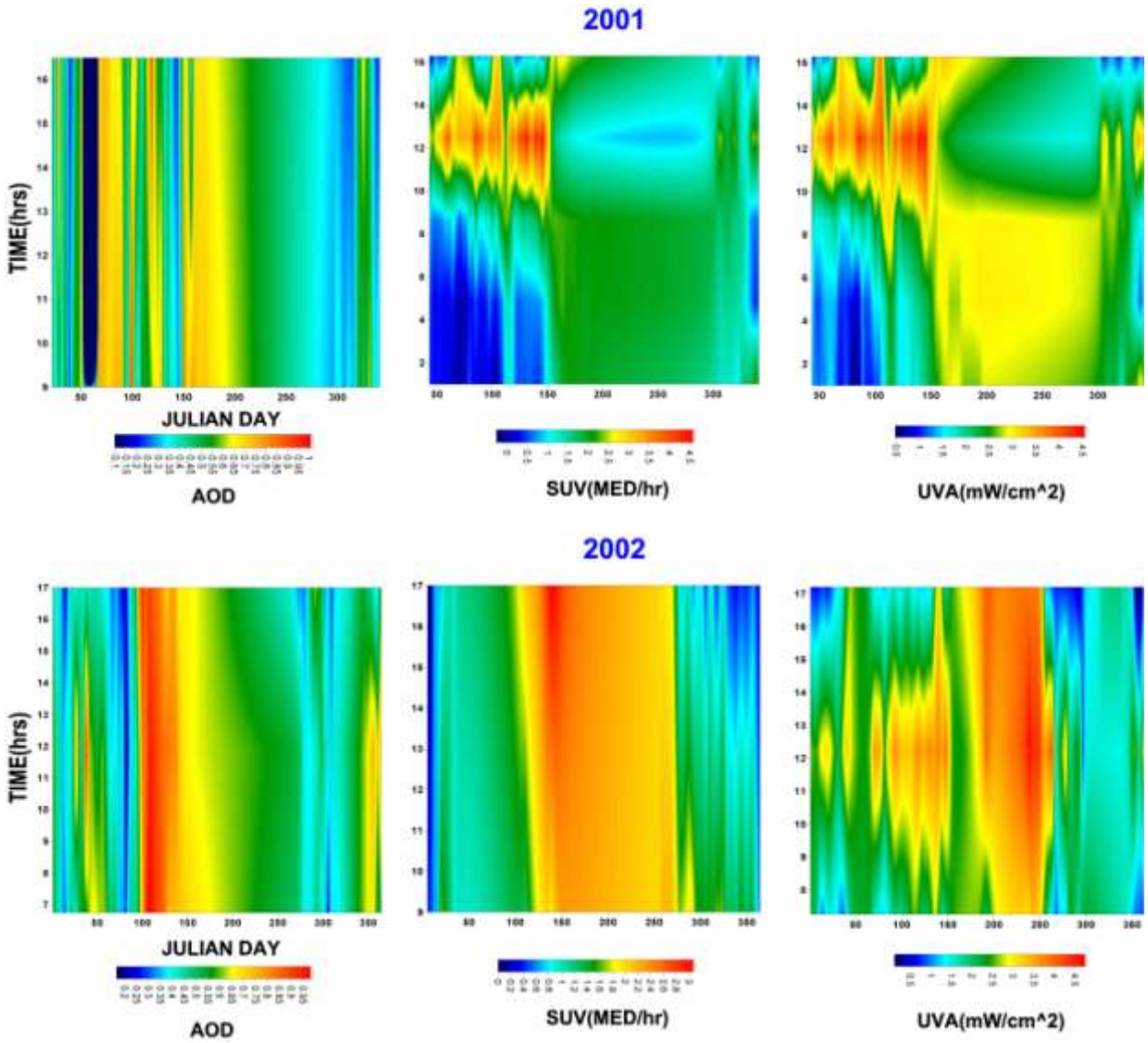


Fig.3.1a. Day to day variation of AOD, SUV, UVA during 2001 & 2002

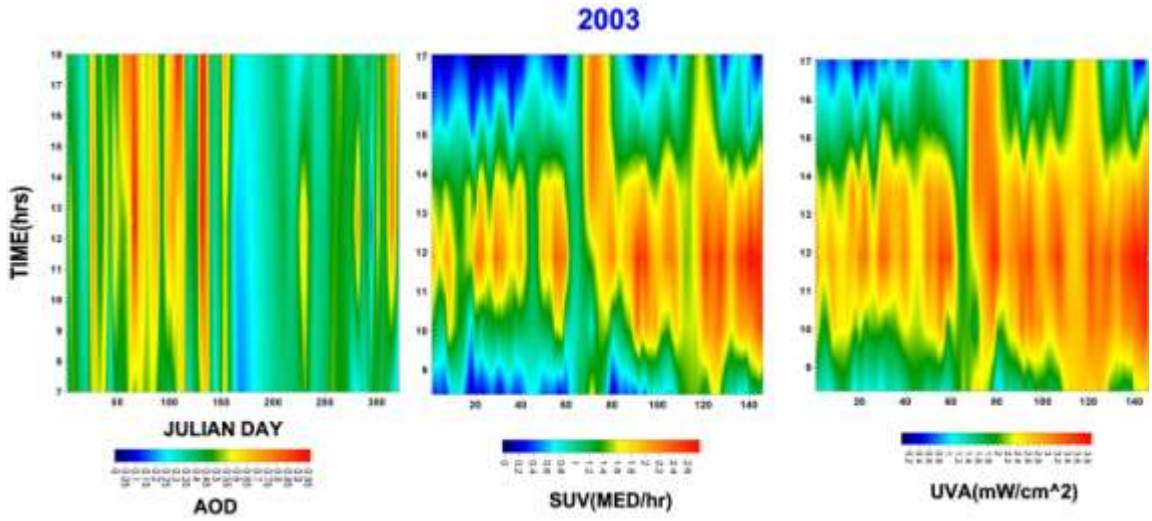


Fig.3.1b. Day to day variation of AOD, SUV, UVA during 2003 & 2004

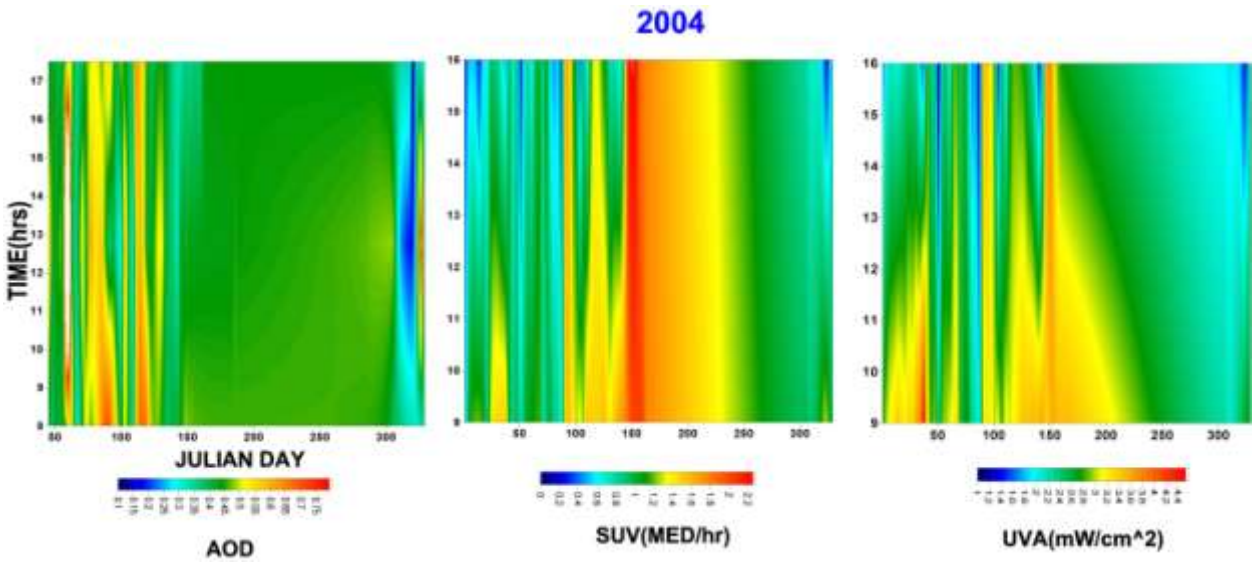
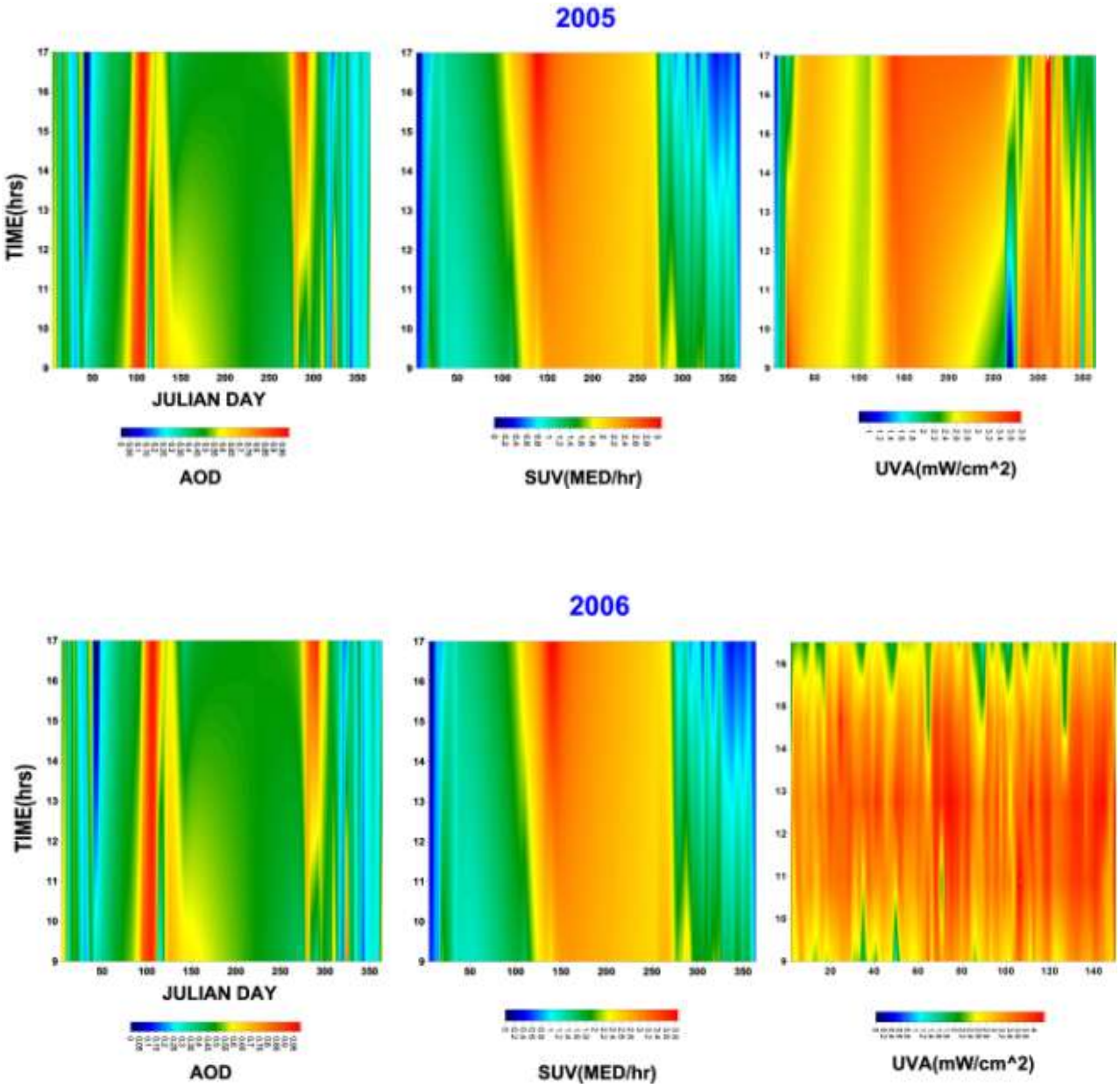


Fig.3.1c. Day to day variation of AOD, SUV, UVA during 2005 & 2006



3.2 Variation of UV-B radiation on high pollution and low pollution days

In the present study an attempt has been made to study the impact of variations in aerosol loading on SUV intensities. Fig.3.2a,b shows the representative example of diurnal variation of AOD during relatively high pollution day (10 Apr. 2006) and low pollution day (09 Apr. 2006) days. The relative humidity on both the days is around 55%. During high pollution days, AOD at 500nm ranges from 0.63 to 0.88, whereas during low pollution days it ranges from 0.49 to 0.81. During low pollution days SUV ranges from 0.82 to 3.33 MED/hr, whereas during high pollution days SUV ranges from 0.62 to 2.78 MED/hr. The diurnal SUV variation throughout the course of the day shows Gaussian type of variation. However it is interesting to note that diurnal course of SUV curve is bell shaped during low aerosol loading day where as distortion in the shape of the curve has been observed during high aerosol loading. SUV is moderately stronger during afternoon hours. UV radiation is much more attenuated at high solar zenith angles in the early morning and late afternoon because of increased absorption by stratospheric ozone during its increased path length through the atmosphere. Radiation at the UV wavelengths is scattered much more than visiblewavelengths. This results in a drastic decrease in UV radiation reaching the surface. The slant path is minimum around the summer time, which leads to the largest UV exposure. Day to day variation of AOD and SUV during2004, 2005, and 2006suggested that

SUV has significantly reduced during the days having high aerosol loading [Fig.3.3(a-c)]. This observation is similar to other studies cited in the literature (Krzyscin and Puchalski., 1998; Kylling et al., 1998). UV radiation has historically been more intense during the summer because of its low columnar ozone and the closest earth-sun separation occurrence during the summer.

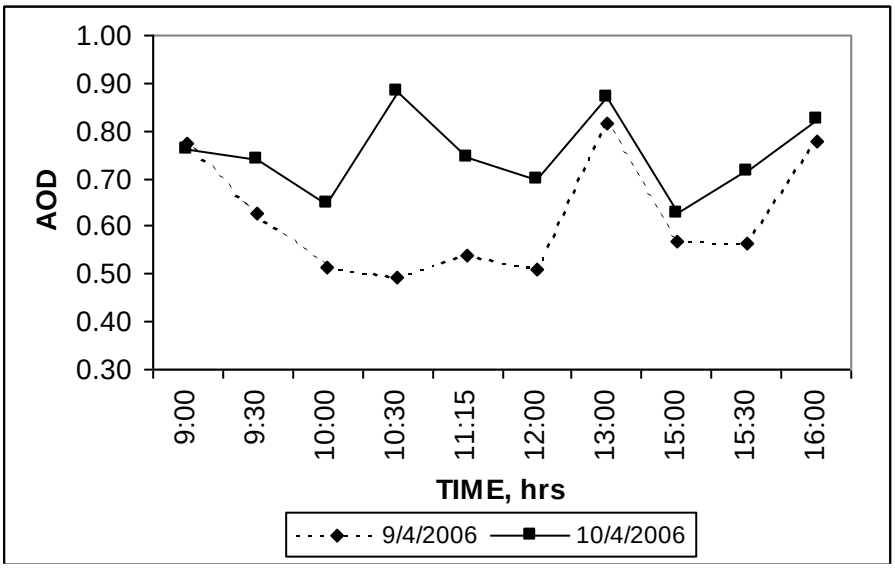
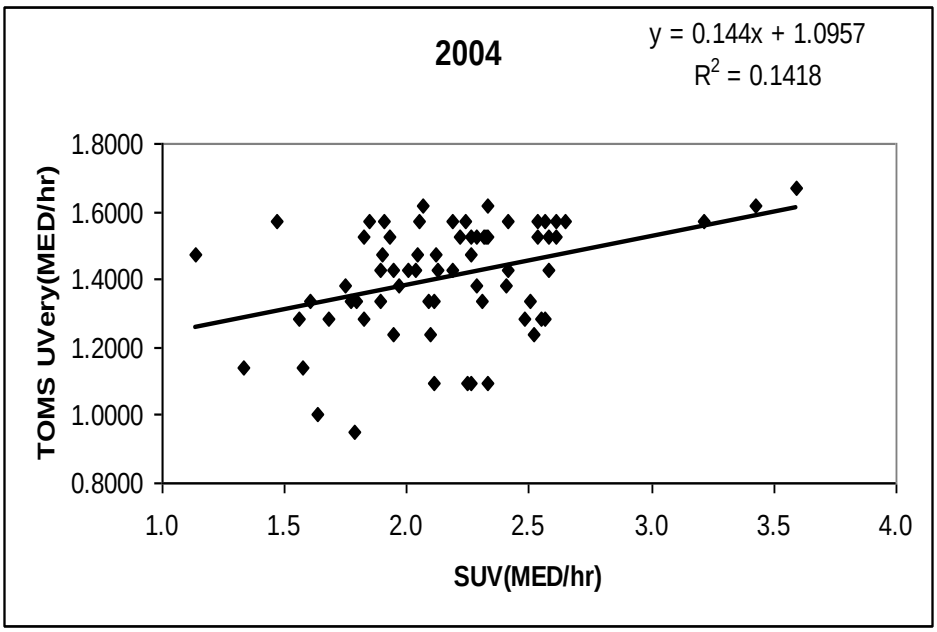


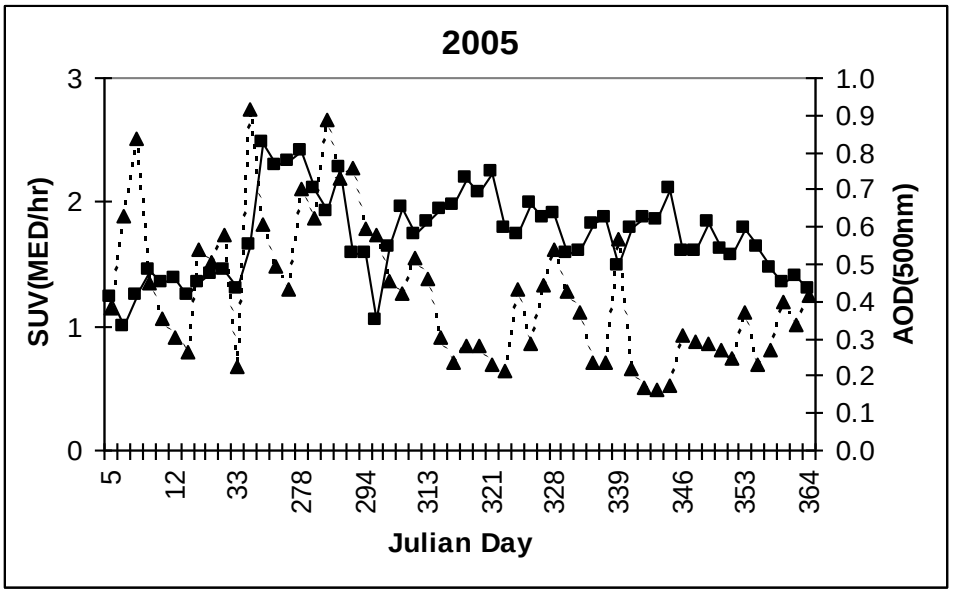
Fig.3.2.1Variation of AOD on 09 April, 2006 and 10 April, 2006

Fig.3.2.2.Variation of SUV on 09 April, 2006 and 10 April, 2006

(a)



(b)



(c)

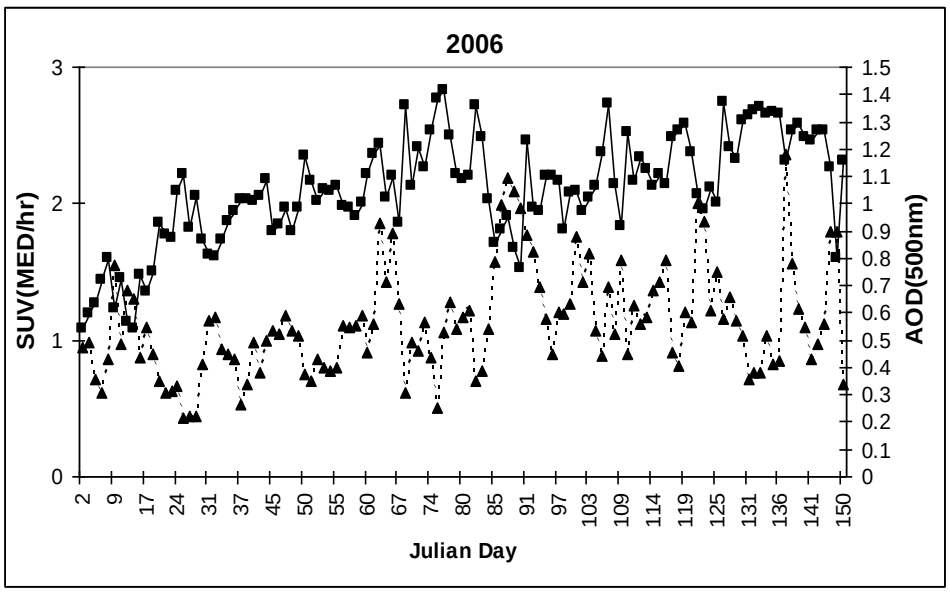
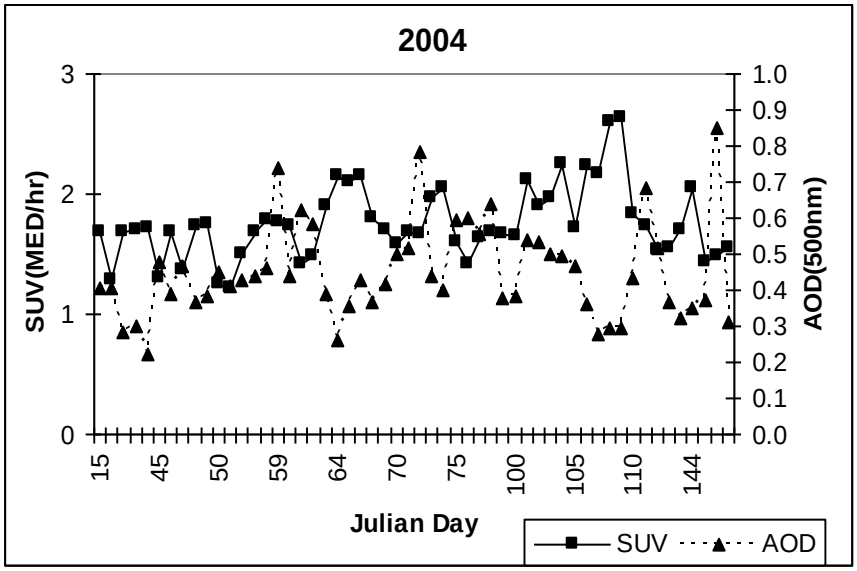
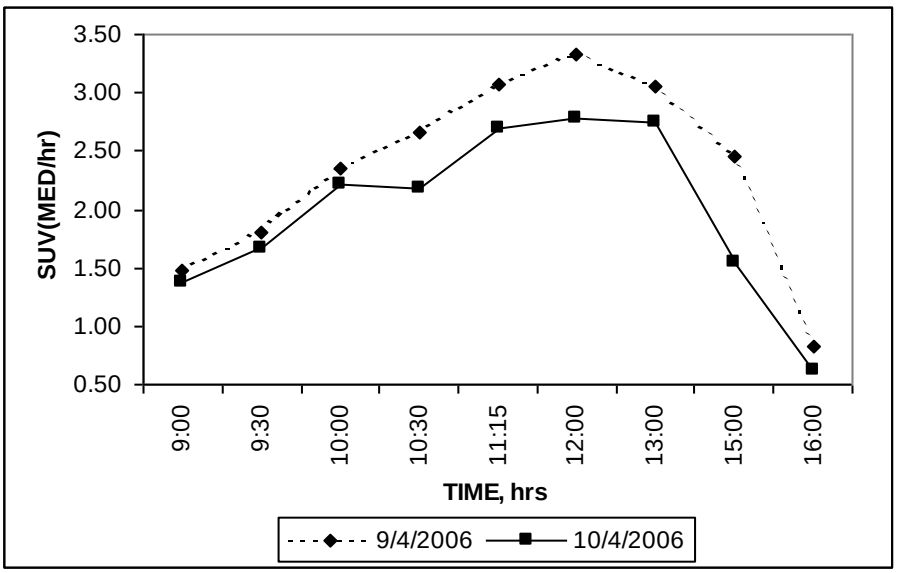


Fig 3.3(a-c). Day to day variations of SUV & AOD(500nm) during 2004, 2005 & 2006





3.4: Relationship between satellite and ground based measurements of SUV and TOMS UV_{ery}

For finding out the relationship between aerosol and the surface erythemal UV radiation. The measured surface erythemal UV irradiances for the years 2004 and 2005 were compared with TOMS UV erythemal radiation and scatter plots are shown in Figures 3.4a, 3.4b. Ground measured SUV showed a positive correlation with TOMS UV_{ery} during the period with the corresponding slopes of 0.144 and 0.0397with values of r^2 0.1418 and 0.4753 respectively.

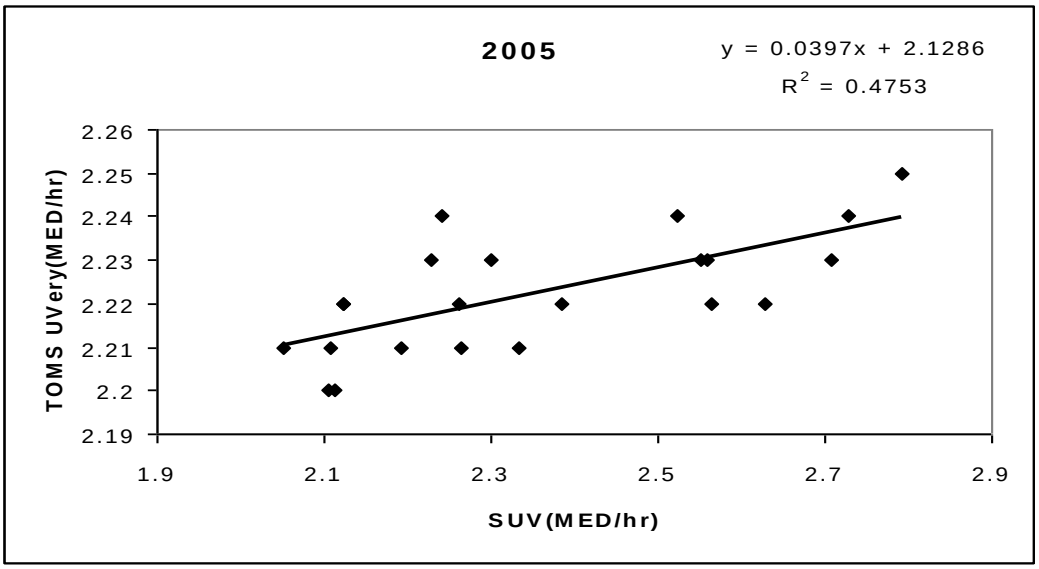
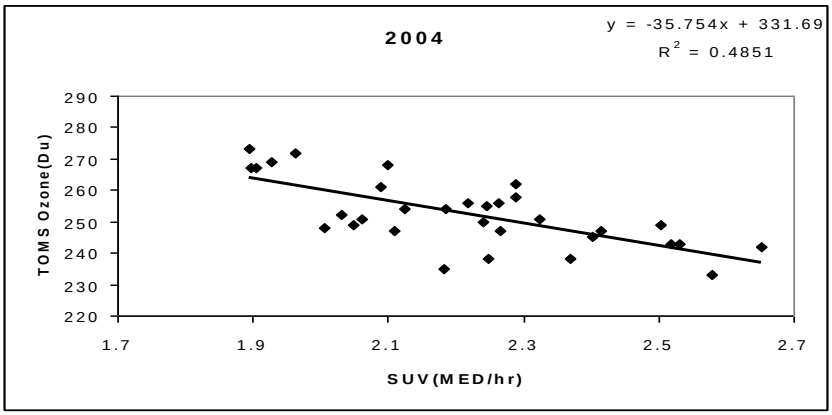


Fig 3.4(a, b) Scatter plots of SUV & TOMS UVery during 2004 & 2005

3.5:Impact of aerosols on total columnar ozone

SUV and AOD showed negative correlation with total columnar ozone.(Fig 3.5.1(a-c),Fig.3.5.2(a-c)). OMI measured ozone during 2005 suggested a clear gaussian pattern of minimum concentration during winter and maximum during summer . Good correlation was observed between sunphotometer measured columnar ozone and TOMS Ozone as shown in Fig.3.5.3(a-c) with (r^2=0.8222) during 2004. 2005 r^2=0.8856) and 2006 (r^2=0.7034) also a good correlation was observed between Sunphotometer measured ozone and OMI ozone &.. . Both satellite and ground based measurements suggest high atmospheric aerosol loading during summer season (March-May) and low during winter season (Dec-March). The presence of high aerosol loading during summer season has been considered as main reason for the observed low correlation between TOMS ozone and ground measured total columnar ozone. It has been inferred from the ground based measurements that AOD showed negative correlation (r^2=.2945) with OMI ozone during 2005.



(a)

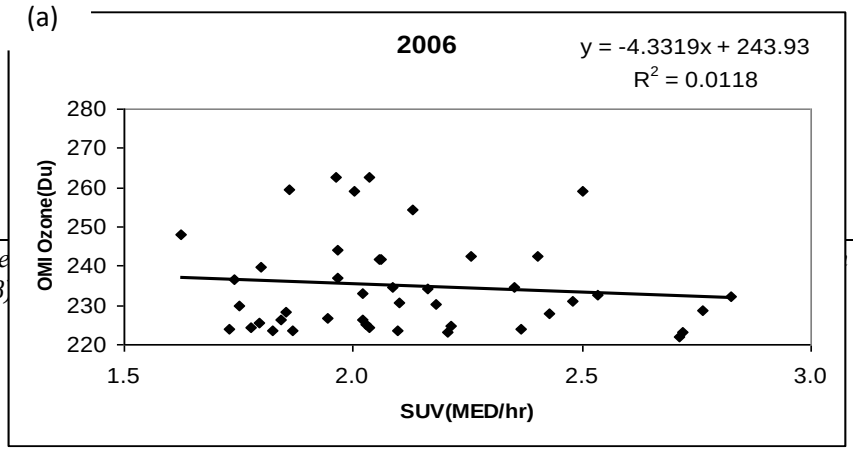


Fig.3.5.1 (a-c) Scatter plots of SUV & TOMS Ozone during 2004, 2005&2006

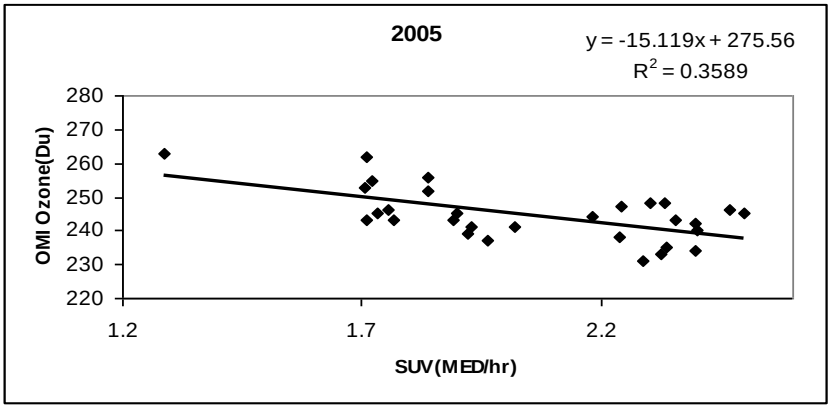
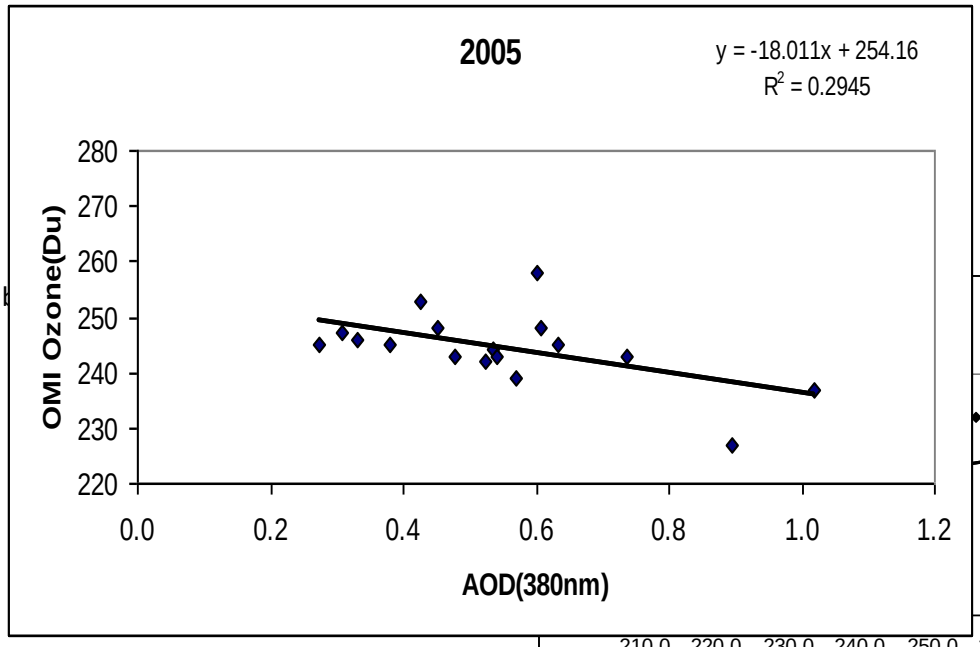
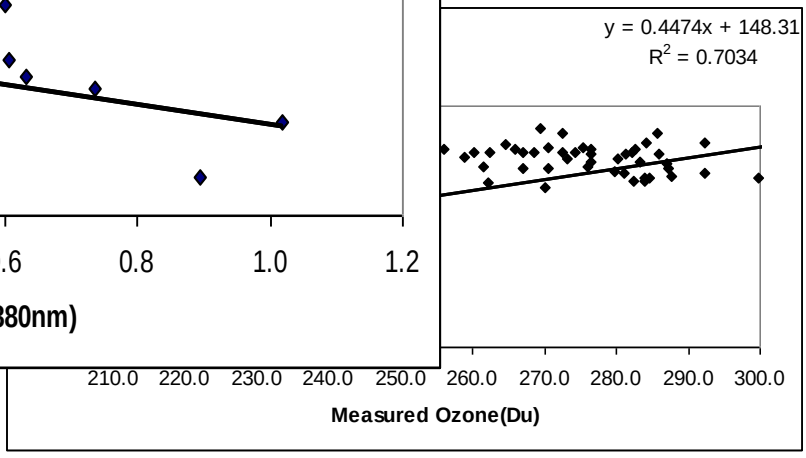


Fig.3.5.2 (a-c) Scatter plots of AOD& Ozone during 2004 , 2005&2006

(a)



(b)



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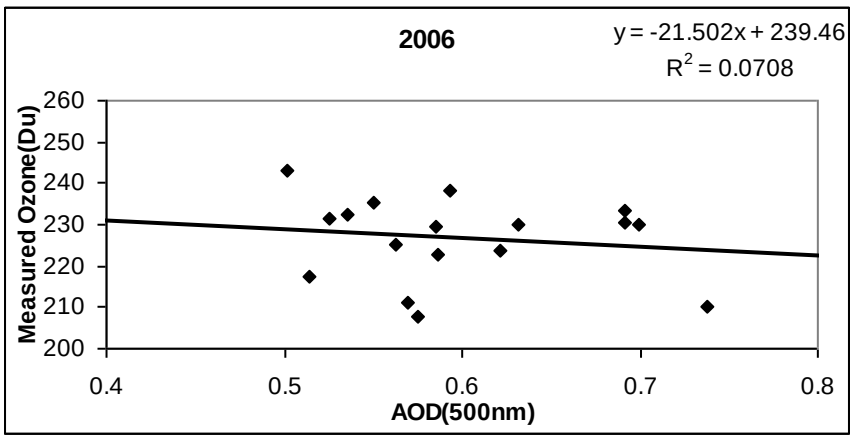
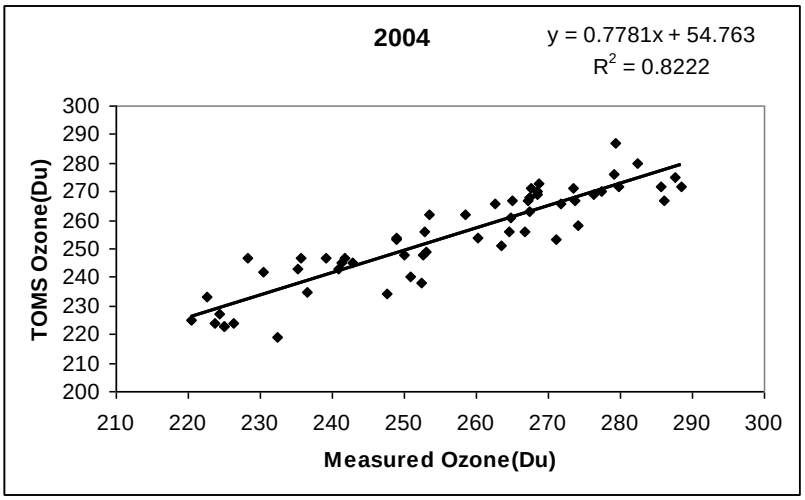
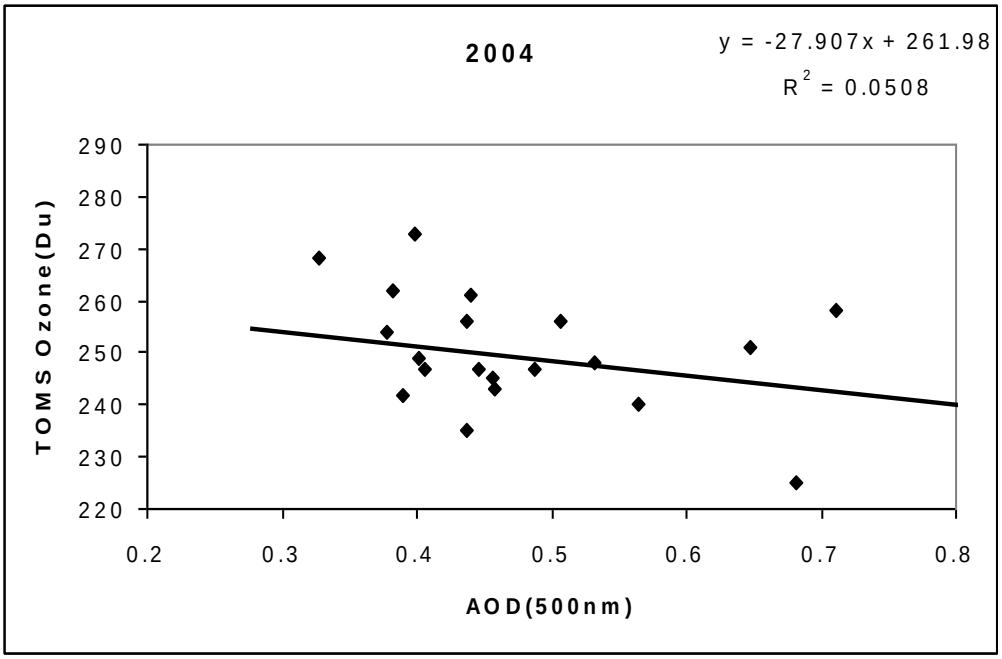
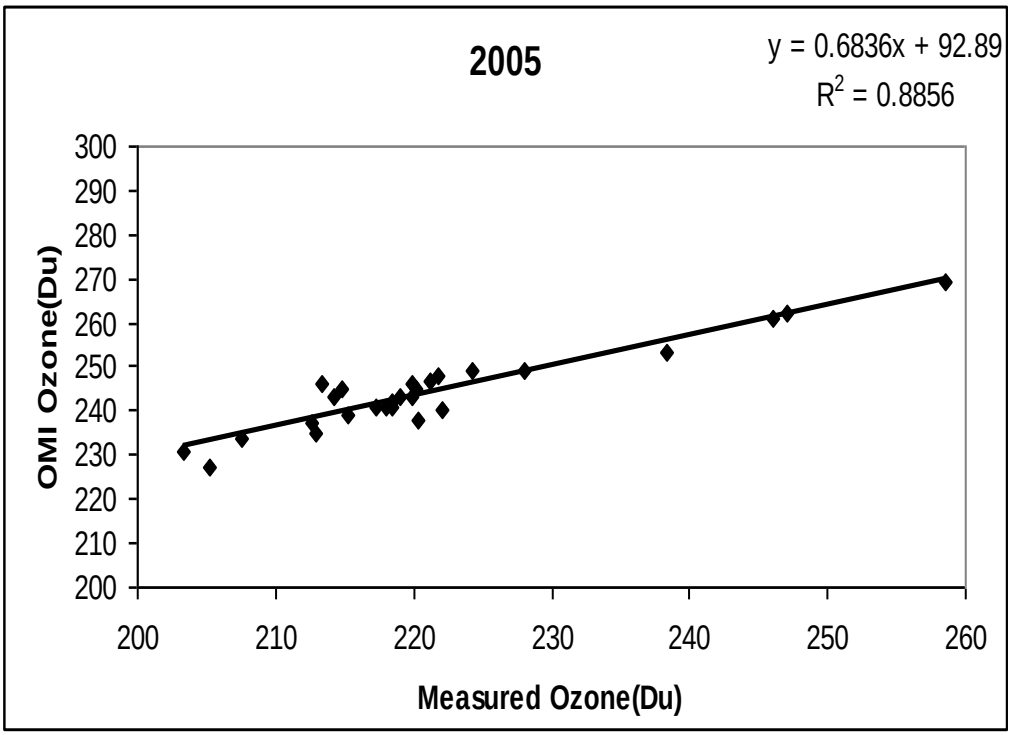


Fig5.3.3 (a-c) Scatter plots of ground measured Ozone &TOMS Ozone during 2004,2005&2006







3.6. Summary and Conclusions of the chapter

Results of the study suggest that tropospheric aerosol loading has significant impact on variations in the ground reaching UV_{ery} radiation in tropical urban environment at 500nm.The results of study suggest that SUV decreases at the rate of nearly 0.1 MED/hr per unit increase in aerosol optical depth.

The seasonal variation of SUV and UVA at noon time show relatively low values during December and January, around (SUV= 1MED/hr and UVA =2mW/cm^2) except for the year 2003. The values are high in 2003 compared to other years (SUV=2.6MED/hr, UVA=3.8 mW/cm^2). The values reached maximum during March and May (>3MED/hr). Comparison of day to day variation of AOD, SUV and UVA suggested that different levels of aerosol loading in the boundary layer results in significant modulation of solar UV radiation reaching the ground. The aerosol loading is observed to be high during 2002, where as low SUV observed during 2002 also supports the impact of aerosols on the reduction of ground reaching SUV, especially during summer season.

Ground measured SUV showed negative correlation with columnar ozone ground measurements. TOMS columnar ozone during 2005 and 2006 suggested a clear gaussian pattern of minimum concentration during winter and maximum during summer.

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