

Variation in Erythemal UV Dose for Indian Cities as Observed from Global Ozone Monitoring Experiment Data

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Abstract

Variation in Erythemal UV Dose (EUVD) for five Indian cities and their expected critical limits has been studied using the data obtained from Global Ozone Monitoring Experiment (GOME). The EUVD values are found to be higher and peak earlier at places located at lower latitudes than at higher latitudes. They are higher during summer / monsoon compared to winter. Seasonal variation in EUVD is more pronounced at higher latitudes compared to lower latitudes. EUVD variations show a negative correlation with solar activity and are observed to be well within the statistically calculated critical limits for these five Indian cities.

Introduction

Every living organism has limits to the amount of solar ultraviolet irradiance, which it can endure, and this amount must be within appropriate levels for life to persist. According to ecologist Shelford (1977), each environmental factor has both minimum and maximum limits called critical limits beyond which a particular species finds it difficult to survive (Eugene, 1983). The solar UV radiation is classified as UV-A (320 - 400 nm), UV-B (280 - 320 nm) and UV-C (200 - 280 nm), based on the wavelength of radiation. While UV-C radiation is completely absorbed by atmospheric ozone and other gases, most of the UV-A radiation reaches the earth's surface, which is, however, not harmful to biological life on earth. The UV-B radiation, which is partially absorbed by ozone and reaches the earth's surface, is harmful to plants and animals. Of the global UV radiation at the ground, 94% is UV-A and 6% is UV-B. Due to the higher energy levels of UV-B, even this small fraction of UV dose is responsible for inducing sunburn and tanning, influencing the immune system, being the main cause of snow blindness, is an important factor in the induction of cataracts, contributes significantly to the aging of the skin and eyes, and is effective in causing skin cancer. However, decrease in UV - B beyond a certain limit would result in reducing the formation of vitamin D in the skin, which is essential for life on earth (Glerup, 2000). The solar UV-B irradiance at any location depends on the solar zenith angle, column ozone content, column aerosol content, cloud cover and the altitude of the observation site (Green, 1974). Singh *et al.*, (2006), have studied the effect of atmospheric aerosols on Erythemal UV Dose (EUVD) at a polluted urban location Delhi and a relatively cleaner site Port Blair (Andaman Islands) during March 2002. The observations at both sites were taken under clear sky conditions and the column ozone values were almost similar. They have observed that UV-B radiation intensities were 65% less at Delhi than at Port Blair, thus indicating that UV-B radiation forcing is influenced by Aerosol Optical Depth (AOD). Extensive ground based and satellite measurements and model calculations have been done to analyze the UV irradiance, particularly in the UV-B and erythemal region both in India and abroad (Blumthaler, *et al.*, 1994; Zerefos, *et al.*, 1995; Herman, *et al.*, 1996; Bodhaine, *et al.*, 1997; Herman, *et al.*, 1999). In view of these considerations, the variation in EUVD for five Indian cities: Chennai (13.08 °N, 80.30 °E, 60 meters above sea level), Hyderabad (17.37

°N, 78.43 °E, 536 meters above sea level), Mumbai (18.93 °N, 72.85 °E, 10 meters above sea level), Ahmedabad (23.05 °N, 72.67 °E, 55 meters above sea level) and New Delhi (28.62 °N, 77.22 °E, 239 meters above sea level) have been discussed in this paper using the data obtained from Global Ozone Monitoring Experiment (GOME), for the period 1996 – 2001. The expected upper and lower critical limits (UCL and LCL) for EUVD have also been calculated statistically.

Data and analysis

GOME-based EUVD data for the period 1996 – 2001 have been developed by Ronald Van der A, Michiel van Weele and Jos van Geffen of TEMIS UV team and has been obtained from the website : www.temis.nl. Daily EUVD (kJ/m^2) has been estimated from the integration of erythemal UV index, as derived from satellite observations, from sunrise to sunset, with a time step of 10 minutes after taking the cloud cover information based on the International Satellite Cloud Climatology Project (ISCCP) database into account. The validation of the EUVD is, however, preliminary. The EUVD is computed at latitude/longitude grid with cells measuring 0.5 by 0.5 degrees, which amounts to about 50 x 50 km at the equator. The 'monthly climatology' is an average over all individual days of a given month for all available years. The 'monthly average' is an average over all individual days of the given month of the given year. Total cloud fraction for the period 1/1/2000 – 31/12/2000 has been obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS). MODIS is one of the first passive satellite radiometers designed to observe aerosols from an altitude of about 700 km. It measures reflected solar radiance and terrestrial emissions in 36 wavelength bands between 0.405 and 14.385 μm , with resolutions between 250 m to 1 km. It was launched aboard Terra satellite in late 1999. The Goddard Chemistry Aerosol Radiation and Transport (GOCART) model contains gridded monthly averaged data of total cloud fraction with a spatial resolution of $2.5^\circ \times 2.0^\circ$.

Results and discussions

Variation of EUVD with latitude and season:

The variations in EUVD for five Indian cities: Chennai, Hyderabad, Mumbai, Ahmedabad and New Delhi have been studied using the data obtained from GOME, for the period 1996 – 2001. The EUVD values are found to be higher for places located at lower latitudes than at higher latitudes for all months of the year (Fig. 1).

This is because when UV radiation passes through the atmosphere, it is partially absorbed by ozone and scattered by air molecules, aerosol particles and clouds. The total columnar ozone is minimum at the tropics where it is produced and increases at higher latitudes where it is transported. Apart from this, as the solar zenith angle is lower at the tropics and increases at higher latitudes, the UV – B radiation has to pass through a shorter path through the atmosphere in the tropics and is therefore less absorbed and scattered compared to higher latitudes, where it passes through a comparatively longer path through the atmosphere and is therefore absorbed and scattered to a greater extent.

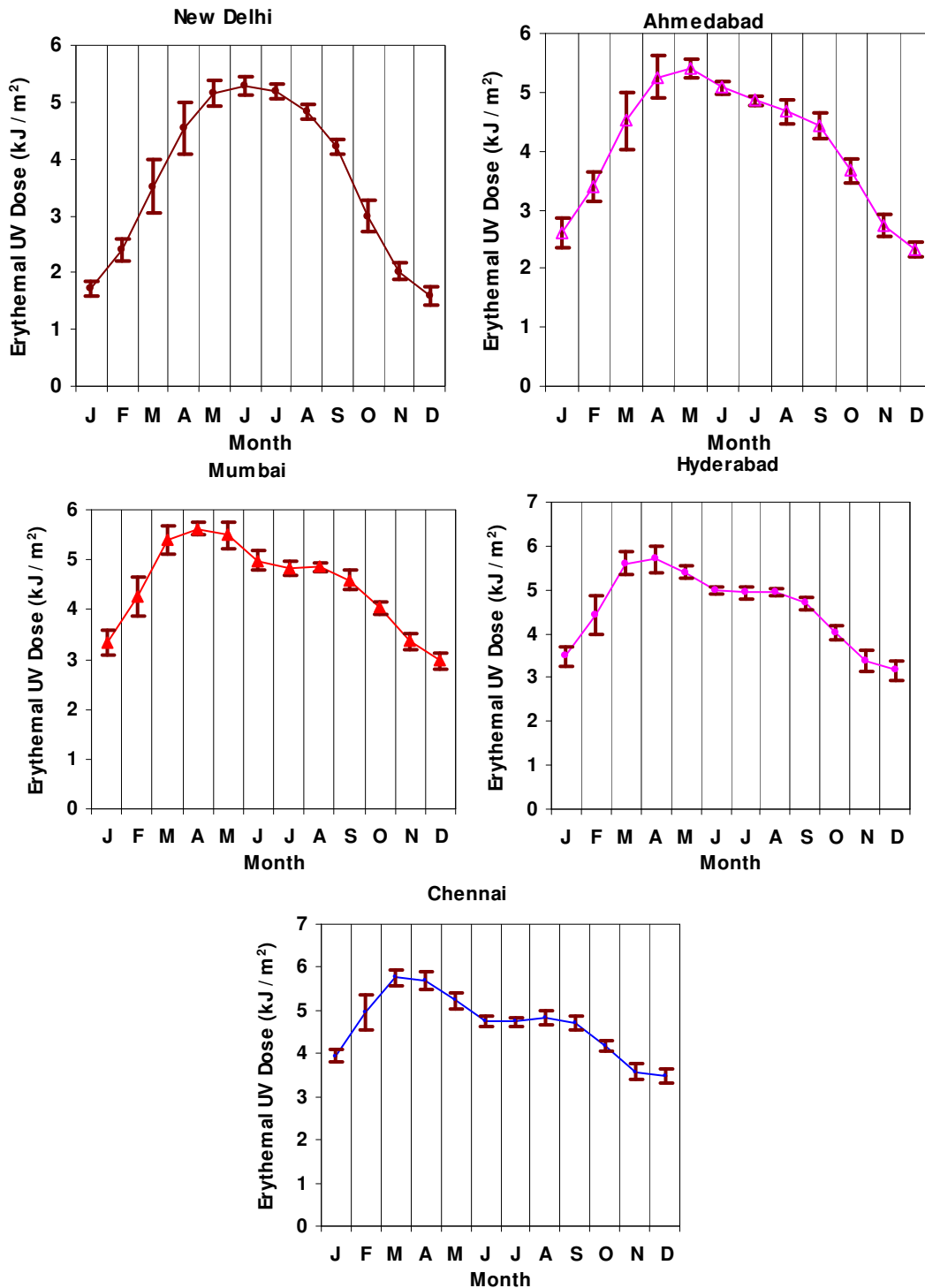


Fig.1: Monthly climatology for Erythemal UV Dose (EUVD) for different Indian cities (Source: <http://www.temis.nl/>)

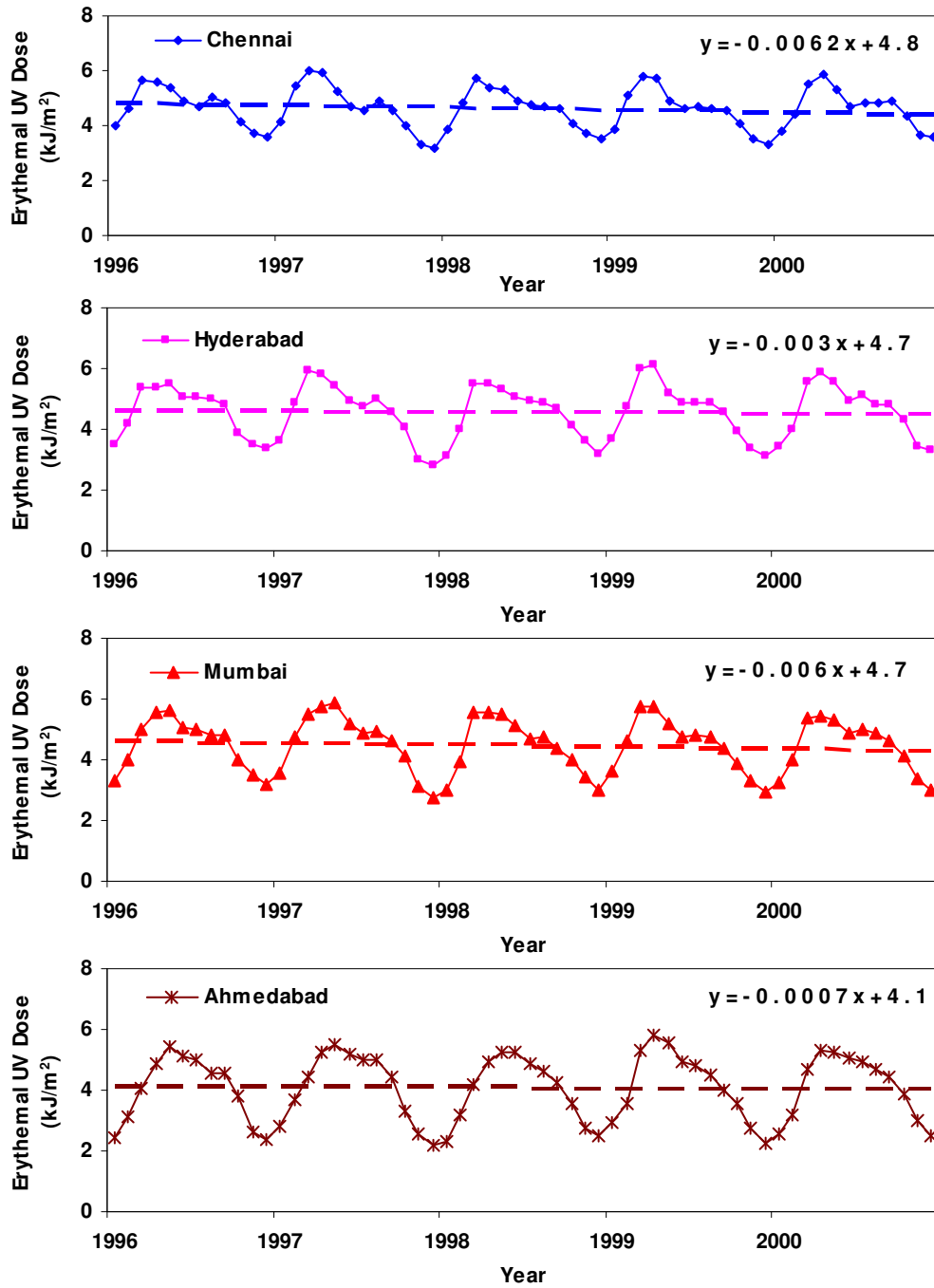
Although the EUVD at all the five Indian cities is minimum in December (winter), it increases to reach a maximum in March at Chennai, in April at Mumbai and Hyderabad, in May at Ahmedabad and in June at New Delhi after which it decreases (Fig.1). Thus, the EUVD

values are found to peak earlier at places located at lower latitudes than at higher latitudes. They are found to be higher during summer / monsoon months when the sun is directly overhead, compared to winter months when the sun is lower in the sky. Standard deviation for EUVD at Chennai, Hyderabad and Mumbai is maximum in February and at Ahmedabad and Delhi, it is maximum in March. Seasonal variation in EUVD are more pronounced at higher latitudes compared to lower latitudes, as observed from Fig.1 (Table-1). The difference between maximum (summer) and minimum (winter) values of EUVD is 3.7 kJ/m² at New Delhi, 3.07 kJ/m² at Ahmedabad, 2.65 kJ/m² at Mumbai, 2.53 kJ/m² at Hyderabad and 2.29 kJ/m² at Chennai. This is because the Solar Zenith Angle (SZA) at the lower latitudes is low and varies very little throughout the year resulting in high EUVD and lesser difference between summer and winter values compared to places at higher latitudes where the SZA is high and varies significantly from summer to winter.

Variation of EUVD with solar activity:

The output radiation of the sun varies over a range of timescales of which the largest variation is due to the 11-year solar cycle that can be estimated by the average number of sunspots. The variation in solar irradiance is dependent on wavelength, with greater variability at shorter wavelengths (Solanki, *et al.*, 1998). Models and data estimates from the Upper Atmosphere Research Satellite Solar Stellar Irradiance Comparison Experiment instrument shows that although the total solar irradiance varies by only about 0.1% over the 11-year solar cycle, the amplitude of variation is as high as 8.3% for wavelengths in the 200 nm range and 0.85% for wavelengths in the 300 nm range (Lean, J., 2000). As the solar output increases with increase in solar activity, EUVD is also expected to increase with increase in solar activity. However, it is observed that the monthly mean EUVD (except for Delhi) exhibits a decreasing trend (Fig. 2; Table- 1) with increase in solar activity from 1996 – 2000. The variation in EUVD for the declining phase of solar activity from 2001 to 2006 could not be studied, as the monthly mean EUVD data from GOME was not available for this period.

The small decreasing trend in EUVD with increasing solar activity may be attributed to an increase in population growth and rapid development at these urban cities, resulting in a gradual increase in pollutants and soot aerosols (Norris, 2001; Ramanathan *et al.*, 2005), which absorb and scatter a substantial amount of solar radiation. More over cloud cover has also increased over southern India in the recent years (Norris, 2001). Although the effect of clouds on UV radiation is difficult to quantify because of their rapid temporal variation, height, thickness and amount, a uniform cloud layer generally leads to a decrease in irradiance at the surface of the earth. However, local surface UV irradiance can be increased if clouds are not obstructing the disk of the sun and additional radiation is reflected from the side of a broken cloud field toward the ground (Nack and Green, 1974; Mims and Frederick, 1994). Basu (2001) has observed that cloud cover is less over the northern and central parts of India.



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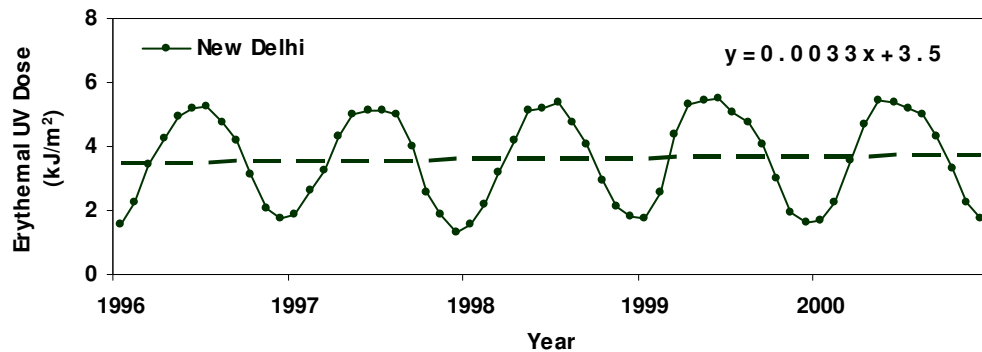


Fig. 2: Trend of monthly average Erythemal UV Dose (EUVD) for different Indian cities from 1996 - 2000 (source: <http://www.temis.nl/>)

Table- 1: Summary of Erythemal UV Dose (EUVD) and total cloud fraction observed at different Indian cities (sources: <http://www.temis.nl/> and MODIS GOCART model)

City (Latitude)	Average monthly maximum EUVD (kJ/m ²) for the period from 1996 - 2001	Average monthly minimum EUVD (kJ/m ²) for the period from 1996 - 2001	Ratio of maximum EUVD for the period from 1996 - 2001	Trend of EUVD from 1996 - 2000	Total cloud fraction
Chennai (13.08 °N)	5.76 in Mar	3.47 in Dec	Che/Che = 1.00	Decreasing trend of 0.67 % / year	0.65
Hyderabad (17.37 °N)	5.70 in Apr	3.17 in Dec	Hyd/Che = 0.990	Decreasing trend of 0.31 % / year	0.40
Mumbai (18.93 °N)	5.62 in Apr	2.97 in Dec	Mum/Che = 0.976	Decreasing trend of 0.60 % / year	0.40
Ahmedabad (23.05 °N)	5.40 in May	2.33 in Dec	Ahm/Che = 0.934	Decreasing trend of 0.09 % / year	0.30
New Delhi (28.62 °N)	5.29 in Jun	1.59 in Dec	Del/Che =	Increasing	0.25

Total cloud fraction obtained from MODIS Goddard Chemistry Aerosol Radiation and Transport model (GOCART) for the period 1/1/2000 – 31/12/2000 (Fig. 3) in India shows that cloud fraction is higher at Chennai (0.65), Hyderabad (0.40), Mumbai (0.40) and Ahmedabad (0.30) compared to New Delhi (0.25). Thus, in general, the decreasing trend in EUVD is found to be higher for places having higher cloud fraction (except for Hyderabad and Mumbai). The higher decreasing trend in EUVD at Mumbai compared to Hyderabad may be because, although the cloud fraction for Hyderabad and Mumbai are same, the altitude of Hyderabad above sea level (536 meters) is higher than that of Mumbai (10 meters). Moreover, Mumbai being a more densely populated and developing city compared to Hyderabad, the level of aerosols and pollutants is also higher. Thus, gradual increase in pollutants, soot aerosols and cloud cover might be responsible for the observed decreasing trend in EUVD with increasing solar activity. Also a small uncertainty in the integration of Erythemal UV index, derived from satellite observations at these places, affecting the estimation of EUVD cannot be ruled out.

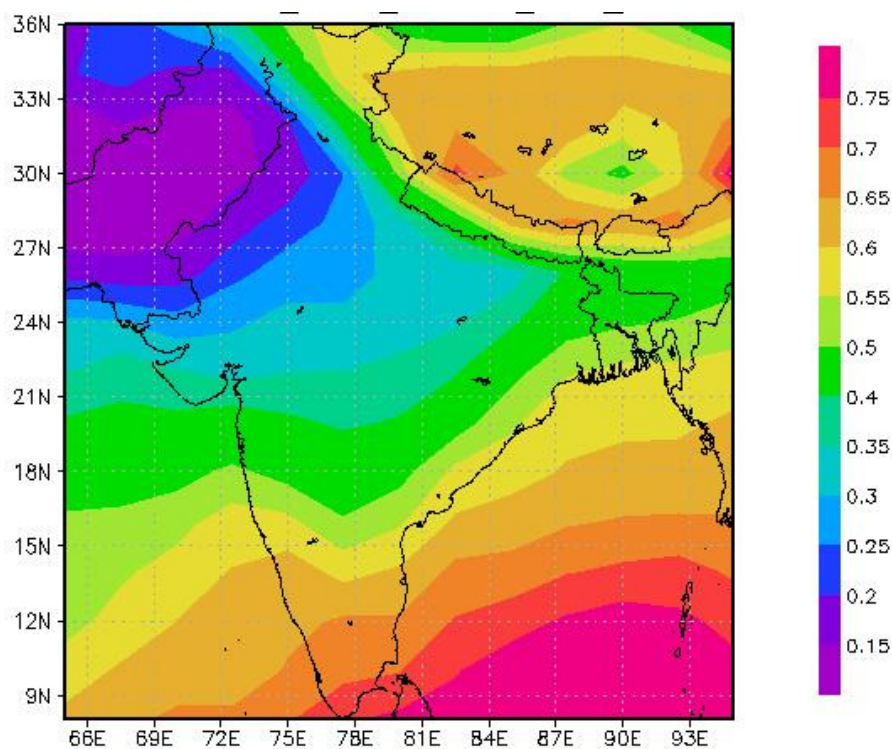


Fig.3: Total cloud fraction obtained from MODIS Goddard Chemistry Aerosol Radiation and Transport (GOCART) model for the period 1/1/2000 – 31/12/2000 in India

Critical limits for EUVD:

Under equilibrium, living organisms and vegetation become gradually adapted to the prevalent natural dose of solar ultraviolet radiation. Living organisms and vegetation in the tropical region are able to tolerate a higher UVD compared to their counterparts at higher latitudes. Since increase in UV dose is responsible for inducing several negative effects on human beings and vegetation, but its decrease beyond a certain limit would result in reducing

the formation of vitamin D in the skin, it is necessary to determine the upper and lower critical limits for EUVD. A statistical control chart, known as the 'Shewhart chart', separates the signal from noise. It is essentially a time plot of observations with critical limits added. If the variation in EUVD values are normal and in control, then all the points in the time plot should lie within the critical limits. The critical limits indicate that, when the variability of the process is large, some special cause (new and unanticipated source of variation) is likely to be operating. When an observation exceeds the Upper Critical Limit (UCL), or lies below the Lower Critical Limit (LCL), a search for the special cause should be initiated. The LCL and UCL for EUVD are given by the relations:

$$\begin{aligned} \text{UCL} &= (\text{Average EUVD value}) + (3 * \text{Standard Deviation } \sigma) \\ \text{LCL} &= (\text{Average EUVD value}) - (3 * \text{Standard Deviation } \sigma) \end{aligned}$$

Even when a process is in control (that is, no special causes are present in the system), there is approximately a 0.27% probability of a point exceeding the 3-sigma critical limits. For a Shewhart control chart using 3-sigma limits, this false alarm occurs on average once in every 370 observations. The upper and lower critical limits for the EUVD in different Indian cities has been estimated statistically using the data from 1996 – 2001. The Shewhart charts for different Indian cities are plotted in Fig. 4.

According to the definition of "in control", the data points should meet the following four criteria:

- (1) No sample point should lie outside the critical limits.
- (2) Most points should lie near the average line.
- (3) Nearly equal number of points should lie above and below the average line.
- (4) The points should be randomly distributed.

Since the actual EUVD are observed to be well within the respective +/- 3 σ (critical limits), and all the four criteria for control are met, Fig. 4 suggests that the EUVD variations for these five Indian cities are under statistical control.

Conclusion

The variations in EUVD for five Indian cities have been studied using the data obtained from GOME, for the period 1996 – 2001. The EUVD values are found to be higher and peak earlier at places located in lower latitudes compared to higher latitudes and are found to be higher during summer / monsoon compared to winter. Seasonal variations in EUVD are more pronounced at higher latitudes compared to lower latitudes. EUVD variations (except for New Delhi) show a negative correlation with solar activity from 1996 – 2000. The EUVD variations for these five Indian cities are found to be under statistical control.

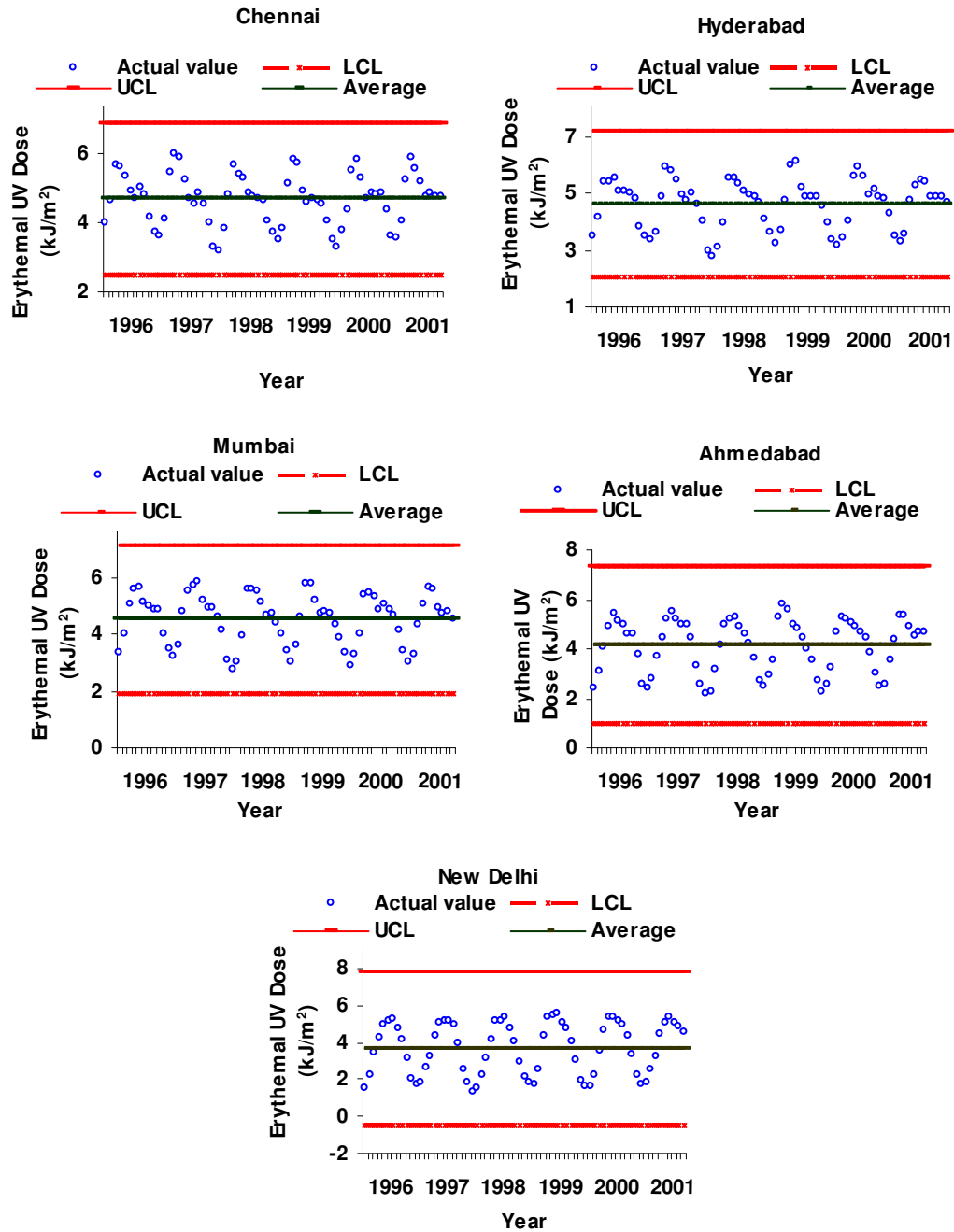


Fig. 4: Shewhart chart (statistical control chart) representing the upper critical limit (UCL) and lower critical limit (LCL) for Erythemal UV dose in different Indian cities from 1996 – 2001. [<http://www.temis.nl/>]

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