Indian J. Phys. **73B** (3), 463-472 (1999)

IJP B
— an international journal

Erythemal and aerosal studies at Maitri, Antarctica during austral spring of 1995

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Received 17 February 1998, accepted 28 December 1998

Abstract : A comparative study of aerosol content at the Maitri region of Antarctica for the 6th, 11th and 14th Indian Antarctic expeditions has been made with a multiwavelength sunphotometer It was found that the aerosol contents were low during 1987 and 1995 compared to 1992 This indicates the effect of Pinatubo eruption in June 1991. The Erythemal dose of UV-B has been also monitored during the austral spring/summer of 1995, and the ozone hole formation has been observed through enhanced doses of UV-B at Maitri. In the presence of a low content of aerosol, an anticorrelation between UV-B and ozone has been observed

Keywords : UV-B, aerosols and erythemal dose, Maitri, Antarctica

PACS No. : 42.68 Jg, 95.85.Mt

1. Introduction

Recently, many studies are being made on aerosols, UV-B, ozone and their interrelationship [1-3]. Aerosols, whether anthropogenic or from volcanic eruptions in the troposphere have been found to cause a decrease in the UV-B irradiance. In non-urban areas of industrialized countries, this decrease ranges from 5 to 18% since the industrial revolution. This reduction may partly or fully offset the increase in UV-B caused by stratospheric ozone depletion in the Northern hemisphere (4).

Stratospheric aerosols are sometimes caused by volcanic eruption. They seriously affect stratospheric ozone (5). The mechanism of this depletion has been ascribed to one or more of the following causes, direct chemical loss through a heterogeneous process, aerosol induced changes in radiative heating which affects ozone transport and higher loss rates caused by aerosol interaction with the solar radiation. Stratospheric aerosols also increase the transmission of UV-B to the surface due to scattering and this enhancement increases with solar zenith angles and absorption optical depth (6). Under appropriate conditions of aerosol and ozone depletion, the UV-B irradiance at Antarctica has been theoretically shown to exceed that of tropics (6). UV-B irradiance on ground is modified by the presence of clouds. Clouds can either increase or decrease UV-B radiations. Additional radiations can be reflected onto the detector by the cloud. This causes an increase, or the irradiance is reduced due to direct obscuration of the sun by clouds. It has been seen that from 1979 to 1990 the amount of total ozone has decreased over most of the globe ; small (3 to 5%) losses at mid-latitudes, large (6 to 8%) losses at high latitudes and no loss near the equator (7). In a related observation, the total irradiance on an average during the last 15 to 39 years has been found to decrease by 3.7 ± 1.3% per decade in Germany (8). About 10% of the total ozone amount is found in the troposphere of the northern hemisphere as confirmed by balloon measurements (9).

In a cloudless atmosphere, the enhancement in UV-B due to ozone depletion can be calculated (10) but the effect of precipitation and cloudiness can not be calculated quantitatively (11). The trend of the ozone hole depletion over Antarctica shows that during 1995 the ozone hole was spread over a longer period, but the depletion of ozone was considerably less when compared to 1993 or 1994. The depletion is expected to be high again in 1996. This prediction is based on the quasi-biennial oscillation (QBO) which is related to air transport from the tropics to Antarctica (12). Ozone loss rates have been greater when the winds were easterly for several months preceding the ozone hole period. Ozone loss maxima has been seen during 1987, 1989, 1991 and 1994. The periodicity was broken in 1992 due to large scale aerosol loading from the Pinatubo volcanic eruption.

This paper describes the observations on aerosol, erythemal dose and daily total ozone taken at Maitri (70^0 46'S, 11^0 44'E) over Antarctica during the austral spring and summer of the year 1995/96 and the interrelation between these parameters.

2. Observations

The atmospheric turbidity due to suspended particulates has been obtained from spectral measurement of direct solar radiation. The measuring instrument has an accurate bandwidth of wavelengths (± 2 nm) and a half width of 5-6 nm. The linearity being less than 0.3%. The optical system full view angle is 2.4^0, slope angle is 0.8^0 and windows are made of quartz glass. The instrument is also stable against ambient temperature changes which can introduce a major error while working at very low temperatures. An 'Eko' (Japan) make four wavelength sunphotometer has been used to record irradiance at wavelengths of 368, 500, 675 and 778 nm. The instrument is pointed to the Sun, and the light after passing through the optical guide tube reaches the narrow band interference filters which are mounted on a filter wheel. A selection switch is provided to adjust the amplification. Ambient temperature can also be read. Measurements were undertaken only on clear days (Diagram 1a).

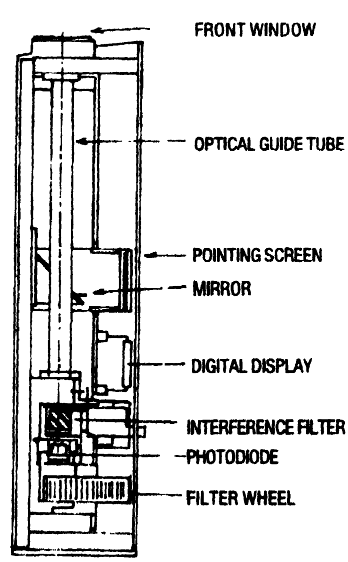

Diagram 1a. Instrument for spectral measurement of direct solar radiation.

The UV-B irradiance was measured in terms of erythemal dose using a Solar Light (USA) made 501 UV-Biometer. The spectral response of the instrument (Diagram 1b) is similar to the erythemal action spectrum.

It can indicate the effectiveness of solar radiation for the induction of sunburn, phytoplankton mortality, skin elastosis and thymine dimers. The instrument consists of two parts : a detector and a recorder.

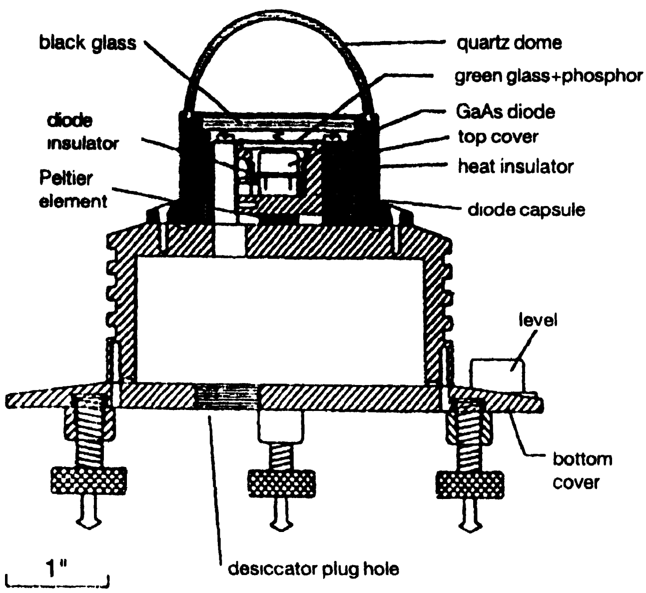

Diagram 1b. Instrument for measurement of UV-B irradiance.

The detector measures the global UV-B and it was mounted on top of a building so that the solar irradiance is not obstructed by any structure. The quartz dome was regularly cleaned to remove dust and snow. The solar light goes through the input filter that eliminates the visible component. Then the partially filtered light containing the whole UV spectrum excites the phosphor which produces the visible light. The visible light emitted by the phosphor is detected by the Gallium Arsenide (Ga-As) diode. The diode and the phosphor are encapsulated in a metal enclosure which is thermostated by the Peltier element. The current produced by the Ga-As diode is amplified and converted to frequency inside the detector. The temperature of the detector is also converted to frequency. The frequency signal from the detector is transmitted to the recorder.

The recorder was kept below in the hut maintained at a constant temperature. It can keep 5248 blocks of data in memory which amounts to half hourly data for about 3.5 months. The data were periodically transferred to a computer using a communication software. The system was kept running round the clock during all-sun days. The data were measured in units of MED/Hr (5.83 × 10-6 W/cm^2). One MED/Hr would cause minimal redness of the average skin after one hour of irradiation (Total energy-21 mj/cm^2).

3. Results and discussion

Atmospheric turbidity is the extinction of direct solar radiations by aerosols. The direct solar intensity (I) for a particular wavelength is :

$$I_\lambda = Io_\lambda \exp-(Tm_\lambda + To_\lambda + TR_\lambda)m, \quad (1)$$

where

I_λ = The irradiance at wavelength (λ) at the observing point,

Io_λ = The irradiance on top of the atmosphere at the mean Sun-Earth distance

Tm_λ = Extinction coefficient due to aerosols,

To_λ = Absorption coefficient of ozone,

TR_λ = Rayleigh scattering coefficient,

m = The absolute air-mass.

The apparatus used does not read the absolute values of I_λ directly but a value that is proportional to it. Io_λ is an instrument calibration constant.

Tm_λ can be calculated by

$$Tm_\lambda = 1/m \; ln \; Io_\lambda / I_\lambda - (To_\lambda + TR_\lambda). \tag{2}$$

'λ' has been selected (viz. 368, 500, 675, 778 nm) so as not to be absorbed by CO_2 or water vapour. The above equation can be modified for a more practical application to :

$$Tm_\lambda = 1/m \; ln \; (Eo_\lambda / E_\lambda . S) - (P / Po TR_\lambda + To_\lambda). \tag{3}$$

where Eo_λ are the calibration constants obtained from Langley plots drawn for each wavelength separately ; E_λ-meter reading ; S-Mean Sun-Earth distance ; Po-standard pressure at sea level (1013.2 mb) ; P-station atmospheric pressure ; m-1/sin h (approx) ; h - solar elevation angle. A Langley plot is a curve between air-mass (m) along the X-axis and the meter reading (E_λ) along the Y-axis. The curve is extrapolated to get the E_λ value corresponding to zero airmass (m = 0) and this value of E_λ is defined as Eo for that particular wavelength.

A pair of extinction coefficients for two different wavelengths can be used to calculate Angstrom's wavelength exponent α that is related to the aerosol size distribution :

$$\alpha = \ln \frac{Tm_{\lambda_1}}{Tm_{\lambda_2}} \quad \ln \lambda_2 \tag{4}$$

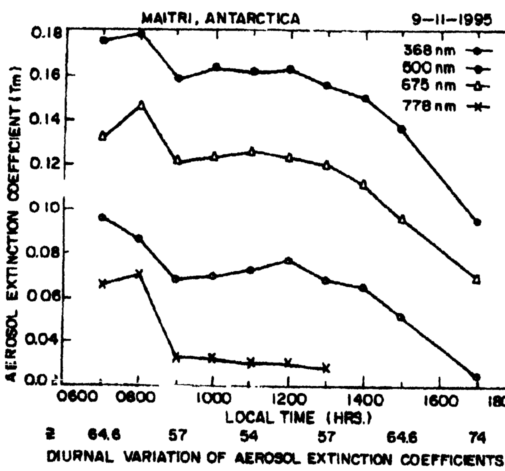

Figure 1.

Local noon observations have been taken for all available sunny days (63 days) between the period March 1995 to January 1996 with the variation in temperature ranging from –32.6 C to + 8C. Figure 1 shows the diurnal variation of the aerosol extinction coefficient (Tm_λ). The higher values observed during early hours is due to the presence of thin clouds which were cleared after 0900 hrs. Figure 2 shows the seasonal variation of Tm_λ. The flat part without any observation corresponds to no-Sun or low-Sun days. It shows that the extinction coefficients have large values for middle wavelengths of 500 nm and 675 nm, but smaller values exist for wavelengths of 368 nm and 778 nm. These observations indicate that the majority of aerosols present in the Antarctic atmosphere were of average size and both the fine as well as coarse particulates are less common. For low solar elevation angles Tm_λ values for 778 nm tend to be higher than for other wavelengths (Figure 2).

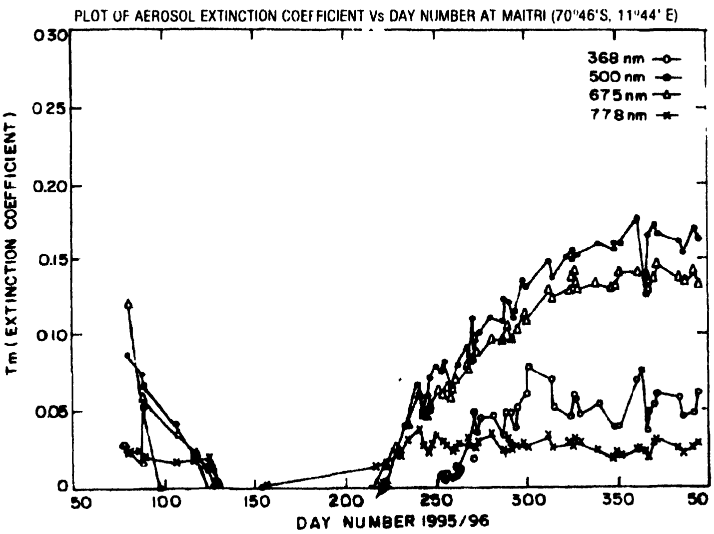

Figure 2.

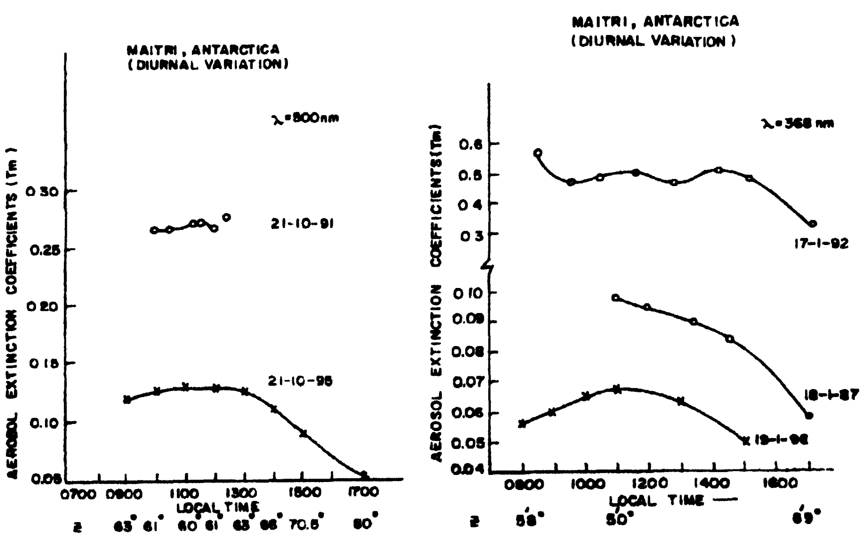

Figure 3. (a) (b)

Figures 3a and 3b show a comparison of the aerosol extinction coefficients observed over Maitri during different visits in 1987, 1992 and 1995. It is observed that for a wavelength of 368 nm, Tm_λ values (extinction coefficients) for 17th January, 1992 are much higher than those of 18th Jan., 1987 and 19th Jan., 1996. Since the days are almost identical the effect of zenith angle is neglected and the difference is due to the atmospheric aerosol content. Similarly, the observations taken on 21st Oct., 1991 when compared with that of taken on 21st Oct., 1995 shows that the 1991 values were much higher. It also shows the effect of Pinatubo which erupted in June, 1991 in Philippines and could be seen in Antarctica by October of the same year. It further increased in Jan. 1992 as seen in Figure 3a/3b. The curves corresponding to 1987 and 1995/96 are quite sharp compared to those of 1991/92, indicating thereby the presence of a stable background of aerosols conforming to their volcanic origin. The possibility of the sharp rise due to Polar Stratospheric Clouds is ruled out as the observations were taken during clear sky conditions.

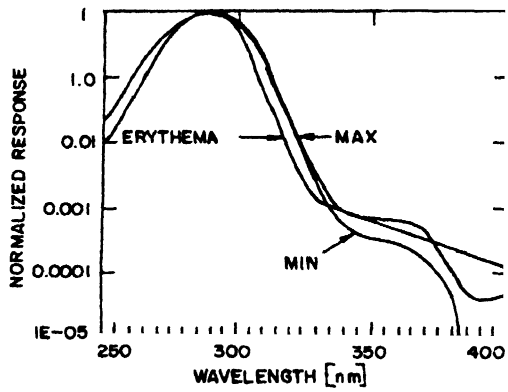

Figure 4.

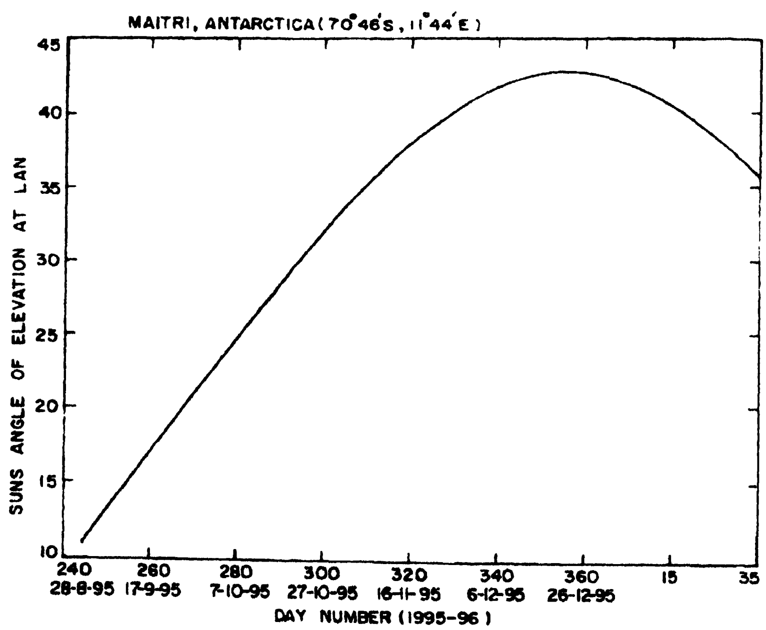

Figure 5.

Figure 4, shows the normalized spectral response of 501 UV-Biometer detector and erythemal action spectrum of human skin. It only shows that the sensitivity of the detector and the human skin are quite identical. In Antarctica, there is a large variation of the solar angle of elevation over the year. Figure 5 shows the variation of solar angle of elevation at local apparent noon (LAN) after the polar winter at Maitri. It varies from 0 to 42.67 deg at the site of Maitri, where there is no sun from 22nd May to 21st July. Similarly, the Sun does not set for about two months around 22nd December.

Figure 6 shows the daily average erythemal dose against the day number. The flat portion of the curve indicates the period when the system was non-operational. The variations

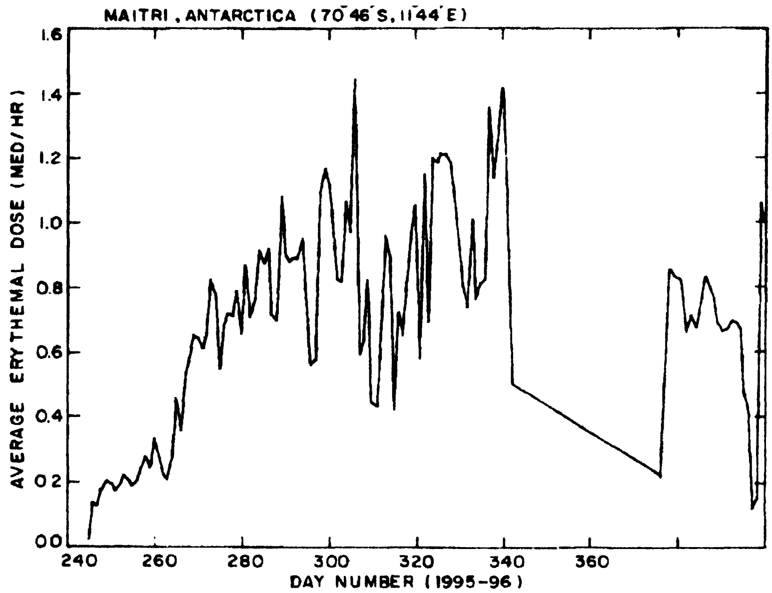

Figure 6.

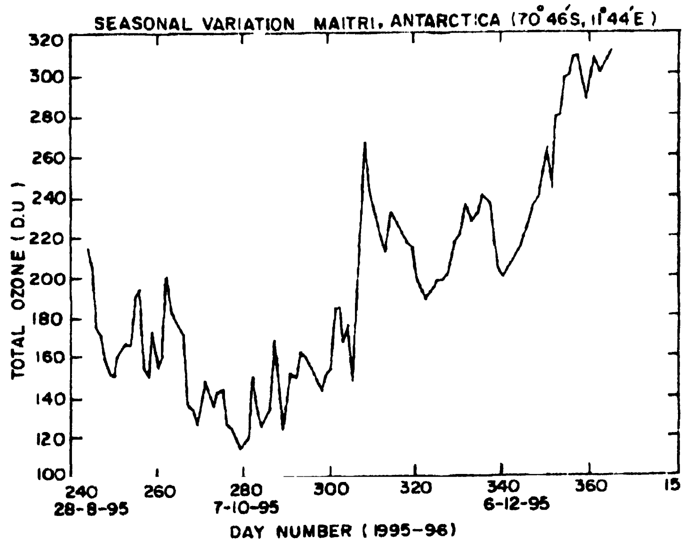

Figure 7.

present in the curves are ascribed to various weather parameters like cloud, snow, aerosol and ozone. Figure 7 shows the variation of total ozone over the period during the austral spring, commonly known as ozone-hole period. The data were based on direct solar observations and were received from a nearby Russian base 'Novolazarevskaya'.

Figure 8 is the normalized combination of Figures 5, 6 and 7. As the solar elevation starts increasing after the polar nights, the erythemal dose is expected to rise monotonically if the other parameters, such as, ozone remain constant. In a real situation where severe ozone depletion is observed during the ozone hole period, the rise in erythemal dose is expected to be more than that caused by Solar elevation. This is marked in Figure 8 as the anticorrelation between ozone and erythemal dose. In the absence of any aerosols in the atmosphere, an increase of total ozone will be accompanied by a proportional decrease in the erythemal dose because of the absorption of the UV-B wavelengths by ozone. But under real conditions, the aerosols, present in atmosphere play a role. They absorb and scatter the radiations in different directions with a result that the radiations reaching the ground are less than those without aerosols. Thus the anticorrelation between UV-B and Ozone does not remain a simple affair of two parameters and is masked by the presence of aerosols and clouds. But over Antarctica, this anticorrelation could be observed due to a lesser aerosol loading of the atmosphere. The data between the day numbers 343 (1995) and 10 (1996) could not be taken due to instrumental failure. Figure 9 shows the diurnal variations of the erythemal dose on two clear days viz. 28.9.95 and 24.11.95 for zenith angles of 69 deg and 50.3 deg respectively at local apparent noon ; the total amount of erythemal dose was 5.712 MED and 27.667 MED respectively. A comparison has been made between the irradiance at Delhi (28.63° N, 77.22° E) and at Maitri (70.77° S, 11.73° E) at local noon on 5th Dec, 1995 at zenith angles of 51 deg and 48.5 deg ; UVB irradiance recorded at Delhi and Maitri was 1.28 MED/hr and 3.482 MED/hr respectively. This experimental observation conforms to the theoretical calculation of Roger Davies (6). He found that under

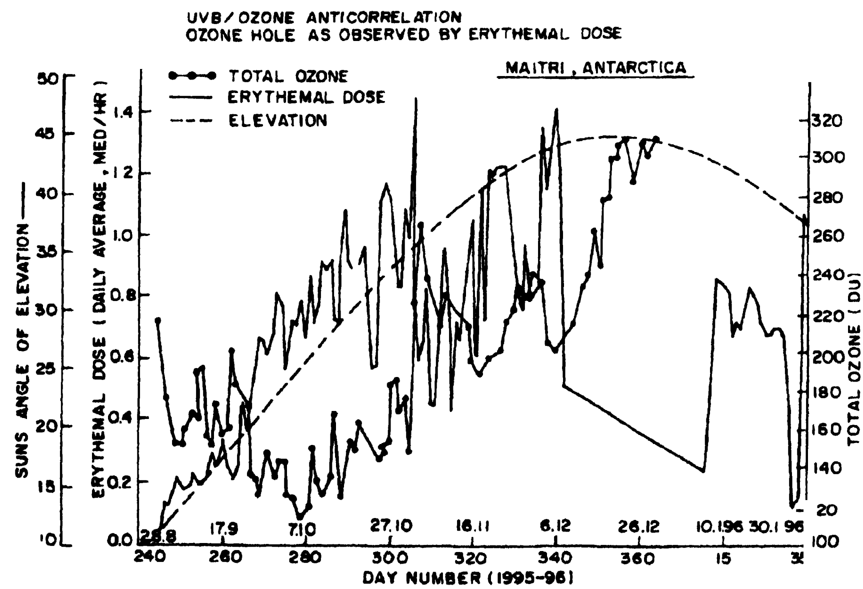

Figure 8.

the conditions of low ozone and high zenith angle of the Sun, the UV-B irradiance over Antarctica can be more than that in the tropics. Possibly, the difference in aerosol loading will be a major contributor to erythemal dose difference between Delhi and Antarctica.

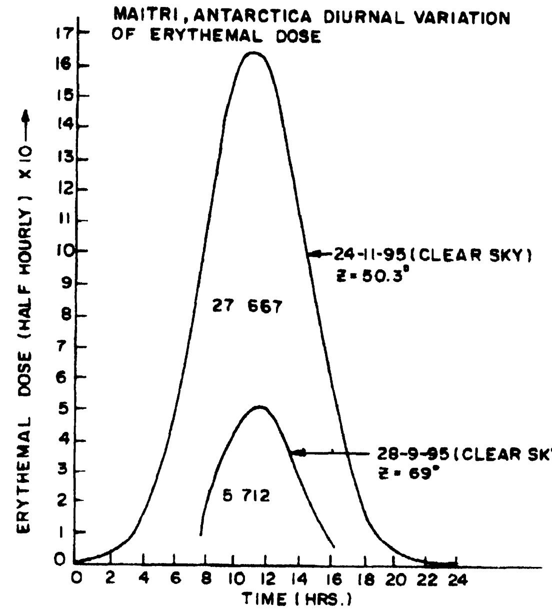

Figure 9.

4. Conclusion

Observations at Maitri show that the aerosol extinctions found during 1987 and 1995 are similar but much smaller than those found during 1992. This indicates the presence of Pinatubo aerosols in Antarctica. The presence of an ozone hole during the austral spring could also be observed through enhanced doses of UV observed, over and above the increase due to increasing solar elevation despite the mixed sky conditions.

Acknowledgment

One of the authors (SDS) is thankful to the Department of Ocean Development, New Delhi for providing facilities to over-winter and work in Antarctica as the leader of the 14th Indian Antarctic Expedition.

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