Indications of Atmospheric Ozone Decrease in Solar UV-B Flux Changes During the Total Solar Eclipse of 24 October 1995

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ABSTRACT

Solar ultraviolet flux measurements in the biological band at 290-320 nm have indicated a sharp increase in the ground reaching solar ultraviolet total flux during the recovery phase of the 24 October 1995 solar eclipse event. The flux values came back to their normal control day value within about two hours after the total recovery phase of the eclipse. The solar flux changes at the visible and near infrared wavelengths did not show any such increase in flux except at 600 nm, which is in the Chappius band for ozone absorption. The observed changes indicate that the increase in the flux could be due to a decrease in the atmospheric columnar ozone. From a numerical calculation it is inferred that a 4.6 % decrease in ozone could produce the observed UV flux increase.

(Key Words: Solar eclipse, UV Flux, Ozone)

1. INTRODUCTION

The monitoring of the solar ultraviolet irradiance at the earth's surface, particularly the UV-B (Ultraviolet - band B) between 280-320 nm, is very important from a biological viewpoint, though this flux forms a very minute fraction of the total solar irradiance. The solar UV flux absorbed in the atmosphere drives the photo-chemical processes which maintain the atmospheric ozone layer, besides being responsible for many other processes in the upper atmosphere . Many studies have indicated the relationship between atmospheric ozone and various indicators of solar activity (Barton and Robertson, 1975; Rizk, 1992). The most plausible mechanism coupling these two is the change in the solar UV flux, from solar maximum to solar minimum and consequent changes in the ozone levels at various heights. During a solar eclipse event, the solar irradiance at the earth's surface is significantly reduced, depending on the extent to which the lunar occultation obstructs the suns direct rays, thereby affecting the photochemical and dynamic processes in the atmosphere due to the change in the solar flux. The effects may initially be seen on a local scale which may at times, affect even global circulations. Keeping these facts in view, the ground reaching solar ultraviolet (UV)

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flux in the biological band, and the direct solar flux in the visible and near infrared (IR) regions have been monitored during the total solar eclipse of 24 October 1995 at Visakhapatnam (17.7° N, 83.3° E), a low latitude station on the east coast of India. The observed changes in the ground reaching total UV flux and the corresponding changes in the direct solar flux at visible and near IR wavelengths have been discussed, keeping in mind the mechanisms responsible for their variation.

2. EXPERIMENT AND METHODOLOGY

A UV B photometer which measures the ground reaching total (direct+diffuse) solar flux at four discrete wavelengths namely 290, 300, 310 and 320 nm is in operation at Visakhapatnam. The spectral selection in this radiometer is done with narrow band interference filters mounted on a circular filter wheel, which is rotated with the help of an automatic motor drive assembly such that each filter stays in the field of view for 48 seconds. The time taken for the changeover from one filter to another is approximately 12 seconds. The full bandwidth at half maximum of the filters is 10 nm. Preceding the filter wheel assembly, is an integrating sphere to which a quartz hemispherical dome window is placed for collecting both the direct and diffuse radiation. The wavelength selected radiation is focused onto the photomultiplier tube which is connected to a data logger. A cycle time of 5 minutes is required for the complete rotation of the filter wheel to cover all four wavelengths including one dark count to set the time resolution at each wavelength to five minutes. The full details of the system are available in Srivastava *et al.* (1995). This system has been calibrated at the National Physical laboratory, New Delhi, India for retrieving the flux in absolute flux units of W/ Sq. cm./ nm.

The other system which measures the direct solar radiation at the visible and near IR wavelengths at nine discrete wavelengths namely 400, 450, 500, 600, 650, 750, 850, 940 and 1025 nm, is the Multiwavelength Radiometer which is analogous to the filter wheel radiometers (Shaw *et al.*, 1973). The half power bandwidth of the filters is 5 nm. This system measures the ground reaching direct solar flux with the help of collimating and focusing optics and a UDT 455 Photo detector - amplifier sensor. The system has automatic data acquisition and sun tracking electronics (Krishna Moorthy *et al.*, 1993).

3. RESULTS AND DISCUSSION

Both the UV-B Photometer and Multiwavelength Radiometer systems were operated on days with completely clear skies in the month of October 1995. The eclipse of 24 October 1995 started at 07:32 hrs at the observing location, with maximum obscuration at 08:44 hrs. The eclipse ended at 10:08 hrs and the degree of maximum obscuration was 81%. Figure 1 shows the variation of the ground reaching UV-B flux on the eclipse day (Solid line) along with the monthly mean variation (Vertical bars) for all the other days (13 days with 2 sigma variance), excluding the eclipse day, at a typical wavelength of 310 nm. It may be seen from the figure that with the first contact of the eclipse at 07.32 hrs the UV flux started decreasing with increasing lunar occultation, and reached a minimum value at the time of maximum obscuration at 08:44 hrs with no time lag. With the decrease in solar obscuration the flux
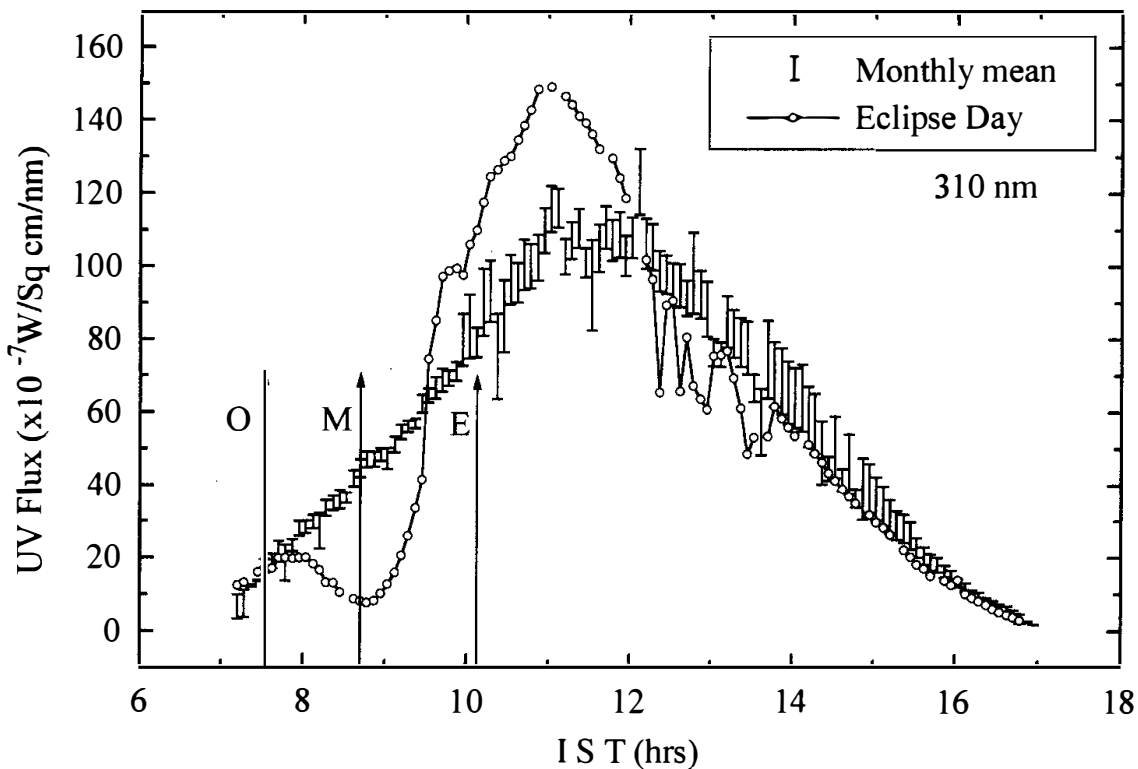
Fig. 1. Variation of the Solar UV total flux on the eclipse day (solid line) along
with the monthly mean (vertical bars) at 310 nm. The arrows indicate
the onset (O), the maximum phase (M) and the end (E) time of the eclipse.

started recovering. The interesting feature to be observed is the sharp increase in the flux
during the recovery phase. After the eclipse event, the flux values increased sharply even
beyond the control day average. Higher values of flux are seen for about 2 hours after the last
contact and the flux recovered it's normal mean value within about two hours after the eclipse
event. Such a feature is observed at all four UV wavelengths at which the UV-B Photometer
operates.

In contrast, the direct solar flux at the visible and near IR wavelengths, as recorded by the
MWR system, do not show any such increase as may be seen in Figure 2, where the variation
of the direct solar flux at two typical wavelengths of 450 nm (typical visible) and 850 nm
(typical near IR) on the eclipse day (solid line), and the monthly mean (of 9 days' regular
observation) excluding the eclipse day (Vertical bars), are plotted. As this system is meant to
evaluate the aerosol optical depths it does not need calibration and hence the intensity is
shown as the output of the system in Volts. Excluding the dip seen during the eclipse period,
which is caused by the progressive lunar occultation of the sun's disc during the onset of the
eclipse and the subsequent recovery, there is no appreciable change in flux after the eclipse
period The total optical depths retrieved from the direct solar flux measurements using the
Langley technique (see Figure 3) do not show any significant variation at the visible and near
IR wavelengths on the eclipse day(the data during the whole eclipse period, i.e. from 07:30
AM to 10:30 AM on the eclipse day, is not considered in evaluating the total optical depths)
indicating that the transparency of the atmosphere did not change on the eclipse day. How-
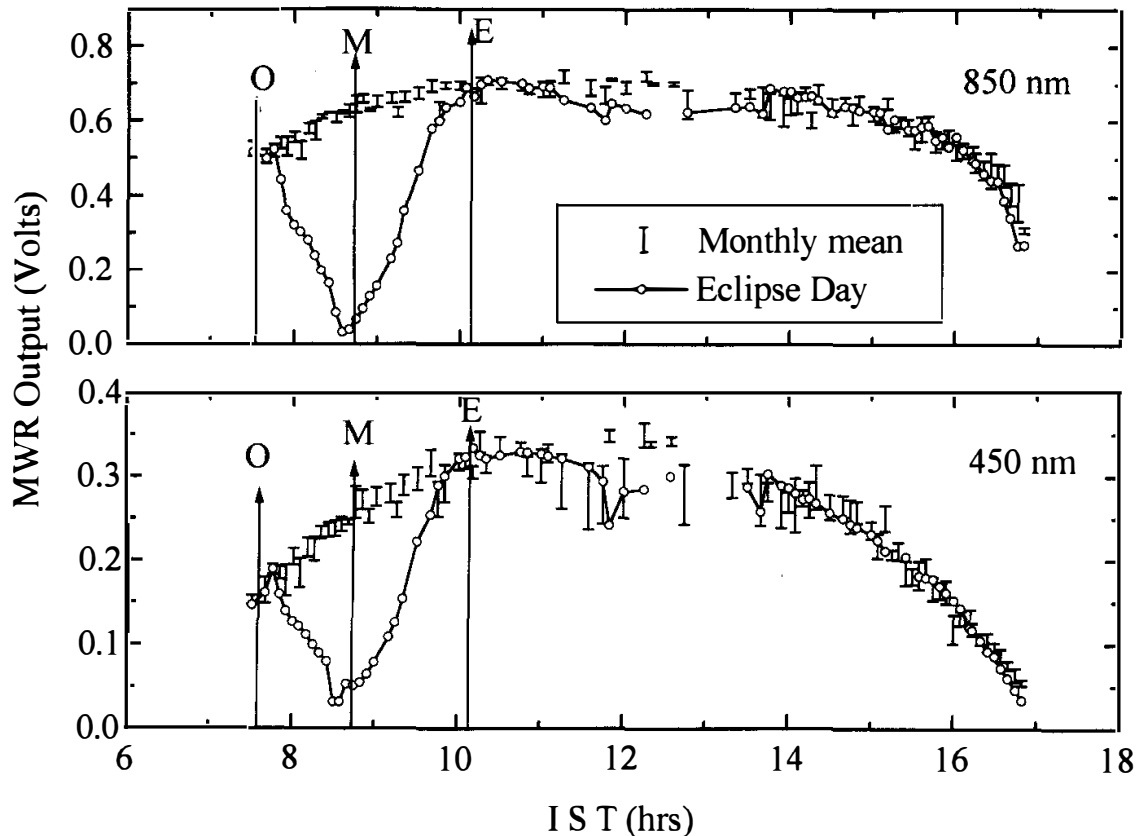
Fig. 2. Variation of the Solar flux at typical visible (450nm) and near IR
(850nm) wavelengths on the eclipse day (solid line) along with the
monthly mean (vertical bars) . The arrows indicate the onset (O), the
maximum phase (M) and the end (E) time of the eclipse.

ever, a small change in the total optical depth is seen at 940 nm which is close to the central
wavelength of the $\rho \sigma \tau$ band for the water vapour absorption. With this station being a coastal
station, the day to day variability in atmospheric water vapour is more, and hence the optical
depth shows a large variability. An interesting observation from the MWR system during the
total solar eclipse is that the direct solar flux at 600 nm, which is in the Chappius band for
ozone absorption, shows a small increase in direct solar flux for about an hour after the eclipse
event. Such an increase is seen only at this wavelength and not at any other wavelength in
either the visible or the near IR regions. Thus it is observed that the solar flux at ozone
sensitive wavelengths in the UV and visible solar spectrum increased for about one hour after
the eclipse event (see Figures1 and 4), which indicates lower atmospheric columnar ozone
during the eclipse recovery phase and for about one hour after the eclipse event, compared to
that on a normal day.

It has been reported from experimental as well as theoretical studies that the atmospheric
ozone balance is disturbed during total solar eclipse events, though photochemical phenomena
do not fully accounts for these changes (Chatterjee, 1983; Bojkov, 1968; Hunt, 1965). It has
been reported that a drop in columnar ozone may be observed shortly before and after the
maximum phase of the eclipse (Osherovich *et al* 1974; Mims and Mims.,1993). Subbaraya
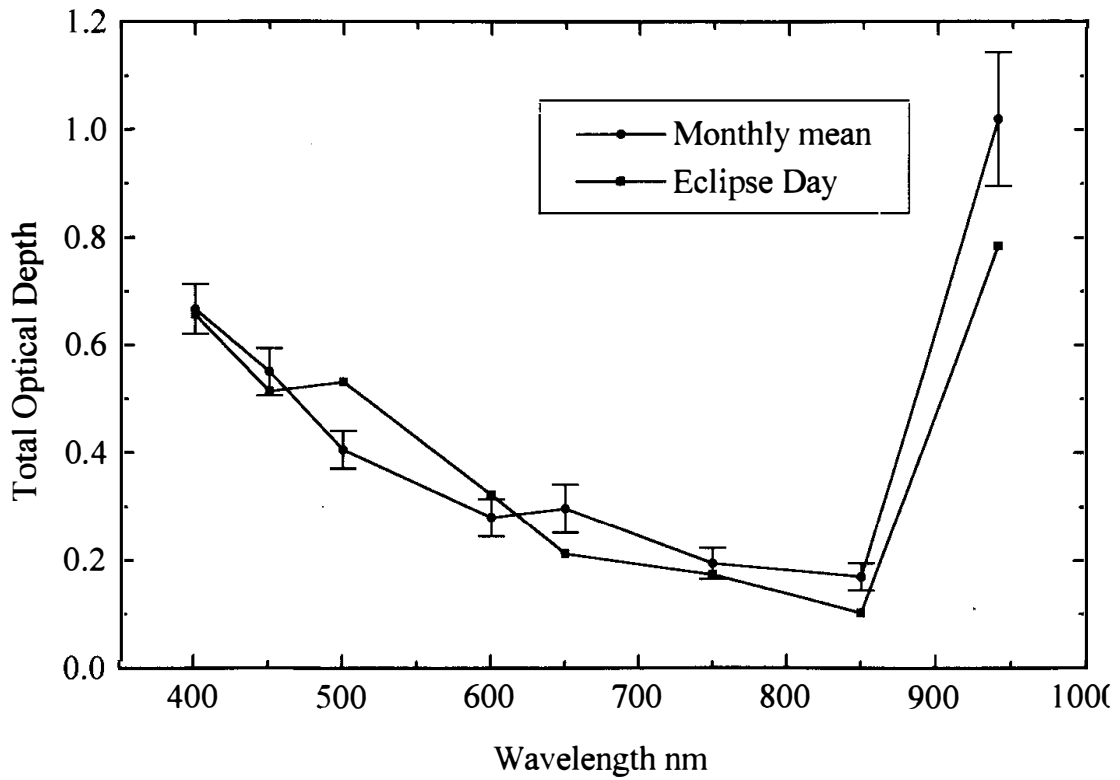(1983), from rocket measurements made during the total solar eclipse of 1981, reported a

Fig. 3. Spectral variation of total optical depths on the eclipse day (solid line with open circles) and the monthly mean (line with vertical bars).
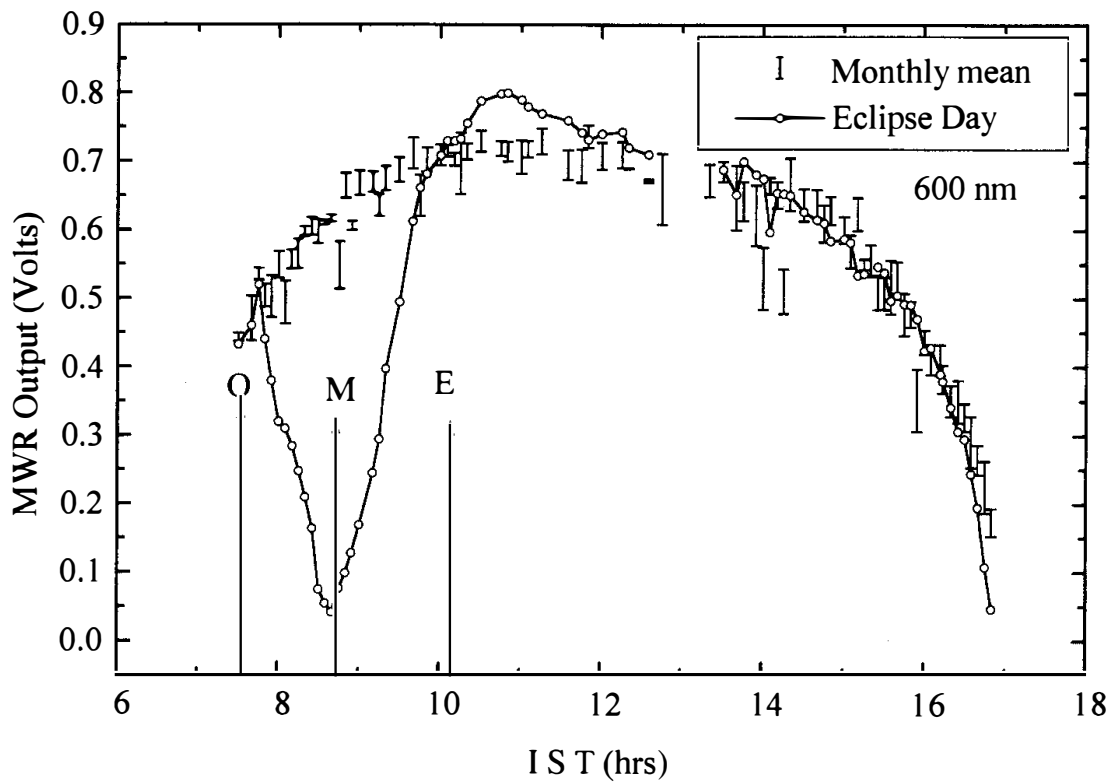

Fig. 4. Variation of the flux on the eclipse day (solid line) along with the monthly mean (vertical bars) at 600nm. The arrows indicate the onset (O), the maximum phase (M) and the end (E) time of the eclipse.

height dependent change in the atmospheric ozone. A surface ozone decrease from 41 μ gm/m^3 to 37 μ gm/m^3 and about a 3% decrease (~ 10 DU) in total ozone have been reported by Chatterjee (1983) during the total solar eclipse of 1981. An eclipse perhaps disturbs the photo-chemical balance of ozone due to the change in the available solar UV flux which is impor-tant in the production and destruction of ozone. It is also believed that part of the ozone seen in the upper troposphere comes from the stratosphere by diffusion, and as there is a differen-tial change in the ozone levels at various heights, an eclipse may also effect the transport of ozone resulting in temporary changes. Furthermore, due to the cooling of the atmosphere and damping of all convective processes during a solar eclipse event, the surface levels of ozone may decrease.

From the observed changes in the UV and visible flux, it is felt that the increases seen at the UV wavelengths and at 600 nm after the totality of the eclipse could be due to the changes in ozone either at the surface level or in the total columnar ozone or both. As the UV B instru-ment measures the total integrated direct and diffuse flux, it is sensitive to ozone changes both at the surface level as well as at the columnar level. However, the change in the direct solar flux at 600 nm in the Chappius absorption band for ozone clearly indicates a decrease in the columnar ozone for a short period of one to two hours after the eclipse event.

An attempt has been made to calculate the expected change in the columnar ozone to produce the observed changes in the ultraviolet flux following the semi empirical formula for calculating the global solar middle ultraviolet radiation reaching the ground (Green *et al.*, 1974). According to the semi-empirical equation given by them, the direct solar radiation at any Solar zenith angle (θ) and wavelength (λ) can be expressed as

$$B(\theta,\lambda) = H(\lambda) \cos\theta \exp[-A_t(\theta,\lambda)]$$

Here $H(\lambda)$ represents the solar radiation at wavelength λ which can be represented by

$$H(\lambda) = k[1 + (\lambda - \lambda_0)/d]$$

where $k = 0.522$ w/m^2/nm, $d = 37$ nm and $\lambda_\bullet = 300$ nm. The expression for $A_t(\theta,\lambda)$ is given by

$$A_t(\theta,\lambda) = W_{oz} k_{oz} \exp[-(\lambda - \lambda_0)/d_0] seq_{oz}\theta + W_a k_a (\lambda/\lambda_0)^{va} seq_a\theta + W_p k_p (\lambda/\lambda_0)^{vp} seq_p$$

In the above equation (3) $Seq_i\theta = [1 - Sin^2\theta/q_i]$ and $q_i = [1 + y_i/R]^2$.

Here y_i is the effective radius of the *i*th species and R is the radius of the earth. W_{oz} is ozone concentration, W_a is air concentration and W_p is particulate concentration.

The diffuse radiation F (q, 1) is given by

$$F(\theta,\lambda) = H(\theta,\lambda) \exp[-D(\theta,\lambda)]$$

Here $D(\theta,\lambda)$ is given by

$$D(\theta,\lambda)= k'_{oz} \exp[kk_o W_{oz} - (\lambda-\lambda_o)/\delta \; Speq(\theta)] \; seq(\theta,q_i)+k_{ap} \; seq(\theta,q_z)$$

Here $Speq(\theta) = 1/(1-\sin^2\theta/q)^{1/2}$. All the k's in the above equation are the absorption coefficients of the respective species and the v's are the power law exponents for those species (Please see Green *et al.*, 1974 for details).

The total radiation I is the sum of direct and diffuse components given by

$$I_{total} = H(\lambda) \; [\cos\theta \exp (-A_t (\theta,\lambda) + \exp (-D(\theta,\lambda))]$$

The neutral air parameters have been incorporated from the available rocket and balloon data from the observing location and nearby rocket stations. The particulate parameters have been taken from the experimental observations carried out on site (Niranjan *et al.*, 1995; Krishna Moorthy *et al.*, 1993). Numerical calculations using the above equations have shown that a 4.6 % (i.e. 0.012 atm-cms) decrease in columnar ozone could produce the observed increases in the solar UV flux. It has been reported by the India Meteorological Department that according to Dobson measurements, the total ozone in the atmosphere fell by 5.8 % from the normal 260 Dobson units level at Delhi (The Hindu, 1995), during the eclipse event of 24th October 1995.

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