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Correlation of Biologically Effective UV-B Irradiance versus Ozone at Visakhapatnam (17.7 deg North, 83.3 deg East)

N. V. Krishna Prasad[1], K. Niranjan[2], M. S. S. R. K. Sarma[1] and N. Madhavi[3]

[1.] *Department of Physics, G.I.T, GITAM University, Visakhapatnam, India*
[2.] *Department of Physics, Andhra University, Visakhapatnam, India*
[3.] *Department of Statistics, Andhra University, Visakhapatnam, India*

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Ground reaching biologically effective UV-B irradiance will be affected by various atmospheric parameters, such as: ozone, solar zenith angle, earth–sun distance, clouds, aerosols, etc. Ozone is a main component in the lower atmosphere which controls incoming UV-B irradiance. It is a known fact that total column ozone and ground reaching UV-B irradiance are inversely correlated. The aim of this paper is to study the correlation between biologically effective UV-B and ozone at coastal urban location Visakhapatnam. A regression model that was developed with measurements made by a UV-B photometer operated at Visakhapatnam in 1990 (Krishna Prasad et.al. 2005) is now reused to estimate the incoming UV-B irradiance by inputting satellite measured TOMS ozone for the year 2010. In the analyzed period (January 2010 – December 2010) variation of estimated UV-B irradiance with ozone for different wavelengths is found for different zenith angles. The correlation between estimated UV-B irradiance and TOMS ozone in this station has been studied and results are presented in this paper.

Keywords: *TOM's ozone, UV-B irradiance, RAF, solar zenith angle, wavelength.*

1. Introduction

Increase in the ground reaching solar UV-B irradiance in a biological band (280-320 nm) due to continuous decrease in stratospheric ozone for the recent two decades has gained a large significance because of its adverse affects on the human, animal and plant species. It is reported that a decrease in stratospheric ozone and an increase in UV-B radiation are inversely correlated by 100% (Cutchis 1974). However, this correlation may vary according to the specific wavelength, season and solar zenith angle (Bias et. al. 1994). Consequences of increased exposure of the human body to UV-B radiation include skin cancer, though UV-B radiation does not penetrate far into the body as it is absorbed in superficial tissue layers of 0.1 mm depth (Longstreth et.al.1998). Even though its primary effects are limited to skin and eyes, it has effects like erythema, sunburn and tanning which are due to 0.5 % of the incident radiation. Relative effects of various wavelengths on producing erythema are given by Everett et al. (1966). Madronich et.al. (1998) reported an annual erythemal dose of 2.35 MJ/m2 with an increase in erythemal induction by 4 +/ – 1.5 %, and skin cancer by 4.7 +/ – 1.7 % during 1979 to 1993 for a subtropical latitude. To assess significant changes in the incoming biological ultraviolet radiation with ozone depletion, the values of RAF (Radiation Amplification Factor) are calculated for various effects like erythema, DNA (plants & human), skin cancer, etc. It is known that the increase in UV-B irradiance strongly depends on a wavelength (in addition to its dependence on a solar zenith angle, ozone, etc), and to assess a particular biological effect, an action spectrum that makes sensitivity of a wavelength dependent on UV change is to be considered.(Madronich et.al. 2003).

An attempt is made to estimate the incoming UV-B irradiance at Visakhapatnam during the year of 2010 by using satellite measured column ozone, RAF and a solar zenith angle as inputs. This paper reports the correlation between estimated UV-B irradiance as a function of solar zenith angle, wavelength and ozone at Visakhapatnam in 2010.

2. Regression Technique

It is known that the incoming UV-B irradiance (I) is a function of total ozone (T) and solar zenith angle (χ). The functional relationship between the three is given by

$$\ln I = a + RAF \ln(T) + C(\chi) + u \quad (1)$$

where:
a – regression constant,
RAF and c – regression coefficients,
U – a disturbance term, which has $N(O,\sigma^2)$ distribution.

Further, RAF is known as a radiation amplification factor which expresses the dependence of UV-B flux on total ozone and is given by

$$RAF = -\frac{d[\ln I]}{d[\ln T]} \quad (2)$$

Expr. (2) may be also expressed as

$$RAF = -\frac{\left(\frac{dI}{I}\right)}{\left(\frac{dT}{T}\right)} \quad (3)$$

which gives the relative change in effective irradiance corresponding to the relative change in ozone.

Eq. (1) can be written as

$$Y = \beta_1 + \beta_2 X_2 + \beta_3 X_3 + u \quad (4)$$

where

$\beta_1 = a$, $\beta_2 = RAF$,
$\beta_3 = c$, $Y = \ln I$,
$X_2 = \ln T$ and
$X_3 = \chi$

In a deviation form Eq. (4) can be expressed as

$$Y = \beta_2 x_2 + \beta_3 x_3 + (u - \bar{u}) \quad (5)$$

Using the ordinary least squares, we can obtain the estimated parameters as

$$\begin{bmatrix} \hat{\beta}_2 \\ \hat{\beta}_3 \end{bmatrix} = \begin{bmatrix} \sum x_2^2 & \sum x_2 x_3 \\ \sum x_2 x_3 & \sum x_3^2 \end{bmatrix}^{-1} \begin{bmatrix} \sum y x_2 \\ \sum y x_3 \end{bmatrix} \quad (6)$$

where

$$x_{i2} = X_{i2} - \overline{X_2}, \text{ etc.}$$

Further

$$\hat{\beta}_1 = \bar{Y} - \hat{\beta}_2 \bar{X}_2 - \hat{\beta}_3 \bar{X}_3$$

By using the known values of *ln* I, *ln* T, and χ the estimated model would be

$$\left(\widehat{\ln I}\right) = \hat{a} + \left(R\hat{A}F\right)\ln T + \hat{c}\,\chi \quad (7)$$

3. Results and Discussion

3.1. Variation of UV-B irradiance with ozone for different wavelengths at different solar zenith angles

In general, action spectra have been developed for evaluating biological effects corresponding to ozone reductions. Action spectra allow a photo-biologist to draw some conclusions regarding a biological pigment or a molecule that absorbs the radiation and mediates the effect within an organism. The criteria often used to develop the action spectra are directed to this traditional use in photobiology and these, along with many technical constraints, limit the usefulness of the action spectra as weighting functions (Stratospheric Ozone and Human Health Project, Environmental Effects of Ozone Depletion:1994 Assessment). Here the effect of ozone is not taken into consideration since it is a known fact that the biological effect is strongly wavelength dependant and the impact of ozone absorption strongly varies with the wavelength (Fig 1.by Madronich et.al 1998). Hence the variation of ozone along with the wavelength should be taken into consideration which is necessary to estimate the amount of sensitivity of a particular effect at a particular solar zenith angle. Keeping this in view the relation between ozone, UV-B irradiance is studied as a function of wavelength and solar zenith angle.

The values of RAF, a and c for different solar zenith angles for different wavelengths are given in Table 3.1. This Table shows the values of a (regression constant), RAF (radiation amplification factor) and c (regression coefficient) calculated from the above model by giving the measured UV-B, TOMS zone to three different wavelengths and to different solar zenith angles at Visakhapatnam.

Table 3.1. Table showing values of RAF , a and c for different wavelengths 280,290 and 310 nm at different solar zenith angles

Wavelength	**280 nm**			**290 nm**			**310 nm**		
Angle	**a**	**c**	**RAF**	**a**	**c**	**RAF**	**a**	**c**	**RAF**
12.5^0	47.92	-0.1309	8.65	29.20	-0.06	5.49	45.88	-0.09	7.45
17.5^0	15.99	-0.02	3.30	28.91	-0.15	5.10	36.77	-0.003	6.11
27.5^0	5.75	-0.01	1.68	7.65	-0.16	1.81	20.73	-0.03	3.11
37.5^0	34.44	-0.06	6.34	17.30	-0.07	2.19	15.01	-0.008	2.28

The above values correspond to the model developed with the values of TOMS ozone and UV-B irradiance measured for three wavelengths as inputs at Visakhapatnam in 1990. At present the values of satellite measured TOMS ozone for the year 2010 are taken as one input along with the existing values of RAF , *a* and *c* shown above and the corresponding UV-B irradiance are estimated. Graphs are plotted with ozone on axis *x,* estimated UV-B irradiance on axis y for three different wavelengths, for different solar zenith angles. The graphs indicate the variation of estimated UV-B irradiance as a function of ozone corresponding to various wavelengths at the fixed solar zenith angles. It is observed that the estimated UV-B irradiance and ozone are inversely correlated within a range of 90% for different wavelengths at fixed solar zenith angles.

3.2. Anti-correlation between ozone and estimated UV-B irradiance for three wavelengths at different solar zenith angles

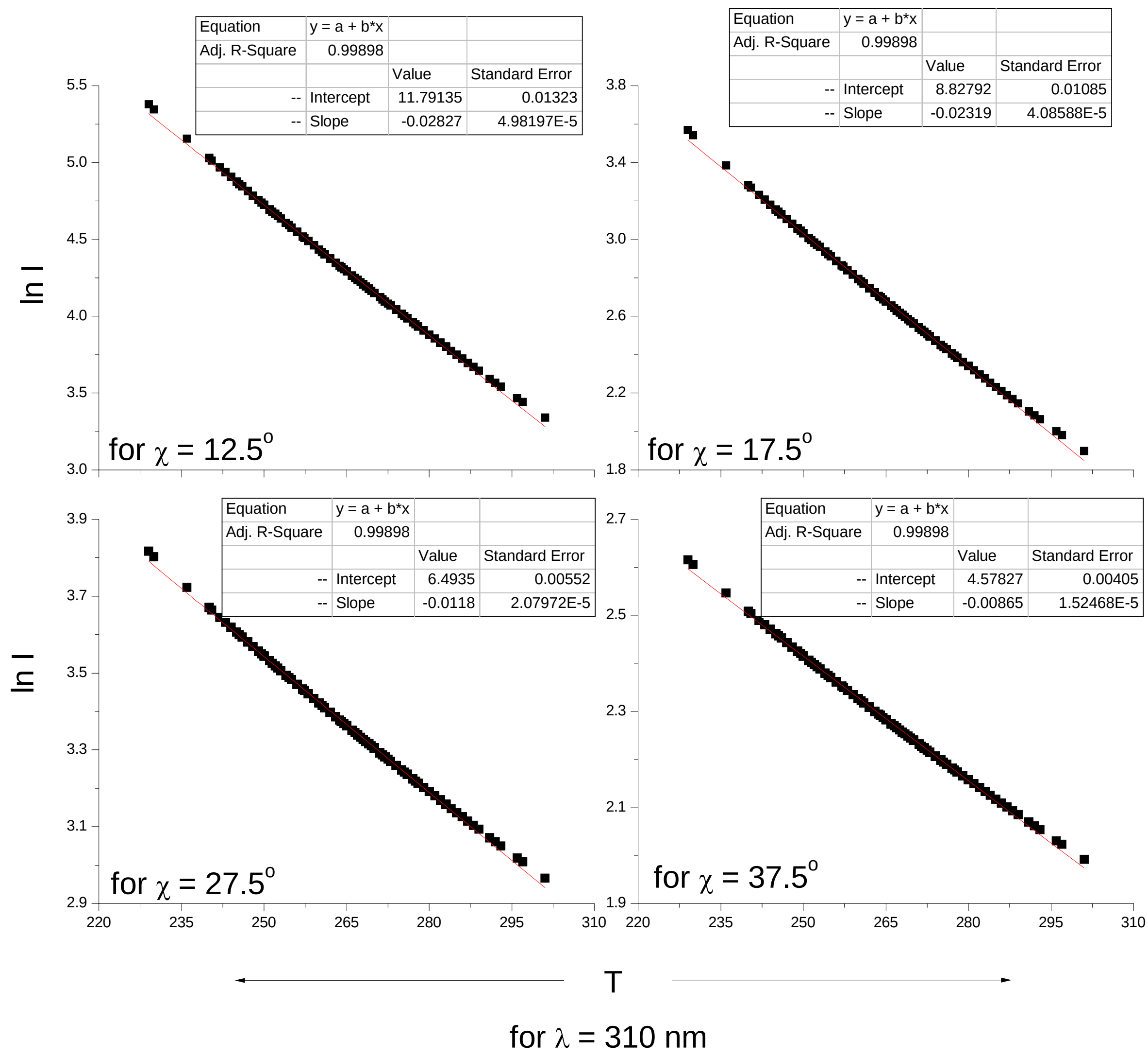

Fig. 3.3.1. Correlation between Toms ozone and estimated UV-B irradiance for a wavelength of 310 nm at different solar zenith angles

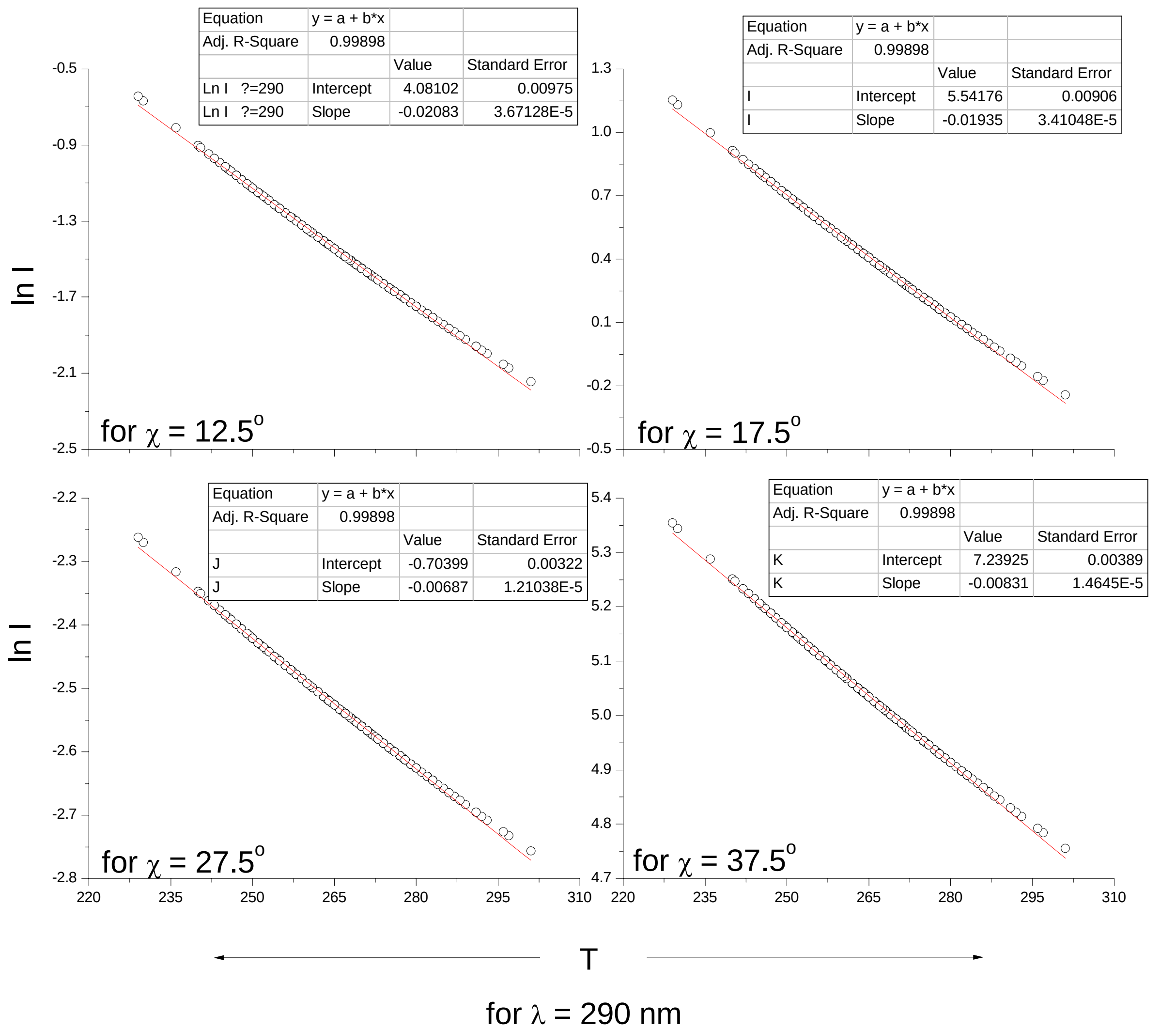

Fig. 3.3.2. Correlation between Toms ozone and estimated UV-B irradiance for a wavelength of 290 nm at different solar zenith angles

Table 3.2.shows the anti-correlation values (adjusted R^2) for estimated UV-B irradiance and TOMS ozone for three wavelengths 310nm , 290nm and 280 nm as a function of solar zenith angle.

Table 3.2. Table showing the anticorrelation values for estimated UV-B irradiance and ozone for three wavelengths 310,290 and 280 nm for different solar zenith angles

Wavelength	310 nm	290 nm	280 nm
Solar Zenith Angle	**R^2**	**R^2**	**R^2**
12.5^0	0.99	0.99	0.99
17.5^0	0.96	0.99	0.99
27.5^0	0.99	0.99	0.99
37.5^0	0.98	0.99	0.99

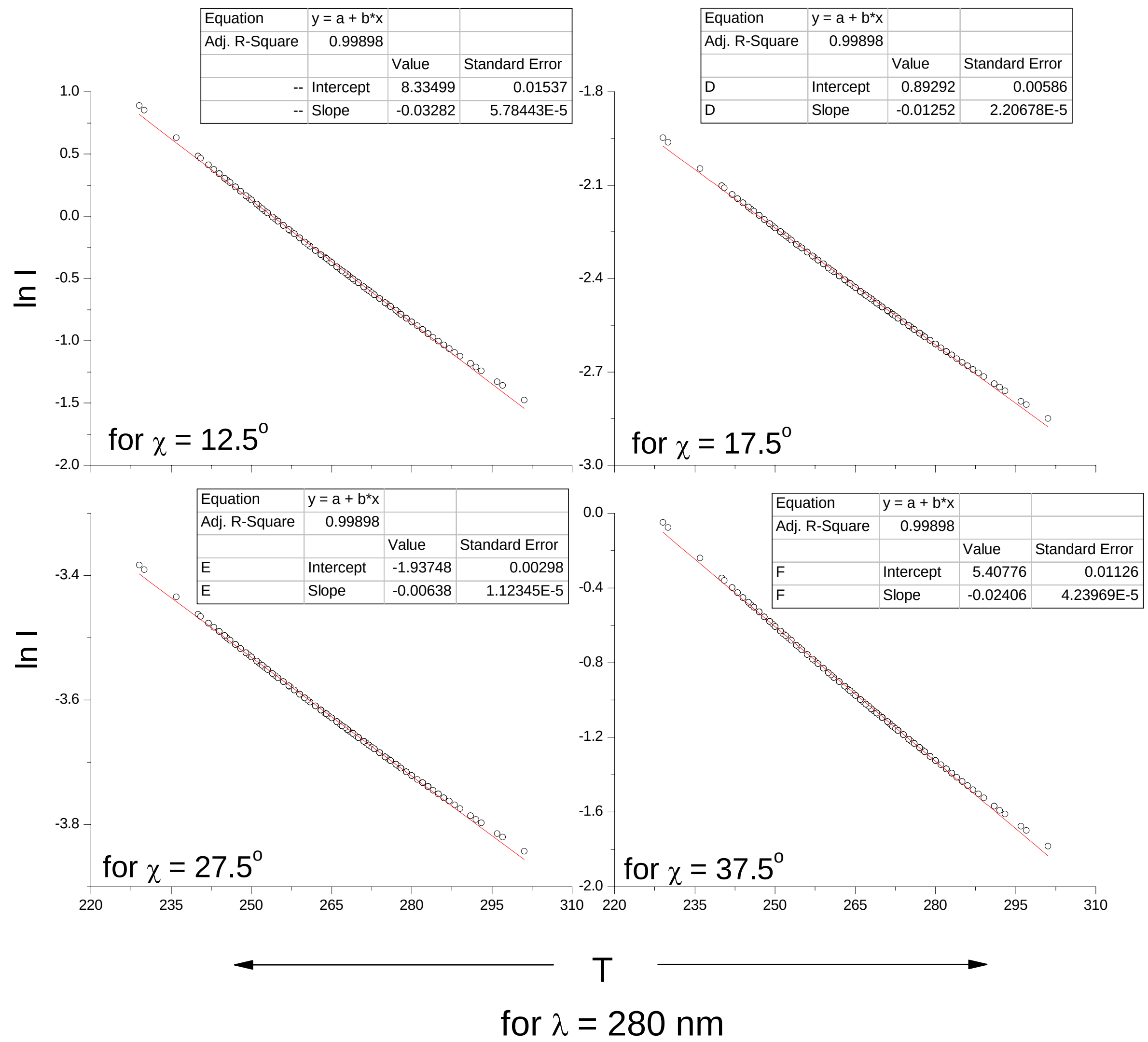

Fig. 3.3.3.1. Correlation between Toms ozone and estimated UV-B irradiance for a wavelength of 280 nm at different solar zenith angles

4. Conclusions

The present paper estimates the incoming irradiance at Visakhapatnam for the year 2010 by inserting TOMS ozone as one input, a fixed solar zenith angle as one input and the corresponding RAF values as the other input into the regression model developed exclusively for this station.

The graphs above show an inverse correlation between ozone and estimated UV-B irradiance up to 90%. The above results indicate that the regression model developed for this station long ago could still be used to estimate the incoming UV-B irradiance as a function of known inputs like solar zenith angle and TOMS ozone. However, to obtain higher efficiency the results need to be compared to the measurements made by a ground based instrument.

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Biologiškai aktyvios UV-B spinduliuotės ir ozono sluoksnio korealiacija Visakhapatnam regione (17,7° Šiaurės platumos, 83,8° Rytų ilgumos)

N. V. Krishna Prasad[1], K. Niranjan[2], M. S. S. R. K. Sarma[1], N. Madhavi[3]

[1]*Fizikos fakultetas, G.I.T, GITAM universitetas, Indija*
[2]*Fizikos fakultetas, Andros universitetas, Indija*
[3]*Statistikos fakultetas, Andros universitetas, Indija*

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Straipsnio tikslas – įvertinti biologiškai aktyvios UV-B radiacijos ir ozono sluoksnio kitimo Visakhapatnam regiono priekrantėje koreliaciją. Nuotoliniai UV-B spinduliuotės matavimai 2010 m. taikant TOMS metodiką yra lyginami su 1990 m. sukurtu regresijos modeliu, paremtu UV-B fotometro matavimais. Straipsnyje analizuojamieji rezultatai gauti skirtingais metodais ir laiko periodais.