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Full Length Research Paper

Regression analysis of biologically effective UV-B irradiance versus ozone at Visakhapatnam (17.7°N, 83.3°E)

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Atmospheric variables that affect ground reaching UV-B irradiance include ozone, solar zenith angle, earth–sun distance, clouds, aerosols, etc. It is a known fact that total column ozone and ground reaching UV-B irradiance are inversely related. The aim of this paper is to estimate the variation of the biologically effective UV-B irradiance with variation in ozone at a coastal urban location, Visakhapatnam for the period, January 2010 to December 2010. A regression model that was developed with measurements made by a UV-B photometer operated at Visakhapatnam in 1990 (Krishna and Niranjan, 2005) is now reused to estimate the incoming UV-B irradiance by inputting TOMS ozone for the year 2010. An attempt was made to compare both measurements which are reported in this paper. For the analyzed period (January 2010 to December, 2010), variation of estimated UV-B irradiance with ozone for different wavelengths is found for different solar zenith angles. To assess the biological effects of incoming UV-B irradiance, erythemal irradiance was estimated and its variation with ozone as a function of wavelength and solar zenith angle was reported. These results indicate the efficiency of the regression model developed for this station.

Key words: UV-B irradiance, regression, ozone.

INTRODUCTION

Decrease in stratospheric ozone and consequent increase in the ground reaching solar UV-B irradiance in the biological band (280 to 320 nm) for the last couple of decades has gained large significance due to its adverse affects on the human, animal and plant species. It is reported that a 1% decrease in stratospheric ozone could cause about 2% increase in UV-B radiation (Cutchis, 1974). It may vary according to the specific wavelength, season and zenith angle of the sun. The consequences of increased exposure of the human body to UV-B radiation is characterized by the physical properties of this radiation. UV-B radiation does not penetrate far into the body as it is absorbed in the 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 is due to 0.5% of the incident radiation. The relative effects of various wavelengths in producing erythema are given by Everett et al. (1966). Madronich et al. (1998) reported an annual erythemal dose of 2.35 MJ/m^2 with an increase in erythemal induction by 4±1.5% and skin cancer by 4.7±1.7% during 1979 to 1993 for subtropical latitude approximately. UV-B irradiance also has influences on the immune system, aging of the skin, eyes and cause skin cancer. Previous studies indicate that these effects do not increase with an increase in UV-B irradiance. In addition to these effects of UV-B irradiance on human society, it also shows significant influence on animals, agriculture, forest, plants and crops (Caldwell et al., 1998; Teveni et al., 2008). To assess the significant changes in the incoming biological ultraviolet radiation with ozone

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depletion, the values of RAF (Radiation Amplification Factor) are calculated for various effects like Erythema, DNA (Plants and Human), skin cancer, etc. It is a known fact that the increase in UV-B irradiance strongly depends on wavelength (in addition to its dependence on solar zenith angle, ozone, etc) and to assess a particular biological effect, an action spectrum that gives the sensitivity of wavelength dependent UV change is to be considered (Micheletti et al., 2003). Once an action spectrum was developed based on the wavelength, the biologically effective irradiance E_λ can be calculated (Parisi et al., 2003) where E_λ represent the incoming UV flux at wavelength λ and S_λ represent the spectral response to a particular effect at wavelength λ. The integration range depends on the corresponding band of wavelengths considered (Wong and Parisi, 1999). For different biological effects, the values of S_λ are calculated and the corresponding effective irradiances E_{eff} were estimated and their analysis with respect to zenith angle was reported by Prasad et al. (2010).

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

REGRESSION TECHNIQUE

The goal of regression analysis is to determine the values of parameters for a function that cause the function to best fit a set of data observations that one provides. In linear regression, the function is a linear (straight-line) equation. For example, if we assume that a variable (UV-B irradiance) increases by a constant amount each year depending on two other variables (ozone and solar zenith angle) which are independent of each other, the following linear function would predict its value as a function of the two independent variables.

For an analysis such as this, we must provide a data file containing the values of the dependent and independent variables for a set of observations. In this example, each observation data record would contain three parameters UV-B, Ozone and solar zenith angle for different days. The more observations you provide, the more accurate will be the estimate of the parameters.

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

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

where a is the regression constant, RAF and c are the regression coefficients and u is the disturbance term, which has $N(O,\sigma^2)$ distribution. Further, RAF is known as Radiation Amplification Factor which expresses the dependence of UV-B flux on total ozone and is given by

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

(Martin, 2000)

Equation (2) can also be 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. Equation (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 deviation form (4) can be expressed as

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

Using 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 $x_{i2} = X_{i2} - \overline{X_2}$ etc. (Johnston, 1984)

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

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

RESULTS AND DISCUSSION

Variation of erythemal irradiance with solar zenith angle

The variation of biologically effective erythemal irradiance with respect to ozone is given by RAF which is defined as the percentage increase in the incoming biological UV for a given species that would result from a 1% decrease in the amount of total columnar ozone (Madronich et al., 1998). RAF values indicate the sensitivity of a particular biological effect to the corresponding change in ozone. Madronich et al. (1998) reported the values of RAF's for different biological effects with the help of different action spectra. They also studied the trends in biologically active radiation (Erythema) by using the action spectrum suggested by McKinlay and Diffey (1987) and TOMS ozone data (1978 to 1992) for various latitudes and reported that for latitudes lying between 10° to 20°N where the current station Visakhapatnam (17.7° N) lies have 0% change per decade and for latitudes lying between 20° and 30°N, it is having 1% change per decade. The change in RAF for erythemal irradiance at Visakhapatnam is reported to decrease from 7.2 to 2.5 with increase in solar zenith angle from 10° to 54° (Krishna et al., 2010). The values of RAF for various biological effects like DNA damage, etc., indicate almost 2.5% decrease for corresponding increase of 1% in

Table 1. (Values corresponding to the model developed with actual values of TOMS Ozone and UV-B irradiance measured at Visakhapatnam in 1990 as inputs).

Solar zenith angle (°)	a	c	RAF
12.5	44.32	-0.09	7.20
17.5	36.20	-0.02	5.94
27.5	18.63	-0.03	2.78
37.5	16.87	-0.02	2.56

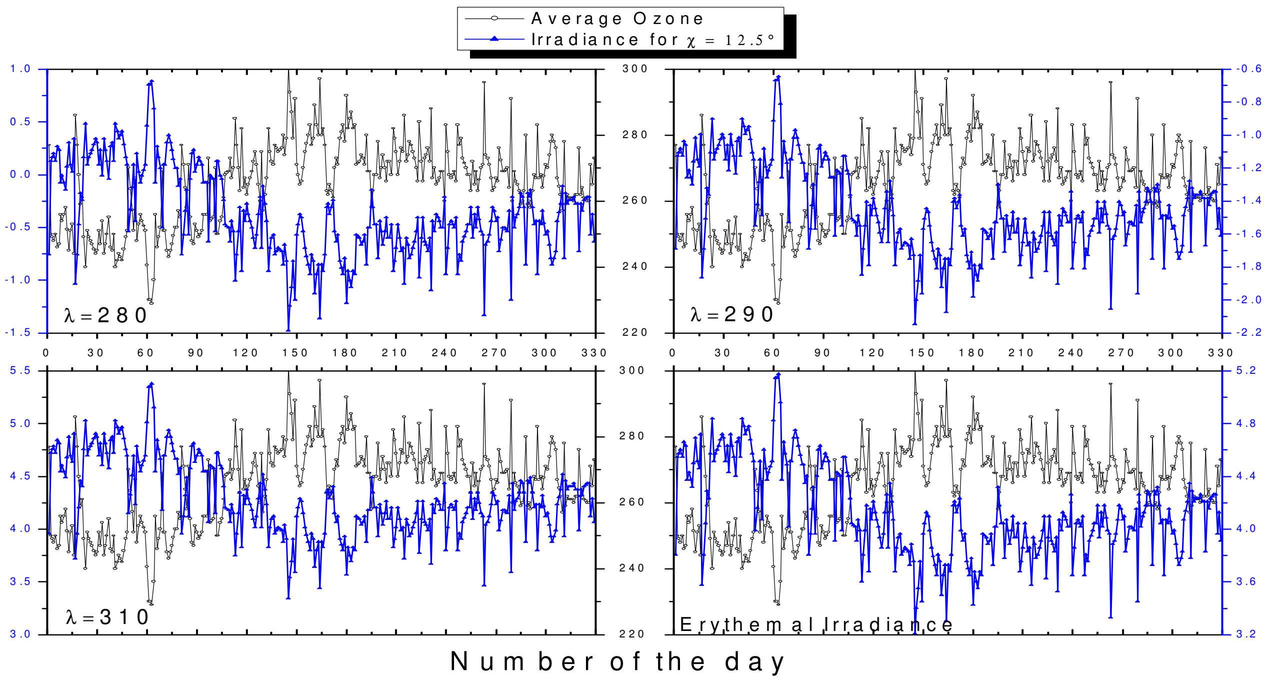

Figure 1. Variation of estimated irradiance with ozone for three wavelengths (280, 290 and 310 nm) and variation of erythemal irradiance with ozone as a function of solar zenith angle (12.5°).

ozone. This paper reports the variation of estimated erythemal irradiance at Visakhapatnam by taking the inputs Table 1. These values correspond to the model developed with actual values of TOMS Ozone and UV-B irradiance measured at Visakhapatnam in 1990 as inputs. In addition to these values, satellite measured TOMS ozone for the year 2010 is taken as input and the corresponding erythemal irradiance was estimated. Graphs plotted indicate the variation of erythemal irradiance as a function of ozone corresponding to various solar zenith angles. It is observed that the erythemal irradiance and ozone are inversely correlated with a range of 80 to 87% for different solar zenith angles.

Variation of UV-B Irradiance with ozone for different wavelengths

Traditionally, action spectra have been developed for very different purposes than evaluating biological effects corresponding to ozone reductions. Action spectra allow a photo-biologist to draw some conclusions regarding the biological pigment or molecule that absorbs the radiation and mediates the effect within an organism. The criteria often used to develop action spectra are directed to this traditional use in photobiology and these, along with many technical constraints, limit the usefulness of 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 varies strongly with wavelength (Figures 1-4; Madronich et al., 1998, Micheletti et al., 2003). Hence the variation of ozone along with 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.

The values of RAF, a and c for different solar zenith

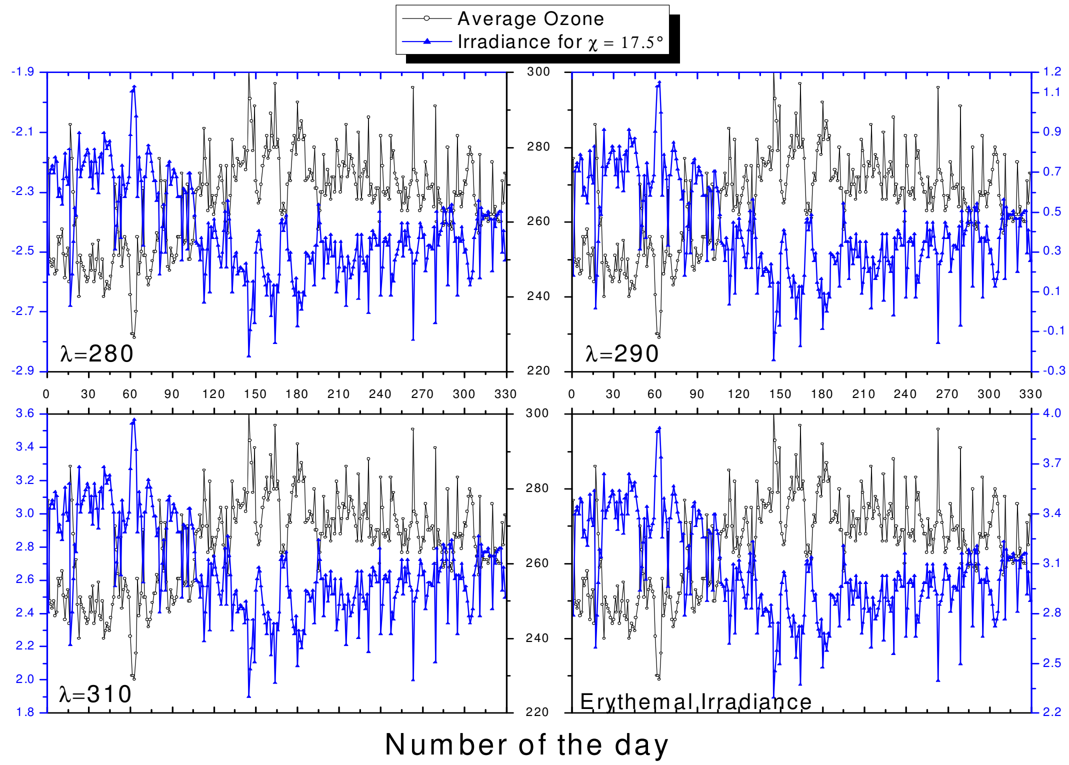

Figure 2. Variation of estimated Irradiance with ozone for three wavelengths (280, 290 and 310 nm) and variation of erythemal irradiance with ozone as a function of solar zenith angle (17.5°).

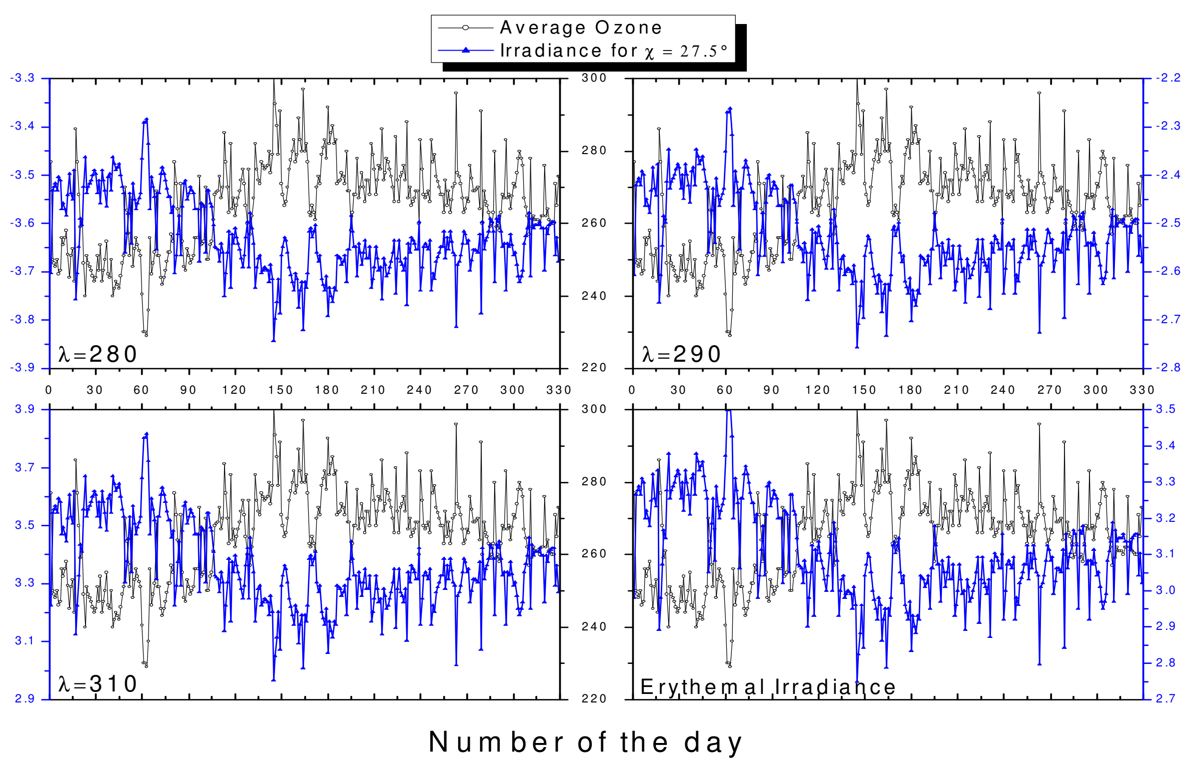

Figure 3. Variation of estimated irradiance with ozone for three wavelengths (280, 290 and 310 nm) and variation of erythemal irradiance with ozone as a function of solar zenith angle (27.5°).

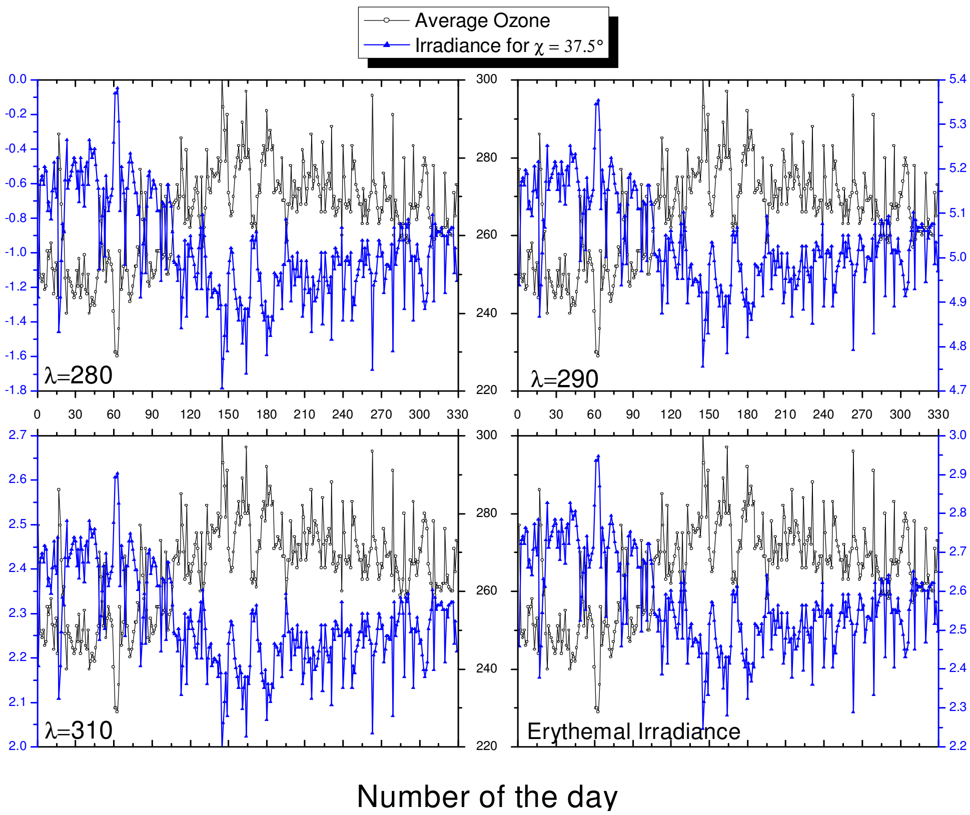

Figure 4. Variation of estimated irradiance with ozone for three wavelengths (280, 290 and 310 nm) and variation of erythemal irradiance with ozone as a function of solar zenith angle (37.5°).

Table 2. (Values corresponding to the model developed with values of TOMS Ozone and UV-B irradiance measured for three wavelengths at Visakhapatnam in 1990 as inputs).

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

angles for different wavelengths is given in Table 2. These values correspond to the model developed with values of TOMS Ozone and UV-B irradiance measured for three wavelengths at Visakhapatnam in 1990 as inputs. In addition to these values, satellite measured TOMS ozone for the year 2010 is taken as input and the corresponding UV-B irradiance was estimated. Graphs plotted indicate the variation of estimated UV-B irradiance as a function of ozone corresponding to various wavelengths at fixed solar zenith angles. It is observed that the estimated UV-B irradiance and ozone are inversely correlated with a range of 72 to 80% for different wavelengths at fixed solar zenith angles.

Conclusion

The present paper estimates the incoming irradiance at Visakhapatnam for the year 2010 by substituting TOMS ozone as one input, fixed solar zenith angle as one input and the corresponding RAF values as other input into the regression model developed exclusively for this station. The graphs show inverse correlation between ozone and estimated UV-B irradiance up to 80%. Erythema is one of the biological effects that affect human skin and hence the analysis was mainly focused on erythema. Similarly, the graphs indicate the variation of erythemal irradiance with ozone as a function of solar zenith angle was found to be inversely correlated up to 87%. These results indicate that the regression model developed for this station long back 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, the results need to be compared with measurements made by a ground based instrument to obtain more efficiency.

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