Geofísica Internacional
ISSN: 0016-7169
silvia@geofisica.unam.mx
Universidad Nacional Autónoma de México
México

Guarnieri, Ricardo André; Guarnieri, Fernando Luís; Balbueno Contreira, Danieli; Franco Padilha, Liana; Echer, Ezequiel; Pinheiro, Damaris Kirsch; Passaglia Schuch, Augusta Maria; Makita, Kazuo; Schuch, Nelson Jorge

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Geofísica Internacional, vol. 43, núm. 1, january-march, 2004, pp. 17-22
Universidad Nacional Autónoma de México
Distrito Federal, México

*Geofísica Internacional (2004), Vol. 43, Num. 1, pp. 17-22*

# Ozone and UV-B radiation anticorrelations at fixed solar zenith angles in southern Brazil

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Received: March 31, 2002; accepted: November 6, 2002

**RESUMEN**

En este trabajo se utilizaron datos del año 2000 de radiación UV-B medidos con un Radiómetro UV-B (*Eko Instruments* MS-210W) instalado en el sur de Brazil, en el Observatorio Espacial del Sur (OES/CRSPE/INPE – MCT), y datos de la columna total de ozono medidos por el TOMS (Total Ozone Mapping Spectrometer). Se compararon la concentración de ozono y de radiación UV-B para varios ángulos zenitales solares fijos. Con una selección de días claros se obtiene una anticorrelación de –0.86 para los ángulos zenitales de 70° y 55°, y de –0.97 para 40°. Así, las variaciones de ozono explicaron 74-94% de la variabilidad de UV-B durante el año 2000 en el OES. Se determinó que una disminución del 1% en la concentración de ozono produce un aumento del mismo orden en la radiación UV-B.

**PALABRAS CLAVE:** Ozono, radiación ultravioleta, ángulos solares zenitales fijos, cubierta nubosa, cielo claro.

**ABSTRACT**

Anticorrelation behavior between total ozone column and UV-B radiation was observed for clear sky conditions during the year 2000 at the Southern Space Observatory OES/CRSPE/INPE – MCT (29.44°S, 53.82°W) located in the southern part of Brazil. To eliminate geometrical dependence of the solar angular position in relation to the instrument, UV-B radiation was measured at fixed solar zenith angles. The UV-B radiation (280-315 nm) was measured by an *Eko Instruments* model MS-210W radiometer, and total ozone column data was obtained by a Total Ozone Mapping Spectrometer on board of the NASA Earth Probe satellite. Correlation coefficients varied from R = -0.86 at 70° and 55°, to R = -0.97 at 40°. Ozone variations explained 74 to 94% of the UV-B variability. A 1% reduction in ozone resulted in an increase of about 1% in UV-B for the solar zenith angles studied.

**KEY WORDS: O**zone, ultraviolet radiation, anticorrelations, fixed solar zenith angles, cloud coverage, clear sky.

## INTRODUCTION

The Sun emits a broad spectrum of radiation, but ultraviolet radiation represents a small part of its total intensity and is among the most variable components. In terms of its biological effects, ultraviolet radiation is divided in three main ranges: UV-A (315-400nm), UV-B (280-315nm) and UV-C (100-280nm) (Madronich *et al*., 1998).

UV-B radiation is strongly absorbed by stratospheric ozone, and its intensity at the surface depends on the ozone layer concentration (Madronich *et al*., 1998). UV-B radiation has been reported to cause skin cancer, ocular damages and other effects on human health as well as in animal and plants (Roy *et al*., 1994; Kane *et al*., 1998; Madronich *et al*., 1998; van der Leun *et al*., 1991, 1994, 1998).

Reduction of the atmospheric ozone concentration and UV-B radiation increase were observed over the Antarctic Continent, due to the Antarctic Ozone Hole phenomenon (Frederick and Snell, 1988; Lubin and Frederick, 1989a, 1989b; 1991; Roy *et al*., 1994; Kirchhoff and Echer, 2001). Secondary effects of the ozone hole over South America have been reported (Bojkov *et al*., 1995; Kirchhoff *et al*., 1996, 1997).

The natural variation of UV radiation intensity on the Earth's surface is dependent on geometrical factors (solar zenith angle, Earth-Sun distance, altitude and latitude) and atmospheric factors (cloud coverage, aerosols and ozone content) as well as on ground albedo (Díaz *et al*., 2000). In normal conditions of ozone, the UV-B radiation variation depends mainly on cloud coverage and solar zenith angle (Lenoble, 1993; Blumthaler *et al*., 1994). The annual solar zenith angle variation is greater in high latitudes, thus leading to a large seasonal variation in UV-B radiation.

UV-B radiation is continuously measured by the UV-B radiometer at the Southern Space Observatory - OES/CRSPE/INPE – MCT (29.44°S, 53.82°W) in São Martinho da Serra, Rio Grande do Sul, in southern Brazil (Schuch *et al*., 1997) since July 1999. The main objective of the present work is estimating the anticorrelation between ozone concentration and UV-B at fixed solar zenith angles during the year 2000 at the Southern Space Observatory.

## METHODOLOGY

UV-B radiation measurements used in this work were obtained by a MS-210W model radiometer manufactured by Eko Instruments Co. (Eko Instruments, 1999, 2000) installed at Southern Space Observatory. The equipment measures the broad band radiation in the interval of 280 - 315 nm that corresponds exactly to UV-B range.

This equipment was developed for meteorological measurements (non-weighted spectrum), consisting of a sensor associated with several optical devices as diffusers, interference filters, fluorescent lens and blockage filters. The sensor output corresponds to a DC voltage level proportional to global UV-B radiation incident on the diffuser, located inside the quartz dome. The equipment is connected to a data acquisition system able to collect data for a period of about 23 days. The data are recorded at a sample rate of one measurement per minute.

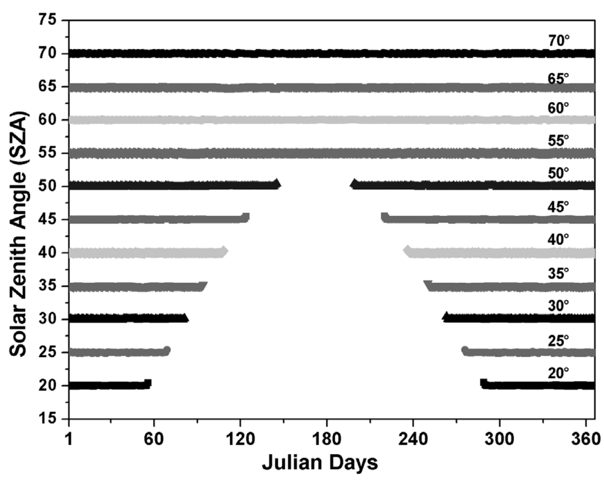


Fig. 1. Solar Zenith Angles occurrence periods over the year 2000, at the OES/CRSPE/INPE – MCT.

The clouds attenuate the intensity in the ultraviolet band (Lenoble, 1993; Blumthaler *et al*., 1994; Díaz *et al*., 2000) hindering its direct correlation with ozone. Previous studies showed that the correlation coefficients obtained using all data of the year 2000, including cloudy days, were very small. For example, at solar zenith angle of 55° the correlation coefficient obtained was R = -0.20 (Guarnieri *et al*., 2001). Therefore, only the UV measurements performed in clear sky conditions were used in this work. The selection of clear sky days was based in a visual inspection of the radiometer daily curves. The Figures 2 and 3 show, respectively measurements in conditions of clear and cloudy sky days taken out by the radiometer. Only 35 out of 366 days inspected showed daily variation similar to that one seen in Figure 2 and these 35 days were selected for further analysis.

An algorithm was implemented in C language to determine the exact occurrence time for each solar zenith angle

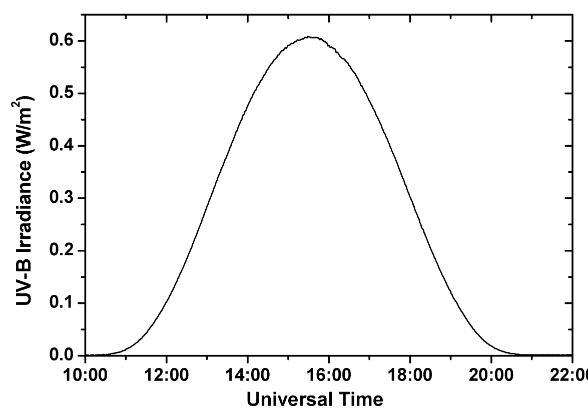


Fig. 2 UV-B daily behavior in conditions of clear sky (June14,2000).

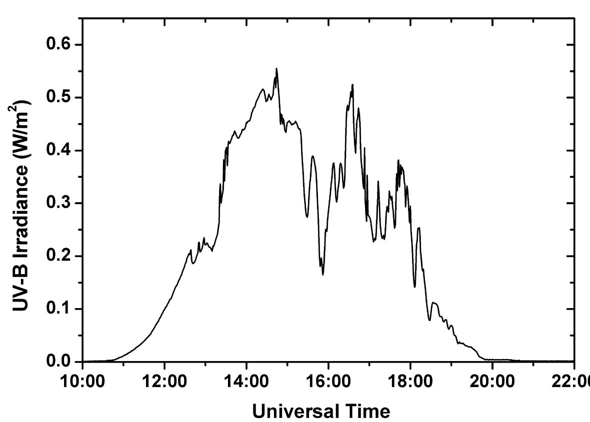


Fig. 3. UV-B daily behavior in conditions of cloudy sky (June15, 2000).

chosen in the year 2000. The radiometer acquires data at 1 minute rate. It is important to mention that when the zenith angle of interest occurs twice a day (in the morning and in the afternoon) the algorithm only choose the first appearance, that is in the morning.

A second implemented algorithm finds the value and time of UV-B intensity (in W/m$^2$) from the daily radiometer data files for the chosen solar zenith angle. The result is a file for each solar zenith angle consisting of UV-B measurements for the 35 days selected by the visual inspection.

The Total Ozone Mapping Spectrometer – TOMS, currently installed on board of NASA's Earth Probe Satellite has been measuring the Total Ozone Column since 1996 in indirect way, through the mapping of the Ultraviolet light emitted by the Sun and scattered by the Earth's atmosphere back towards the satellite (London, 1985; NASA/TOMS, 2000).

The daily ozone data used in this work, in Dobson Units (DU), was obtained through TOMS/NASA *webpage - http://jwocky.gsfc.nasa.gov.*

## RESULTS

The fixed solar zenith values used in this work can be seen in the Figure 1 together with its occurrence periods during the year 2000 at Southern Space Observatory (Observatório Espacial do Sul - OES). Due to the latitude of the Southern Space Observatory it was verified that small zenith angles do not occur in winter time and only angles greater than approximately 52° can be observed along the whole year.

After collecting the daily ozone data and UV-B radiation intensities for each fixed solar zenith angle for the 35 days with clear sky conditions, direct comparisons between these measurements were performed.

The correlation coefficients were calculated by using percentage variations of ozone (DU) and UV-B (W/m$^2$) in relation to the average of these parameters in the analyzed data group for each solar zenith angle. Figure 4 show an example for the fixed solar zenith angle of 55°. The percentage variations were calculated through the following relations:

$$\Delta_{Ozone} = (O_3^{Day} - O_3^{Average})*100 / O_3^{Average} \quad (1)$$

$$\Delta_{UV\text{-}B} = (UV^{Day} - UV^{Average})*100 / UV^{Average}. \quad (2)$$

In these expressions, $\Delta_{Ozone}$ and $\Delta_{UV\text{-}B}$ represent, respectively, the daily deviation in relation to the ozone and UV-B radiation averages in percentage. $O_3^{Day}$ is the TOMS daily data, in Dobson Units, and $UV^{Day}$ is the radiometer daily data, in W/m$^2$, for each fixed solar angle. $O_3^{Average}$ and $UV^{Average}$ are, respectively, the total ozone column and UV-B radiation averages values for the data group used in each fixed angle.

For a better visualization of the anticorrelation behavior, a linear fit (y = A + B*x) adjustment was applied. For each solar zenith angle, it was determined the slope of the line (B) and the point in the line crossed by the y-axis (A) for the adjusted curve as well as the correlation coefficients (R). These values are presented in the legend of Figure 4.

As can be seen in Table 1, the number of points of each fixed solar zenith angle is different due to the fact that angles smaller than 52 degrees do not occur along the whole year at the OES latitude.

In Figure 4, it can be observed that the function fit is a line crossing near the origin. In Table 1, it is observed that the A values are quite smaller than twice Error-A values. It means that the A is near to zero (y ≅ B*x). Thus, the B values correspond to an estimation of the increases in UV-B percentage relative to ozone reduction of about 1%.

It was also observed that the calculated correlation coefficients presented high values, resulting in R = -0.86 ($R^2$ = 0.74) for 70° solar zenith angle, and R = -0.97 ($R^2$ = 0.94) for 40° solar zenith angle. The correlation coefficients were statistically significant at 99% confidence level using the t test as shown in Table 1. This confirms the anticorrelation behavior between the data and validates what was mentioned in the previous paragraph.

By the percentage of the $R^2$ values it was observed that 74% to 94% of the UV-B variations were explained consid-

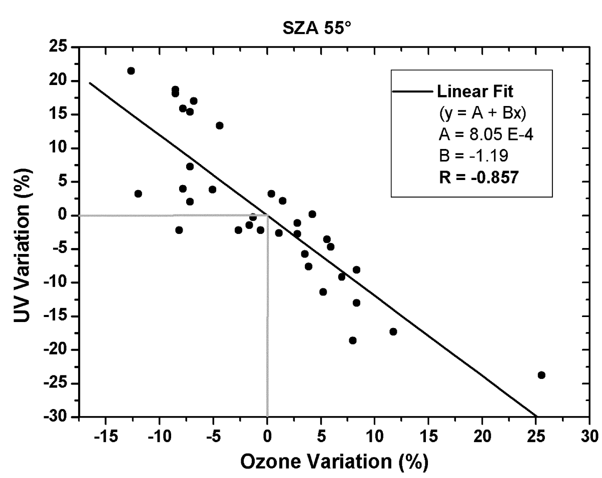


Fig. 4. Correlation for 55° solar zenith angle for year 2000.

**Table 1**

Correlation coefficients (R) and their Confidence Levels (CL), and A and B values for the Linear Fits (y = A + Bx) with their error values for each Solar Zenith Angle (SZA).

| SZA | Points | A | Error-A | B | Error-B | R | CL |
|---|---|---|---|---|---|---|---|
| 20° | 13 | -4.59E-5 | 0.702 | -0.87 | 0.122 | -0.91 | 99% |
| 25° | 16 | 2.44E-4 | 0.607 | -1.05 | 0.094 | -0.95 | 99% |
| 30° | 17 | 2.54E-4 | 0.627 | -1.17 | 0.090 | -0.96 | 99% |
| 35° | 17 | -4.93E-5 | 0.632 | -1.21 | 0.091 | -0.96 | 99% |
| 40° | 19 | -3.02E-4 | 0.600 | -1.37 | 0.087 | -0.97 | 99% |
| 45° | 23 | -4.98E-4 | 0.964 | -1.26 | 0.142 | -0.89 | 99% |
| 50° | 32 | 6.35E-4 | 0.954 | -1.18 | 0.123 | -0.87 | 99% |
| 55° | 35 | 8.05E-4 | 0.968 | -1.19 | 0.125 | -0.86 | 99% |
| 60° | 35 | 7.40E-4 | 0.989 | -1.29 | 0.127 | -0.87 | 99% |
| 65° | 35 | -7.94E-7 | 0.968 | -1.39 | 0.125 | -0.89 | 99% |
| 70° | 35 | -1.91E-3 | 1.174 | -1.43 | 0.151 | -0.86 | 99% |

ering only ozone variations at fixed solar zenith angles and clear sky conditions at OES during the year 2000.

Figure 5 shows the total ozone column (in Dobson Units) and UV-B radiation (in W/m$^2$) seasonal behavior for the solar zenith angle of 55°. It can be clearly seen the opposite behavior between the data. For instance, a very high ozone value equal to 365 DU (the highest value of the black line) corresponded to a very low UV-B intensity value equal to 0.41 W/m$^2$ (the smallest value of the gray line) on July 19.

The ozone and UV-B seasonal behavior, in terms of percentage variations and in relation to the averages, is presented in Figure 6. For the same day (July 19), the ozone increases in relation to the average was about 25.5% which corresponded to an UV-B reduction of about 23.8%. On April 24, a value of about 7.1% smaller than the ozone average caused an UV-B increase of about 7.2%.

All studied correlations, using ozone data, in Dobson Units, and UV-B radiation, in W/m$^2$, instead of percentage variations are represented in the Figure 7. Each points group and linear fit correspond to an analyzed solar zenith angle. The values, in parenthesis, beside each solar angle are representing the percentage variations caused in UV-B for an ozone variation of about 1%. These values were determined using the slope of line (B) obtained by linear fits of each fixed solar zenith angle showed in the Table 1.

## CONCLUSIONS

In order to study ozone and UV-B correlations independently of others factors, a filtering method was employed

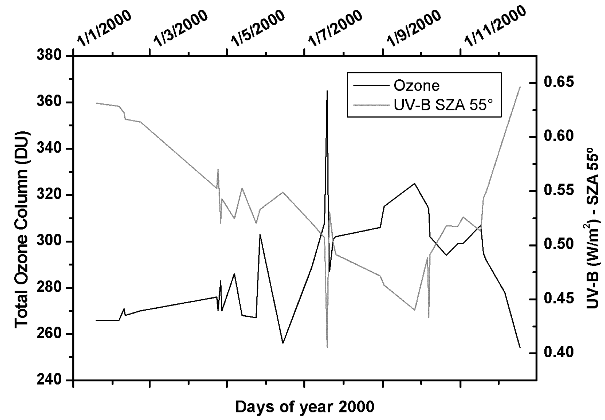


Fig. 5. Total Ozone Column (Dobson Units) and UV-B radiation (W/m$^2$) seasonal behavior for 55° solar zenith angle, using 35 clear sky condition days for year 2000.

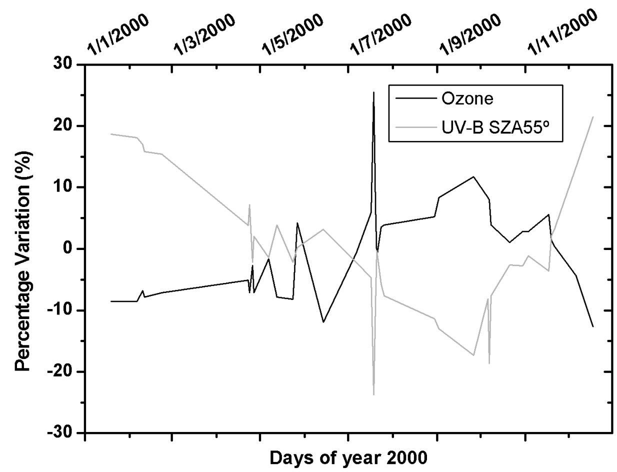


Fig. 6. Seasonal behavior of Ozone and UV-B percentage variations, in relation to the averages.

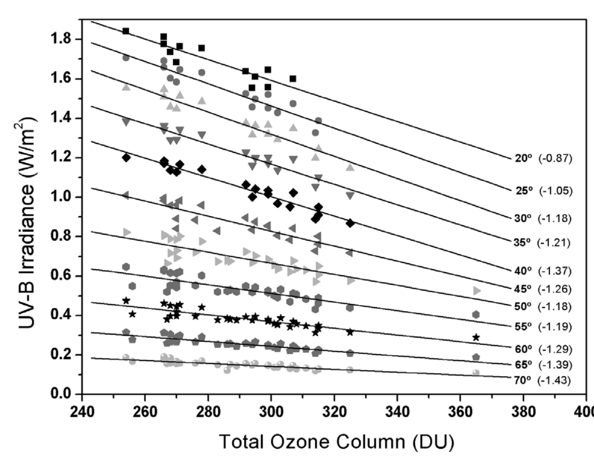


Fig. 7. UV-B Irradiance measurements as a function of Total Ozone. Data are grouped according to solar zenith angle. Values in parentheses indicate the percent change in UV-B for a 1% change in Total Ozone (B values indicated in Table 1).

to remove the cloud effect (using data obtained only in clear sky conditions) and the geometrical effect of the solar angle (using fixed solar zenith angle).

With the selection of clear sky conditions data group, it was observed a considerable improvement of the correlation coefficients in relation to those obtained when using whole year data. For example, the correlation coefficient obtained for the solar zenith angle of 55° was R = -0.20 when whole year data were used. Using the clear sky data group, it was obtained a correlation coefficient of R = -0.86.

The correlation coefficients varied between R = -0.86 for 70° and 55° solar zenith angle and R= -0.968, for 40° solar zenith angle. These values are close to those calculated by Basher *et al*. (1994) who reported correlation coefficients between 0.85 and 0.95 for UV-B measurements in clear sky conditions and ozone measured by satellite.

Decreases in total ozone column values can produce considerable UV-B radiation enhancements. In this work, it was calculated that ozone variations of about 1% produce increases in total UV-B radiation between 0.87 – 1.43%.

At fixed solar zenith angle and clear sky conditions the ozone variations explained 74 to 94% of the UV-B variability during the year 2000 in the OES.

## ACKNOWLEDGEMENTS

The authors are grateful to National Institute for Space Research (INPE) and to Brazilian Space Agency (AEB/MCT) for providing resources and infrastructure, to NASA/TOMS Program for making the ozone data available, to Takushoku University (Japan) for lending the UV-B radiometer MS-210W installed at the Southern Space Observatory (OES/CRSPE/INPE – MCT) through an International Cooperation between Brazil and Japan, and also to Prof. Dr. Nalin B. Trivedi and Dr. Lúcia Schuch Boeira for important suggestions and to the following institutions for financial support: Federal University of Santa Maria (UFSM), MMA, FINEP, CNPq, FAPERGS and CAPES.

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