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Effect of Stratospheric Ozone in UVB Solar Radiation Reaching the Earth's Surface at Qena, Egypt

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ABSTRACT

This study describes the relationship between UVB and total ozone column (*TOC*) at a subtropical location through the period from 2001 to 2005. To analyze the relationship between *TOC* and UVB, the dimensionless parameter UVB transmission (K_{tUVB}) and slant total ozone column (Z) were estimated. The results show an opposite seasonal behavior for K_{tUVB} and Z in all sky conditions at Qena, Egypt (26.20°N, 32.75°E, 96 m above sea level). In order to quantify the UVB transmission variations produced by slant path ozone changes (Z), a linear regression between these two variables for cloud–free cases were employed. The correlation (r^2) of this relationship was equal to 0.7 for the daily values. In addition, this value (r^2) was increased for the monthly average (0.8). This study led to the values of UVB Radiation Amplification Factor (RAF) for the daily and monthly mean values in cloudless sky conditions that were equal to 1.0014 and 1.05, respectively.

Keywords:
Total ozone column
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1. Introduction

UV radiation refers to a specific portion of the Sun's energy reaching the Earth's surface. It could be simply stated that UV radiation is that portion of the electromagnetic spectrum between 100–400 nm. It is known that UV highly varies at Earth's surface. Kerr (2005) and WMO (2003) explained all the factors that affect surface UV solar radiation. They mentioned that the absolute intensity of UV irradiance at the Earth's surface as a function of wavelength is proportional to the solar spectrum. Other factors that affect the intensity and angular distribution of surface UV irradiance are geometrical and geophysical variables. The geometrical variables are the distance between the Earth and Sun and the solar zenith angle of the Sun at a specific time and location on the Earth's surface. Geophysical variables include atmospheric constituents that absorb or scatter radiation as it passes through the atmosphere or scatter radiation at the Earth's surface. The UVB (280–320 nm) and UVC (100–280 nm) radiation represents that portion of the spectrum that is capable of damaging biological organisms. At surface the UV effectiveness in producing a biological response, include also UVA (320–400 nm) although the maximum effectiveness is at shorter wavelengths i.e. UVB. UVC is completely absorbed in the upper atmosphere. In addition, the UV wavelengths most affected by ozone reductions are in the UVB band with some effect also in the UVA. Radiation at shorter wavelengths is absorbed completely by even relatively small amounts of ozone and by atmospheric oxygen.

The potential for increased solar ultraviolet (UV) radiation reaching the Earth's surface in response to ozone reduction has been a major concern since the first signs of ozone depletion in the early 1980s (WMO, 2007). The influence of stratospheric ozone on the transmission of UV radiation through the atmosphere is well understood and has been extensively discussed in several studies and the ozone assessments (Herman et al., 1999; Newchurch et al., 2003; WMO, 2007). New evidence for increases of surface UVB radiation due to stratospheric ozone depletion in Antarctica, particularly during the period of the ozone hole in spring, has been reported from observations (Bernhard et al., 2004; Bernhard et al., 2006). In addition, summertime enhancements of surface UV were reported also at northern high latitudes during episodes of low ozone in the stratosphere caused by chemical destruction and transport processes (Galliani et al., 2002; Orsolini et al., 2003). The summertime UV irradiance at southern midlatitudes greatly exceeds that at northern midlatitudes. On the other hand, global ozone measurements from satellites imply significant UVB increases at high and midlatitudes of both hemispheres, but only small changes in the tropics. Such estimates however assume that cloud cover and tropospheric pollution have remained constant over these years (Madronich et al., 1994). Stratospheric ozone levels in both the polar and non–polar regions are near their lowest point since measurements began in the 1970's. Current UVB radiation levels show increases relative to the values in the 1970's (UNEP, 1998; UNEP, 2007). However, reductions in stratospheric ozone allow more UVB radiation to reach the Earth's lower atmosphere and surface.

The protection of the Earth's living systems from UVB and UVC radiation is a result of the absorption of this radiation by ozone. While there is some ozone in the lower atmosphere (troposphere), it is small compared to the amount in the stratosphere. It is not the purpose of this study to discuss the chemistry that has resulted in reductions of stratospheric ozone but to describe how changes in the ozone layer can affect the UVB solar radiation. The most important factor is the total amount of ozone that solar radiation encounters before reaching the Earth's surface. This is referred to as "column ozone" since it is the total amount of ozone in a column between the Earth's surface and the top of the stratosphere. This is normally expressed as Dobson Units (DU). The amount of ozone the radiation passes through is dependent not only on its concentration in the atmosphere but also dependent on the elevation above sea level and the angle of the Sun with respect to a point on the Earth's surface. The higher the elevation above sea level, the shorter is the path through the atmosphere that the radiation has to travel. This results in increasing irradiance. The lower the Sun is in the sky, the longer the path through the atmosphere and the greater the amount of ozone the radiation encounters as it passes to the Earth's surface thus lowering the irradiance. The angle of the Sun depends on three factors: the latitude, the time of year, and the time of day. This angle is referred to as the solar zenith angle (SZA) and is the angular difference in degrees between directly overhead and the Sun's actual position.

The main objective of this work is to describe how changes in the ozone layer could affect the UVB solar radiation at Qena, Egypt through the period from 2001 to 2005. Thus, the relationship between the amount of solar UVB reaching the Earth's surface and the total ozone column was investigated.

2. Data and Methods of Analysis

2.1. Measured data

Egyptian Meteorological Authority (EMA) in cooperation with South Valley University (SVU) has measured the global solar radiation, broadband UVB radiation and other meteorological parameters. The EMA is responsible for the scientific advice and calibration of the Egyptian Monitoring Network. Hourly values (hour integral irradiance in MJ m^{-2} h^{-1}) of UVB and global solar radiation (G) at the horizontal surface were collected at SVU-meteorological research station through the period from 2001 to 2005. This station is located at Qena, Egypt (26.20°N, 32.75°E, 96 m above sea level) and can be defined as an urban site. The Model UVB-1 Ultraviolet broad band radiometer No., 960842, Yankee Environmental Systems, Inc. (YES) was used to measure the total irradiance from 280 to 320 nm. In addition, the Precision Spectral Pyranometer (PSP) No., 16317IS (an ISO 9060 secondary standard Pyranometer spectral range 295–2 800 nm) used for the precise measurement of global solar radiation. The PSP is the most common Pyranometer used by National Meteorological Authorities in worldwide meteorological networks. The Combilog Datalogger (No. 1020, TH. Friedrichs & CO., Germany) recorded the values of hourly UVB and G. The accuracy of the pyaranometers corresponds to the first class according to the World Meteorological Organization classification (WMO, 1990). These instruments are calibrated each year against a reference instrument traceable to the World Radiometric Reference (WRR) maintained at Davos, Switzerland (WRC, 1985; WRC, 1995). The absolute accuracy of calibration is ±3-4%, (El–Metwally, 2004). The resolutions of these instruments are 1 W m^{-2}.

Ozone measurements were supplied from a site within several hundred kilometers of Qena (220 km) at Hurgada (27.23°N, 33.8°E). Hurgada and Qena are within the satellite spatial resolution (the horizontal spatial resolution is 1 latitude×1.25 longitudes). Data of Total Ozone Mapping Spectrometer (TOMS) instruments were used that are provided by NASA Goddard Space Flight Center (NASA, 2010a). Version 8 of the TOMS processing algorithm was used (NASA, 2010b). TOMS observes the backward scattered Earth solar radiance in several bands. This information is used to estimate spatially distributed daily values of total ozone column amount expressed in Dobson Units (DU) (McPeters et al., 1998; Serrano et al., 2008; Anton et al., 2009). McPeters et al. (1998), Serrano et al. (2008), and Anton et al. (2009) used TOMS data to study the relation between the atmospheric ozone and erythemal ultraviolet irradiance between 280 and 400 nm (UVER). In addition, McPeters et al. (1998) concluded that the TOMS global ozone is about only 1% higher than the ground measurements in 30 mid–northern latitude stations. Furthermore, Fioletov et al. (2002), Masserot et al. (2002), Balis et al. (2006), Ialongo et al. (2008), and Kazadzis et al. (2009) illustrated a good agreement between satellite and ground based ozone data. TOMS (Earth Probe: 1996–2005) pass over Hurgada approximately between 10:00 and 12:00 UTC, thus the used ground data of UVB represents an average for values recorded in the mentioned interval. Similarly, solar zenith angles were averaged for the mentioned interval. As a result, this study deals with 1 552 simultaneous data of UVB, G and total ozone column (TOC) through the period from 2001 to 2005. The used data represented varied values of solar zenith angles ≤60°. The values of UVB and those of single daily TOMS ozone could be taken as the representative value for the whole 2–h period. This means that all data used in this work are obtained as a daily average between 10:00 and 12:00 UTC.

2.2. Estimated data

Hourly values of hemispherical transmittances for UVB (280–320 nm) and G (K_{tUVB} and K_t, respectively) were estimated during the period from 2001 to 2005. K_t is known as clearness index. It is defined as the ratio of global solar radiation on a horizontal surface at the ground (G) to the corresponding quantity outside the Earth's atmosphere (G_{ext}) (El-Nashar, 1991):

$$K_t = \frac{G}{G_{ext}} \tag{1}$$

where G_{ext} (MJ m^{-2} h^{-1}) is computed in the hour from astronomical formula as in the following equation (FAO, 2006):

$$G_{ext} = \frac{12*60}{\pi} I_{sc}\left[1+0.33\cos(\frac{2\pi D_n}{365.25})\right]\left[(\omega_2-\omega_1)\sin\phi\sin\delta\right] \\ \left[(\sin\omega_2-\sin\omega_1)\cos\phi\cos\delta\right] \tag{2}$$

where I_{sc} is the solar constant, φ is the geographical latitude of Qena (26.2°), D_n is the day number, δ is the solar declination and ω_i (i=1 and 2) is the solar hour angle at the beginning of period and at the end of period, respectively.

Foyo-Moreno et al. (1998) have estimated UV hemispherical transmittance in the following way:

$$K_{tUV} = \frac{UV}{UV_{ext}} \tag{3}$$

where UV_{ext} is the extraterrestrial UV radiation value on a horizontal surface. It is given by:

$$UV_{ext} = I_{SCUV}(\tfrac{12}{\pi})E_0 \int_{\omega_2}^{\omega_1} \sin(SEA)\, d\omega \tag{4}$$

where SEA is the solar elevation angle, E_0 is the correction factor for the eccentricity of the Earth's orbit, and I_{SCUV} is the UV solar constant. It has been obtained from the spectral values given by Frohlich and Wherli (Iqbal, 1983).

In analogue with the broadband and UV cases, UVB hemispherical transmittance can be defined in the following way (Kudish et al., 2005):

$$K_{tUV} = \frac{UVB}{UVB_{ext}} \tag{5}$$

where UVB_{ext} is the extraterrestrial UVB radiation value on a horizontal surface. It is given by:

$$UVB_{ext} = I_{SCUVB}\left(\tfrac{12}{\pi}\right)E_0 \int_{\omega_2}^{\omega_1} \sin(SEA)\, d\omega \tag{6}$$

where I_{SCUVB} is the UVB solar constant (21.51 W m^{-2}). It has been obtained from the spectral values given by Frohlich and Wherli (Iqbal, 1983).

In order to study the relationship between the amount of UVB reaching the Earth's surface and the total ozone column, it is necessary to take into consideration the other factors that are affecting the solar UVB reaching the Earth's surface such as: zenith angle, cloudiness, aerosols, surface albedo and altitude. Thus, the cases that are selected to study this relationship have nearly constant values of the other factors (Serrano et al., 2008). Clear sky cases have been selected. Most studies consider only measurements at fixed values of the solar zenith angle. However, in the present paper, UVB measurements were taken under different zenith angles. It is obvious that the UVB radiation that reaches the Earth's surface will depend on the ozone amount crossed along the actual slant path more than on the ozone amount in the vertical column. Thus, to take into account the effects of this variable, the UVB values were normalized to its extraterrestrial values and the stratospheric ozone concentration was divided by *cosine* of the solar zenith angle. Therefore, a slant ozone column (*Z*) can be introduced in this study. The slant total ozone column (DU) represents the actual ozone amount in the atmosphere that the solar radiation passes through. Serrano et al. (2008) and Anton et al. (2009) have defined it as follows:

$$Z = \frac{TOC}{\mu} \tag{7}$$

Although Equation (7) is valid only for the direct solar irradiance, Anton et al. (2009) have used it as a good approximation for the global solar irradiance (direct+diffuse). Their argument refers to the largest part of ozone absorption that occurs at high altitudes before the scattering processes by aerosols and clouds.

Similarly, Serrano et al. (2008) have used slant ozone column to propose a natural expansion of Radiation Amplification Factor (*RAF*) for UVER to consider all solar zenith angle cases together. *RAF* is a useful indicator of the sensitivity of UVER to ozone changes. High *RAF* values indicate that the UVER values are strongly sensitive to changes in stratospheric ozone, while small RAF values indicate that UVER is less sensitive to ozone changes. In this direction, they analyzed the relationship between measurements of UVER recorded at Badajoz, Spain and the total ozone column estimated by the instrument TOMS/NASA for that location during the period from February 2001 to December 2005. The new *RAF* parameter is formulated by power equation using slant ozone (*Z*) and UVER atmospheric transmission (K_{tUVER}) values as follows (Serrano et al., 2008):

$$K_{tUVER} = CZ^{-RAF} \tag{8}$$

where *C* is related to other atmospheric constituents that also scatter and absorb UVER, such as cloudiness, aerosols and tropospheric ozone.

In analogue with the UVER case, it is possible to use *Z* to quantify the relationship between UVB transmission (K_{tUVB}) and the total ozone column. Thus, Equation (8) can be written as follows:

$$K_{tUVB} = CZ^{-RAF} \tag{9}$$

In addition, the determination of the Radiation Amplification Factor for UVB (*RAF*) can be estimated. *RAF* is considered one of the frequently used means that is used to express the impact of ozone depletion on UVB values. RAF is defined as the percentage increase in UVB that would result from a 1% decrease in the column amount atmospheric ozone (McKenzie, 1991). Thus, it was proposed to study the relationship between atmospheric ozone and UVB. In addition, it has been used widely as a useful parameter during the last years (Serrano et al., 2008; Anton et al., 2009). Values of *RAF* for various biological processes are reported in Madronich et al. (1998).

3. Results and Discussions

More details about the evolution of UVB values at ground level in Qena can be found in the works by Adam and El Shazely (2007), Basset and Korany (2007), and Robaa (2008). Robaa (2008) studied the distribution of the daily values of UVB solar radiation at ground level in this area. On the other hand, Abdelmegeed et al. (2004) and Kassem (2009) discussed the ozone variability over Qena. The purpose of this study is not to discuss the variability of the total ozone column *TOC* and UVB solar radiation but to describe how changes in the ozone layer can affect the UVB solar radiation reaching to the ground level. Figures 1 and 2 summarize only the daily variation of *TOC* (DU) and UVB values in Qena through the period from 2001 to 2005. Table 1 concludes the monthly, seasonally and completely period average and standard deviation of both *TOC* and UVB.

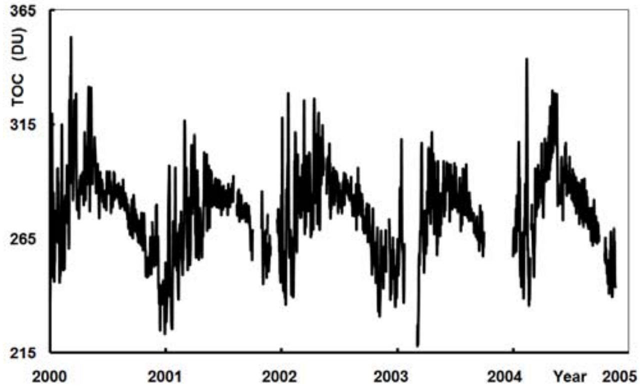

Figure 1. *Daily variation of total ozone column (TOC) at Hurgada through the period from 2001 to 2005.*

Through the period from 2001 to 2005, *TOC* showed an average of 277±18 DU. Maximum total ozone column (*TOC*) was 353 DU in 8 March 2001, while the minimum ozone concentration became 223 DU and occurred in 28 December 2001. The ozone seasonal cycle of the whole period is shown in Figure 1. TOC is maximum in springtime while the minimum value occurred in autumn. The average of TOC through the spring and autumn were 288±13 DU and 257±10 DU, respectively. The seasonal variation of the UVB values in all sky conditions differs according to the variations of the solar zenith angle accompanied by spikes due to the effect of clouds (Figure 2). Maximum and minimum values of UVB were observed as 0.0150 MJ m^{-2} h^{-1} and repeated for 10 different days (through the summer and late springtime) and 0.0010 MJ m^{-2} h^{-1} on 22 January 2004, respectively. The daily average of UVB through the summer and autumn were

0.0122±0.0015 MJ m^{-2} h^{-1} and 0.0053±0.0025 MJ m^{-2} h^{-1}, respectively. UVB showed an average of 0.0098±0.0035 MJ m^{-2} h^{-1} through the period of this study.

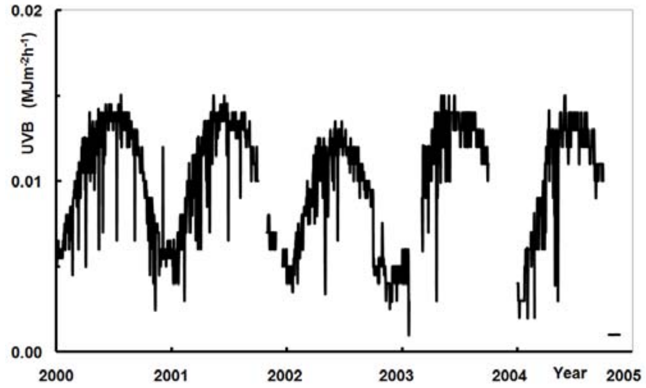

Figure 2. *Daily mean variation of the UVB values averaged between 10 and 12 UTC hours at Qena through the period from 2001 to 2005.*

Table 1. *Monthly, seasonal and complete period mean of both TOC and UVB, standard deviation (SD) and number of days (n) through the whole period of this study (2001- 2005)*

Period of time	UVB (MJ m^{-2} h^{-1})		TOC (DU)		n
	Mean	SD	Mean	SD	
January	0.0053	0.0009	259	18	132
February	0.0062	0.0021	268	18	130
March	0.0088	0.0020	284	23	122
April	0.0106	0.0019	280	17	148
May	0.0118	0.0022	294	14	146
June	0.0130	0.0016	288	12	145
July	0.0132	0.0010	287	6	150
August	0.0127	0.0011	284	5	139
September	0.0118	0.0013	277	5	148
October	0.0097	0.0019	268	6	116
November	0.0051	0.0023	256	10	93
December	0.0044	0.0021	252	12	83
Winter	0.0068	0.0022	269	22	387
Spring	0.0121	0.0019	289	14	453
Summer	0.0122	0.0015	280	8	495
Autumn	0.0053	0.0025	257	11	217
2001-2005	0.0098	0.0035	277	18	1552

The relationship between total ozone column and UVB can be analyzed by considering the dimensionless parameter UVB transmission (K_{tUVB}) and slant ozone. Simultaneous variation of K_{tUVB} and Z values through the period of this study was employed. Figure 3 shows the variation of daily values for K_{tUVB} and Z in all sky conditions during the whole period of this study for Qena. The two variables show an opposite seasonal behavior. The low values of the slant ozone column during summer time produce high UVB transmission values in this season. The opposite pattern is observed during the winter. Monthly average of slant ozone column and UVB transmission values show the relationship between them in a clearer way than those of daily values. Figure 4 illustrates the variation of monthly average of slant ozone column and UVB transmission values. In winter months, UVB transmission values are lower than those in summer months. This is due to the fact that the slant ozone column crossed by UVB radiation is higher in winter than in summer. Anton et al. (2008), Serrano et al. (2008) and Anton et al. (2009) stated that the marked annual cycle of slant ozone column is mainly caused by variations in the length of the optical path due to changes on the solar elevation. In addition, Anton et al. (2008) explained that the monthly variability of the slant ozone column is mainly controlled by changes on the total ozone column which presents a higher variability during winter and early spring at middle latitude. Vaughan and Price (1991) pointed out this fact is mainly due to the variation in synoptic weather systems at middle and high latitudes that notably affect the fluctuations in lower stratosphere ozone. The opposite seasonal behavior for K_{tUVB} and Z in all sky conditions at Qena agrees with the Badajoz "38.99ºN, 07.01ºW" (Serrano et al., 2008), Caceres "39.48ºN, 06.34ºW" and Plasencia "40.06ºN, 06.04ºW" stations (Anton et al., 2009).

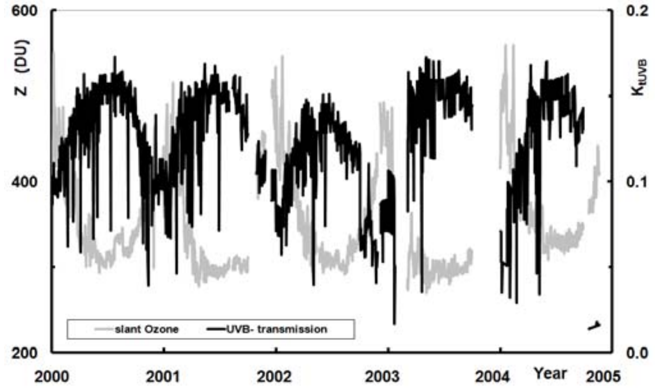

Figure 3. *The daily mean evolution of UVB transmission (K_{tUVB}) and slant ozone column (Z) for the period 2001to 2005 at Qena station.*

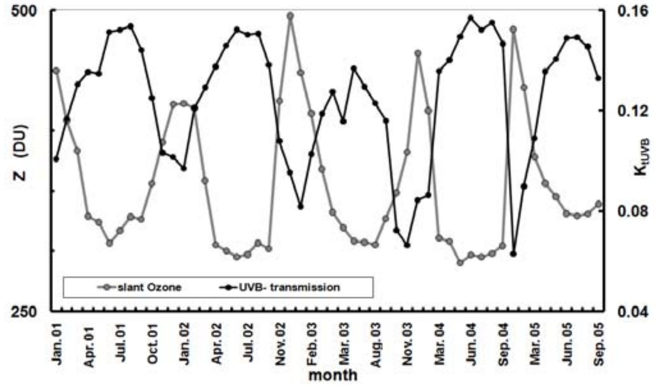

Figure 4. *The monthly mean variation of slant ozone column (Z) and UVB transmission, K_{tUVB}, at Qena station through the period from 2001 to 2005.*

In order to quantify the UVB transmission variations produced by slant path ozone changes (*Z*), the relationship between these two variables was performed for cloud–free cases as shown in Figure 5. In this study, the atmospheric transmission for solar total horizontal irradiance or clearness index (k_t) was used to represent the cloudiness condition. Foyo–Moreno et al. (1999), Canada et al. (2000), Murillo et al. (2003), and Serrano et al. (2008) have been previously shown that the clearness index is useful to represent the cloud cover. Many authors such as Kudish et al. (1993) and Udo (2000) have used the value 0.65 as a threshold. But Serrano et al. (2008) have identified the clear sky cases by a clearness index value higher than 0.75. In the present study, the clearness index values that are higher than 0.6 were used to represent the clear sky conditions. This is because that the cases containing the clouds have clearness index values less than 0.6 through the period of this study. An important advantage of this study is that the cloudiness index measurements are simultaneous with UVB measurements.

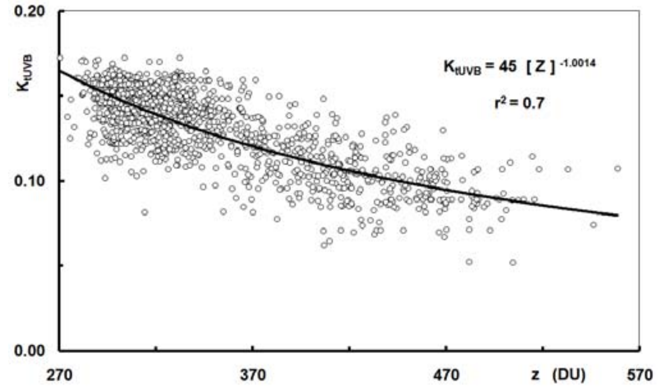

Figure 5. *Power law regression between UVB atmospheric transmission (K_{tUVB}) and slant ozone amount (Z) for clear cases at Qena through the period from 2001 to 2005. The coefficient of the power law function (1.0014) gives the RAF value.*

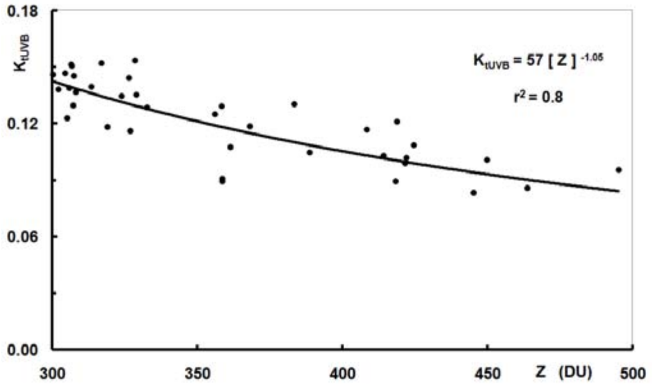

Figure 6. *Power law regression between monthly average of UVB atmospheric transmission and slant ozone column for cloud–free through the period from 2001 to 2005. The coefficient of the power law function (1.05) gives the RAF value.*

A linear regression analysis between the daily values of UVB transmission and slant ozone was performed to quantify the relationship between them (Microsoft Office Excel 2007 and SPSS 10 software for windows were used). The dependence of UVB transmission on slant ozone using a power law relationship is given by Equation (10). The correlation (r^2) of this relationship was 0.7 (i.e. 70% of the variability has been explained by the computed regression line). The rest of variance should be attributed to the variability of other factors that are not considered in this work such as aerosols and tropospheric ozone. The correlation (r^2) of the power relation between UVB transmission and Z increased for the monthly average to 0.8 (Equation 11).

$$K_{tUVB} = 45(Z)^{-1.0014} \tag{10}$$

$$K_{tUVB} = 57(Z)^{-1.05} \tag{11}$$

From Equations 10 and 11 [comparison with Equation (9)], the values of *RAF* for the daily and monthly mean values in cloudless sky conditions were equal to 1.0014 (Figure 5) and 1.05 (Figure 6), respectively. This means that the percentage of increase in UVB that would result from a 1% decrease in the slant column ozone were 1.0014% and 1.05% for the daily and monthly mean values in cloudless sky conditions. This value indicates that if there is a decrease of 1% in slant ozone value at Qena, then, UVB values increase 1.0014% and 1.05% for the daily and monthly mean values in cloudless sky conditions. High slant ozone changes produce evident non-linear UVB transmission.

In this work, the values of *RAF* were near to those of the other authors. Madronich et al. (1998) reviewed the values of *RAF* for UVB (280–315 nm), UVB (280–315 nm) and erythemal UV. In their study, they mentioned that the *RAF* values of UVB (280–315 nm) for different values of total ozone column (290 DU and 305 DU) were equal to 1.29 and 0.99, respectively. In addition, the values of RAF of UVB (280–320 nm) for ozone 290 DU and 305 DU were equal 0.89 and 0.71 respectively. Recently, Serrano et al. (2008) have proposed Equation (1) to determine *RAF* for erythemal UV. Their reported values were equal to 1.31 and 1.41 for the daily and monthly mean values in cloudless sky conditions.

4. Conclusions

This study leads to an opposite seasonal behavior for UVB transmission and slant ozone (*Z*) in all sky conditions at Qena, Egypt. The monthly averages of these parameters (K_{tUVB} and *Z*) show this opposite seasonal behavior in a clearer way than those of the daily values. In addition, the relationship between the daily values of UVB transmission and slant ozone was quantified under cloudless sky conditions and a power relation was given with a good correlation (r^2=0.7) i.e., 70% of the variability of UVB transmission has been explained by the change of slant ozone and 30% of this variability should be attributed to the variability of other factors that are not considered in this work such as aerosols and tropospheric ozone. Furthermore, the values of UVB Radiation Amplification Factor (*RAF*) for the daily and monthly mean values in cloudless sky conditions were equal to 1.0014 and 1.05, respectively. This means that if there is a decrease of 1% in slant ozone value at Qena, then, UVB values increase 1.0014% and 1.05% for the daily and monthly mean values in cloudless sky conditions, respectively.

References

Abdelmegeed, A.M., El Shazly, S.M., Kassem, K.O., 2004. Measurements of surface ozone in Qena, Egypt. Fourth Annual Meeting of the European Meteorological Society P0056, EMS04-A00463.

Adam, M.E.N., El Shazly, S.M., 2007. Attenuation of UVB radiation in the atmosphere: clouds effects at Qena (Egypt). *Atmospheric Environment* 41, 4856-4864.

Anton, M., Serrano, A., Cancillo, M.L., Garcia, J.A., 2009. An empirical model to estimate ultraviolet erythemal transmissivity. *Annales Geophysicae* 27, 1387-1398.

Anton, M., Serrano, A., Cancillo, M.L., Garcia, J.A., 2008. Total ozone and solar erythemal irradiance in South-Western Spain: day-to-day variability and extreme episodes. *Geophysical Research Letters* 35, art. no. L20804.

Balis, D., Brinksma, E., Kroon, M., Amiridis, V., Zerefos, C., 2006. Validation of OMI total ozone using ground-based Brewer observations. Atmospheric Science Conference, European Space Agency, 8-12 May, ESA SP-628, ESRIN, Frascati, Italy.

Basset, H.A., Korany, M.H., 2007. The global and UVB radiation over Egypt. *Atmosfera* 20, 341-358.

Bernhard, G., Booth, C.R., Ehramjian, J.C., Nichol, S.E., 2006. UV climatology at McMurdo Station, Antarctica, based on version 2 data of the National Science Foundation's Ultraviolet Radiation Monitoring Network. *Journal of Geophysical Research D:Atmospheres* 111, art. no. D11201.

Bernhard, G., Booth, C.R., Ehramjian, J.C., 2004. Version 2 data of the National Science Foundation's Ultraviolet Radiation Monitoring Network: South Pole. *Journal of Geophysical Research D:Atmospheres* 109, D21207, 1-18.

Canada, J., Pedros, G., Lopez, A., Bosca, J.V., 2000. Influences of the clearness index for the whole spectrum and of the relative optical air mass on UV solar irradiance for two locations in the Mediterranean area, Valencia and C´ordoba. *Journal of Geophysical Research-Atmospheres* 105, 4759-4766.

El-Metwally, M., 2004. Simple new methods to estimate global solar radiation based on meteorological data in Egypt. *Atmospheric Research* 69, 217-239.

El-Nashar, A.M., 1991. Solar radiation characteristics in Abu Dhabi. *Solar Energy* 47, 49-55.

FAO, 2006. FAO corporate document repository. http://www.fao.org/docrep/x0490e/x0490e07.htm#solar radiation.

Fioletov, V.E., Kerr, J.B., Wardle, D.I., Krotkov, N., Herman, J.R., 2002. Comparison of Brewer ultraviolet irradiance measurements with total ozone mapping spectrometer satellite re-trievals. *Optical Engineering* 41, 3051-3061.

Foyo-Moreno, I., Vida, J., Alados-Arboledas, L., 1999. A simple all weather model to estimate ultraviolet solar radiation (290-385 nm). *Journal of Applied Meteorology* 38, 1020-1026.

Foyo-Moreno, I., Vida J., Alados-Arboledas, L., 1998. Ground-based ultraviolet (290-385 nm) and broadband solar radiation measurements in southeastern Spain. *International Journal of Climatology* 18, 1389-1400.

Galliani, A., Siani, A.M., Casale, G.R., 2002. An investigation on a low ozone episode at the end of November 2000 and its effect on ultraviolet radiation. *Optical Engineering* 41, 3082-3089.

Herman, J.R., McKenzie, R.L., Diaz, S.B., Kerr, J.B., Madronich, S., Seckmeyer, G., 1999. Ultraviolet radiation at the Earth's surface, Chapter 9 in Scientific Assessment of Ozone Depletion: 1998, Global Ozone Research and Monitoring Surface Ultraviolet Radiation: Project–Report No. 44. World Meteorological Organization, Geneva, Switzerland.

Ialongo, I., Casale, G. R., Siani, A.M., 2008. Comparison of total ozone and erythemal UV data from OMI with ground-based measurements at Rome station. *Atmospheric Chemistry and Physics* 8, 3283-3289.

Iqbal, M., 1983. An Introduction to Solar Radiation, Academic Press, Canada.

Kassem, K.O., 2009. Variability of Surface and Total Column Ozone in Qena and Cairo (Egypt). Phd Thesis, South Valley University, Egypt.

Kazadzis, S., Bais, A., Arola, A., Krotkov, N., Kouremeti, N., Meleti, C., 2009. Ozone monitoring instrument spectral UV irradiance products: comparison with ground based measurements at an urban environment. *Atmospheric Chemistry and Physics* 9, 585-594.

Kerr, J.B., 2005. Understanding the factors that affect surface ultraviolet radiation. *Optical Engineering* 44, art. no. 041002.

Kudish, A.I., Lyubansky, V., Evseev, E.G., Ianetz, A., 2005. Inter-comparison of the solar UVB, UVA and global radiation clearness and UV indices for Beer Sheva and Neve Zohar (Dead Sea), Israel. *Energy* 30, 1623-1641.

Kudish, A.I., Wolf, D., Machlav, Y., 1983. Solar radiation data for Beer Sheva, Israel. *Solar Energy* 30, 33-37.

Madronich, S., McKenzie, R.L., Bjorn, L.O., Caldwell, M.M., 1998. Changes in biologically active ultraviolet radiation reaching the Earth's surface. *Journal of Photochemistry and Photobiology B: Biology* 46, 5-19.

Madronich, S., McKenzie, R., Bjorn, R., Caldwell, M., 1994. Changes in ultraviolet radiation reaching the Earth's surface: In Environmental Effects of Ozone Depletion: 1994 Assessment - Stratospheric Ozone and Human Health Project, United Nations Environment Programme (UNEP).

Masserot, D., Lenoble, J., Brogniez, C., Houet, M., Krotkov, N., McPeters, R., 2002. Retrieval of ozone column from global irradiance measurements and comparison with TOMS data, A year of data in the Alps. *Geophysical Research Letters* 29, art. no. 1309.

McKenzie, R.L, Matthews, W.A., Johnston, P.V., 1991. The relationship between erythemal UV and ozone, derived from spectral irradiance measurements. *Geophysical Research Letters* 18, 2269-2272.

McPeters, R.D., Bhartia, P.K., Krueger, A.J., Herman, J.R., Wellemeyer, C.G., Seflor, C.J., Jaross, G., Torres, O., Moy, L., Labow, G., Byerly, W., Taylor, S.L., Swisler, T., Cebula, R.P., 1998. Earth Probe Total Ozone Mapping Spectrometer (TOMS) Data products User Guide, Technical Report TP-1998-206895, NASA.

Murillo, W., Canada, J., Pedros, G., 2003. Correlation between global ultraviolet (290-385 nm) and global irradiation in Valencia and Cordoba (Spain). *Renewable Energy* 28, 409-418.

NASA, 2010a. Available at: ftp://toms.gsfc.nasa.gov.

NASA, 2010b. Available at: http://toms.gsfc.nasa.gov/version8/version8-update.html.

Newchurch, M.J., Yang, E.S., Cunnold, D.M., Reinsel, G.C., Zawodny, J.M., Russell, J.M., 2003. Evidence for slowdown in stratospheric ozone loss: First stage of ozone recovery. *Journal of Geophysical Research-Atmospheres* 108, art. no. 4507.

Orsolini, Y.J., Eskes, H., Hansen, G., Hoppe, U.P., Kylling, A., Kyro, E., Notholt, J., Van Der, A.R., Von der Gathen, P., 2003. Summertime low-ozone episodes at northern high latitudes. *Quarterly Journal of Royal Meteorological Society* 129, 3265-3275.

Robaa, S.M., 2008. On the estimation of UV-B radiation over Egypt. IDOJARAS, *Quarterly Journal of the Hungarian Meteorological Service* 112, 45-60.

Serrano, A., Anton, M., Cancillo, M.L., Garcia, J.A., 2008. Proposal of a new erythemal UV radiation amplification factor. *Atmospheric Chemistry and Physics Discussion* 8, 1089-1111.

Udo, S.O., 2000. Sky conditions at Ilorin as characterized by clearness index and relative sunshine. *Solar Energy* 69, 45-53.

UNEP, 2007. Environmental effects of ozone depletion: 2006 assessment and its interactions with climate changes. United Nations Environmental Programme.

UNEP, 1998. Environmental effects of ozone depletion: 1998 assessment, Technical Report, United Nations Environmental Programme.

Vaughan, G., Price, J.D., 1991. On the relation between total ozone and meteorology. *Quarterly Journal of the Royal Meteorological Society* 117, 1281-1298.

WMO, 2007. Scientific assessment of ozone depletion: 2006, global ozone research and monitoring project. Technical Report 50. World Meteorological Organization.

WMO, 2003. Scientific assessment of ozone depletion: 2002, global ozone research and monitoring project. Technical Report 47, World Meteorological Organization.

WMO, 1990. Guide to meteorological observations methods. Tn-8, Geneva, Switzerland, Chapter 9. WMO Secretariat, 925-932.

WRC, 1995. International pyreheliometer comparison (IPC VII), 25 September-13 October. Working Report, No. 188, Davos, Switzerland.

WRC, 1985. Sixth international pyreheliometer comparison (IPC VI), 1-18 October. Working Report, No. 137, Davos, Switzerland.