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UV-B RADIATION FORECAST OVER ASWAN

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Abstract: The primary subject of this paper is the procedure for forecasting UV-B radiation over Aswan (32.78ºE, 23.97ºN). The forecast quantity of UV-B radiation is based on an empirical formula, relating UV-B radiation to the global solar radiation and the total amount of ozone at Aswan. The UV-B radiation forecast is produced in three steps. First, total ozone is estimated over Aswan using a regression relationship between the thickness of two atmospheric layers and total ozone. Second, we used the residual method to deduce a formula relating the global solar radiation values by means of surface atmospheric variables. Finally, the forecasted total ozone and the forecasted global solar radiation are fed to the formula to obtain the UV-B radiation forecast. The above steps were applied for different seasons and also on the annual values. The highest strong correlation occurs during autumn and winter for ozone, and at spring and autumn for global solar radiation.

Keywords: UV-B radiation, Aswan, ozone, global solar radiation

INTRODUCTION

Recent changes to the stratospheric ozone levels have attracted strong interest from the scientific and environmental communities as well as from the policy makers. The most significant influence on received clear-sky UV-B is that which results from variation in the atmospheric ozone (Frederick *et al*., 1993). This result is very important, especially when it is noted that the ozone column trend takes a downward direction in extratropical latitudes (Bojkov *et al*., 1990). UV-B radiation levels at the Canadian border have increased 4% per decade since 1980 (Brett, 1998). The amount of UV-B radiation received at the ground level depends on various temporal, spatial and meteorological factors, such as time of day, season, latitude, altitude, clouds, surface albedo, ozone, air particulate and aerosols (Frederick et al., 1989). Any small increases in UV-B flux could be offset by other competing factors. In fact, some studies (Berger and Urbach, 1982; Scotto et al., 1988) have shown lower levels of UV-B radiation reaching the ground. These decreases have been attributed to scattering and absorption by pollutant gases and dust particles (Grant, 1988) and also tropospheric ozone. The atmospheric parameters strongly affect UV-B values measured at the surface of the earth.

It is known that Ω (the daily total ozone amount) is linked with the meteorological conditions; this correlation has been appreciated since the beginning of research on atmospheric ozone. Thus the fluctuation of daily total ozone becomes an interesting feature in atmospheric research. Significant statistical relationships between Ω, measured in Dobson units (DU), and a number of meteorological variables have long been known (e.g., Dobson et al., 1929; Reed, 1950; Normand, 1953; Vaughan and Price, 1991; Abdel Basset and Gahein, 2000 and 2003).

These relationships have recently been used in the short-term forecasting of Ω for middle and high latitudes (Burrows *et al*., 1993, 1995; Poulin and Evans, 1994; Austin *et al*., 1994; Vogel *et al*., 1995). These statistical relationships are, however, regionally and seasonally variable in their strengths (e.g., Ohring and Muench, 1960; Schubert and Munteanu, 1988; Mote *et al*., 1991; Petzoldt *et al*., 1994).

Early studies based on a limited number of ground station reports (e.g., Dobson *et al*., 1929) helped to establish a firm meteorological basis for the observed daily variation of ozone. Reed (1950) pointed out that the variations are not only caused by chemical processes but also have dynamical origins, expressed by sudden increases in total ozone accompanying a marked increase in tropopause pressure, such as found during the passage of a cold front or depression. This can be interpreted simply as an increase in the depth of ozone and the ozone-rich stratosphere or as a combination of vertical and horizontal advection of ozone.

Ozone absorbs most of the harmful ultraviolet radiation emitted by the sun before it reaches the earth's surface. This absorption creates a heat source, which leads to a heating layer in the atmosphere (stratosphere) giving a temperature increase with height. The Laboratory of Atmospheric Physics (University of Thessaloniki) provides an approach used for regional ozone forecasting (Vogel *et. al*., 1995); this approach is based on results from detailed statistical calculations showing strong correlation between Ω and a meteorological parameter in the lower stratosphere and higher troposphere. From this point of view we can use the thermal structure of atmosphere in the ozone forecasting technique. Ozone is found in two different height regions in the atmosphere: at heights between about 10 and 50 km in the stratosphere, and closer to the surface in the troposphere. The aim of this study is to forecast the UV-B radiation from the global solar radiation and the total amount of ozone at Aswan (32.78ºE, 23.97ºN).

DATA AND METHODOLOGY

Stratospheric ozone measurements at Egypt

A global network of ozone observing stations formed part of the ambitions plans for the International Geophysical Year (IGY) of 1957. During this year, the World Meteorological Organisation (WMO) assumed responsibility for the collection of ozone data from the IGY. In collaboration with the International Ozone Commission, the organisation developed and coordinated standard procedures, thereby ensuring uniform high quality ozone measurements. As early as October 1967 the Egyptian Meteorological Authority (EMA) introduced regular monitoring of ozone at Cairo using the Dobson Spectrophotometer No. 96. During 1973 Cairo became Regional Ozone Center (ROC) for ozone stations at North Africa and Middle East. One of the ROC's responsibilities is the study of the variation of ozone over Egypt. Therefore, in 1984 the EMA started to measure ozone amount over Aswan (Upper Egypt) by Dobson Spectrophotometer No. 69. To study the effect of South European Ozone (SEO) for Egypt, EMA measured ozone by Brewer Spectrophotometer No. 143 over Mersa Matruh (coastal station) at November 1998.

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Because the nature of ozone over the Red Sea area was unclear, WMO and EMA started to measure the total amount of ozone over Hurghada (GAW station) by Dobson Spectrophotometer No. 59 at (November 2000). Table 1 illustrates the location, WMO numbers and Ozone ID number of our ozone stations. The instruments are maintained in good condition, and we obtain high quality ozone data that is needed not only for long-term monitoring but also in the forecasting technique of UV-B.

	Cairo	**Aswan**	**Matruh**	**Hurghada**
WMO No.	62371	62414	62306	62464
Ozone ID.	152	245	376	409
Latitude (degrees)	30.08N	23.97N	31.33N	27.28N
Longitude (degrees)	31.28E	32.78E	27.22E	33.75E
Elevation (metres)	037	193	035	007
Instrument	Dobson # 096	Dobson # 069	Brewer # 143	Dobson # 059
Elements measured	O_3	O_3	O_3 UV-B	O_3
Started	October 1967	December 1984	November 1998	November 2000
Last calibration	Dahab, 2004	Dahab, 2004		Dahab, 2004

Table 1. The Egyptian Ozone Stations.

ECMWF Data

Meteorological upper air data used in this study has been taken from the archives of the European Center for Medium Range Weather Forecasting (ECMWF). It consists of the geopotential height (Z) in metres on regular latitude-longitude grid points with resolution of 2.5° by 2.5°. The data available at 1200 UTC during the period 1986 to 1989 at isobaric levels 1000, 850, 700, 500, 400, 300, 250, 200, 150 and 100 hPa. We obtained the geopotential height in metres over Aswan by interpolation.

Residual Method

The success of a statistical forecasting method does to some extent depend on the technique applied, but it depends even more on the selection of the predictors. After choosing a number of predictors from the physical point of view, the problem is determining the best way to use them. One method is by using them one by one in successive correction manner. In this case we started with the best of these predictors. The residual method has been applied to explore the possibility of forecasting total ozone values by means of values of depth of heights (the thickness of different layers). The values of Ω during the period of study have been taken as dependent variable (predictand) and the corresponding values of the thickness of different layers are the independent variables (predictors).

First step: the correlation coefficient (r) between the values of total ozone and the thickness of different layers (predictors) has been estimated. The predictor has the strongest r with the predictand, which has been used to be the first predictor. Then the regression line and the regression coefficients are determined. The error between the actual and estimated value of total ozone was taken as a predictand.

Second step: the aforementioned error was subjected to the process performed in the first step. The second step is repeated with new predictors (if we have many predictors) until the additional predictors have no significant effect on the predictand, and there is no need for any further iteration steps (i.e. the improvement can not be expected to be very great with adding new predictors). This method was applied at Aswan, and we deduced five equations: and equation for each season and the fifth to represent the annual variation.

ESTIMATION OF DAILY TOTAL OZONE AMOUNT (Ω)

In this section we investigate the relationship between Ω in DU and the depth of height in metres (the thickness of different layers of the atmosphere) at Aswan. The method was based on the fact that short-term variations of total ozone content can be brought into empirical relation with thermal structure of atmosphere, namely, with short-term variations of tropospheric and stratospheric temperature.

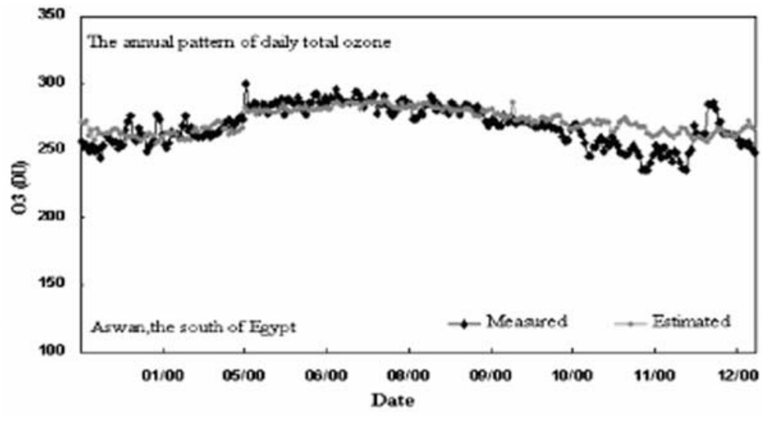

Fig. 1a. Measured and estimated Ω at Aswan.

We investigated the relation between Ω and the thickness of two layers ΔZ_1 and ΔZ_2, where ΔZ_1 is the height difference between 500 hPa and 1000 hPa or 700 hPa, and ΔZ_2 is the height difference between 100 hPa and 500 hPa or between 300 hPa and 100 or 200 hPa. The strong relationship between Ω, ΔZ_1 and ΔZ_2 was used to deduce a linear regression equation relating the above parameters. We used the residual method to deduce such relationship and it was applied on the seasonal and annual data.

The daily values of four years of geopotential height data from the ECMWF with the actual measurements of Ω have been used to deduce five equations to estimate Ω at Aswan. The last equation (1e) represents the daily values of the year while the other four equations (1a- 1d) represents the four seasons.

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Table 2 shows the number of steps, the predictor used in each step, the regression coefficients arising in each step (A_i, B_i), the mean absolute error (MAE) and root mean square error (RMSE) arising from the error between the actual and estimated data after each step, and multiple correlation coefficient (R) from a stepwise regression analysis. It is clear that two predictors have been used to reach a reasonable total multiple correlation values for the four seasons and the annual. The high value of the total multiple correlation appeared in autumn.

(a) Winter

Step No	ΔZ	Regression coefficients		MAE	RMSE	R
		A_i	B_i			
1	500-1000	733.056	-0.08336	9.7527	12.4154	-0.46
2	100-500	936.2444	-0.08763	9.3011	12.0145	0.61

$$\Omega = 1669.3004 - 0.08336 * Z(500-1000) - 0.08763 * Z(100-500) \qquad (1a)$$

(b) Spring

Step No	ΔZ	Regression coefficients		MAE	RMSE	R
		A_i	B_i			
1	500-700	717.0259	-0.16143	11.1951	14.3955	-0.3
2	200-300	665.3124	-0.24485	10.5451	13.2608	-0.5

$$\Omega = 1382.3383 - 0.16143 * Z(500-700) - 0.24485 * Z(200-300) \qquad (1b)$$

(c) Summer

Step No	ΔZ	Regression coefficients		MAE	RMSE	R
		A_i	B_i			
1	500-1000	741.1255	-0.07762	6.9683	8.7716	-0.3
2	100-500	609.8589	-0.05633	6.6506	8.4029	0.58

$$\Omega = 1350.9844 - 0.07762 * Z(500-1000) - 0.05633 * Z(100-500) \qquad (1c)$$

(d) Autumn

Step No	ΔZ	Regression coefficients		MAE	RMSE	R
		A_i	B_i			
1	500-1000	-333.5746	0.10351	5.8274	7.3449	0.62
2	100-300	-67.3821	0.00972	5.8002	7.3390	0.75

$$\Omega = -400.9567 + 0.10351 * Z(500-1000) + 0.00972 * Z(100-300) \qquad (1d)$$

(e) Annual

Step No	ΔZ	Regression coefficients		MAE	RMSE	R
		A_i	B_i			
1	500-1000	-159.6035	0.07504	11.5462	14.4819	0.46
2	100-300	-522.9647	0.07528	11.1586	14.1015	0.65

$$\Omega = -682.5682 + 0.07504 * Z(500-1000) + 0.07528 * Z(100-300) \qquad (1e)$$

Table 2. Aswan regression coefficients (A_i, B_i) of Ω estimation, (MAE), (RMSE), and (r) from a stepwise regression analysis during (a) Winter, (b) Spring, (c) Summer, (d) Autumn, and (e) for the annual data.

We applied the five deduced equations (1a-1e) to estimate Ω for the period from 1 January to 31 December 2000, where the measured Ω was available on a daily basis.

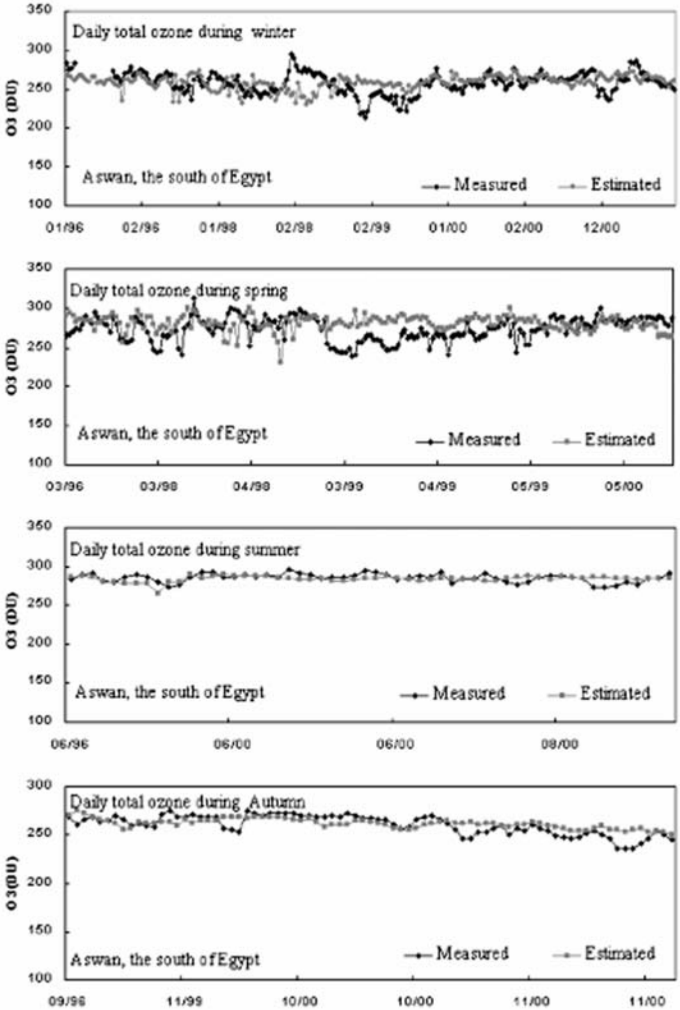

Fig. 1b. Measured and estimated Ω at Aswan during the different seasons.

Figure 1a shows the measured and estimated values of Ω during the aforementioned period, and Figure 1b illustrates the measured and estimated values of Ω for the four seasons. Generally, the highest agreement between the measured and estimated values of Ω occurred during the summer and autumn seasons. Also a good agreement between the measured and estimated values of Ω appeared with the annual pattern, except during October and November.

ESTIMATION OF DAILY GLOBAL SOLAR RADIATION (*G*)

The daily global solar radiation (*G*) in MJ m^{-2} was estimated depending on meteorological variables: mean, maximum, and minimum surface temperature (Tmean, Tmax, Tmin) in degrees Celsius (ºC).

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Also daily mean relative humidity (RH), cloud amount (CLD) as a fraction of tens, and daily mean surface pressure (PRESS) in hPa. We deduced a statistical regression equation relating the global solar radiation *G* (as dependent variable) to the above meteorological variables (as independent variables). We used also the residual method to deduce the relation between the global solar radiation (*G*) and the various surface parameters.

(a) Winter

Step No	Predictors	Regression coefficients A_i	Regression coefficients B_i	MAE	RMSE	R
1	RH	23.50082	-0.16158	1.7637	2.2167	-0.45
2	CLD	0.75657	-0.98957	1.5431	1.8876	-0.52
3	PRESS	-159.9828	0.16091	1.5243	1.8292	0.625
4	T_{max}-T_{min}	-1.09058	0.08274	1.5124	1.8201	0.699

$$G = -136.81599 - 0.16158 * RH - 0.98957 * CLD + 0.16091 * PRESS + 0.08274 * (T_{\max} - T_{\min}) \tag{2a}$$

(b) Spring

Step No	Predictors	Regression coefficients A_i	Regression coefficients B_i	MAE	RMSE	R
1	CLD	26.65243	-1.51004	1.9966	2.6661	-0.68
2	RH	4.74032	-0.2062	1.6747	2.3267	-0.704
3	T_{mean}	-0.99396	0.03901	1.6649	2.3154	0.742
4	PRESS	-83.23336	0.08413	1.6492	2.2944	0.783

$$G = -52.83457 - 1.51004 * CLD - 0.2062 * RH + 0.03901 * T_{mean} + 0.08413 * PRESS \tag{2b}$$

(c) Summer

Step No	Predictors	Regression coefficients A_i	Regression coefficients B_i	MAE	RMSE	R
1	CLD	27.8362	-0.9285	1.0343	1.3104	-0.44
2	T_{mean}	9.14503	-0.2659	0.9419	1.2111	0.498
3	RH	2.94426	-0.15168	0.8632	1.0995	0.592
4	PRESS	-40.5999	0.04124	0.86	1.0967	0.67

$$G = -0.67441 - 0.9285 * CLD - 0.2659 * T_{mean} - 0.15168 * RH + 0.04124 * PRESS \tag{2c}$$

(d) Autumn

Step No	Predictors	Regression coefficients A_i	Regression coefficients B_i	MAE	RMSE	R
1	T_{mean}	6.41325	0.50103	1.6533	2.0229	0.78
2	CLD	0.54622	-1.26147	1.4307	1.7017	0.804
3	PRESS	45.43114	-0.04594	1.4226	1.6958	0.82
4	RH	-0.16302	0.00583	1.4205	1.6949	0.86

$$G = 52.22759 + 0.50103 * T_{mean} - 1.26147 * CLD - 0.04594 * PRESS + 0.00583 * RH \tag{2d}$$

(e) Annual

Step No	Predictors	Regression coefficients A_i	Regression coefficients B_i	MAE	RMSE	R
1	RH	32.23647	-0.35907	2.4694	3.1366	-0.77
2	CLD	0.70514	-0.98547	2.2880	2.9060	-0.78
3	PRESS	168.3881	-0.17038	2.1727	2.8265	0.803
4	T_{max}-T_{min}	1.97953	-0.14135	2.1605	2.8071	0.825

$$G = 203.30924 - 0.35907 * RH - 0.98547 * CLD - 0.17038 * PRESS + 0.14135 * (T_{\max} - T_{\min}) \tag{2e}$$

Table 3. Aswan regression coefficients (A_i, B_i) of (G) estimation, (MAE), (RMSE), and (r) from a stepwise regression analysis during (a) Winter, (b) Spring, (c) Summer, (d) Autumn, and (e) for the annual data.

The values of *G* during the period of study have been taken as the dependent variable (predictand) and the other variables (RH, CLD, PRESS, Tmax, Tmin and Tmean) as predictors. Since there are significant differences between observed *G* in different seasons, we developed five separate relations, one to represent the annual and the other to represent the four seasons. Table 3 shows the number of steps (the number of predictors), the regression coefficients arising in each step (A_i, B_i), the mean absolute error (MAE) and root mean square error (RMSE) arising from the error between the actual and estimated data after each step, and multiple correlation coefficient (R) from a stepwise regression analysis. The results have been illustrated in Table 3 and Figure 2. It can be shown that:

- Good agreement between the actual and estimated annual values of G (Figure 2a), where the total multiple correlation reached 0.825 after using four predictors. The higher values of G over Aswan occurred during the summer season.

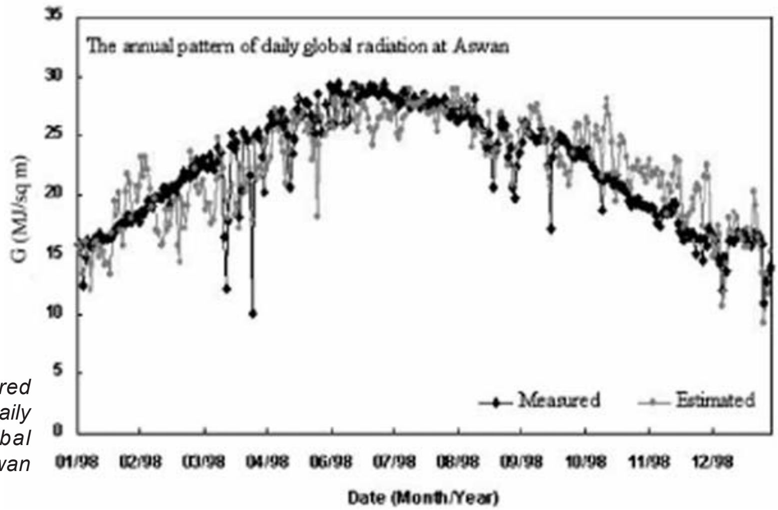

Fig. 2a. Measured and estimated daily total global radiation at Aswan during 1998.

- In summer, although we start with small R=-0.44 with the first predictor CLD, we reached a reasonable total multiple correlation value (0.67) after using the four predictors.
- For autumn, the total multiple correlation reached 0.86 after using four predictors. This high value of the total multiple correlation has appears clear in Figure 2b, where a good agreement between the two time series was observed.

Equations 2a to 2e illustrate the multiple regression equations for the four seasons and for the annual pattern. They were applied to another separate period of data to evaluate their accuracy. Figure 2a shows the actual and estimated daily global solar radiation in 1998.

It also illustrates that the estimated values of the daily total global radiation are more perturbed than the actual values. These differences (fluctuations) between actual and estimated data are not found in Figure 2b, which means that it is better to deduce the global solar radiation from the seasonal equations than the annual equation. Figure 2a shows a good agreement between actual and estimated values of *G* for the four seasons, especially summer.

(a) Winter

Step No	Predictors	Regression coefficients		MAE	RMSE	R
		A_i	B_i			
1	Global	-0.00963	0.00283	0.00308	0.00413	0.872
2	Ozone	0.02838	-0.00011	0.00291	0.00384	0.889

$$UVB = 0.01875 + 0.00283 * G - 0.00011 * \Omega \tag{3a}$$

(b) Spring

Step No	Predictors	Regression coefficients		MAE	RMSE	R
		A_i	B_i			
1	Ozone	0.04004	0.00012	0.0079	0.00946	0.672
2	Global	-0.08238	0.00318	0.0037	0.00468	0.88

$$UVB = -0.04234 + 0.00318 * G + 0.00012 * \Omega \tag{3b}$$

(c) Summer

Step No	Predictors	Regression coefficients		MAE	RMSE	R
		A_i	B_i			
1	Ozone	0.04993	0.00011	0.005	0.0075	0.54
2	Global	-0.0673	0.0024	0.0037	0.0063	0.80

$$UVB = -0.01737 + 0.0024 * G + 0.00011 * \Omega \tag{3c}$$

(d) Autumn

Step No	Predictors	Regression coefficients		MAE	RMSE	R
		A_i	B_i			
1	Global	-0.01989	0.00347	0.0023	0.0028	0.943
2	Ozone	-0.00374	0.00001	0.0022	0.00267	0.954

$$UVB = -0.02363 + 0.00347 * G + 0.00001 * \Omega \tag{3d}$$

Table. 4. Aswan regression coefficients (Ai, Bi) of daily UV-B radiation estimation, (MAE), (RMSE), (r) from a stepwise regression analysis during (a) Winter, (b) Spring, (c) Summer, (d) Autumn.

ESTIMATION OF DAILY UV-B IRRADIANCE

As a result of the documented strong relation between UV-B radiation and global solar radiation and also with ozone, this enabled us to deduce an equation relating UV-B radiation to *G* and Ω. In this section we applied the residual method to obtain an empirical formula deducing UV-B (dependant variable) from *G* and Ω (independent variables). Table 4 shows the number of predictors, the regression coefficients arising in each step (A_i, B_i), the MAE and RMSE between the actual and estimated data after each step, and multiple correlation coefficient (R) from a stepwise regression analysis. It is clear that the total multiple correlation reached a value of more than 80 % in the four seasons via our two predictors (*G* and Ω). The highest total multiple correlation, occurring in autumn, of 0.95 is quite high, so it is associated with lowest MAE and RMSE (0.0022 and 0.00267).

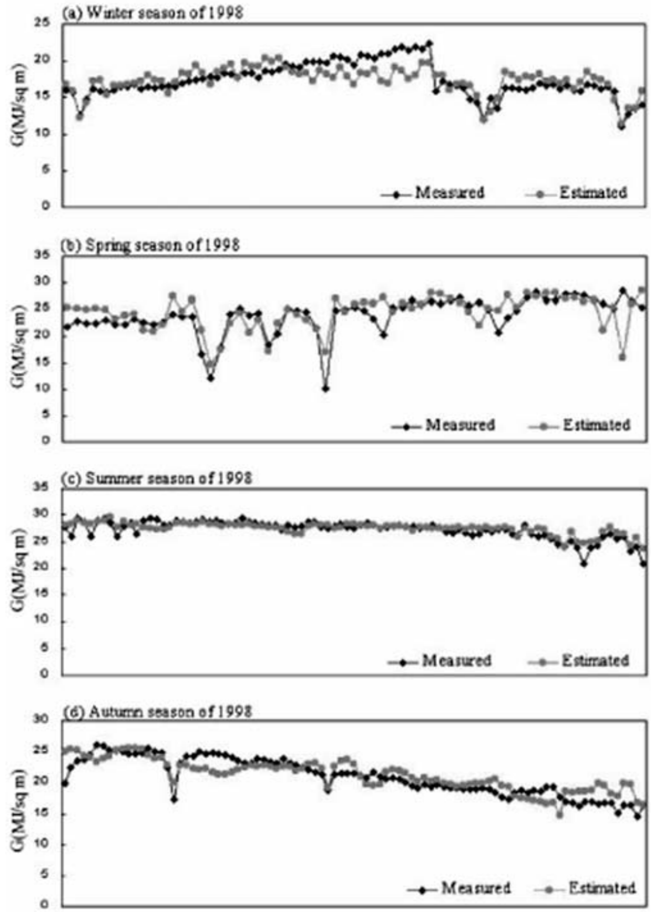

Fig. 2b. Measured and estimated G at Aswan through the different sasons.

Equations 3a to 3d represent the obtained empirical formulas used to estimate UV-B radiation for each season. To verify these equations we applied them to discrete periods of data during different seasons. Very good agreement between the actual and estimated values of UV-B radiation occurred in the different seasons, as shown in Figure 3.

CONCLUSIONS

The relationships between ozone content with the thickness of two different layers in the troposphere have been investigated over a period of four years. We found that there is strong correlation between ozone and the thickness of layers for the four seasonal and the annual values. The residual method has been used to evaluate linear regression equations relating the total amount of ozone to the thickness during the four seasons and the annual.

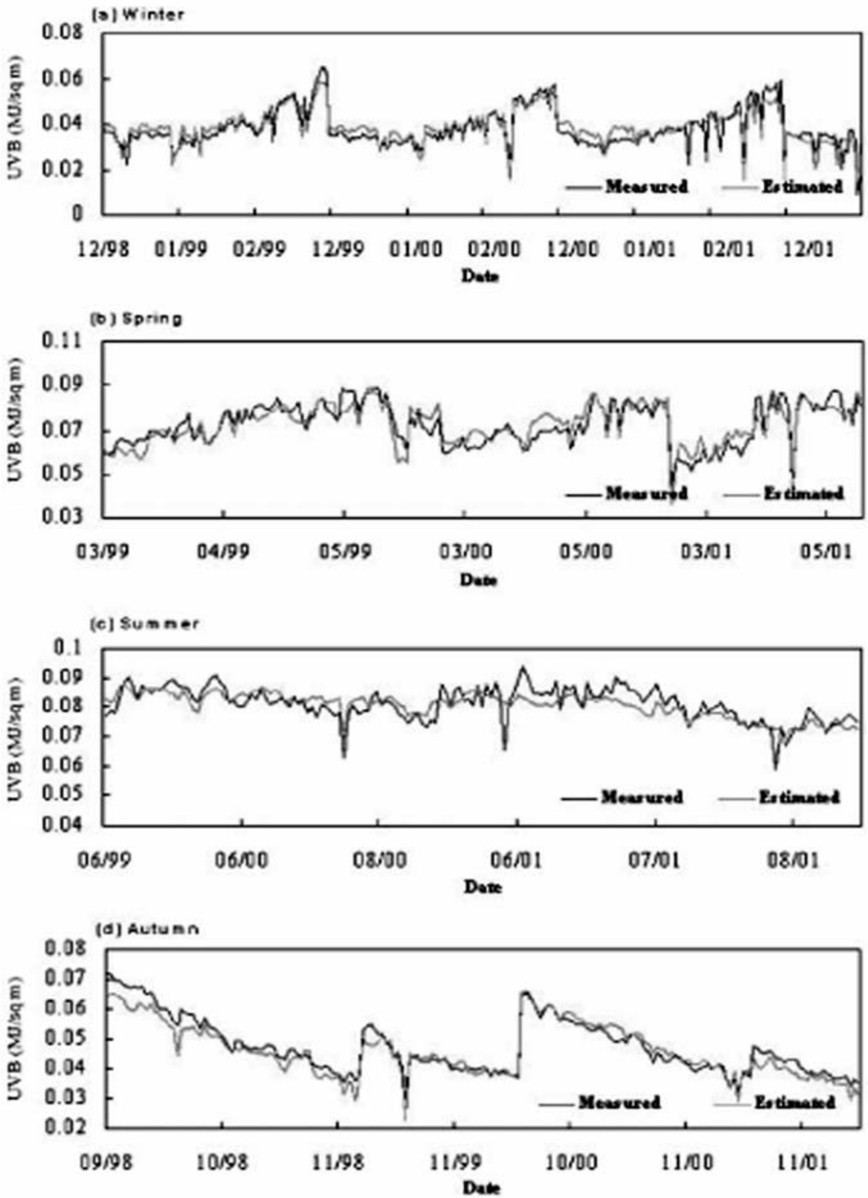

Fig. 3. Measured and estimated daily UV-B radiation at Aswan through the different seasons.

These equations were applied to another period and promising results were found, which will lead to an estimate of the amount of ozone from the thickness. Also, we deduced five regression equations to estimate the global solar radiation using meteorological variables.

We found strong correlation between UV-B and global radiation; we achieved 87 % and 94 % correlation during the winter and autumn seasons respectively. We obtained multiple regression equations to estimate UV-B from ozone and global solar radiation, with 88 % correlation during winter and spring and 80 % and 95 % during summer and autumn respectively.

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