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SPECTRAL ANALYSIS AND FORECAST OF OZONE OVER EGYPT

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ABSTRACT
In this paper the relationships between total ozone amount and meteorological variables have been deduced for eight stations of Egypt. Residual method has been applied to estimate total column ozone (TCO) values using the meteorological variables. Empirical equations relating TCO with these variables have been deduced for the eight stations. Very good correlation coefficient between the actual and estimated values of ozone has been found. The obtained good relations make us able to estimate and forecast ozone amount whether there are meteorological stations or not, by using numerical weather prediction models outputs. Spectral analysis of the daily, monthly and annual values of TCO data of the eight stations has been examined. It is found that the annual wave is the dominant wave in all stations. This wave simply represents the seasonal variation caused due to meridional circulation. There are five significant dominant waves appear in the annual time series of the most stations, the wave length of these waves are 2.8, 2.6, 4.5, 18 and 9 year respectively. The first and second waves are qualitatively matches the quasi-biennial oscillation. The last wave which has a period of approximately 9 years clearly matches the solar sunspot cycle period, while the wave 4.5 year cycle seem to be associated with the El-Nino Southern Oscillation.

Keywords: Total column ozone, Residual method, Meteorological variables, Empirical equations, Spectral analysis, the dominant waves, seasonal variation, the quasi-biennial oscillation, El-Nino Southern Oscillation.

1. INTRODUCTION
It is known that the daily total ozone amount (O3) is linked with meteorological elements (e.g., Dobson et al., 1929). The nature of day-to-day total ozone fluctuations has been of considerable interest for many years. Significant statistical relations between O3 and a number of meteorological variables have long been known (Reed, 1950; Normand, 1953; Vaughan and Price, 1991; Abdel Basset and Gahein, 2000, 2003). These relationships have recently been used in short-term O3 forecasting in middle and high latitudes (Burrows et al., 1993, 1994; Poulin and Evans, 1994; Austin et al., 1994; Vogel et al., 1995). These statistical relations are, however, regionally and seasonally independent (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 ozone variation. Reed (1950) pointed out that ozone variations are not only caused by chemical processes but also have dynamical origins. For example sudden increases in total ozone generally accompany marked increase in tropopause pressure occurred 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 that leads to temperature increases with height (stratosphere). The laboratory of atmospheric physics, University of Thessaloniki, provides an approach for regional ozone forecasting (Vogel .et.al., 1995). This approach is based on results from detailed statistical calculations showing strong correlation between O3 and meteorological parameters in the lower stratosphere and higher troposphere. Thus the thermal structure of the atmosphere can be used to forecast ozone.

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Since the detection of the Antarctic ozone hole in the late 1980s (Farman et al., 1985), interest in total ozone changes has increased strongly in the scientific community and general public, due to the direct link with changes in biologically active UV radiation (e.g., Calb´o et al., 2005). Multiple linear regression models including independent variables, also called explanatory variables or covariates, which represent atmospheric variability have been used to assess and analyze the attribution to long-term total ozone trends. The most commonly-used covariates include: the 11-yr solar cycle, the Quasi-Biennial Oscillation (QBO), (linear) trends attributed to anthropogenic ozone depleting substances (ODS), and atmospheric aerosol load after volcanic eruptions (e.g., Fioletov et al., 2002; Steinbrecht et al., 2006; Vyushin et al., 2007; SchnadtPoberaj et al., 2011; WMO, 2003, 2007, 2011). In addition variables describing decadal/long-term climate variability, like, e.g., the El Niño/Southern Oscillation (ENSO), the Arctic Oscillation (AO), the North Atlantic Oscillation (NAO), and the Antarctic Oscillation (AAO), have been included in such analyses. There is broad agreement within the scientific community that negative long-term ozone trends at mid-latitudes between the 1980s and mid-1990s are dominated by changes in ODS, while short-term changes are attributable to dynamical phenomena such as horizontal advection and convergence of mass related to changes in tropospheric and lower stratospheric pressure systems (e.g., Wohltmann et al., 2007; M¨ader et al., 2007; Koch et al., 2005). ***The objective of this work is to study the periodicity of the monthly and annual values of the total column ozone data over Egypt. Also, this work aimed to estimate total ozone amount using some meteorological variables.***

2. DATA

2.1 Ozone data

In Egypt there are four stations providing ground-based total ozone measurements. Table 1 illustrates the name, location, the instrument type used to measure total ozone and the period of measurements for each station. Occasionally, there are missing data (about 1% of the total data) which need to be dealt with in some fashion for calculation of the climatology. Linear interpolation is used to estimate missing values in order to make the time series complete, which enables a computation of monthly and yearly means and a time series analysis of the daily data.

Table 1: Ground based stations over Egypt

station	Latitude(°)	Longitude(°)	Height (m)	Instrument	Available Data
Cairo	30.08°N	31.28°E	37	Dobson # 096	1968 to 2014
Aswan	23.97°N	32.78°E	193	Dobson # 069	1984 to 2014
Matrouh	31.33°N	27.22°E	35	Brewer # 143	1998 to 2014
Hurghada	27.28°N	33.75°E	7	Dobson # 059	2001 to 2014

We also extract another four time series of TCO for the previous four stations from reanalysis ERA- Intrem total column ozone data (http://apps.ecmwf.int/datasets/data/interim-full-moda). To cover and represent the different regions of Egypt we also obtain the time series of TCO for the stations Alex (29^{o}E, 31^{o}N), Ismail (32^{o}E, 30^{o}N), Dahab (34^{o}E, 28^{o}N) and Ewinat (28^{o}E, 22^{o}N). The comparison between TCO of ground based station and its corresponding reanalysis data has been verified over Cairo and represented in Figure 1. It is found that there is a very good agreement between observed and reanalysis data, where the correlationcoefficient is 0.91 and the root mean square error is 6.1, this good agreement allowing us to use this data in our study.

Figure 2 shows the study area and the location of eight stations, four of them are the ground-based stations while the other four stations we used the reanalysis ozone data. The reanalysis daily and monthly data for total amount of ozone and other meteorological parameters are obtained from (http://apps.ecmwf.int/datasets/data/interim-full-moda). ERA-Interim reanalysis data is the latest global atmospheric reanalysis data set of the European Center Weather Forecast (ECMWF) with period from 1979 till 2014.

2.2 Meteorological 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 surface meteorological variables: ultra violet radiation (uvb), solar surface radiation (ssrd), bounder layer height (blh), surface pressure (sp), relative humidity (rh), and temperature at 2 meter (t2m) and Dew point temperature at 2 meter (d2m) level. And the upper air data are: geopotenial high (z), relative humidity (rh), temperature (t) and the thickness between different gepotenial height levels. The data is regular latitude-longitude grid points with resolution of 1^{o}x1^{o}. at levels 1000, 850, 700, 500, 400, 300, 200, and 100 hPa.

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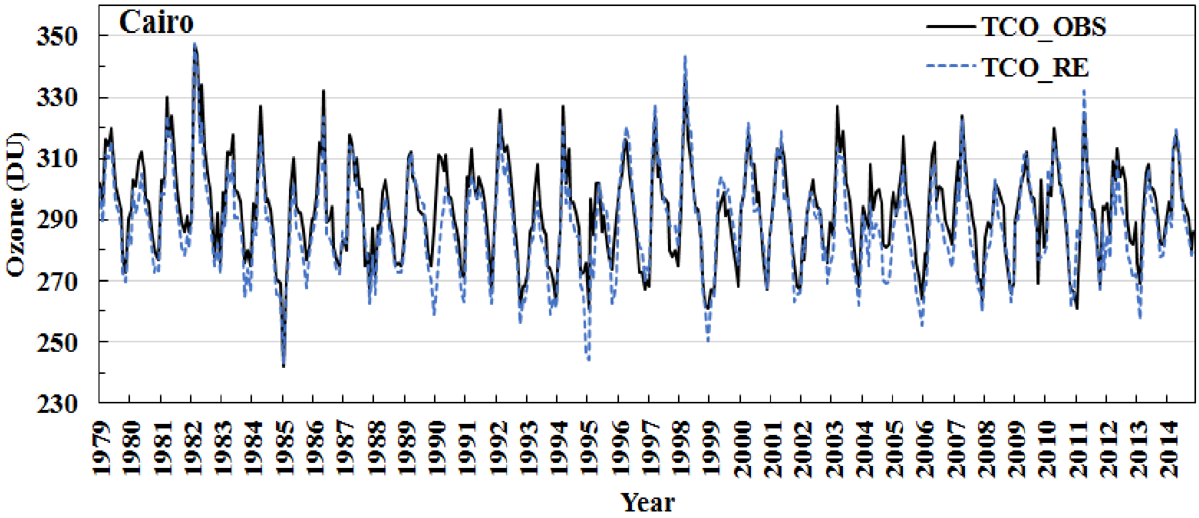

Fig. 1: Comparison between ground based and reanalysis monthly TCO over Cairo during the period from 1979 to 2014.

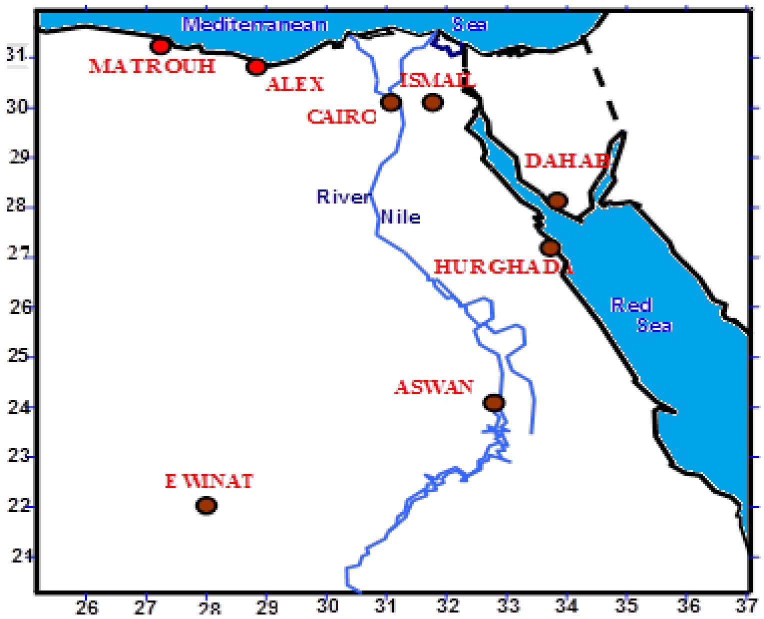

Fig. 2: Map of selected total column ozone stations over Egypt

3. METHODOLOGY

3.1 Coefficient of variation (COV)

A coefficient of variation (COV) of TCO for each individual station has been determined as follows:

COV= 100 * SD / μ

Where, SD is the standard deviation and μ is the temporal mean for N years.

Linear regressions by using Least Square method (Panofsky and Brier, 1963) method have been applied to study the trend and fluctuations of ozone over the studied area.

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3.2 Spectral Analysis

Fast Fourier Transformation (FFT) provides an efficient method of computing the finite discrete Fourier transform (Cooley and Tukey, 1965). The efficiency of the FFT made it practical to compute the spectrum directly in the frequency domain without the use of lag correlation functions. The FFT spectrum is noisy, but reflects the amplitude relationship in the original signal reasonably well. Also it is suitable for the analysis of short waves.

Climatological time series could be represented by a sequence (Xj) of ozone measurement expressed by the relation.

$$X_j = \overline{X} + \sum_i \left(a_i\, Sin(2\Pi i\, j/P) + b_i\; Cos(2\Pi i\, j/p)\right), i = 1, 2, ...n/2 \qquad (1)$$

In the FFT method of power spectral estimation, the transformation from the time to the frequency domain is made by obtaining the Fourier coefficients applying the relations;

$$a_i = (2/n)\sum_j X_j\;\; Sin\; (2\Pi i\; j/P), i = 1, 2, ...(n/2) \qquad (2)$$

$$b_i = (2/n)\sum_j X_j\;\; Cos\; (2\Pi i\; j/P), i = 1, 2, ...(n/2) - 1 \qquad (3)$$

$$b_{[n/2]} = (1/n)\sum_j X_j\;\; Cos(2\Pi i\; j/P) \qquad (4)$$

Where j=1,2,….. , n, n is the number of observation, P is the record length or fundamental period (equals to nΔX where ΔX is the spacing of the observations in time), i is the harmonic number and (n/2) the integer part of n/2.

The raw spectral estimates are then computed by;

$$S_i = C_i^2/2 = (a_i^2 + b_i^2)/2, \qquad i = 1, 2, ...(n/2) - 1 \qquad (5)$$

Where $C_i$is the amplitude of the i^{th} harmonic and i and j are integer values. The phase angle ϕ may be given by the following relation;

$$\phi = \arctan(a_i/b_i) \qquad (6)$$

For simplicity in interpretation, the terms of sines and cosines corresponding to a given harmonic may be combined into a single term (Panofsky and Brier, 1963). The combined term is given by:

$$C_i\, Cos\,(2\Pi i\,(j - j_i)/P) = a_i\; Sin(2\Pi i\; j\;/P) + b_i\; Cos(2\Pi i\; j/P) \qquad (7)$$

Where $j_i$is the point at which the i^{th} harmonic attains a maximum value. This is given by the relation;

$$j_i = \phi P/2\Pi i \qquad (8)$$

Therefore, $X_j$could be expressed in the following simple relation;

$$X_j = \overline{X} + \sum_i C_i Cos\left(2\Pi i\,(j - j_i)/P\right) \qquad (9)$$

The spectral values are equally spaced and occur at 1/P,2/P,3/P,………,(n/2)/P. However, on the wavelength scale, the values are unequally spaced and occur at P/1,P/2,P/3,...,P/(n/2).

4. RESULTSAND DISCUSION

4.1 Daily, monthly and auual variation of TCO

Table 2 shows the daily, monthly and annual analysis of TCO for the four ground based stations. It illustrate that the higher daily, monthly and annual values of TCO occurs over northern station (Matrouh) while the lower values appears over the southern station (Aswan). Which means that the TCO decreases from higher to lower latitudes? The mean value of TCO over Matrouh is 300 DU while for Aswan is 270 DU. The range between the maximum and minimum daily values of each station decreases from northern to southern station except at Cairo. Table 2 shows also the COV of the daily, monthly and annual time series of each station. The COV of the daily time series of Matrouh is 8.0, while for the monthly and annual time series are 5.5 and 2.6 respectively. Obviously, the COV of the daily time series of each station is greater than that of the monthly and the annual time series. Also, it is clear that the COV of the daily, monthly and annual time series decreases gradually from northern station (Matrouh) to the southern station (Aswan), which concludes that the COV is function of latitudes. To see if a long term trend can be identified based on the daily data, a linear regression is applied to the daily values, resulting in a decreasing trend (in Cairo) of -0.0004 DU /day or -0.1181 DU/year. Positive trends indicate increasing in TCO at Matrouh, Hurgada and Aswan, its values are 0.001, 0.0013, 0.0007 DU / day or 0.8761, 0.447 and 0.5223 DU/year respectively. Figure 3 displays the annual means of the four ground stations over Egypt station.

Table 2: The mean, maximum, minimum and the range between maximum and minimum of the daily, monthly and annual TCO for the four stations.Also, the COV and trend values of TCO of the four stations.

Staion		N	Mean	Max	Min	Range	COV	trend
Matrouh	Daily	5900	300	433	233	200	8.0	0.001
	Monthely	193		348	266	82	5.5	
	Annual	17		306	273	33	2.6	0.8761
Cairo	Daily	13150	293	431	212	219	7.4	-0.0004
	Monthely	434		347	244	103	5.4	
	Annual	36		307	282	25	1.7	-0.1181
Hurgada	Daily	5113	281	361	225	136	6.1	0.0013
	Monthely	168		307	248	59	4.7	
	Annual	14		285	275	10	1.2	0.447
Aswan	Daily	10986	270	336	207	129	6.3	0.0007
	Monthely	357		297	226	71	5.7	
	Annual	31		278	235	43	3.0	0.5223

Table 3 shows the seasonal analysis of total column ozone (TCO) for the four ground based stations. It is clear that there is a considerable seasonal variation of TCO for each station, where the difference between mean TCO of spring and autumn in the northern station (Matrouh) is 24.8 DU while for the maximum values the difference is about 41.7 DU. Also, the maximum seasonal values of TCO appears in spring followed by summer while the minimum seasonal values of TCO occurs in autumn for the four stations. Table 3 illustrates also the coefficient of variation (COV) and the trend by least square method for the seasonal values of TCO of four stations. The maximum COV for each station appears in winter and spring respectively, while the minimum appears in summer of all stations except for Hurgada. The trend values illustrate that there is an increase of TCO for the seasons of the four stations except at the winter of Cairo.

4.2 Periodicity analysis of TCO

Periodicity of the monthly and annual time series of the observed (ground based) and reanalysis total column ozone values of the Egypt stations has been examined. Analysis of the observed and reanalysis monthly time series of TCO for our stations shows that the annual wave is the dominant wave in all stations. This wave simply represents the seasonal variation caused due to meridional circulation. Results of the spectral analysis of the annual values of observed and reanalysis TCO for Egypt meteorological stations are given in table 4, Figure 4 and Figure 5. It is clear that there are five significant waves appear in the annual time series of the most stations. The first one is 2.8 years, it appears in the 6 stations, and the second is 9 years appears in 3 stations. The third wave is 18 years appears in 5 stations while the fourthis 4.5 years appears in 5 stations. The wave with wave length 2.6 years appears in 6 stations while the last wave which is 3.6 years appears in the time series of one station (Hurgada). Table 4 shows that although there is a difference in the record length of the observed and reanalysis data there are some waves appears in the two records (2.8, 2.9, 2.6 and 4.5). Due to the short length of the annual observed time series of Hurgada there is no significant waves appear (Figure 4).

The wave with a period of approximately 9 years is clearly matches the solar sunspot cycle period (Wilson, 1994). The dominant waves 2.8 ~2.6 years that appear with the analysis of the annual time series of our stations seem to be associated with quasi-biennial oscillation (QBO). Spectral weight analysis is performed where the relative strength of semiannual, annual and quasi-biennial oscillations are determined with respect to the integrated power spectra (V. Homonnai et al 2013). V. Madhu, (2014) found two prominent oscillations are present in total column ozone one with a

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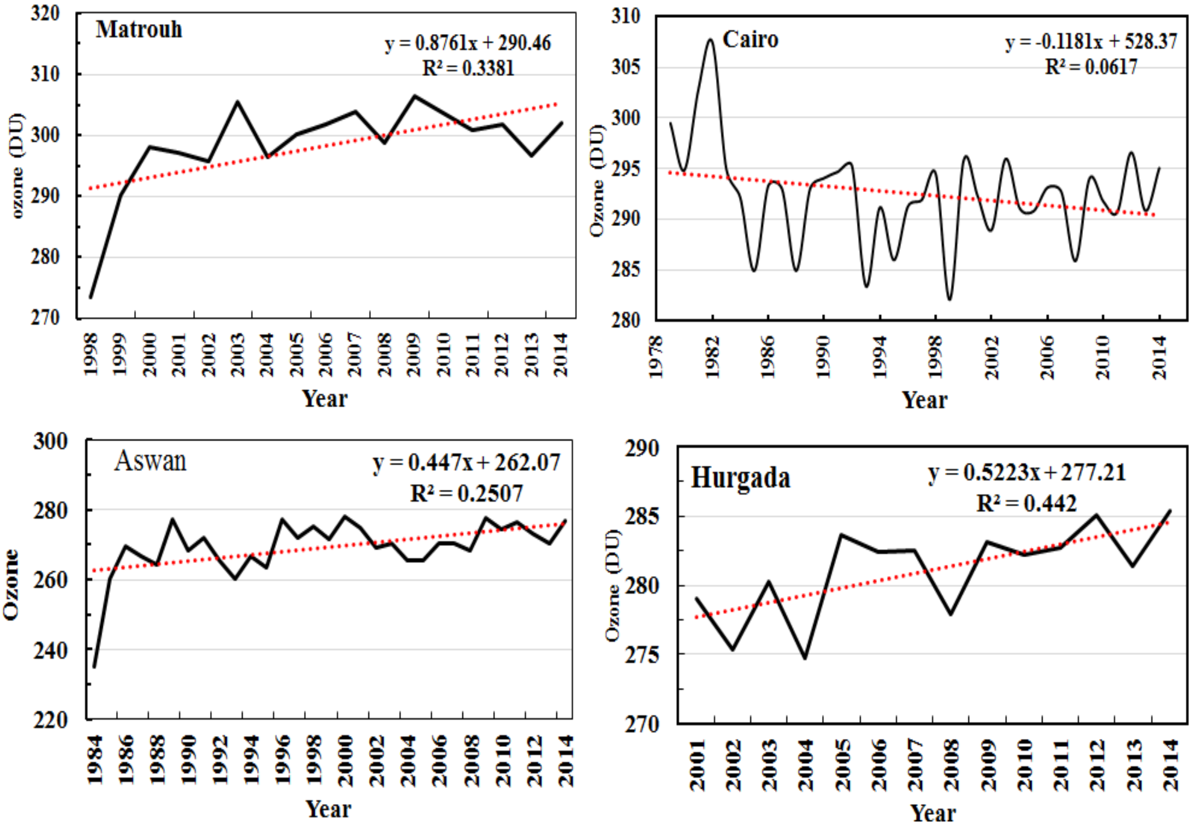

Fig. 3: The annual of TCO variation over (Mmatrouh from1998, Cairo from 1979, Hurgada from 2001 and Aswan from 1984 to 2014 for all station

Table 3: The mean, maximum, minimum and the range between maximum and minimum of the seasonal values of TCO for the four stations.Also, the COV and trend values of TCO of the four stations.

Staion	Season	Mean	Max	Min	Range	COV	trend
Matrouh	**Win**	297	307	279	28	3.2	0.39
	Spr	318	335	301	34	3.0	0.57
	Sum	301	310	294	16	1.2	0.53
	Aut	284	293	275	18	1.7	0.46
Cairo	**Win**	287	300	260	40	4.4	-0.15
	Spr	308	333	287	46	3.3	0.04
	Sum	295	306	281	25	2.0	0.19
	Aut	278	292	264	28	2.1	0.07
Hurgada	**Win**	270	277	260	17	2.2	0.06
	Spr	292	299	280	19	2.0	0.48
	Sum	292	300	287	13	2.0	0.37
	Aut	273	280	263	17	1.0	0.84
Aswan	**Win**	258	271	237	34	3.4	0.34
	Spr	279	292	264	26	2.7	0.24
	Sum	**286**	**298**	**267**	**31**	**2.1**	**0.07**
	Aut	**266**	**280**	**248**	**32**	**2.6**	**0.06**

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Table 4: The dominant waves that appears in the annual ozone time series of the reanalysis and observed data of Egypt stations.

Station	The domaniant Waves	
	Reanalysis data	Observed data
Matrouh	2.8 -2.6- *4.5*- 18	2.8
Alex	*4.5* – 9	
Cairo	2.8 - 2.6 – 4.5- 18	2.8- 2.9- 2.4- 4.7- 11.8
Ismail	2.8 - 2.6 – 4.5- 18	
Hurgada	3.6 - 9 - 4.5 - 18	------
Dahab	2.8- 2.6 - 9 - 4.5- 18	
Aswan	2.8 -2.6 -4.5	2.4 - 31
Ewinat	2.8- 2.6- 18	

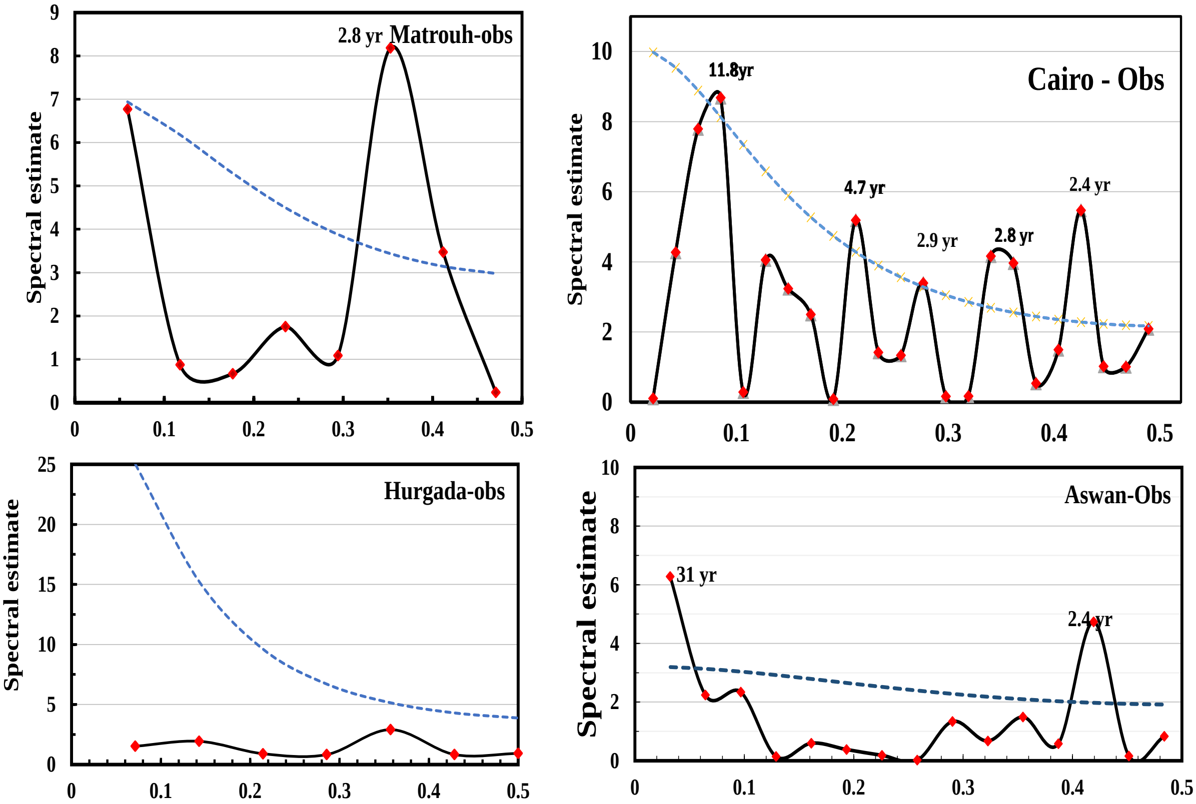

Fig. 4: Spectral analysis of the annual ozone for ground based stations.

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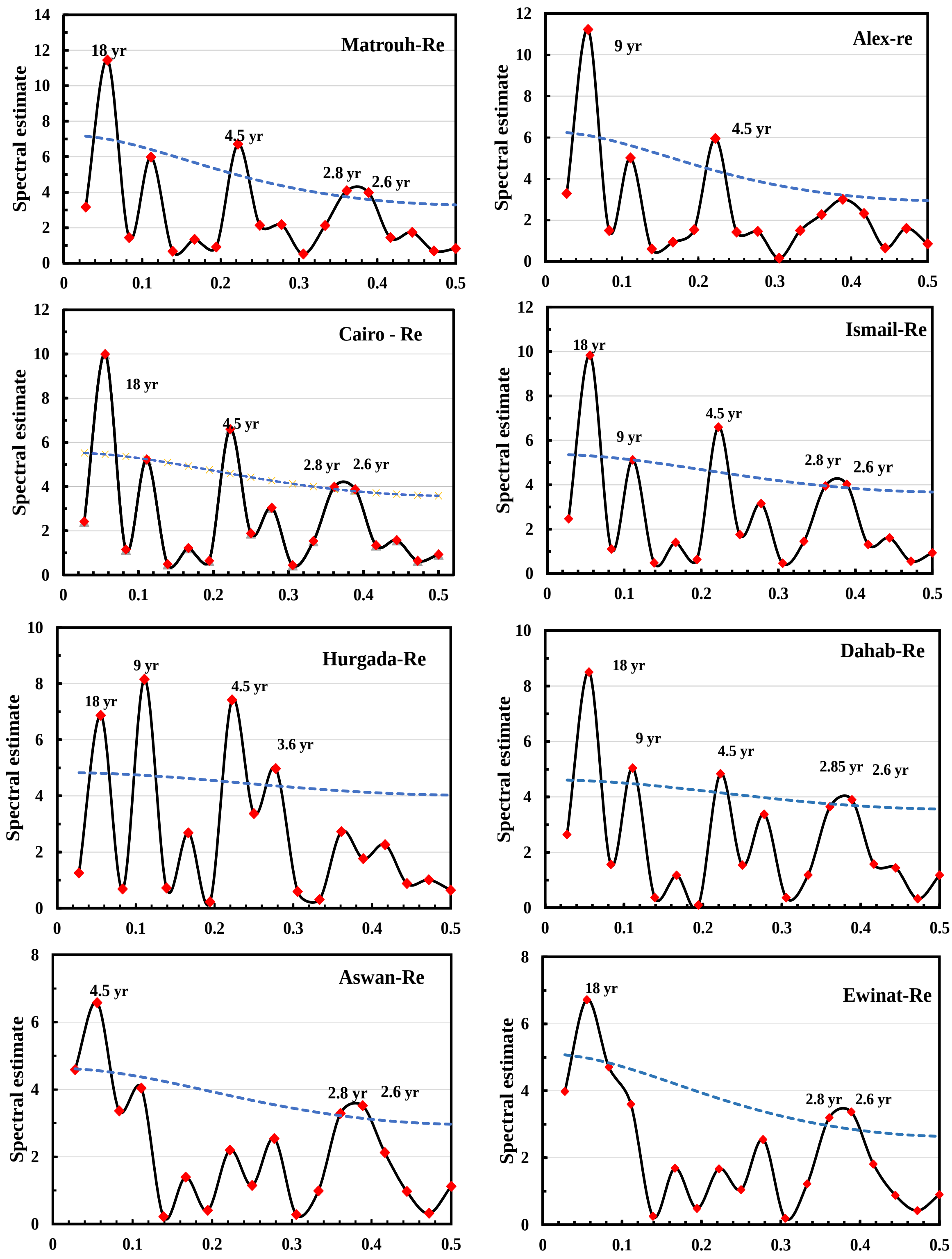

Fig. 5: Spectral analysis of the annual ozone for reanalysis data stations.

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periodicity of 16 to18 months and the other with 28 to 32 months (QBO periodicity) apart from the annual oscillations. These oscillations are found to be significant at above 95% level of confidence when tested with Power Spectrum method.Scherhag (1967) found that with quasi-biennial oscillation (QBO) appears to affect the overall mean temperature of the entire (northern hemisphere) atmosphere from the surface up to 16 km. The changes in solar UV-B radiation reaching the ground has been documented recently with that the QBO also affects clear sky UV solar irradiances at Thessaloniki, Greece (Zerefos et al., 1998). Udelhofen, et al. (1999) performed a detailed time series analysis for the Australian continent, based on TOMSerythemal exposure dose observations. They associated changes of UV erythemal exposure, to phases of the QBO and the solar activity cycles. Cabrera and Fuenzaliada (1999) reported evidence of the QBO in measurements of UV solar irradiance at Santiago, Chile. The relative importance of the QBO cycle to the amplitude of the annual variation of the UV erythemal dose was examined by the ratio of the QBO amplitude over the amplitude of the annual variation at the same latitude, and for different latitude zones (Zerefos et al, 2001).

Also, studies have shown that there may be two fundamental time-scales in the interannual variability of the monsoon-ocean-atmosphere system, i.e. a quasi-two 6 years cycle associated with tropical biennial oscillation (TBO) and a 3.1, 4 and 5.6 year cycle associated with the El-Nino Southern Oscillation (ENSO). The ocean (El-Nino) may cause oscillations of between 3 and 8 years (WMO, 1985, Malcher and Schonwiese, 1987). Also minor peaks at periods in the range of 3 - 5 years appear to be associated with the southern oscillation, Folland et al. (1984). Other waves (9 - 18 years) seem to match the sunspot cycle and the period of 5.6 years, the second harmonic of sunspot cycles (Kane and Trivedi, 1985).). MankinMak (1995) found that 5.6 and 2.8 year cycles in the marine surface temperature clearly delineate El-Nino and La Nina events

4.3 Estimation of ozone from meteorological variables

Residual method has been applied to explore the possibility of forecasting total ozone average values by means of the values of some meterological paramterses at each station. The monthly values of total ozone during the period 1979 to 2010 have been taken as the dependent variable (predicted) and the corresponding values of othere parameters are the independent variables (predictors).

First step, the correlation coefficient (C.C) between the values of total ozone and each predictor has been determined. The predictor which has the strongest C.C with the predicted (total ozone) has been used to be the first predictor, and 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 predicted.

Second step, the mentioned above error was subjected to the process performed in the first step. The second step has been repeated with new predictors until the additional predictors have no significant effect on the predicted and there is no need for any further steps (i.e. the improvement cannot be expected to be very great with adding new predictors).

In table 5 the surface meteorological variables used are: ultra violet radiation (uvb), solar surface radiation (ssrd), bounder layer height (blh), surface pressure (sp), relative humidity (rh), and temperature at 2 meter (t2m) and Dewpoint temperature at 2 meter (d2m) level. While the upper air variables used are: geopotenial high (z), relative humidity (rh), temperature (t) and the thickness between diffrenetgepotenialhight levels z(100-200) and z(100-500).

Third step, the verification from the equations and parameters which are selected is performed during the period from 2011 to 2014.

In this section, the relation between TCO and the above meteorological variables have been investigated. Empirical equations relating the total ozone with these variables have been deduced by applying the residual method for each station of the Egypt. Tables 5 show the number of steps, the predictor, the regression coefficients (Ai, Bi) the root mean square error (RMSE) and mean absolute error (MAE) arising from the error between the actual and estimated data after each step, and multiple correlation coefficient (C.C) from a stepwise regression analysis for 8 stations over Egypt. Figures6 illustrate actual (solid line) and estimated (dashed line) TCO from 1979 to 2010 for 8 stations of Egypt and verifying the equation from 2011 to 2014. The results of residual method shown in tables 3 and figures 6 can be summarized as follows.

- Good agreement between the actual and estimated values of ozone for the stations Alex, Cairo and Ismail is found, where the total multiple correlation coefficient reaches to 0.756, 0.69 and 0.676 respectively after using four predictors. The reasonable values of total multiple correlation coefficients have been appeared clear in Figure 6 where a good agreement between the actual and estimated time series of ozone is observed.

- Very good agreement between the actual and estimated values of ozone for the stations Matrouh, Dahab, Hurgada, Aswan and Ewinat, where the total multiple correlation coefficient reaches to 0.783, 0.79, 0.786, 0.846 and 0.857 (which is quite high) respectively after using three predictors. The high values of total multiple correlation coefficients have been appeared clear in Figure 7 (Ewiant) where a very good agreement between the actual and estimated time series of ozone is observed.

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Table 5: The predictor used in each step, the regression coefficients arising in each step (Ai, Bi), MAE and RMSE arising from the error between the actual and estimated data after each step, and multiple correlation coefficient (R) from a stepwise regression analysis for the stations Matrouh, Alex, Cairo, Ismail, Dahab, Hurgada, Aswan and Ewinat.

Stations	step No.	predictors	Regression coefficients		RMSE	MAE	C.C
			A_i	B_i			
Matrouh	1	uvb	22.342	0.00001	6.69302	5.7439	0.479
	2	d2m	20.14173	-2.30748	6.19244	4.9349	0.735
	3	blh	-18.72297	0.0294	7.19541	5.93045	0.766
	4	z(100-200)	-424.9814	0.101	8.15036	6.59647	0.783
Alex	1	uvb	229.6226	0.00003	6.53063	5.61118	0.468
	2	Tmp100	-13.81139	1.1651	5.44171	4.52773	0.709
	3	sp	-65.20069	-1.24007	5.94119	4.69117	0.717
	4	T2m	297.4103	-0.0072	6.0856	4.95447	0.756
cairo	1	rh1000	370.9226	-154.8099	7.67416	6.17861	0.565
	2	z(100-200)	-533.4017	0.01271	8.56909	7.04776	0.628
	3	blh	-18.54736	0.02566	9.58203	7.60458	0.684
	4	r850	-7.76657	19.19345	8.89494	7.06735	0.69
Ismail	1	r1000	354.751	-129.983	7.59092	6.04532	0.558
	2	z(100-200)	-597.6566	0.01424	8.4629	6.9247	0.638
	3	blh	-14.47078	0.01889	9.40485	7.4403	0.679
Dahab	1	ssrd	249.8543	0.0001	10.87778	9.01437	0.729
	2	z(100-500)	652.8194	-0.00636	7.614	6.12452	0.777
	3	r850	-6.63915	24.9562	6.66013	5.43951	0.79
Hurgada	1	uvb	244.929	0.00002	6.93675	5.72044	0.771
	2	T100	39.70494	9.24939	6.30333	5.72044	0.783
	3	blh	-9.77217	0.01361	7.15234	5.84697	0.786
Aswan	1	uvb	229.6226	0.00003	8.71308	7.19922	0.802
	2	d2m	-13.81139	1.1651	8.30654	6.83432	0.838
	3	T200	-65.20069	-1.24007	7.17081	5.71466	0.84
	4	z(100-200)	297.4103	-0.0072	7.02802	5.63897	0.846
Ewinat	1	T2m	222.8886	1.83116	7.06002	5.54761	0.839
	2	T200	46.44217	0.8816	7.4804	5.90008	0.847
	3	d2m	1.36274	-0.64488	6.63449	5.22861	0.857

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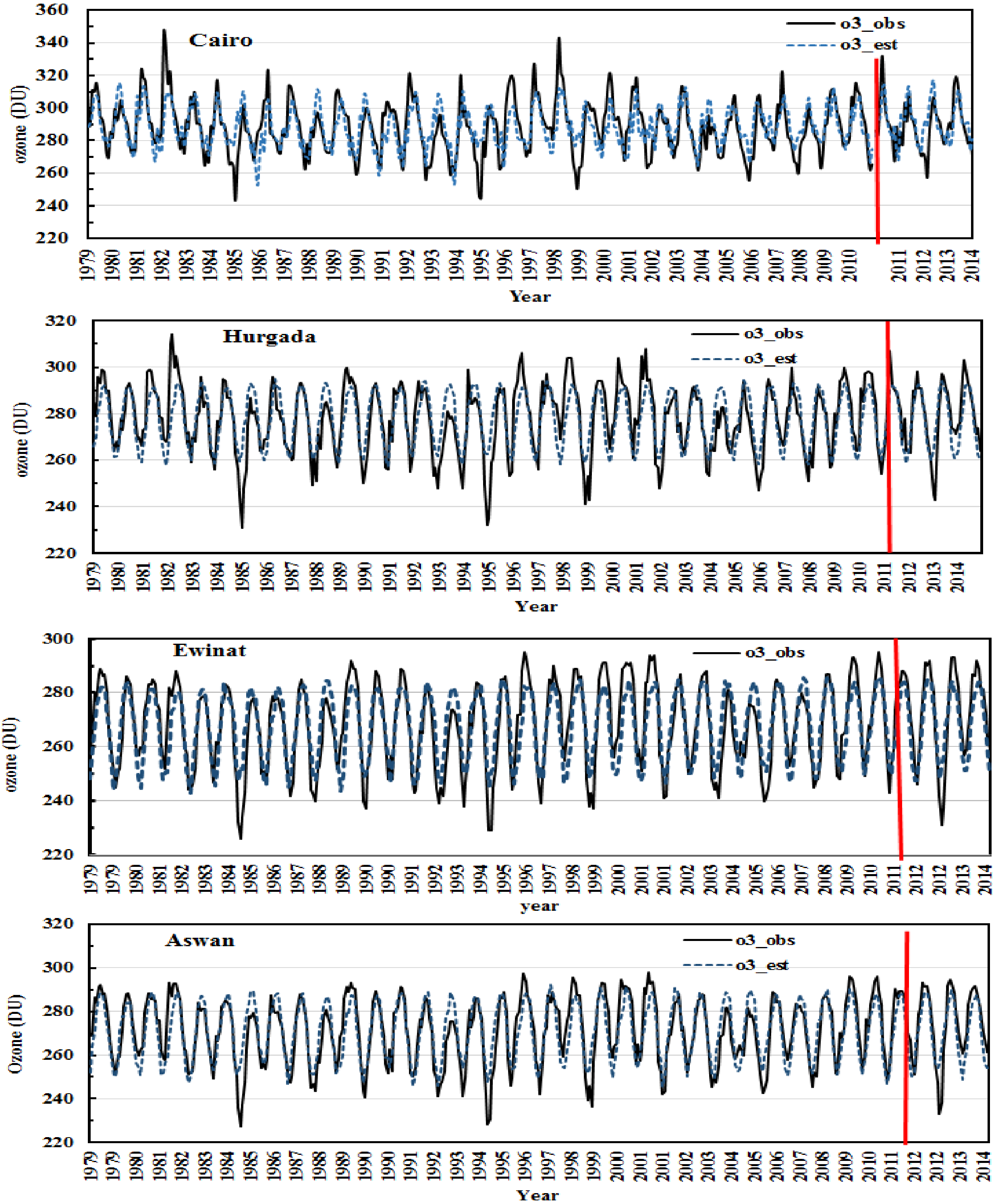

Fig. 6: Actual (solid line) and estimated (dashed line) TCO from 1979 to 2014 for the stations Cairo,Hurggada, Aswan and Ewinat.

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4.4 The multiple regression equations

The multiple regression equations for the predicting values of the total ozone over Egypt stations from the known predicting values can be written in the following forms:

$$O3(mat) = -151.22064 + 0.00001 * uvb - 2.30748 * d2m + 0.02940 * blh + 0.01010 * z(100 - 200) \quad (10)$$

$$O3(alex) = 1383.21204 + 0.00001 * uvb + 2.32410 * tmp100 - 0.91583 * sp - 1.03100 * t2m \quad (11)$$

$$O3(Cai) = -188.79303 - 154.8099 * r1000 + 0.012710 * z(100 - 200) + 0.025660 * blh + 19.19345 * r850 \quad (12)$$

$$O3(ism) = -257.40228 - 129.98300 * r1000 + 01424 * z(100 - 200) + 0.01889 * blh \quad (13)$$

$$O3(Dah) = 896.03455 + 0.00001 * ssrd - 0.00636 * z(100 - 500) + 24.95672 * r850 \quad (14)$$

$$O3(Hur) = 274.86177 + 0.00002 * uvb + 0.53074 * t100 + 0.01361 * blh \quad (15)$$

$$O3(asw) = 448.02082 + 0.00003 * uvb + 1.16510 * d2m - 1.24007 * t200 - 0.00720 * z(100 - 200) \quad (16)$$

$$O3(ewi) = 270.69351 + 1.83116 * t2m + 0.88160 * t200 - 0.64488 * d2m \quad (17)$$

5. SUMMARY AND CONCLUSION

Periodicity of the monthly and annual values of total column ozone data of the Egypt stations has been examined. It is found that the annual wave is the dominant wave in all stations. This wave simply represents the seasonal variation caused due to meridional circulation. Also, there are six significant waves appear in the annual time series of the most stations. The first one is 2.8 years, it appears in the 6 stations, and the second is 9 years appears in 3 stations. The third is 18 years appears in 5 stations while the fourth is 4.5 years appears in 5 stations. The first wave which has a largest frequency has a period of 2.8 years, which qualitatively matches the quasi-biennial oscillation (QBO). The second wave which has a period of approximately 9 years and this clearly matches the solar sunspot cycle period (Wilson, 1994). The shorter waves (2.8 – 2.6 years) seem to be associated with the QBO. This connection has been mentioned by Angell et al. (1966), Scherhag (1967), and Lamb (1972). Lamb (1972) noted that a QBO is related to the southern oscillation, which is the strength of subtropical high belt in both northern and southern hemispheres. Also, studies have shown that there may be two fundamental time-scales in the interannual variability of the monsoon-ocean-atmosphere system, i.e. a quasi-two year cycle associated with tropical biennial oscillation (TBO) and a 2.4, 3.6, 4.5 and 4.7 year cycle associated with the El-Nino Southern Oscillation (ENSO). The ocean (El-Nino) may cause oscillations of between 3 and 8 years (WMO, 1985, Malcher and Schonwiese, 1987). Also minor peaks at periods in the range of 3 - 5 years appear to be associated with the southern oscillation, Folland et al. (1984). Other waves (9 – 11.8 years) seem to match the sunspot cycle and the period of 4.5 years, the second harmonic of sunspot cycles (Kane and Trivedi, 1985).

This work also aimed to estimate the total amount of ozone from the meteorological variables. Residual method has been applied to explore the possibility of forecasting total ozone average values by means of the values of these meteorological variables for each station of Egypt. The monthly values of total ozone during the period 1979 to 2010 have been taken as the dependent variable (predictand) and the corresponding values of the meteorological variables are the independent variables (predictors). Empirical equations relating the total ozone with these variables have been deduced at each station of Egypt. Very good agreement between the actual and estimated values of ozone for the middle and southern stations of Egypt have been found, where the total multiple correlation coefficient ranges reached to greater than 0.8 (which is quite high) at some stations. The obtained good relations make us able to estimate and forecast of ozone whether there are meteorological stations or not, by using numerical weather prediction models outputs.

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