The observed relationship between Ozone layer with Meteorological Parameters and Solar Indices.

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Abstract
The relationship between the Ozone layer and meteorological parameters (rainfall, relative humidity, cloud cover, maximum and minimum temperature), also the contribution of Ozone layer with solar indices (sunspot number and solar flux) were examined for 12 years (1999-2010) for Ikeja over Nigeria. The enhancement of surface ozone concentration has been observed in association with the increasing sunspot numbers. This feature is more significant in May, July, September and October. We observed strong correlations between the Ozone layer with rainfall, relative humidity, cloud cover, maximum and minimum temperature with values of 0.531, 0.668, 0.512 0.586 and 0.551 respectively. The relationship between Ozone with sunspot number and solar flux were 0.677 and 0.474. The accuracy of the regression is tested by computing MBE, RMSE and t-test statistic for each of the variables with standard techniques..

Keywords: Ozone layer, solar flux, sunspot number and meteorological Parameter

1.0 Introduction

At the stratospheric layer, the ozone protects us from harmful ultraviolet radiation, the ozone decomposition is a global issue that needs to be resolved by reducing emissions that destroys the ozone shield into the atmosphere. Literatures revealed that the ultraviolet radiation is classified into three groups according to their wavelength UVA (315–400 nm), UVB (280–315 nm) and UVC (100–280 nm). The higher the energy, the shorter the wavelength and the radiation are more harmful. The UVB is the most dangerous radiation that reaches the surface of the Earth. The changes of the stratospheric ozone quantity could alter the concentration of reactive tropospheric gases due to the changes of UV radiation intensity [1, 2]. Several studies have established that changes in air temperature and relative humidity are the two major meteorological parameters for the prediction of ozone and observation [3-11].

In Japan, the ground-level ozone (O3) concentrations have recently been noticed, the relationship between temperature, wind speed and ground level ozone concentrations in the summer over the Kanto area of Japan were investigated using both statistical analyses and numerical models. It was observed that there is a close relationship between meteorological conditions and ground level ozone concentrations over the Kanto area of Japan. The impact of meteorological factors on ozone concentration was investigated during the period of 2000–2003 in Taiwan [12]. It was observed that the meteorological conditions in southern Taiwan tend to increase ozone concentrations during this period. The influence of meteorological factors on ozone levels at Slavonia (Croatia) and noticed that the variation of ozone concentrations during the summer period of the year 2002 is around 67%, this could be accounted for by changes in temperature, solar radiation, and wind speed [13]. The abundance of oxides of nitrogen (NO) is responsible for the reduction of ozone at Kannur Town, while the relatively small concentration of NO occurs at Kannur University campus (KUC), leads to higher concentration of ozone. It was further revealed that the ozone production has a strong positive correlation to the temperature and has a negative correlation to the relative humidity at these locations in India [14]. Also the impact of temperature and relative humidity on indoor ozone concentrations during the Harmattan. A strong correlation coefficient of 0.75 and -0.63 for ozone was found with temperature and relative humidity respectively [15].

The effect of Sunspot numbers (SSN) and solar Magnesium II core wing ratio (Mg II) to the variations of stratospheric ozone (O3) concentrations were examined in some cities in Nigeria [16]. There is no significant correlation between the MgII and the ozone concentrations in these cities, while good relationship between SSN and the ozone concentrations. The relationship between surface ozone and sunspot numbers (SSN) were investigated in the east coast of southeast India, the increase in surface ozone in association with an increase in sunspot numbers was observed during May and October in the period 1996-2004 [17]. The negative relationship between solar activity and total column ozone variation in Lagos, both at monthly level and annual level, showing that the total column ozone decreases with increasing solar activity [18]. Linear regression analysis was investigated between the ozone concentrations and sunshine hours in Nigeria for the period (1997-2005) gave a significant negative correlation between the two meteorological parameters [19]. Study of ozone and meteorological data demonstrate a notable solar cycle variation of ozone, temperature, and zonal wind at both the upper and lower stratosphere. It was observed that the variations of upper stratospheric ozone and temperature were in phase with one another and the largest variation of upper stratospheric zonal wind occurred at middle latitudes near winter solstice in both hemispheres [20-22].

In the present work we investigate the connection between variability of stratospheric ozone with rainfall, relative humidity, cloud cover, maximum and minimum temperature. Also, statistical analyses to ascertain the influence of the sunspot numbers and the solar flux on the stratospheric ozone variations in Lagos, Nigeria

2.0 Data and methods

Stratospheric Ozone, rainfall, relative humidity, cloud cover, maximum and minimum temperature data used in the present study are taken from the Archives of Nigerian meteorological Agency Oshodi, Lagos State, Nigeria. The data obtained covered a period of twelve years (1999-2010) for Ikeja at Latitude 6.39^{o} and longitude 3.23^{o}. Both sunspot numbers (SSN) and solar flux 10.7 cm radio emission values for the same period are taken from OMNIWEB (http://omniweb.gsfc.nasa.gov/form/dx1.html).

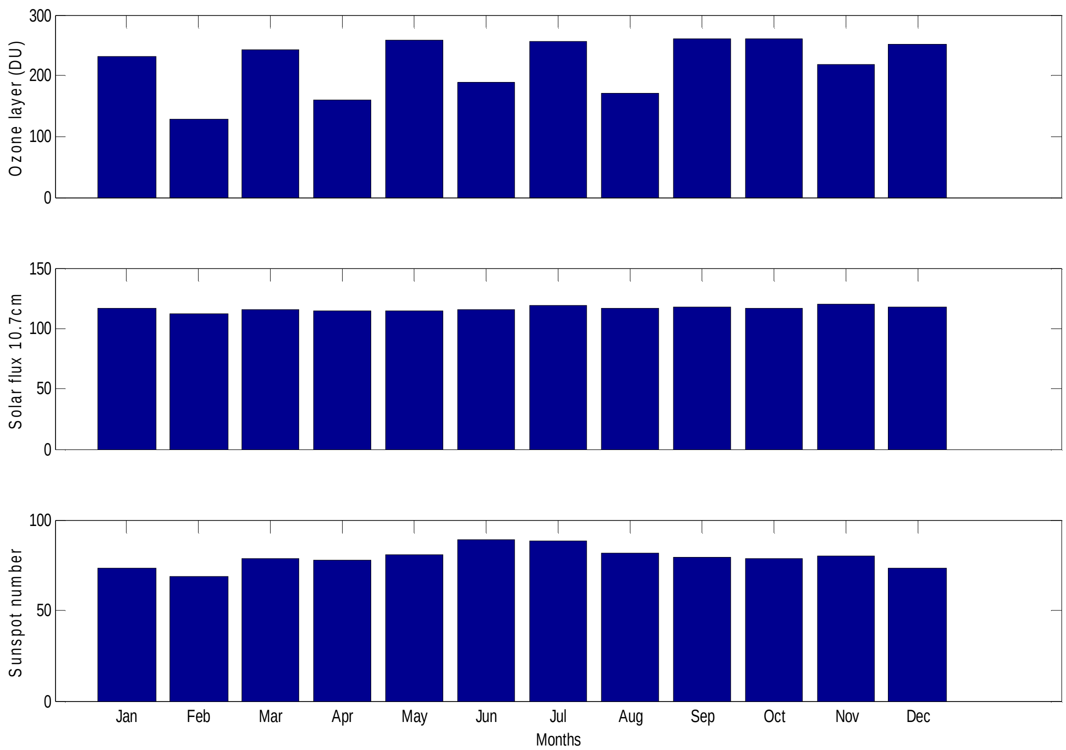

Figure 1. Monthly average of Ozone layer, Solar flux 10.7 cm and Sunspot number between 1999-2010.

The incoming solar radiations at a wavelength of 10.7 cm are often used as a measure for changes in solar output at UV wavelengths. If variation in solar output were the cause of ozone depletion, a gradually decreasing output are observed in February, April, June and August.

2.1 Correlation between stratospheric ozone layer and meteorological parameter

The regression variable of the stratospheric ozone layer and five independent variables (meteorological parameter) of relative humidity (RH), rainfall (RF), cloud cover (CC), maximum temperature (T_{max}) and minimum temperature (T_{min}), were used to develop the equations to estimate the stratospheric ozone layer. In order to get the best model for the study location, we proposed linear relationship between the stratospheric ozone layer and other meteorological parameters. The general regression equations developed for each meteorological parameter were of the form

$$O_3 = a_o + a_1 RH \qquad (1)$$

$$O_3 = a_o + a_2 RF \qquad (2)$$

$$O_3 = a_o + a_3 CC \qquad (3)$$

$$O_3 = a_o + a_4 T_{max} \qquad (4)$$

$$O_3 = a_o + a_5 T_{min} \qquad (5)$$

Where a_o is the intercept and a_1-a_4 is the coefficient to be determined. The regression equations (6-10) were developed to determine the stratospheric ozone layer for Lagos using different meteorological parameter RH RF, CC, T_{max} and T_{min}.

$$O_3 = 218.99 + 0.4797\text{RH} \qquad (6)$$

$$O_3 = 256.01 + 0.0195RF \qquad (7)$$

$$O_3 = 183.64 + 10.8576\text{CC} \qquad (8)$$

$$O_3 = 288.34 + \text{-}0.9553\text{T}_{max} \qquad (9)$$

$$O_3 = 318.65 + \text{-}2.5136\text{T}_{min} \qquad (10)$$

2.2 Statistical model evaluation of regression equations

The accuracy of the regression equations is assessed using correlation coefficient, root mean square error (RMSE), Mean bias error (MBE), and t test statistic, how meteorological conditions have an influence the variations in ozone level.

$$R = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{(n-1)d_x d_y} \qquad (11)$$

where n is the number of pairs xy of the data point, d_x and d_y are the univariate standard deviations.

$$R^2 = \frac{\sum_{i=1}^{n}\left[2\left(x_i - y_i\right)\right]}{\sum_{i=1}^{n}\left[2\left(x_i - y_i\right)\right]} \tag{12}$$

This can be expressed as

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left[2\left(x_i - y_i\right)\right]}{\sum_{i=1}^{n}\left[2\left(x_i - y_i\right)\right]}, \qquad 0 \le R^2 \le 1 \tag{13}$$

$$RMSE = \left(\sqrt[2]{\sum_{i=1}^{N}\frac{(di)^2}{N}}\right) \tag{14}$$

$$MBE = \left(\sum_{i=1}^{N}\frac{di}{N}\right) \tag{15}$$

Where N is the total number of observations and di is the deviation between ith calculated values and ith is the measured values. A zero value for the MBE is ideal and a low RMSE is desirable. The RMSE test provides information on the short term performance of the study model as it allows a term by term comparison of the actual derivation between the calculated and measured the values.

The two sample t-test is used to examine the hypothesis that the means of two Gaussian distribution are identical. It can be used to determine if the both sets of the samples come from the same populations.

$$t = \frac{|a - b|}{\sqrt{\frac{n_a + n_b}{n_a n_b} \cdot \frac{(n_a - 1).s_a{}^2 + (n_b - 1).s_b{}^2}{n_a + n_b - 2}}} \tag{16}$$

where n_a and n_b are the sample sizes and S^2a and S^2b are the variances of the two samples a and b. The null hypothesis can be rejected if the measured t-value is higher than the critical t-value, which depends on the number of degrees of freedom and the significance level. Table 1 shows the statistical performance of the regression model evaluated by R, R^2, MBE, RMSE and t-test statistics.

Table1: shows the statistical analysis of the ozone layer and other Parameters for Ikeja.

Parameters	Correlation Coefficient (R)	Coefficient of determination (R^2)	RMSE	MBE	t-statistics
Rainfall	0.530	0.281	2.513	-0.121	0.076
Relative Humidity	0.668	0.446	2.207	0.014	0.018
Maximum Temp	0.586	0.343	2.403	-0.055	0.045
Minimum Temp	0.551	0.303	2.474	-0.099	0.063
Cloud cover	0.474	0.244	2.577	-0.129	0.102

Table 1 depicts the meteorological conditions which have significant impacts on the stratospheric ozone layer during the period of 2000–2003. The meteorological conditions in Ikeja tend to increase ozone concentrations during this period. The correlation between ozone concentrations, rainfall, relative humidity, maximum and minimum temperature values revealed a strong positive correlation except cloud cover which exhibit weak correlation.

2.3 Correlation between stratospheric ozone layer and solar indices

Section 2.2 examines the influence of sunspot number and solar flux 10.7cm on the stratospheric ozone layer using linear regression analysis (see Table 2). The correlations of coefficient 0.677 exist between stratospheric ozone layer and SSN. The coefficient of determination of 0.458 implies that 45.80% of stratospheric ozone can be accounted by SSN. The correlation coefficient that exists between stratospheric ozone layer and SF is 0.424. The coefficient of determination is 0.180 which implies that 18.0% of stratospheric ozone can be accounted for by SF.

Table2: shows the statistical analysis of ozone layer between SSN and SF for Ikeja.

Parameters	Correlation (R) coefficient	Coefficient (R^2) of determination	RMSE	MBE	t-statistics
Sunspot Number (SSN)	0.677	0.458	2.182	-0.121	0.016
Solar flux (SF)	0.424	0.180	2.684	0.143	0.169

This implies that sunspot numbers have direct influences on ozone variation, while a low significant relationship between ozone and solar flux 10.7cm at Ikeja was noticed. The analyses of the influences of the changes in meteorological conditions on variations in ozone are very helpful for better understanding variations in ozone concentrations. Variation is in ultraviolet wavelength, which is absorbed by stratospheric ozone. But ozone concentration varies with the sunspot cycle, reaching a maximum during sunspot maximum.

3.0 Discussion of the result

Table 1 summarizes the regression analysis obtained from Eqs. (5-10), the correlation coefficient (0.474- 0.668) are high for the variables. This implies that stratospheric ozone layer has a significant relationship between relative humidity, rainfall, cloud cover, maximum and minimum temperature. The accuracy of the regression is tested by computing MBE, RMSE and t-test statistic for each of the variables with standard techniques. The negative values for MBE signifies under estimate and positive value signifies over estimates, while the RMSE gives information on short term performance of the correlation between the predicted and the observed values. The response of ozone to relative humidity and maximum temperature are statistically significant ($p < 0.05$, Table 1). Table 2 illustrates the contribution of solar indices and the stratospheric ozone layer. The t-statistic values indicated that the data were statistically significant at 95 % confidence level between the stratospheric ozone layer and sunspot number; however, the low t-s values demonstrated excellent performance of the regression model. This implies that sunspot numbers have strong forcing on the increase in ozone concentrations at Ikeja, also there may be the direct insolational effect on the ozone balance in ozonosphere. The correlations shown in Table 2 indicate that the solar variations are important driver of climate. The atmospheric ozone layers are regarded as one of the major parameters for connecting solar activity to weather responses. A linear correlation between the stratospheric ozone layer and sunspot number is 0. 677 this implies that the variability of atmospheric ozone may be related to sunspot activity. The sunspot number can be used to estimate or measures the variation in the stratospheric ozone layer. Weak significant levels and correlation were exhibited between solar flux and stratospheric ozone layer. If the correlation coefficient is weak, it implies that the relationship is weak; such relationship may be attributed to nonlinear.

It has been shown that there is a tendency towards an increase in the ozone concentration as a result of increase in temperature; this is observed from the correlation between the maximum, minimum temperature and the maximal ozone concentration at the end of the observed period. The positive correlation between O3 and temperature noticed is as a result of the radiation influencing the temperature and have an impact on the photochemical reactions, also increase O3 emission leading to an enhance in O3 concentration. The result presented indicates that the relative humidity and rainfall plays an important role in the processes that control the variation in ozone concentration. As the humidity becomes higher, the significant path of the photochemical removal of the O3 will be intensified [23]. Furthermore, the increase in the humidity levels is related to the large amount of cloud cover and atmospheric instability, this result in depletion of O3 layer by the deposition of water droplet as a result of reduction in the photochemical process and the O3 concentration has a strong dependence on humidity [14]. The correlation between O3 and humidity is more pronounced at Ikeja since been an urban location with high amount of pollution. The results of the high correlation from the analysis revealed that ozone layer are strongly affected by meteorological conditions.

Figure 1 depicts, the monthly mean values of ozone, Solar flux 10.7cm and sunspot were lumped together and averaged for each month from January 1999 through December 2010. The monthly average ozone values obtained reflect variations of average latitude and longitude of the station. Ozone concentration increases with increase in sunspot number and surface ozone concentration was considerably higher in the months of May, July, September and October. The surface ozone concentration is more or less same for all the other months. The result of the study revealed that the surface ozone concentration is markedly correlated with sunspot numbers.

Conclusion

The results of the presented investigations confirm the dependence of the ozone layer concentration on meteorological parameters. The ozone layers are positively correlated with the rainfall, relative humidity, cloud cover, maximum and minimum temperature. Data analysis has shown that surface ozone concentrations increase with the increase of temperature and not significantly related to cloud cover. The results suggest that changes in meteorological conditions have significant impacts upon rising ozone layer at Ikeja. The enhancement of surface ozone concentration has been observed in association with the increasing sunspot numbers. Weak significant levels and correlation were exhibited between solar flux and stratospheric ozone layer. The O3 is more significant in May, July, September and October. The positive correlation between O3 and temperature observed is due to the fact that the radiation controls the temperature.

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References

[1] Anet J.G., Rozanov E.V., Muthers S., Peter T., Brönnimann S., Arfeuille F., Beer J., Shapiro A.I., Raible C.C., Steinhilber F. (2013). Impact of a potential 21st century grand solar minimum on surface temperatures and stratospheric ozone. Geophys. Res. Lett. 40, 4420–4425.

[2] Wargan K., Pawson S., Stajne, I., Thouret V. (2010). Spatial structure of assimilated ozone in the upper troposphere and lower stratosphere. J. Geophys. Res. 115, 24316.

[3] Sillman S. and Samson P. J. (1995). Impact of temperature on oxidant photochemistry in urban, polluted rural and remote environments, J. Geophys. Res. 100, 11497–11508.

[4] Dawson J. P., Adams P. J. and Pandis S. N. (2007). Sensitivity of ozone to summertime climate in the Eastern USA: a modeling case study. Atmospheric Environment 41, 1494-1511.

[5] Zeng G., Pyle J. A. and Young, P. J. (2008). Impact of climate change on tropospheric ozone and its global budgets. Atmospheric Chemistry and Phys. 8, 369-387.

[6] Cox W.M. and Chu S.H., (1993). Meteorologically adjusted ozone trends in urban areas a probabilistic approach. Atmospheric Environment Part B-Urban Atmosph. 27, 425-434.

[7] Camalier L., Cox, W. and P. Dolwick P. (2007). The effects of meteorology on ozone in Urban areas and their use in assessing ozone trends, Atmos. Environ. 41, 7127– 7137.

[8] Zheng J., Swall J. L., Cox W. M., Davis J. M. (2007). Interannual variation in meteorologically adjusted ozone levels in the Eastern United States: a comparison of two approaches. Atmospheric Environment 41, 705-716.

[9] Bloomer B. J., Stehr J. W., Piety C. A., Salawitch R. J., Dickerson R. R. (2009). Observed

relationships of ozone air pollution with temperature and emissions. Geophys.Res. Lett. 36, 9803.

[10] Bernard S. M., Samet J. M., Grambsch A., Ebi K. L., Romieu I. (2001). The potential impacts of climate variability and change on air pollution-related health effects in the United States. Environ. Health Perspect. 109, 199-209.

[11] Davis J., Cox W., Reff A., Dolwick P., (2011). A comparison of Cmaq-based and observation-based statistical models relating ozone to meteorological parameters. Atmospheric Environment. 45, 3481-3487.

[12] Chen Y., Liu L., Wan W., Yue X. and Su S.-Y (2009). Solar activity dependence of the topside ionosphere at low latitudes, J. Geophys. Res. 114, A08306,

[13] E. Kovac-Andric E., Brana J. and V. Gvozdic V. (2009). Impact of meteorological factors on ozone concentrations modelled by time series analysis and multivariate statistical methods, Ecological Inform. 4, 117–122.

[14] Nishanth.T and M K S Kumar M. K. S. (2011). Diurnal variation of Surface Ozone with Meteorological parameters at Kannur, India. Advances in Applied Science Res. 2011, 2 , 407-417.

[15] Quansah E., Amekudzi L. K., and Preko K. (2012). The Influence of Temperature and Relative Humidity on Indoor Ozone Concentrations during the Harmattan. Journal of Emerging Trends in Engineering and Applied Sci. 3, 863-867.

[16] Isikwue B. C., Agada P. O. and Okeke F. (2010). The contributions of the solar activity indices on the stratospheric ozone variations in Nigeria. Journal of Emerging Trends in Engineering and Applied Sci. 1, 133-139.

[17] Selvaraj R. S., Selvi S. T. and Priya S.P.V. (2010). Association between surface ozone andsolar activity.Indian Journal of Science and Technology. 3, 332 – 366.

[18] Rabiu A. B. and Omotosho T. V. (2003): Solar Activity and Total Column Ozone Variation In Lagos, Nigeria. Nigeria Journal of Pure and Applied Physics, 2, 17-20.

[19] Obiekezie T.N. (2009). Sunshine activity and total column ozone variation in Lagos, Nigeria. Moldavian Journal of the Physical Sci. 8, 169-172.

[20] Kodera, K. and K. Yamazaki, (1990). Long-term variation of upper stratosphric circulation in the Northern Hemisphere in December J. Meteor. Soc. Japan. 68, 101-105.

[21] Hood L. L., Jirikowic J. L., and McCormack J. P. (1993). Quasi-decadal variability of the stratosphere: Influence of long-term solar ultraviolet variations..,,. J. Atmos. Sci. 50, 3941 – 3957

[22] Chandra S and Mc Peters R. D. (1994). The Solar Cycle variation of Ozone in the stratosphere inferred from Nimbus -7 and NOAA-11 satellite, J. Geophys. Res. 99, 20665-20671.

[23] Elampari K and Chithambarathanu T. (2011). Diurnal and Seasonal Variations in Surface Ozone Levels at Tropical Semi- Urban site,Nagercoil , India, and Relationships with Meteorological Conditions, International Journal of Science and Technology. 1, 80-88