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SOLAR ACTIVITY AND TOTAL COLUMN OZONE VARIATION IN LAGOS, NIGERIA

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Abstract. Impacts of solar activity on the total column ozone variation within an interval of four years (1993-1997) have been investigated at an equatorial station of Lagos (06°33' N, 03°21' E) Nigeria. The linear regression analysis shows a significant negative correlation between mean total column ozone and solar activity both at monthly level ($r = -0.0652$, $r^2 = 0.0043$) and annual level ($r = -0.2671$, $r^2 = 0.07138$). Significant negative correlation ($r = -3798$, $r^2 = 0.1375$) exists between the two variables during low solar activity. The total column ozone decreases with increasing solar activity. Linear fits of the data were proposed. The data length needs to be extended and more data points created in equatorial regions.

1. INTRODUCTION

Atmospheric Ozone O_3, the triatomic molecule of oxygen, has continued to attract interest among other atmospheric constituents mainly due to its influence on the ecosystem. Lipmann [1] and Lefohn [2] among others discussed the impact of atmospheric ozone on humans and animals. Effects of ozone on crop productivity have been studied at various locations [3,4,5,6,7].

Although surface ozone has been monitored intermittently at various locations around the globe for the past several decades [8,9,10], there is need to intensify the measurement of ozone especially in the equatorial zone due to the peculiarity of the zone. Osaghaede [11] reported that WMO in 1957 initiated standard procedure for monitoring ozone which marked the beginning of the WMO Global Ozone Observing System GO_3OS which now networks over 140 stations worldwide.

The variability of the ozone concentration in the atmosphere has become a subject of great concern for researchers in recent times [2,12]. It has been discovered that the tropospheric ozone concentration varies with season, solar radiation, wind speed, temperature, and humidity [13]. Sulman [14] affirmed that "the systematic space and time variations of total ozone do not accord with conditions of photochemical equilibrium but largely reflect the corresponding large scale vertical and horizontal transport mechanism which are at work in the atmosphere." Massambani and Andrade mean yearly values of surface ozone were higher in 1986 and 1991 than the other years.

[15] found a significant influence of solar radiation and ozone precursors on photochemical smog formation at Sao Paulo (Brazil). In a six year study, 1986-1991, Lorenzimi *et. al.* [12] observed that the

Kirchhoff *et. al.*[16] analysed ozonosonde measurement in Natal, Brazil and discovered a spring maximum. Meanwhile Aneja *et. al.*[17] monitored ozone concentration at several sites in the southern eastern United States for four years starting from 1986 and found the highest concentration during the summer months. The distribution and variability of surface ozone in mountainous Switzerland were found by Wunderli and Gehrig [18] to depend heavily on the elevation of the monitoring site and proximity to sources of ozone precursors.

The response of ozone to solar activity and solar ultraviolet rays have been studied by Keating [19] and Keating *et. al.*[20] respectively. Soukharev and Labitzke [21] observed that the response of the stratosphere (the sphere with largest atmospheric ozone distribution) to solar activity oscillations close to the periodity of the solar rotation (27.2 days) has been discussed in many papers. Hood [22] showed a well recognised 27 days periodicity of ozone mixing ratio in the upper stratosphere.

Sunspots, which have been described by Akasofu and Chapman [23] as the centres of activity on the solar surface, have been used to quantify solar activity by Mitra [24], Simeon and Legrand [25], Chapman *et. al.* [26], Campbell [27], and a host of others. The primary aim of this paper is to determine the impact of solar activity on ozone variation in equatorial region using Lagos, Nigeria as a case study. This research quantifies the solar activity phenomena in terms of the sunspot number and seeks answers to the following questions: Is

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there any defined relationship between the surface ozone in equatorial region and solar activity? How sensitive is the total column ozone to solar activity.

2. ANALYSIS

2.1 Data

The dataset used in this investigation consists of the monthly mean values of total column ozone and sunspot number. The monthly mean values of total column ozone in Lagos (06°33' N, 03°21' E), Nigeria were published by Osaghaede [11]. The data covered the period April 1993 to April 1997 and were taken with Dobson Spectrophotometer at the Nigerian Department of Meteorological Services in Lagos. The monthly values for August 1994 and July 1996 that were missed were fitted using the least squares method. The measurement is an initiative of the World Meteorological Organisation (WMO) network of Global Ozone Observing System (GO_3 OS) which has about 140 stations worldwide. The sunspot data was obtained courtesy of Willie Soon of Harvard, U.S.A.

2.2 Monthly Interaction

The mean monthly values of total column ozone and sunspot numbers were subjected to statistical treatment to ascertain the level of linear dependence between the two parameters if any. Linear regression analysis gave the correlation coefficient between total column ozone and sunspot number as - 0.0652. The straight- line probabilistic model has a slope of -0.0339 and intercept of 254.1769. The coefficient of determination r^2 is 0.0043. The least square prediction equation is thus:

$$0_3 = -0.0339 R + 254.1769 \qquad (1)$$

where 0_3 and R are the monthly mean column ozone and sunspot number respectively. Analysis of variance ANOVA and t - test were carried out to test the null hypothesis below at $\alpha = 0.05$.

H_{01}: There is no significant linear relationship between the monthly mean values of total column ozone and solar activity.

The ANOVA result gave the F - value as 7024.009 while the critical F value is 3.940. The t-test has the statistic t as 83.813 while the critical t on the one tail distribution is 1.667.

2.3 Interaction at Low Solar Activity

Year 1996 with yearly mean sunspot number 8.6 is a solar minimum year in which the solar activity is expected to be moderately low compared with the other years in the solar cycle #22 (1986 - 1996). Monthly mean values of total column ozone and sunspot numbers were subjected to linear regression analysis, ANOVA and t-test as before. The regression analysis yielded correlation coefficient of -0.3708 between the two variables. The straight-line probabilistic model has a slope of -0.6682 and intercept of 288.263. The coefficient of determination r^2 is 0.1375. The least squares prediction equation is therefore:

$$0_3 = -0.6682 R + 288.263 \qquad (2)$$

ANOVA and t-test were used to test the null hypothesis stated below at $\alpha = 0.05$

H_{o2} : There is no significant linear dependence between the total column ozone and solar activity during sunspot minimum condition

The ANOVA result gave the F - value as 5936.87 while the critical F is 4.30. The t - test has the statistic t as 77.0051 while the critical t on one tail distribution is 1.7896.

2.4 Year to Year Interaction

The yearly mean values of total column ozone and corresponding sunspot number were further subjected to linear regression, ANOVA and t - test to ascertain the year -to-year dependence of the two variables. Correlation coefficient of -0.2671 exists between the annual mean of total column ozone and sunspot number. The straight-line probabilistic model has a slope of -0.04937 and intercept of 253.908. The coefficient of determination is r^2 = 0.07138. The least square equation is:

$$0_3 = -0.0493 R + 253.908 \qquad (3)$$

ANOVA and t-test were used to test the null hypothesis stated below at $\alpha = 0.05$:

H_{o3} : There is no significant linear dependence between the yearly variability of total column ozone and solar activity.

The ANOVA result yielded the F value as 911.852 and the critical F value, 5.3176. The t-test has the calculated t as 30.197 and the critical t on one tail distribution as 2.132.

3. DISCUSSIONS

The monthly interaction result revealed that the total column ozone has a negative correlation (r =- 0.0652, p< 0.05) with solar activity. A linear relationship exists between the two variables and the best-fit equation given as: 0_3 = -0.0339 R + 241.1709, suggests that about 4% of the decrease in total column ozone is attributed to solar activity. The significance of this linear dependence was justified by the t test as t statistic value (83.813) is greater than the t critical (1.607) at $\propto = 0.05$. The linear dependence is further confirmed by the ANOVA result as the calculated F (7024.009) > critical F (3.940) which leads to the rejection of the first null hypothesis and the affirmation of the alternative hypothesis that there is significant linear relationship between the monthly total column ozone and solar activity.

When the solar activity is expected to be moderately low, negative coefficients of correlation (-0.3708) and regression (-0.6682) were obtained with magnitudes greater than the values obtained for the combined monthly interaction discussed above. These greater magnitudes may be due to the smoothening of the data as only the solar minimum condition was considered. The regression coefficient implies that 66% of decrease in total column ozone can be attributed to increasing solar activity at sunspot minimum condition.

The ANOVA and t- test result reject the second null hypothesis H_{02}, since F calculated (5936.87) > F critical (4.301) and t statistic (27.051) > t- critical (1.790) and accept the alternative that there is a significant linear dependence between the total column ozone and solar activity during sunspot minimum condition.

Linear relationship exists between the year -to - year variability of total column ozone and solar activity. This is securely adjudged by the negative correlation and regression coefficients of - 0.02671 and - 0.0494 respectively. About 5% of the decrease in year -to-year variability of the total column ozone is attributed to the solar activity.

The ANOVA and t-test result combined to reject the third null hypothesis as the calculated F value (911.85) > F critical (5.318) and t-statistic (30.197) > t critical (2.132); and accept the alternative hypothesis that there is significant linear dependence between the yearly variability of total column ozone and solar activity.

Generally the analysis reveals a significant negative correlation between total column ozone and solar activity within the period under consideration. To the best of our knowledge this is the first time the impact of solar activity on ozone variation is studied in Lagos and in equatorial zone as a whole and so our result has no basis for comparison. However this negative correlation at equatorial region of Lagos underscore the result of Zerefos *et. al.*[28] and Cappelani and Kochler [29]. Zerefos *et. al.*[28] obtained a negative correlation between the solar UVB at 305nm measured at a solar zenith angle of 63° and total column ozone for 5 years (1991 - 1996) at Thessaloniki (40° N). Also Cappelani and Kochler [29] discovered a clear negative correlation between the monthly mean values of solar UV and the corresponding values of the total column ozone at Ispra (45.80°N,8.63°E) Italy for five year (1993-1997).

The understanding of the sunspot as the centres of activity on the solar surface [23] and our result jointly suggest that the solar UV radiation measured on the ground is a reflection of solar activity, which we quantified by sunspot numbers. The observed negative correlation between ozone and solar activity may further explain the nocturnal ozone maximum earlier on observed and attributed to local atmospheric circulation by Samson [30] and Liu *et. al* [31].

4. CONCLUSIONS

The study of the impact of solar activity on the total column ozone has been carried out at Lagos (06°33' N, 03°21' E), Nigeria – an equatorial zone - for the first time. It is discovered that significant negative correlation exists between the total column ozone and solar activity column at monthly and yearly levels. The following hypotheses have been affirmed:

i. There is a significant linear relationship between the monthly total column ozone and solar activity.
ii. There is a significant linear dependence between the total column ozone and solar activity during sunspot minimum condition.
iii. There is a significant linear dependence between the yearly variability of total column ozone and solar activity.

The negative correlation between total column ozone and solar activity at equatorial station compared well with the negative correlation between total column ozone and solar UV at mid-latitudes.

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