VARIATIONS OF SURFACE TEMPERATURE WITH SOLAR ACTIVITY AT TWO STATIONS IN THE TROPICS.

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Abstract: The response of surface air temperature to solar activity has been investigated at a tropical region, Ibadan (7.43°N, 3.90°E) and Ikeja (6.55°N, 3.35°E), during the solar cycle #22 (1987-1996). A consistent and persistent diurnal variation in surface air temperature exists which shows an almost constant level in the early morning hours (0000 – 0600 hours LT.); a rise at sunrise till about 1500 hr LT., a subsequent fall to the constant level by about 1900 hr LT. at sunset. This is explicable in terms of tropospheric heating mechanisms in response to solar activity. The observed diurnal variation has consistent post-noon maximum at about 1500hr LT and is asymmetric about the maximum. The post local noon maximum may be due to the modulation of the solar effects by the tropospheric constituents capable of absorbing the transient radiant heat from the Sun through the upper atmosphere. Slight negative correlation (-0.4175, Ibadan and -0.2628, Ikeja) exists between the surface air temperature and solar activity at all time levels, which imply that the temperature increases with declining solar activity. Polynomial functions may be more suitable to model the relationship between the surface air temperature and solar activity.
Keywords: surface air temperature, solar activity, post-noon, tropospheric heating

1. INTRODUCTION

The climate of the Earth system is a by-product of a complex interplay of external solar forcing and internal interactions among the atmosphere, the oceans, the land surface, the biosphere and the cryosphere. There is a need for proper understanding of the Sun-Earth connection as an external forcing of the Earth's climate. There has been an age long effort to find a casual chain of relations forming a hypothetical line connecting the processes in the Sun, in the magnetosphere, the middle atmosphere and troposphere. The connection between the Sun and the Earth's terrestrial climate have been investigated by a number of authors; few examples are Dickinson [1], Eddy [2], Foukal and Lean [3], Hansen and Lacis [4], Dewan and Shapiro [5], Friis-Christensen and Lassen [6], Deser and Blackmon[7], and Detwiler[8].

One of the main problems in solar-climatic influences is the instability of the relations found. For different periods and locations, both positive and negative correlations have been found between solar activity parameters and meteorological elements like surface air temperature, sea level pressure, precipitation, etc. (for example [9] and the references therein). Georgieva et al. [10] have shown that the sign of the correlation changes regularly in consecutive centennial solar cycles and seems determined by the North-South asymmetry of solar activity: the correlation is positive when the Northern solar hemisphere is the more active one, and negative when more active is the Southern solar hemisphere.

Mitchell [11] showed that the North American drought cycle exhibits a 22-year modulation characteristic of the Hale solar cycle. Pycha *et al.* [12] discovered a possible relation between geomagnetic activity and air surface temperatures in Prague. Editor@sciencedaily.com [13] suggested that the earth's surface temperature may be strongly linked to variability in solar activity over months or years and reported a clear drop in terrestrial atmospheric temperature after the Sun's magnetic field activity is most intense. However, the extent of climate change attributable to solar forcing remains uncertain [14].

Labitzke [15] and Labitzke and Van Loon [16] shed some light on why previous attempts to find correlations between weather parameters and solar activity on a systematic and long-term basis have failed. SCOSTEP [17] affirmed that the relationship between tropospheric variables and diverse parameters representing solar variability must be examined on a systematic and world-wide basis in order to be able to formulate and test hypotheses of possible trigger mechanisms

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responsible for the effect of very small variations in solar energy deposition on such a high energy density medium as the lower atmosphere.

It is worth mentioning that, several empirical and statistical relationships have been discovered to exist between historical solar and climate data on short- and long-term scales [18]. Rind et al. [19] correlated centennial changes in both the instrumental and proxy climate records with long term solar activity changes. Lean [14] rightly observed that lack of rigorous statistical associations leads climate researchers to often reject empirical evidence for solar effects on climate. In this present researeh we considered sufficient statistical tool in our analysis.

The objective of this paper is to investigate the response of surface air temperature to solar activity in a tropical region for the period 1987 to 1996. We shall attempt to establish the nature of relationship, if there is any, between the earth's surface temperature to solar activity.

2. DATA ANALYSIS AND PRESENTATION OF RESULTS

Data

The daily hourly surface air temperature in °C of all the years 1987 to 1996, in the solar cycle # 22, were obtained from the archives of the Nigerian Department of Meteorological Services in Lagos. The data were obtained from meteorological centers located at the tropical stations of Ibadan (7.43°N, 3.90°E) and Ikeja (6.55°N, 3.35°E). The mean monthly sunspot numbers were obtained courtesy of the Internet services of National Geophysical Data Center (NGDC), Boulder, Colorado, U.S.A.

Monthly mean hourly temperature

Monthly mean of hourly values of surface air temperature were obtained and plotted against local time; this reflects the diurnal variation of surface air temperature at the tropical region. Similar pattern of variation was obtained for all the months in all the years under consideration. In order to avoid cumbersome/bulky report, solar activity effect was used to select the figures for presentation in this paper. The month with the least sunspot number which represents the lowest solar activity during the solar minimum year 1996 (R = 8.6) was identified to be October (R = 0.9). The monthly mean hourly values of Temperature were plotted against local time at Ibadan and Ikeja and presented in Figs. 1 a, b respectively. Also the monthly mean hourly values of Temperature were plotted against local time at Ibadan and Ikeja. for month of June (R= 196.2) with the greatest sunspot number which represents the maximum solar activity during the solar maximum year 1989 (R = 157.6), and are presented in figs 2 a and b respectively.

Solar activity and mean monthly temperature

Scatter diagram of mean monthly Temperature values and mean monthly sunspot number were plotted for all the data in the ten years (1987-1996). This is illustrated in figs 3(a, b) for Ibadan and Ikeja respectively. Linear trendlines were obtained for the diagram as well as their equations and coefficients of determination

$T_{ibadan} = -0.0017R + 26.433 \quad °C; \quad r^2 = 0.0053$

$T_{ikeja} = -0.0013R + 26.894 \quad °C; \quad r^2 = 0:0038$

In order to establish a better relationship between solar activity and monthly mean temperature possibility of a polynomial relationship was explored. The order-two polynomial curves (figs. 4 a and b) give:

$T_{ibadan} = -2x10^{-5} R^2 + 0.0025R + 26.33 \quad °C; \quad r^2 = 0.0074$

$T_{ikeja} = -3x10^{-5} R^2 - 0.0036R + 26.774 \quad °C; \quad r^2 = 0.0073$

Negative correlation coefficients of –0.0728 (with coefficient of determination of 0.00529) and –0.0617 (with coefficient of determination of 0.00381) were obtained for the relationship between the monthly mean values of sunspot numbers and temperature.

ANOVA and t-test were carried out at $\alpha = 0.05$ to test the null hypothesis:

> *H_{01}: There is no significant linear relationship between the monthly mean values of* surface air *temperature and solar activity.*

The ANOVA result gave the calculated F – values for Ibadan and Ikeja as 93.958 and 92.172 respectively while the critical F value is 3.881. For Ibadan data, the t- test has the statistic t as 9.69 while the critical t on the one tail distribution is 1.65; while Ikeja has statistic t and critical t values as 9.60 and 1.65 respectively.

Annual variability of solar activity and temperature

The mean annual values of sunspot numbers and temperature were plotted as scatter diagram (figs 5,6, and 7). Figs.5 a, b Illustrate the scatter diagram with linear trendlines which yield equations:

$T_{ibadan} = -0.0017R + 26.432 \quad °C; \quad r^2 = 0.1743$

$T_{ikeja} = -0.001R + 26.870 \quad °C; \quad r^2 = 0.0691$

Figs. 6 a, b give the same scatter diagram with order–two polynomial trendlines with equations:

$$T_{ibadan} = 3x10^{-5} R^2 - 0.0071R + 26.560 \ °C; \ r^2 = 0.2537$$

$$T_{ikeja} = -2x10^{-6} R^2 - 0.0007R + 26.863 \ °C; \ r^2 = 0.0694$$

Figs. 7 a, b illustrate the same scatter diagram with order-three polynomial curves with equations:

$$T_{ibadan} = 2x10^{-7} R^3 - 1x10^{-5} R^2 - 0.004R + 26.516 \ °C; \ r^2 = 0.2572$$

$$T_{ikeja} = 6x10^{-7} R^3 - 2x10^{-4} R^2 + 0.0092R + 26.724 \ °C; \ r^2 = 0.1089$$

The regression analysis yielded negative correlation coefficients of –0.4175 and – -0.2628 for Ibadan and Ikeja respectively at p=0.01.

ANOVA and t-test were equally used to test the null hypothesis:

H_{o2}: There is no significant linear relationship between the annual variability of surface air temperature and solar activity.

The ANOVA result gave the calculated F – value of 8.153 while the critical F value is 4.414 for Ibadan; for Ikeja, the calculated F- and the critical F- values are 7.899 and 4.414 respectively. For Ibadan, the t- test has the statistic t as 2.855 while the critical t on the one tail distribution is 1.73; while Ikeja has statistic t and critical t values of 2.828 and 1.73 respectively.

Seasonal effects

The data was grouped according to the two predominant seasons in tropical region: wet season (April, May, June, July, August) and dry season (September, October, November, December, January, February, March). The averages of the seasonal temperature and sunspot numbers were obtained for each of the years of solar cycle # 22 and subjected to statistical analysis to ascertain the level, if any exist, of seasonal relationship among the parameters. The negative correlation coefficients of –0.263(r^2 = 0.078) and -0.562 (r^2 = 0.192) exist between the temperature and solar activity during dry and wet seasons respectively at Ibadan. While at Ikeja the negative correlation coefficients of –0.241 (r^2 = 0.058) and –0.208 (r^2 = 0.043) exist between the temperature and solar activity during dry and wet seasons respectively.

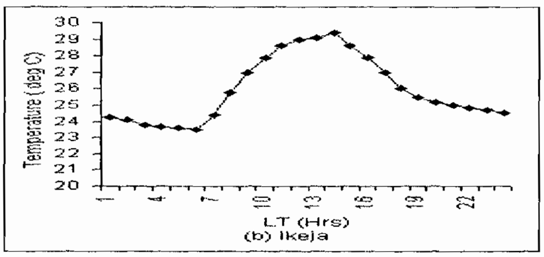

Fig 1. Mean hourly variation of temperature at low solar activity in October 1996

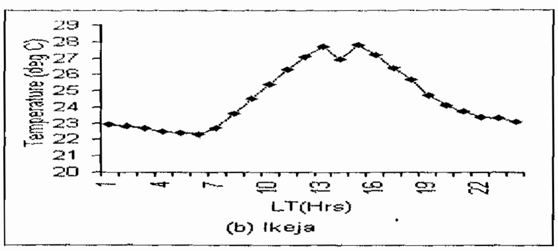

Fig 2. Mean hourly variation of temperature at high solar activity in June 1989

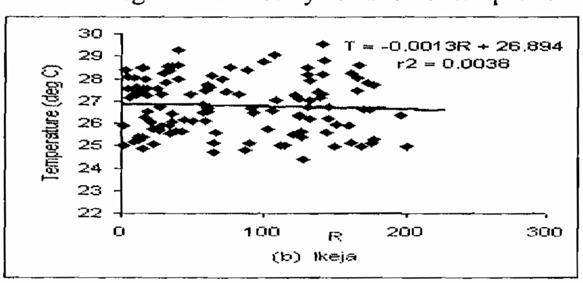

Fig. 3 monthly scatter plot of temperature versus sunspot number with linear trendline

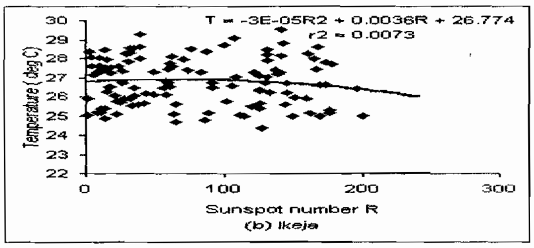

Fig. 4 monthly scatter plot of temperature versus sunspot number with second order polynomial curve

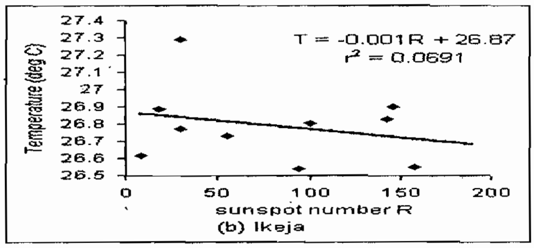

Fig. 5. Annual scatter plot of temperature versus sunspot number with linear fit

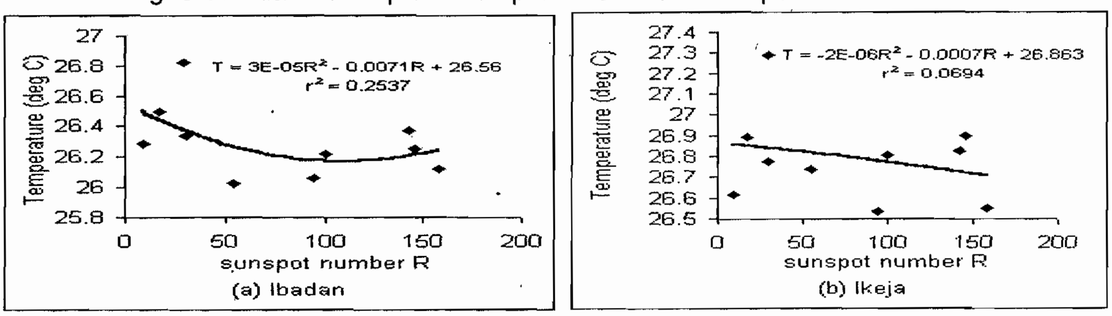

Fig. 6. Annual scatter plot of temperature versus sunspot number with second order polynomial fit

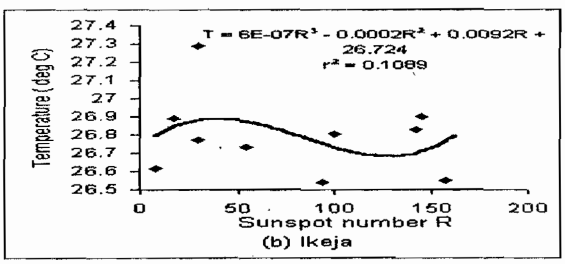

Fig. 7. Annual scatter plot of temperature versus sunspot number with third order polynomial fit

3. DISCUSSIONS OF RESULTS

Diurnal variations

The diurnal variation of surface temperature illustrated in figures 1 a, b and 2 a, b clearly demonstrates a consistent and persistent pattern of diurnal variation in surface temperature with respect to solar local time irrespective of the degree of solar activity. The hourly temperature at Ibadan has an average value of 26.299 °C, and standard deviation 1.872 °C; while the average and standard deviation at Ikeja are 26.792 °C and 1.512 °C respectively. The daytime (0700-2000 hours LT.) average temperature is greater than the nighttime (2000-0700 hours LT. through 2400) value throughout the period. The diurnal variation pattern shows an almost constant level in the early morning hours (0000 – 0600 hours LT.); a rise at sunrise till about 1500 hr LT., a subsequent fall to the constant level by about 1900 hr LT. at sunset. This should be explicable in terms of tropospheric heating mechanisms in response to solar activity. Generally the observed diurnal variation has post noon maximum at about 1500hr LT. and is asymmetric about the maximum. The post local maximum may be due to the modulation of the solar effects by the tropospheric constituents capable of absorbing and retaining the transient radiant heat from the Sun through the upper atmosphere.

Monthly temperature and solar activity.

Scatter diagrams in figs 3 a, b indicate a level of dependence of the temperature on the solar activity as measured by sunspot number r, the slope of the trend line for Ibadan and Ikeja are -0.0017 and -0.0013 respectively. There is obviously a negative relationship between the two parameters. That is the temperature is bound to decrease with increasing solar activity and vice and versa. The non-zero coefficients of determination (0.0053 for Ibadan and 0.0038 for Ikeja) imply that certain proportion of the change in temperature can be solely accounted for by the solar activity. It is noted that when polynomial of order-two was fit into the scatter plot (figs 3 a, b), greater coefficients of determination were obtained for Ibadan (0.0074) and Ikeja (0.0073). This suggests that a polynomial function may be more suitable to model the dependence of surface temperature on solar activity.

Negative correlation (-0.07276 for Ibadan, -0.06173 for Ikeja) between mean monthly values of surface temperature and solar activity, which persists when the months were grouped into dry and wet seasons, implies that the temperature increases with declining solar activity. The responses of the atmospheric dynamics and composition must surely be responsible for this decrease in surface temperature with increasing solar activity. The solar UV, which increases with increasing solar activity, has been shown to exhibit negative correlation with total column ozone at Thessaloniki, Greece [20], and Ispra, Italy [21]. In a recent paper, Rabiu and Omotosho [22] reported a negative correlation between total column ozone and solar activity at Ikeja, Lagos, Nigeria – an equatorial zone. These earlier results indicate that the major stratospheric absorbent, Ozone, suffers more decrease through photochemical reactions enhanced by increasing solar activity and may be responsible for drop in surface temperature as solar activity increases.

Similar negative relationships have been observed in variations of geomagnetic and ionospheric activities with solar activity, for examples Ahn et al. [23] and Rabiu [24]. This similar trend of variation highlights the solar terrestrial-ionosphere-lower atmosphere coupling.

The ANOVA and t-test statistics reject the 1st null hypothesis H_{01}, since calculated F values at Ibadan (93.958) and Ikeja (92.172) are greater than F-critical (3.881). Also t-statistic at Ibadan (9.69) and Ikeja (9.60) are greater than t-critical (1.65). We therefore accept the alternative hypothesis and affirm that there is a significant relationship between the monthly mean values of surface temperature and solar activity.

Annual Variabilty

Negative correlation coefficients exist between the annual means of surface air temperature and sunspot number both at Ibadan (-0.4175) and Ikeja (-0.2628) at p = 0.01. This significant negative correlation stresses the linear dependence of surface air temperature on solar activity. This negative correlation observed at all time scales is quite in agreement with the results of Labitzke [15], Labitzke and Chanin [25], Labitzke and Van Loon [16], Chanin [26], and Nikolashkin et al. [27] who have shown that a negative correlation exists between solar activity and atmospheric temperature up to ~50 km. The ANOVA and t-test statistics reject the 2nd null hypothesis H_{02}, since calculated F values at Ibadan (8.153) and Ikeja (7.899) are greater than F-critical (4.414). Also t-statistic at Ibadan (2.855) and Ikeja (2.828) are greater than t-critical (1.734). Hence we uphold the alternative hypothesis and affirm that there is a significant relationship between the annual variability of surface air temperature and solar activity.

Although the coefficients of determination which depict level of statistical association are still very low as observed by Lean [14]; the significant correlation coefficients that exist between the solar activity and temperature at different time levels justify probable degree of relationship between the components.

The scatter diagrams in Figs. 5,6 and 7 confirm the existence of a model-able relationship between surface air temperature and solar activity at these tropical stations. It is observed that the coefficient of determination improves with the increasing order of polynomial function. For example at Ibadan, r^2 =0.2572 for order 3 is greater than 0.2537 for order 2 which is in turn greater than 0.1743 for a linear function. Similar order of improvement is observed at Ikeja as 0.1089 (for 3rd order) > 0.0694 (for 2nd order) > 0.0691 (for linear trendline). This confirmed the earlier assertion that a polynomial function may be more suitable to model the dependence of surface air temperature on solar activity.

4. CONCLUSIONS

The response of surface air temperature to solar activity has been investigated at two stations in the tropics during the solar cycle #22 (1987-1996), using hourly surface air temperature data at Ibadan (7.43°N, 3.90°E) and Ikeja (6.55°N, 3.35°E). The following conclusion have been made:

i. A consistent and persistent diurnal variation in surface air temperature exists. The diurnal variation pattern shows an almost constant level in the early morning hours (0000 – 0600 hours LT.); a rise at sunrise till about 1500 hr LT., a subsequent fall to the constant level by about 1900 hr LT. at sunset. This is explicable in terms of tropospheric heating mechanisms in response to solar activity. Generally the observed diurnal variation has post noon maximum at about 1500hr LT. and is asymmetric about the maximum.

ii. Significant negative correlation exists between the surface air temperature and solar activity at all time levels. The following two hypotheses were affirmed: a. there is a significant relationship between the monthly mean values of surface temperature and solar activity. b. There is a significant relationship between the annual variability of surface air temperature and solar activity.

iii. Polynomial functions may be more suitable to model the relationship between the surface air temperature and solar activity.

iv. Evidence abounds that there is a hypothetical line linking the processes in the Sun, in the magnetosphere, the middle atmosphere and troposphere.

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