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REGIONAL VARIABILITY OF SUNSHINE INTENSITY IN NIGERIA CLIMATE SYSTEM

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ABSTRACT:
Sunshine is another climatic parameter that may improve our knowledge of the changing climate. Sunshine intensity has theoretically been linked to changes in atmospheric circulation patterns. We attempt empirical linkage of diurnal changes in sunshine intensity to the energy-water budget indicative of environmental changes. Considering six stations (Abuja, Enugu, Port Harcourt, Sokoto, Ikeja and Maiduguri) each representing geopolitical zones of Nigeria, as independent homogenous units of local climate, the mean diurnal sunshine intensity for January 1, 2006 to December 31, 2014 was analysed. The effect of insolation on some atmospheric predictor variables derived from satellite data generated using the NASA Goddard Earth Observing System – Version 1 (GEOS-1) Multiyear Assimilation Timeseries Data, was examined with linear regression and Pearson's correlation techniques. Result of the diurnal sunshine analysis of variance show significant differences for all the stations with the exception of the Maiduguri, suggesting a year-round heterogeneous sunshine intensity. However, the diurnal sunshine time series analysis indicated no significant difference for both Port Harcourt and Ikeja with Ljung Box Q values of 33.08 and 37.30 respectively. While daylight cloud amount and precipitation strongly correlated with top of atmosphere insolation in all the six stations, the partial curve fit models derived for each local climate showed that the effect of sunshine is more on the hydrometeorological components than on temperature and heat budget. These findings improve understanding of local radiation climatology, although, further studies could help to develop new methods to downscale General Circulation Models of climate change for the region.

VARIABILIDADE REGIONAL DA INTENSIDADE DO SOL EM SISTEMAS CLIMÁTICOS NA NIGÉRIA

RESUMEN:
A luz do sol é outro parâmetro climático que pode melhorar nosso conhecimento das mudanças climáticas. A intensidade da luz do sol tem sido teoricamente ligada a mudanças nos padrões de circulação atmosférica. Tentamos a ligação empírica das mudanças diurnas na intensidade do sol com a provisão de energia e água, indicativo de

PALABRAS CLAVE:
Sol, Diário, Clima, Precipitação, Nuvem.

mudanças ambientais. Considerando-se seis estações (Abuja, Enugu, Port Harcourt, Sokoto, Ikeja e Maiduguri), cada uma representando as zonas geopolíticas da Nigéria, como unidades homogêneas independentes do clima local, foi analisada a intensidade média diurna da luz solar de 1 de janeiro de 2006 a 31 de dezembro de 2014. O efeito da insolação em algumas variáveis preditoras atmosféricas derivadas de dados de satélite gerados usando o Sistema de Observação Goddard Earth da NASA - Versão 1 (GEOS-1) Dados de séries temporais de assimilação de vários anos da GEOS-1, foi examinado com regressão linear e técnicas de correlação de Pearson. O resultado da análise de variância diurna do sol mostra diferenças significativas para todas as estações, com exceção do Maiduguri, sugerindo uma intensidade de sol heterogênea durante todo o ano. No entanto, a análise das séries temporais diurnas do sol não indicou diferença significativa para Port Harcourt e Ikeja com os valores de Ljung Box Q de 33,08 e 37,30, respectivamente. Embora a quantidade de nuvens, da luz do dia e a precipitação tenham uma forte correlação com a insolação do topo da atmosfera em todas as seis estações, os modelos de ajuste de curva parcial derivados para cada clima local mostraram que o efeito da luz do sol ocorre mais sobre os componentes hidrometeorológicos do que sobre a provisão de temperatura e calor. Essas descobertas melhoram o entendimento da climatologia da radiação local, embora estudos adicionais possam ajudar a desenvolver novos métodos em escala reduzida de modelos gerais de circulação das mudanças climáticas na região.

INTRODUCTION

The sun is the ultimate source of all energy on earth and is the most important driving force of the climate system (Beer et al, 2000). Sunshine duration can be considered a proxy measure of global radiation. Presently, there is wide-spread evidence that large changes in the level of radiation reaching the ground have and are occurring over large regions of the globe.

Natural and anthropogenic change in the amount of insolation has important implications for climate change studies as well as agriculture, water resources and solar energy applications. Knowledge about solar radiation variability and trends is of great interest because it is a fundamental variable in the energy balance on a range of scales from global to microscale, aside from its impacts on physical and biological systems, and also on the economy and society. Solar radiation received at the top of the atmosphere and by absorption and scattering due to clouds, aerosols, and gases including carbon dioxide, ozone, water vapour, oxygen and nitrogen dioxide.

Several reasons have been given for the global decrease in solar radiation and sunshine hours. According to Standhill and Cohen (2001), increasing atmospheric aerosols and other air pollutants are some of the major causes. The interactions between aerosol loading, optical properties of the atmosphere and cloud cover were reported by Nazarenko and Menon (2005). Sanroma et al (2010) noted that trends in global aerosol content properties in recent decades may play an important role in modulating insolation. Furthermore, Mace et al (2006) also noted that clouds are the main cause of inter-annual and decadal variability of radiation reaching the Earth's surface and therefore they exert a dominant influence on the global energy balance.

As such, cloudiness can contribute to cooling i.e. low-level cloud types linked to their high albedo but also to warming i.e. high cloud types emit less radiation out to space than do low clouds or the clear atmosphere. Romanou et al (2007) reported reduced sunshine radiation globally in climate models over the 20th century. The implication of these is that sunshine is capable of providing climate modelling studies as a reliable response for several climate forcings and feedbacks. This study therefore attempts to empirically establish the links between diurnal changes in sunshine intensity and the energy-water budget indicative of climate and environmental changes. In this paper we concentrate mainly on diurnal time scales over a short term (three year period) as well as long term (thirty year period) mean diurnal weather conditions. Since there are no direct observational data to study the relationships between solar variability and other climatic variables on such long time scales we have to rely on proxy data from remote sensing. Moreover, little is known what role solar variability plays in diurnal climate, a knowledge that may greatly improve climate change modelling. The main open question is: How does the climate system react to changes in solar forcing?

STUDY AREA

Nigeria is one of the largest states in the West African sub-region, south of the Sahara. It extends over a land area of approximately 923,769km2. The country's population is currently estimated at about 154 million. Nigeria has a maximum mean temperature of about 30.5°C in the coastal belt to the south and 34.4°C in the north, with a normal decrease of about 1.4°C per 300m of altitude. It has a minimum mean temperature of about 22.2°C over most of the southern part, falling to 18.8°C in the north. The warmest months are February, March and April in the south and March to June in the north. Rainfall distribution is uneven, from as little as 500mm for areas in the northern fringes of the country to over 3000mm for areas in the eastern section of the coast in the south (Adejuwon, 1981).

Nigeria's climate, like the global climate has been characterized by variations. The average annual temperature over the country has been increasing at a rate of 0.01°C annually (Adelekan, 2000). Weather extremes such as severe rainstorms, intense harmattan haze and excessive heat causing considerable socio-economic effects have become common across the country. Nigeria's natural vegetation reflects the country's diversity of climate and topography. The major determinants of the distribution of vegetation types are the amount of rainfall, relative humidity and length of dry season. The vegetation cover can be broadly grouped into two: the tropical forests and the savannahs.

THEORY AND METHOD

To calculate the amount of sunlight reaching the ground, both the elliptical orbit of the Earth and the attenuation by the Earth's atmosphere has to be taken into account. The extra-terrestrial solar illuminance (Eext), corrected for the elliptical orbit by using the day number of the year (dn), is given by:

$$E_{\text{ext}} = E_{\text{sc}} \cdot \left(1 + 0.033412 \cdot \cos\left(2\pi \frac{\text{dn} - 3}{365}\right)\right), \qquad (1)$$

where dn = 1 on January 1; dn = 2 on January 2; dn = 32 on February 1, etc. In this formula dn-3 is used, because in modern times Earth's perihelion, the closest approach to the Sun and therefore the maximum E_{ext} occur around January 3 each year. The value of 0.033412 is determined knowing that the ratio between the perihelion (0.98328989 AU) squared and the aphelion (1.01671033 AU) squared should be approximately 0.935338.

The solar illuminance constant (E_{sc}), is equal to 128×10^3. The direct normal illuminance (E_{dn}), corrected for the attenuating effects of the atmosphere is given by:

$$E_{\text{dn}} = E_{\text{ext}}\, e^{-cm}, \qquad (2)$$

where *c* is the atmospheric extinction coefficient and *m* is the relative optical airmass. On Earth, solar radiation is obvious as daylight when the sun is above the horizon. When the direct radiation is not blocked by clouds, it is experienced as *sunshine*, combining the perception of bright white light (sunlight in the strict sense) and warming. The warming on the body, the ground and other objects depends on the absorption of the electromagnetic radiation in the form of heat.

The amount of radiation intercepted by a planetary body varies inversely with the square of the distance between the star and the planet. The Earth's orbit and obliquity change with time (over thousands of years), sometimes forming a nearly perfect circle, and at other times stretching out to an orbital eccentricity of 5% (currently 1.67%). The total insolation remains almost constant due to Kepler's second law,

$$\tfrac{2A}{r^2}\, dt = d\theta, \qquad (3)$$

where *A* is the "areal velocity" invariant. That is, the integration over the orbital period (also invariant) is a constant.

$$\int_0^T \tfrac{2A}{r^2}\, dt = \int_0^{2\pi} d\theta = \text{constant} \qquad (4)$$

If we assume the solar radiation power *P* as a constant over time and the solar irradiation given by the inverse-square law, we obtain also the average insolation as a constant. But the seasonal and latitudinal distribution and intensity of solar radiation received at the Earth's surface also varies. Such changes associated with the redistribution of solar energy are considered a likely cause for the global warming and climate change.

For this study, daily sunshine intensity records from the six stations representing each geopolitical zones of the country were collected between January 1, 2006 and December 31, 2008 from the Nigerian Meteorological Agency, Lagos. The stations include Ikeja, Abuja, Enugu, Port-Harcourt, Sokoto and Maiduguri, representing the various climatic belts in the country. While Ikeja and Port-Harcourt were chosen to represent the coastal influence, Enugu was selected to represent the rainforest region. Furthermore, Abuja was selected to represent the savannah belt as well as the central point of the country, whereas Sokoto and Maiduguri were also chosen to represent the extreme North, West and East respectively.

This study also assesses the spatial and mean monthly diurnal distribution of top of atmosphere insolation as well as Monthly Averaged Precipitation (mm/day), Monthly Averaged Atmospheric Pressure (kPa), Monthly Averaged Relative Humidity (%), Monthly Averaged Wind Direction At 50 m Above The Surface Of The Earth (degrees), Monthly Averaged Air Temperature At 10 m Above The Surface Of The Earth (° C) and Monthly Averaged Daylight Cloud Amount (%) for the six stations selected for study. The dataset employed were obtained from the archives of the National Aeronautical and Space Agency of the United States of America (NASA) Langley Research Centre. The data was generated using the NASA Goddard Earth Observing System – Version 1 (GEOS-1) Multiyear Assimilation Timeseries Data using the Pinker/Laszlo shortwave algorithm while cloud data was taken from the International Satellite Cloud Climatology Project DX dataset (ISCCP). The data used for analysis consists of continuous and consistent 28 year coverage, from July 1, 1983 to June 30, 2011 with the averages derived for the monthly and annual assessments. The time series analysis was computed for each of the six stations deriving the Ljung-Box Q Statistics while the generalized regression technique was used to estimate the effect of insolation on the climatic parameters for all the stations put together.

RESULT AND DISCUSSION

We have reviewed a number of studies that were carried out to understand the possible effects of sunshine insolation on the climate system. The moving average of the time series for the diurnal variability of sunshine insolation shows a similar pattern for all the six stations across the country. This pattern is a persistent low intensity between July and September, for all the three years (2006 to 2008) with the consistency most dominant in the northern and southern extremes of Sokoto/Maiduguri and Port-Harcourt/Ikeja respectively. Generally, the R2 statistics of the time series analysis is very low for all the stations ranging between 0.1 and 0.4 for all the stations. This implies that the diurnal sunshine variability though in a direct (positive) relationship with time, is not particularly due to the changes in time.

Furthermore, the diurnal sunshine intensity time series analysis indicated no significant difference for both Port Harcourt and Ikeja with Ljung Box Q values of 33.08 and 37.30 respectively. All the other stations however show significant differences with time although the Root Mean Square Error for all the stations are relatively small, confirming the strength of the analysis.

We now went further to consider to what extent the dependence of the climate system on the amounts and variability of the sunshine intensity for the selected stations. The multivariate regression analysis taking sunshine insolation as the independent factor, indicated that the Monthly Averaged Precipitation (mm/day), Monthly Averaged Relative Humidity (%), Monthly Averaged Air Temperature at 10 m Above The Surface Of The Earth (° C) and Monthly Averaged Daylight Cloud Amount (%) show no significant difference. This implies the dependence of those climatic variables on sunshine insolation for their own internal variability. Invariably, it is suggested that sunshine intensity has limited influence on Monthly Averaged Atmospheric Pressure (kPa) and Monthly Averaged Wind Direction at 50 m Above The Surface Of The Earth (degrees) respectively. The regression equations estimating the relationship of sunshine intensity (insolation) with selected climatic parameters is presented in Table 3.

Finally, taking rainfall as a very significant climate feedback parameter, we went further to model the insolation-rainfall relationship which resulted in a 2nd order polynomial trend with the equation: $y = 9.1858 – 0.0364 x2 + 0.4041 x$ as shown in Fig. 1.

Table 1 Time series statistics of sunshine intensity

	R-squared	RMSE	MAPE	Ljung-Box Q Statistics	Sig.
Abuja	0.20	2.55	77.882	1096.136	0.58
Enugu	0.10	3.691	132.993	210.066	0.56
Port Harcourt	0.12	3.38	251.783	33.08	0.01
Sokoto	0.40	4.172	60.96	17.616	0.48
Ikeja	0.22	2.968	211.733	37.30	0.02
Maiduguri	0.28	3.296	75.83	211.473	0.62

Table 2 Multivariate regression model summary

	Model Summary				ANOVA			
	R	R Square	Adjusted R Square	Std. Error of the Estimate	Regression Sum of Squares	Residual Sum of Squares	F	Sig.
Monthly Averaged Precipitation (mm/day)	0.5	0.287	0.277	2.707	512.936	206.333	28.158	0.02
Monthly Averaged Atmospheric Pressure (kPa)	0.11	0.012	-0.002	1.54	166.036	2.033	0.857	0.358
Monthly Averaged Relative Humidity (%)	0.45	0.199	0.187	15.952	17813.27	4412.633	17.34	0.012
Monthly Averaged Wind Direction At 50 m Above The Surface Of The Earth (degrees)	0.31	0.017	0.003	60.06	252505.7	4375.188	1.213	0.275
Monthly Averaged Air Temperature At 10 m Above The Surface Of The Earth (° C)	0.86	0.035	0.021	2.017	284.888	10.248	2.518	0.017
Monthly Averaged Daylight Cloud Amount (%)	0.73	0.544	0.537	12.312	12638.62	10610.34	83.381	0.02

Table 3 Regression equation estimating the relation of climate variables to insolation

	Unstandardized Coefficients			Standardized Coefficients		
	Constant	B	Std. Error	Beta	t	Sig.
Monthly Averaged Precipitation (mm/day)	-25.246	2.943	0.555	0.536	5.306	0.01
Monthly Averaged Atmospheric Pressure (kPa)	95.005	0.292	0.316	0.11	0.926	0.35
Monthly Averaged Relative Humidity (%)	-69.126	13.611	3.269	0.446	4.164	0.02
Monthly Averaged Wind Direction At 50 m Above The Surface Of The Earth (degrees)	45.093	13.553	12.307	0.131	1.101	0.27
Monthly Averaged Air Temperature At 10 m Above The Surface Of The Earth (° C)	20.097	0.656	0.413	0.186	1.587	0.01
Monthly Averaged Daylight Cloud Amount (%)	-166.895	23.036	2.523	0.737	9.131	0.03

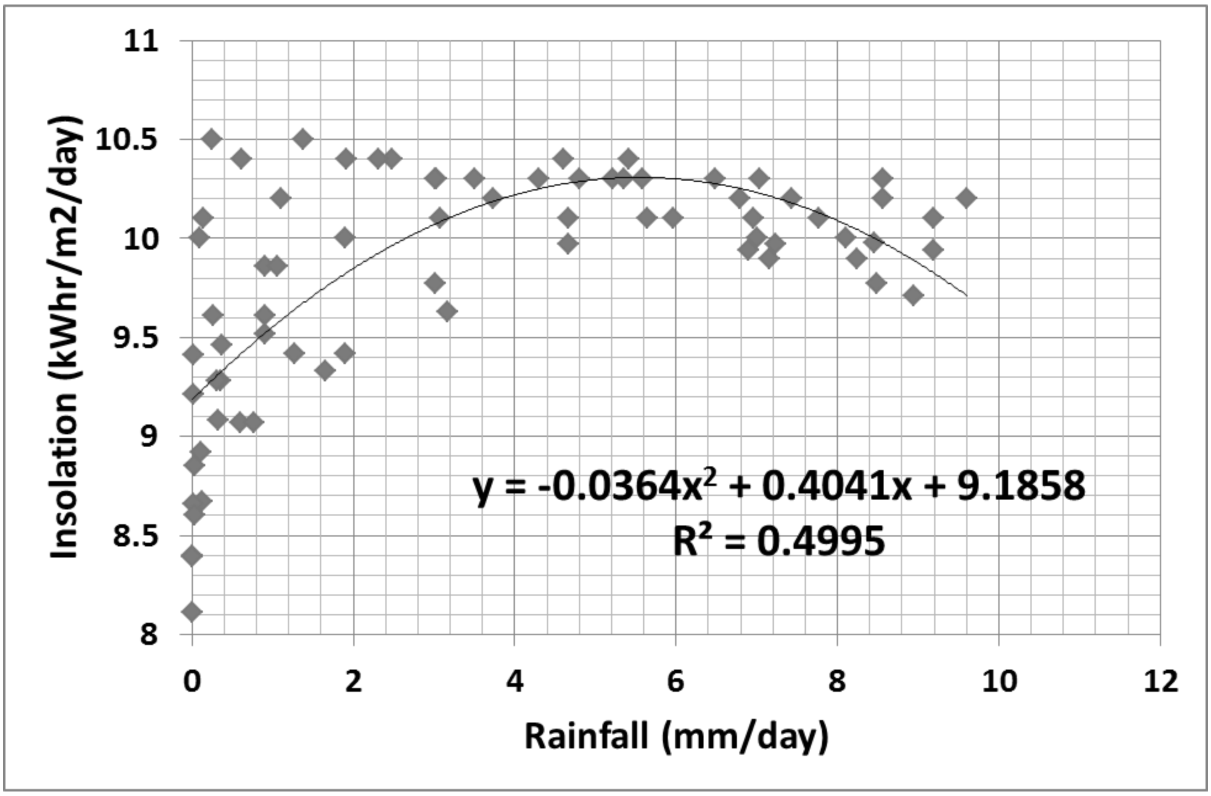

Fig. 1 Insolation-rainfall relationship showing a 2nd order polynomial trend

It has been shown that multi-day, persistent top of air insolation variability determines to some extent the variabilities in the weather condition and by implication in the climate system. These changes have implication for the design and maintenance of infrastructure while improving understanding of local radiation climatology. Further studies could however help to develop new methods to downscale General Circulation Models of climate change for the region.

CONCLUSION

The sun is the engine that drives the climate system. Any change in the global insolation is therefore expected to affect the climate evolution. The observed changes are small, but there are good arguments that larger variations may occur on time scales of decades to millennia. We may have to improve our understanding and quantify the reaction of the climate system to forcing including spectral and frequency dependencies. We may also have to separate solar from non-solar induced climate changes in the past in order to reliably quantify the increasing anthropogenic effects at present and in the future. Although this paper like several others has successfully shown the relation of the climate to variation in solar intensity, suggesting it can play a vital role in climate change modelling, there is still a long way to go. However, we believe it is worth the effort.

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