INVESTIGATION OF THE EARTH'S ALBEDO USING METEOROLOGICAL PARAMETERS OVER MAIDUGURI, NIGERIA

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ABSTRACT

The present study estimate and investigate the variation of albedo for Maiduguri situated in the Sahelian region of Nigeria, using meteorological data of global solar radiation obtained from the National Aeronautics and Space Administration (NASA) extending for a period between 1984 to 2021. Investigation was carried out on the variation of albedo with surface temperature, maximum wavelength, clearness index, global solar radiation, relative humidity and mean temperature. The study found that the estimated surface albedo exhibited a direct opposite relationship with the clearness index, an inverse relationship with the emitting Earth's surface temperature and a direct relationship with the wavelength for the location. The highest value of 0.5125 and lowest value of 0.3344 were found in August and November respectively. The emitting Earth surface temperature ranged between 232.8674 K in August and 251.7177 K in November. This is in agreement with the standard emitting Earth surface temperature (255.0000 K). The values of the maximum emitting wavelength were found to be >4 indicating longwave radiation which is within the infrared region of the electromagnetic spectrum. The results from this study will be useful for the design of solar energy collectors and researches on atmospheric radiative transfer.

Keywords: Albedo, earth surface temperature, global solar radiation, maximum wavelength, Maiduguri

1. INTRODUCTION

"The Sun offers the natural control on the Earth's atmospheric weather and climate. Over the past decades, the quantity of solar radiation arriving at the Earth's surface has been modified, particularly since the industrial reform. Beside the scattering and absorption of solar radiation in the atmosphere, the other means by which the quantity of incoming solar radiation arriving the Earth's surface is modified is through reflection. Reflection is a process where sunlight is re-directed by 180° after striking the particles of the atmosphere. The shortwave reflected solar radiation include; radiation reflected back to space by clouds, radiation reflected from the Earth's surface, and the radiation scattered back to space by particles and clouds in the atmosphere" [1].

"The climatic condition of the location is strongly dependent on the quantity or amount of solar radiation reaching the Earth's surface, therefore, the study of what happens to sunlight as it passes through the atmosphere is paramount to many aspects of science and general knowledge for proper investigation" [2]. "The fraction or proportion of the incident solar radiation that is reflected and scattered back into space is called albedo" [3].

"Albedo relates to the reflection of solar radiation at a surface and therefore defined in terms of it, as the ratio of the reflected solar radiation to the incident solar radiation at the surface, i.e., $\frac{H_r}{H_0}$. The extraterrestrial radiation at the edge of the atmosphere, from the sun, is regarded as the incident solar radiation. Albedo or reflection coefficient is also known as reflectance or reflectivity of a surface; in this regard, the surface albedo of the Earth is considered the same as planetary albedo by many researchers" [4]. "The mean overall albedo of the Earth, its planetary albedo, is around 0.3 and this fraction of incoming radiation is reflected back into space. The remaining 0.7 of the incoming solar radiation is absorbed by our planet" [5 - 6]. "It was assumed though that the reflected radiation, H_r, is both diffuse/scattered and specular in nature, explicitly, it is diffuse if the reflected radiation is uniform or isotropic in all angular directions, and specular if the surface of reflection is smooth with respect to the wavelength of the incident radiation such that the laws of reflection are established" [3].

It was argued by Gutman [7] that "the observed albedo assumed that the radiation field is isotropic. Albedo, been a property of a surface, so, can be used to estimate the brightness of a surface". Parado and Ferreira [8], reported that "materials with high albedo and emittance achieve low temperature when exposed to solar radiation, and thus reduce transference of heat to their surroundings. Thus, albedo is an important input parameter or quantity in evaluating the total insolation on a building or a solar energy collector". "This is significant in the studies that have to do with atmospheric thermal balance. The Earth's albedo affects the quantity of Sun-light absorbed by the planet. It plays a vital role in the energy balance of the Earth's surface, since it defines the rate at which the incident solar radiation is been absorbed" [3].

The purpose of this study was to estimate the values and variation of the earth's albedo at Maiduguri, Nigeria, compare the emitting earth surface temperature to the standard value of emitting surface temperature of the earth, investigate the type of radiation considering wavelength values and to correlate albedo with other meteorological parameters.

2. METHODOLOGY

The monthly meteorological data such as global solar radiation, minimum and maximum temperature and relative humidity data utilized in this study were acquired from the National Aeronautics and Space Administration (NASA) extending for the period 1984 to 2021. The average of the minimum and maximum temperature gives the mean temperature. The location under study was Maiduguri found in the Sahelian region of Nigeria.

The extraterrestrial radiation, H_o on a horizontal surface was estimated using [9 – 17].

$$H_o = \left(\frac{24}{\pi}\right) I_{sc}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]\left[\cos\varphi\cos\delta\sin\omega_S + \left(\frac{2\pi\omega_s}{360}\right)\sin\varphi\sin\delta\right] \quad (1)$$

where I_{sc} is the solar constant numerically given to be 1367 Wm^{-2}, φ is the location's latitude, δ is the solar declination and ω_S is the mean sunrise hour angle for the given month and n is the number of days of the year which begins from 1st of January to 31st of December. The solar declination and the mean sunrise hour angle was computed using the following equations [18] as reported in [19 – 26].

$$\delta = 23.45\sin\left\{360\left(\frac{284+n}{365}\right)\right\} \quad (2)$$

$$\omega_S = \cos^{-1}(-\tan\varphi\tan\delta) \quad (3)$$

The shortwave solar energy balancing at the edge of the Earth's atmosphere was computed using the equation [27].

$$\frac{H_m}{H_o} + \frac{H_a}{H_o} + \frac{H_r}{H_o} = 1 \quad (4)$$

where H_m is the measured global solar radiation (MJm^{-2}day^{-1}), H_o as previously defined is in MJm^{-2}day^{-1}, the ratio $\frac{H_m}{H_o}$ is the fraction of the extraterrestrial radiation, H_o is transmitted through the atmosphere to the ground surface and this ratio is known as the clearness index

[28 – 29]. H_a is the absorbed solar radiation, the ratio $\frac{H_a}{H_o}$ is the solar energy fraction absorbed, and is called the absorption co-efficient or absorbance, and $\frac{Hr}{Ho}$ would be the solar energy fraction reflected back to space, and is called the reflection co-efficient or reflectance [27] while H_r is the shortwave reflected radiation. As reported by Babatunde [27] the ratio $\frac{H_a}{H_o}$ is very small numerically when compared with the other ratios as presented in equation (4), thus, can be neglected, therefore $\frac{H_a}{H_o} \ll 1$. In that fashion equation (4) becomes

$$\frac{H_m}{H_o} + \frac{H_r}{H_o} \approx 1 \quad (5)$$

By this Mathematics, the reflectivity or albedo was estimated using

$$\frac{H_r}{H_o} = 1 - \frac{H_m}{H_o} \quad (6)$$

The Stefan-Boltzmann law [30] was used to calculate the flux density of longwave radiation emitted by the Earth, F_E, and is given by

$$F_E = \sigma T_E^4 \quad (7)$$

where σ is the universal Stefan-Boltzmann constant, $\sigma = 5.67 \times 10^{-8}$ Wm^{-2} K^{-4}, and T_E is the Earth's temperature, in Kelvin (K). F_E was obtained using [30] as

$$F_E = \frac{\left(1 - \frac{H_r}{H_o}\right) F_S}{4} \quad (8)$$

where $\frac{H_r}{H_o}$ is the Earth planetary albedo for the location and F_s is the flux density of solar radiation incident upon the Earth (1368 Wm^{-2}). Combining together equations (7) and (8), the equation that relates the surface temperature of the Earth, T_E to its albedo for the study locations [31] was obtained

$$T_E = \left[\left(\frac{\left(1 - \frac{H_r}{H_o}\right) F_s}{4\sigma}\right)\right]^{1/4} \quad (9)$$

Equation (9) indicated that as the albedo increases the temperature T_E decreases. In atmospheric science the term "shortwave" $(\lambda < \mu m)$ refers to the wavelength band that carries most of the energy associated with solar radiation and "longwave" $(\lambda > 4\ \mu m)$ refers to the band that covers most of the terrestrial (Earth-emitted) radiation. In the radiative transfer literature, the spectrum is basically divided into distinct zones as depicted in figure 1 and the detailed description is found in Wallace and Hobbs [30]. The Wien's displacement law [30] provides the equation for calculating the maximum wavelength of emission at temperature, T_E and is given as

$$\lambda_m = \frac{2897}{T_E} \quad (10)$$

λ_m is in micrometers and T_E in Kelvin.

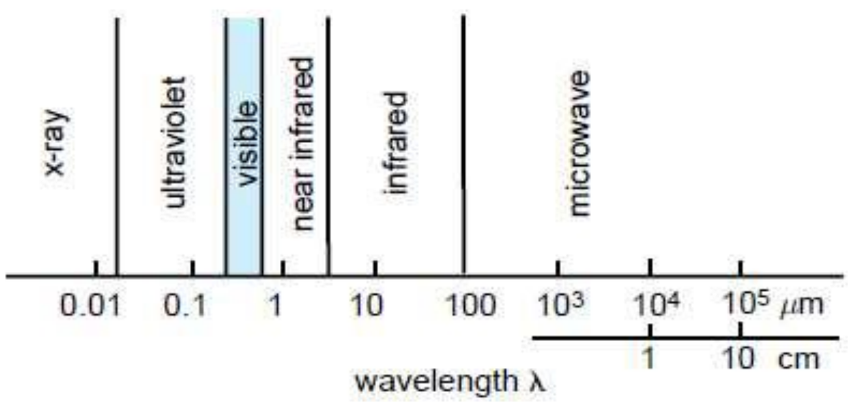

Fig. 1. The electromagnetic spectrum [30]

3. RESULTS AND DISCUSSION

Table 1. Monthly albedo, clearness index, short wave reflected radiation, surface temperature and wavelength for Maiduguri (1984-2021)

Month	H_r/H_o	H_m/H_o	H_r (MJm^{-2} d^{-1})	T(k)	Wavelength (μm)
Jan	0.3495	0.6505	20.2415	250.2792	11.5751
Feb	0.3511	0.6489	21.9221	250.1251	11.5822
Mar	0.3556	0.6444	23.5307	249.6900	11.6024
Apr	0.3901	0.6099	23.1499	246.2812	11.7630
May	0.4119	0.5881	22.3020	244.0421	11.8709
Jun	0.4453	0.5547	20.8165	240.5109	12.0452
Jul	0.4862	0.5134	19.3026	235.9413	12.2785
Aug	0.5125	0.4875	18.3808	232.8674	12.4406
Sep	0.4466	0.5534	20.3732	240.3638	12.0526
Oct	0.3747	0.6253	21.5318	247.8155	11.6901
Nov	0.3344	0.6656	21.0382	251.7177	11.5089
Dec	0.3626	0.6374	19.2155	249.0100	11.6341

Table1 above shows the variation of the monthly average daily albedo, clearness index, short wave reflected radiation, surface temperature and wavelength for Maiduguri. “The monthly albedo increases from the months of January to August and decreased from the months of September to November. Then slightly increases in the month of December. The clearness index decreases from the months of January to August, increases from the months of September to November, then slightly decreased in the month of December. Solar radiation increases from months of January to April, then decreased from months of May to August but slightly increases in the month of September and decreases from the months of October to December. Indicating that the surface temperature and maximum wavelength show opposite relationship for Maiduguri”. [32]

3.1 Analysis of the variation of albedo, surface temperature and maximum wavelength for Maiduguri

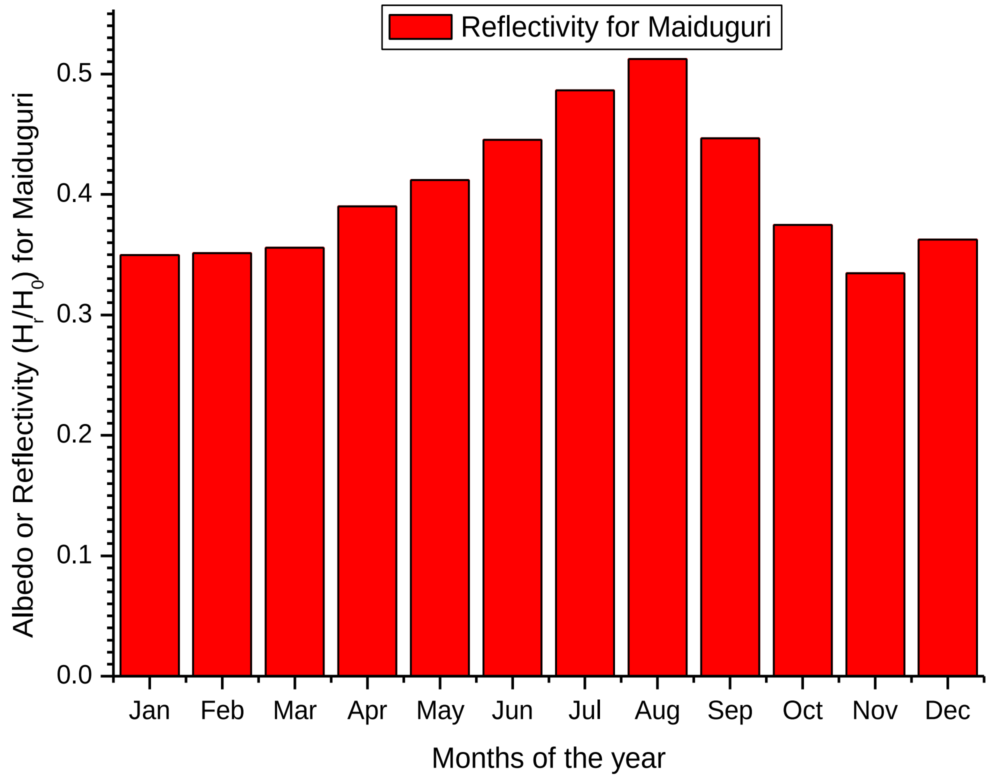

Fig. 2. Monthly average daily reflectivity (H_r/H_o) for Maiduguri (1984-2021)

Fig. 2 shows that the surface albedo for the study area (Maiduguri) ranges between 0.3344 and 0.5125, this value is within the range of surface albedo which varies from 0 for no reflection to 1 for complete reflection of light striking the surface. The figure shows that high values albedo were found in the July, August and September with the highest value in August (0.5125) which corresponds to the lowest clearness index value of 0.4875 and relatively low values of albedo were found in November, December and January with the lowest value in November (0.3344) which corresponds to the highest clearness index value of (0.6656). The highest value of albedo observed in August specifies that this is the month where there is climax of rainfall in Maiduguri and a principally cloudy month; this is to confirm that clouds, aerosols and air molecules of which cloud is the chief are responsible for reflection of solar radiation in Maiduguri. The surface albedo found for Maiduguri ranges between 0.3344 and 0.5125 with the highest value in August (0.5125) during the peak period of rainy season and the lowest in November (0.3344) during the beginning of dry season when it was relatively cloudless and dustless. The result in this study compares favourable well that reported by Audu et al. [2] for Kano and Akpootu and Iliyasu [3] for Sokoto.

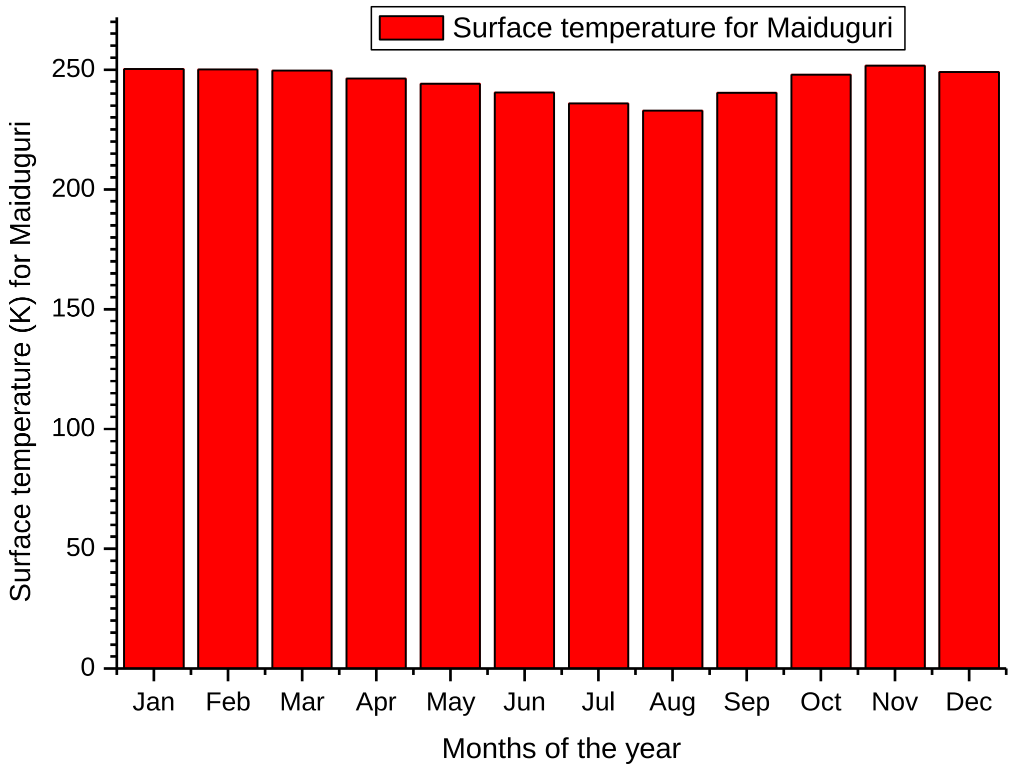

Fig. 3. Monthly average daily surface temperature (K) for Maiduguri (1984-2021)

Fig. 3 depicts the variation of radiated temperature by the earth for the location (Maiduguri). It could be seen from the figure that the highest surface temperature was found in January (250.2792 K) during the dry season period as this is anticipated because the albedo is low during this period, thereby allowing more radiation into the earth which therefore increased the temperature. The lowest temperature occurred during the rainy season in August (232.8674 K) indicating cloudy sky. This corresponds to the highest reflectivity (albedo) with value of 0.5125, this is the cloudiest month for this region, where rainy season is relatively high; the low temperature is expected, as a result of high reflection of solar radiation. In the present study, the surface temperature ranges between 232.8674 K to 250.2792 K. This is in good agreement with that of the earth standard emitting surface temperature (255.0000 K). The results showed that an inverse relationship existed between the earth emitting surface temperature and the planetary albedo.

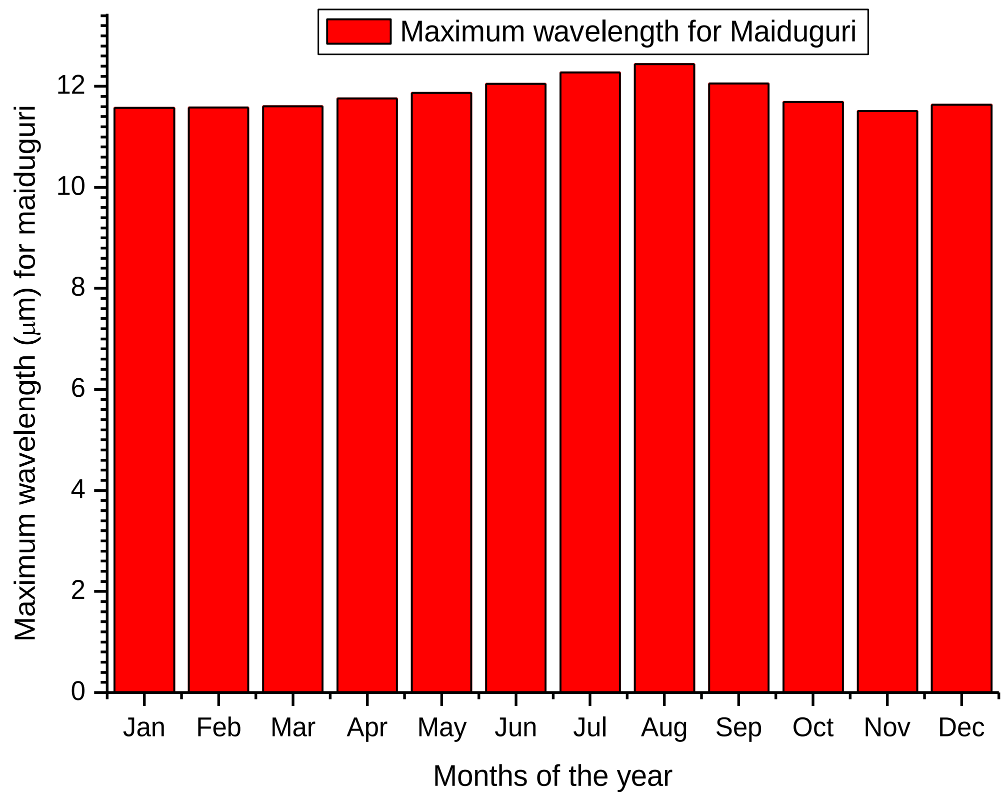

Fig. 4. Monthly average daily wavelength (μm) for Maiduguri (1984-2021)

Fig. 4 depicts the variation of the monthly average daily maximum emitting wavelength for Maiduguri. The highest wavelength was found in August (12.4406 μm) and the lowest in December (11.5089 μm). The peak wavelength ranges from 11.5089 μm to 12.4406 μm, these values agree with that reported in radiative transfer literatures as contained in [30] that for longwave radiation ($\lambda > 4\ \mu m$) of [14]. This indicates terrestrial Earth emitted radiation, and thus found within the infrared region.

3.2 Analysis of the variation of reflectivity with clearness index for Maiduguri

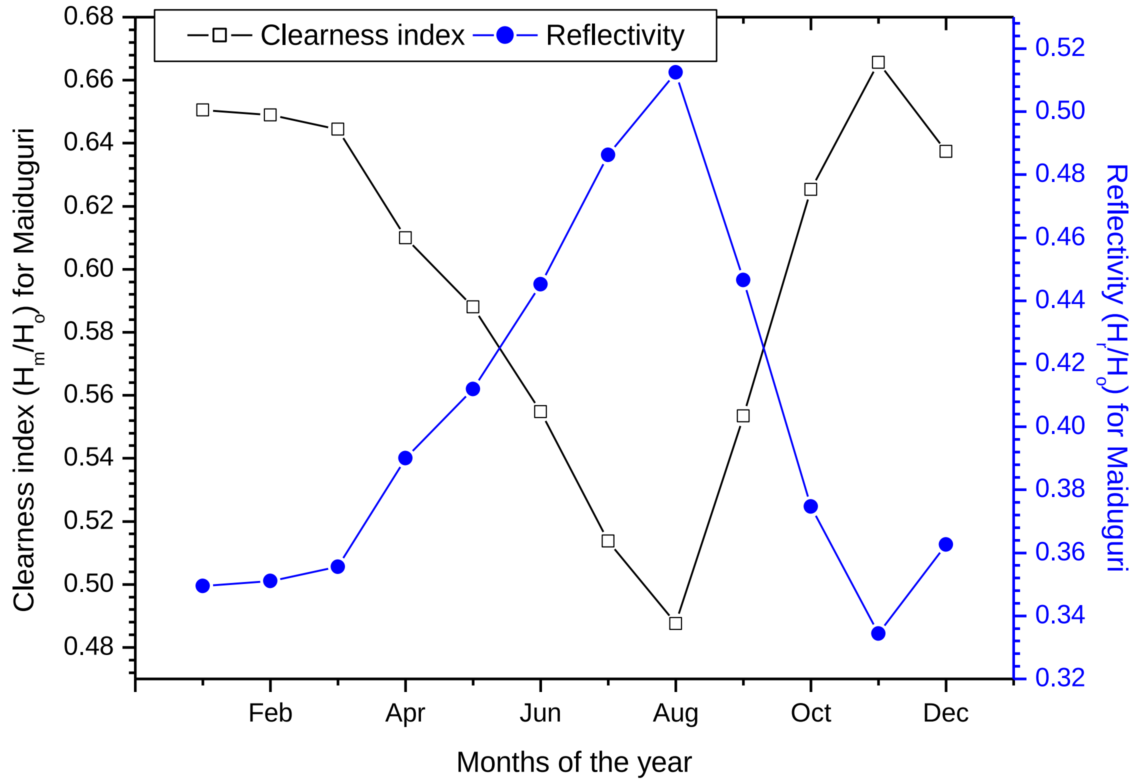

Fig. 5. Comparison between reflectivity (H_r/H_o) and clearness index (H_m/H_o) for Maiduguri (1984-2021)

Fig. 5 correlates the changes that occurred between the reflectance/reflectivity and the clearness index for Maiduguri. It was observed that the lowest clearness index (0.4875) corresponds to the highest reflectance (05125) and this occurred in August. Also, in the month of November, a high value of 0.6656 of clearness index corresponds to a very low value (0.3344) of reflectance. The results investigated than a direct opposite relationship exist between the clearness index and reflectance, mostly in the months between May and September. This shows that beside the rainy season period the sky is clear almost throughout the year for Maiduguri. The degree of the reflectance shows the indentation of the surface brightness and the quantity global solar radiation reflected back to space. Therefore, when the sky is relatively cloudless, albedo or reflection coefficient is expected to be relatively small, signifying availability of solar radiation for solar energy devices. Both the measured global solar radiation (H_m) and the shortwave reflected radiation (H_r) are fractions of the extraterrestrial radiation (H_o), as a result of this, a valid comparison between the clearness index and reflectance can be done. The result revealed that the clearness index is higher than the reflectance throughout the investigation period except in August. The implication is that, since the global solar radiation is towards the ground surface and the shortwave reflected radiation is towards the space, thus, the global solar radiation received on the Earth's surface is higher than the reflected radiation lost to space throughout the months in Maiduguri; indicating accessibility of abundant solar radiation in the location.

3.3 Variation of reflectivity with meteorological parameters for Maiduguri

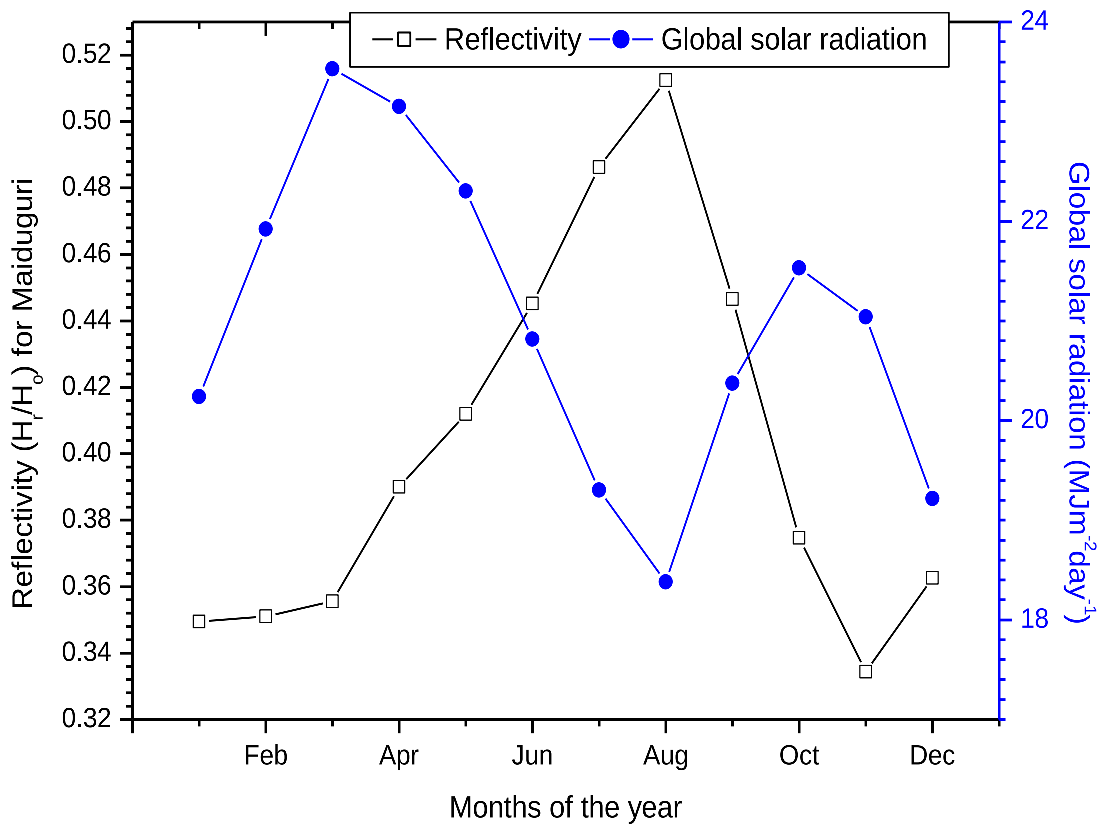

Fig. 6.Variation of monthly mean global solar radiation with reflectivity for Maiduguri (1984 - 2021)

From Fig. 6, it can be seen that there is no uniformity of global solar in the location. High values of solar radiation were observed in the months of March, April and May with values of 23.5307 MJm^{-2}day^{-1}, 23.1499 MJm^{-2}day^{-1}, and 22.3020 MJm^{-2}day^{-1} respectively. The highest global solar radiation value of 23.5307MJm^{-2}day^{-1} was recorded in the month of March in the period under study. Consequently the months of August and December noted the least amount of solar radiation with average values of 18.3808 MJm^{-2}day^{-1} and 19.2155 MJm^{-2}day^{-1} respectively. The lowest global solar radiation value of 18.3808 MJm^{-2}da$y^{-1}$was recorded in the month of December in the period under study. Generally, higher values of solar radiation were obtained in the dry season.

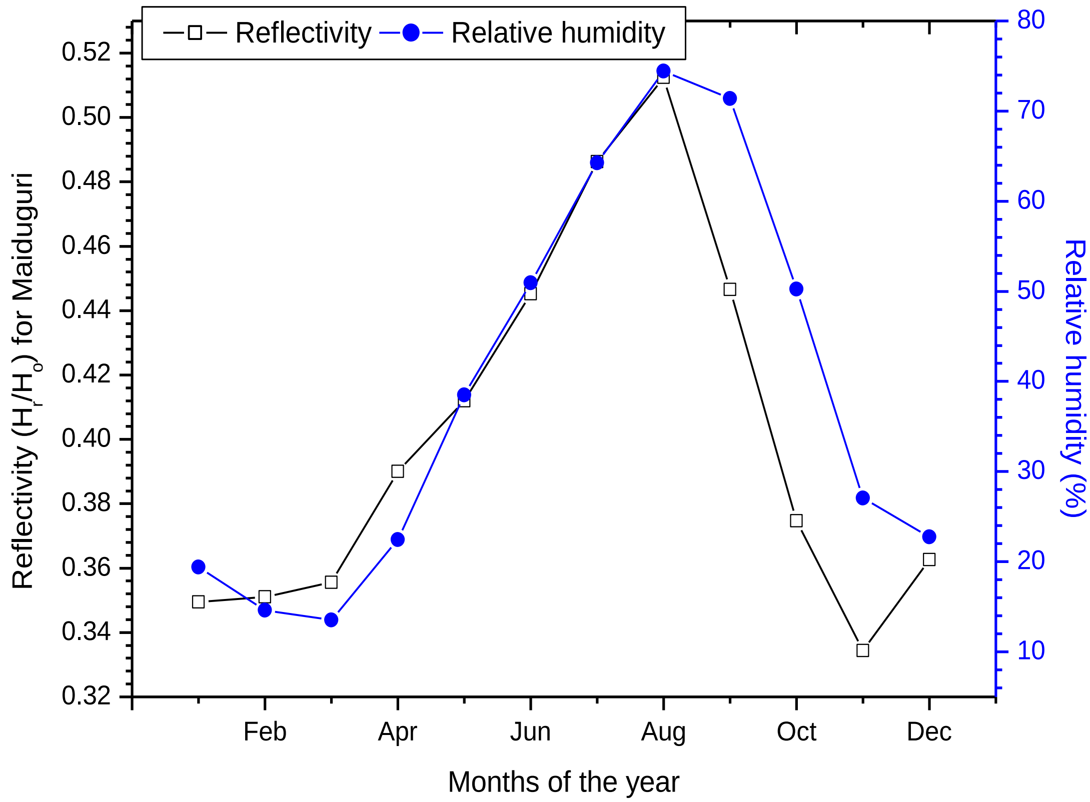

Fig. 7. Variation of monthly mean relative humidity (%) with reflectivity (H_r/H_o) for Maiduguri (1984-2021)

Fig. 7 depicts the monthly variation of relative humidity with reflectivity for Maiduguri during the investigation period. Almost similar pattern of variation was observed for relative humidity with albedo. This is an indication that the atmospheric moisture content can possibly predict albedo values as a direct relationship existed. The maximum and minimum values of 74.4387 % and 13.5187 % of relative humidity were found in August and March respectively. The relative humidity and albedo increase subsequently from March until both attained their maximum values of 74.4387 % and 0.5125 in August respectively. This connotes the variation of relative humidity and albedo is in tandem.

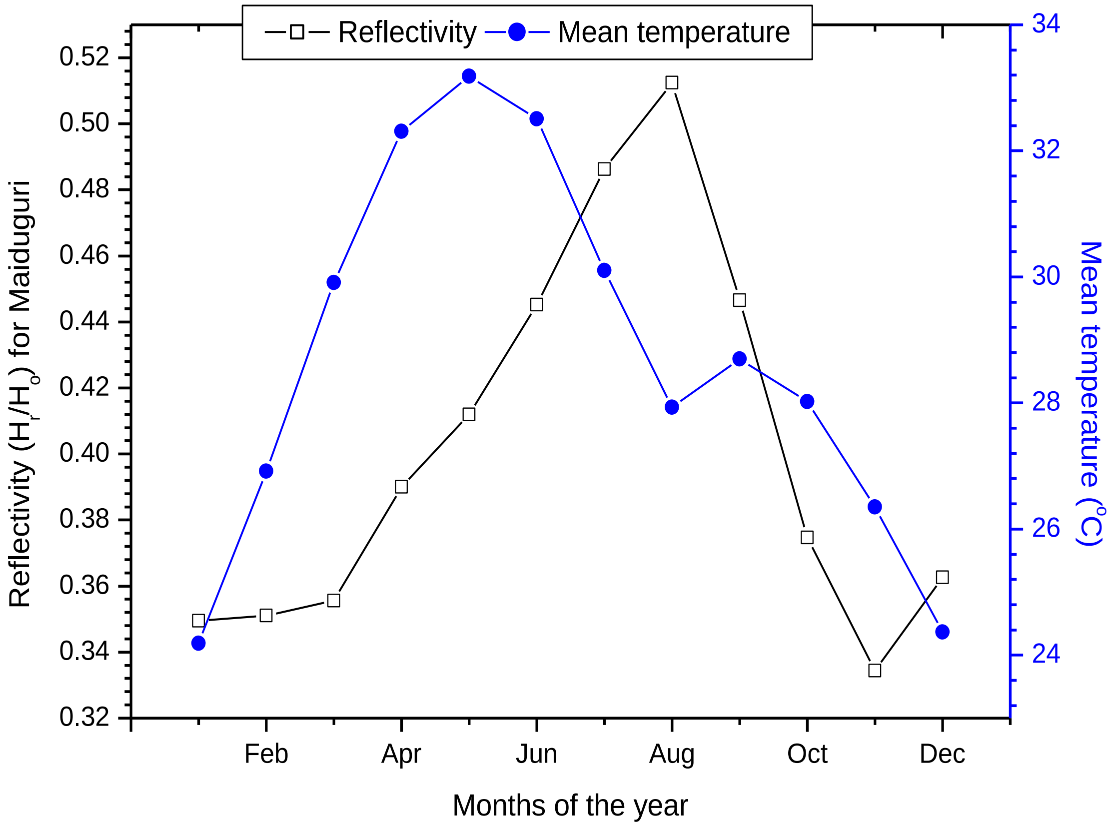

Fig. 8. Variation of monthly mean temperature (℃) with reflectivity (H_r/H_o) for Maiduguri (1984 - 2021)

Fig. 8 depicts the monthly variation of temperature with albedo for Maiduguri. The lowest and the highest temperature values of 24.1867 ℃ and 33.1845 ℃ were observed in the months of January and May respectively, the albedo increases from the months of January with lowest value of 0.3495 to its highest value of 0.5125 in August and decreased from the months of September to November and increased in the month of December. The figure revealed that the highest albedo was found in August. The decreased in temperature from the months of June to August indicates the period rainy season. The result shows that the temperature decreases from the months of June to August, then slightly increased in September and decreases further to December.

4. CONCLUSION

This study looked at how much sunlight is reflected back into space (albedo) at the Earth's atmosphere's edge. It focused on Maiduguri, a place in Nigeria with specific coordinates and altitude. The study used data from NASA to analyze the variation of sunlight reflection over a span of 38 years. The highest and lowest albedo at the surface of Maiduguri was measured in August and November respectively. In August, with a value of 0.5125, while in November with a value of 0.3344. The level of sunlight in Maiduguri is high throughout the year because the clearness index is higher than the albedo. The emitting Earth surface temperature for Maiduguri varied from 238.5837 K in August to 251.1607 K in January. The longest wavelength of radiation in Maiduguri was between 11.5089 μm in November and 12.4406 μm in August. This shows that the radiation in this area is in the form of longwave radiation, which is expected for wavelengths longer than 4 μm. This radiation falls within the infrared part of the electromagnetic spectrum. Models are intended to be developed for estimating surface albedo in our future study.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration among all the authors. The data for the work was sourced and analyzed by author DOA. Author GMA and DOA supervised the work. The work was drafted and edited by Author MU. All the authors in this paper read and approved the final manuscript.

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