SIMULATED REFLECTED SW-RADIATION AND ITS CHARACTERISTIC VARIATION AT ILORIN, NIGERIA

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Abstract

The expression for estimating H_r/H_o, the reflected radiation coefficient or albedo of a surface was used to simulate short-wave (SW) reflected radiation H_r, and reflection coefficient, H_r/H_o, at the Earth's surface at Ilorin (8° 30' N, 4° 34' E) in 2000, where the data used were measured. The temporal variations of the simulated reflectance, H_r/H_o, the clearness index, H/H_o, and cloudiness index, H_d/H of the year were studied to establish any inter-relationship between them. The highest reflectance recorded was 0.644 at the peak period of cloud activity in August, and the lowest was 0.361 in November when it was relatively cloudless and dustless. It was deduced that, characteristically, shortwave solar radiation reflection is a mirror image of shortwave diffuse solar radiation, and that reflectance is a sort of cloudiness index. The albedo therefore deduced from the study, for the Earth–Atmosphere at Ilorin in 2000, ranged between 0.4 and 0.6. These values are consistent with the possible values of albedo of different surfaces covering the Earth's surface. The above equation therefore, would be found suitable for estimating surface albedo.

Keywords: Solar radiation, reflection, albedo

Introduction

In the work on shortwave solar energy balancing at the edge of the atmosphere carried out in 2003 by Babatunde (2003; 2003), the relation

$$H/H_0 + H_a/H_0 + H_r/H_0 = 1 \qquad (1)$$

was used to establish the sw-solar radiation energy balance at the edge of the Earth's atmosphere, where H/H_o is the fraction of the extraterrestrial radiation, H_o, transmitted through the atmosphere to the ground surface, and called clearness index (Babatunde and Aro,1995; Udo,2000), H_a/H_o is the fraction absorbed called the absorption co-efficient or absorptance, and H_r/H_o is the fraction reflected back to space called, here, the reflection co-efficient or reflectance

(Babatunde,2003). Further in the work, H_a/H_o was found to be very small compared with the other ratios and therefore negligible, i.e.

$$H_a / H_o << 1$$

Hence equation (1) becomes

$$H/H_o + H_r/H_o = 1 \text{ (approximately)} \qquad (2)$$

From this, an expression for estimating H_r/H_o was obtained as

$$H_r/H_o = 1 - H/H_o \qquad (3)$$

An equation similar to equation 3 was obtained by Babatunde and Aro (1995) for cloudiness index, H_d/H, i.e.

$$H_d/H = 1 - H/H_o \qquad (4)$$

Thus the two parameters can be said to be twins of the same physical quantity.

Both H_r and H_r/H_o were then estimated using eqn. (3).

The sw- reflected solar radiation, H_r, is understood to include the reflected radiation from the Earth's surface, reflected radiation back to space by clouds, and the scattered radiation back to space by atmospheric particles and clouds. Reflection, with regards to solar radiation, is redirection of radiation by 180^o after striking a surface or any atmospheric particle; it is a lost radiation to the space. The fraction, H_r/H_o, called total wavelengths (0.2 - 4μm) reflection co-efficient or reflectance by all the surfaces on the Earth's surface is known generally as the Earth's surface albedo (Igbal,1983).

Albedo

Reflection of radiation is one of the mechanisms by which solar radiation is depleted in the atmosphere and most of it occurs in clouds in the atmosphere. By its definition, 100% of it is lost to space.

Albedo is related to reflection of solar radiation at a surface and defined primarily as the ratio of the reflected solar radiation to the incident solar radiation at the surface, i.e., H_r/H_o, in this work. It is assumed however that the reflected radiation, H_r, as described above, is both diffuse and specular, that is, 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 satisfied (Igbal, 1983). Gutman (1988) therefore said that the observed albedos assumed that the radiation field is isotropic. The extraterrestrial radiation, H_o, from the sun, at the edge of the atmosphere, was considered the incident solar radiation. Albedo is also known as the reflectance or reflectivity of a surface and that the surface albedo of the Earth is regarded the same as planetary albedo by many scientists (Igbal, 1983).

Albedo, as a property of a surface, is used to determine the brightness of a surface, and therefore according to Prado et al (2005), materials with high albedo and emittance attain lower temperature when exposed to solar radiation, and therefore reduce transference of heat to their surrounding. Thus albedo is very important in evaluating the total insolation on a building or a solar energy collector. It is also important in studies dealing with thermal balance in the atmosphere.

Several other definitions of albedo are rendered based on the source of the reflected radiation, but only a few are mentioned here. The reflected radiation measured at several portions of the electromagnetic radiation is used to estimate the spectral surface albedos (Gutman et al,1989), and the linear combination of them constitutes the broad band surface albedo (Wydick et al, 1987; Brest et al, 1987; Saunders et al, 1990). The Broadband surface albedo is simply surface albedo. Prado et al (2005) gave an encompassing definition of albedo as the specular and diffuse reflectance integrated over 290 and 2500nm wavelength range, which corresponds approximately to 95% of the solar radiation that reaches the Earth's surface. The albedos of the individual surface on the Earth, such as water, vegetation, snow, sand, surfaces of buildings, dry soil, that of the atmosphere, etc, constitute the surface or planetry albedo.

It is therefore the intention in this work to use equation 3 to simulate the daily and monthly averages of the shortwave solar radiation reflection, H_r and reflection co-efficient, H_r/H_o; to study the daily and seasonal variation characteristics of H_r/H_o, and use it to obtain an estimated value of the Earth's albedo at Ilorin.

Data and Data Processing

The data used for this study were the global (total) solar radiation H, and diffuse solar radiation H_d, of wavelength range mostly from 0.2 to 4.0μm, measured at the BSRN station, Physics Department, University of Ilorin. Others were extraterrestrial radiation, H_o at the top of the atmosphere at Ilorin and reflected radiation, H_r in year 2000.

The global (total) radiation was measured using Eppley Pyranometer, PSP with calibration constant of 8.2 x 10^{-6} V/Wm^{-2}, while the diffuse radiation H_d was measured using the Black and White Eppley Pyranometer model 8-48 with calibration constant 9.18 x 10^{-6} V/Wm^{-2}. Extraterrestrial radiation, H_0 and the sw- reflected solar radiation, H_r were computed.

In compliance with the world WRR, sampling rate of 1-second duration of the radiation fluxes was done every minute with integration time of 3-minutes maintained for averaging and recording. From these measured radiation fluxes, the daily and monthly averages of the fluxes and the ratios H/H_o, H_d/H and H_r/H_o were computed. Thus, the sw- solar radiation reflection, and total wavelengths reflection co-efficient or reflectance was simulated for the year 2000 at Ilorin.

Results and Discussions

(a) **Daily variations of H/H_0, H_d/H, H_r/H_0 compared**

The graphs of the daily variation of the reflection co-efficient, H_r/H_o, cloudiness index, H_d/H and clearness index, H/H_o, in year 2000 are presented in Figs. 1-4 for February, April, August and November, representing four periods of different atmospheric or sky conditions in the year. By them the variation patterns of the parameters were studied and compared, and the atmospheric conditions causing the variations were identified.

Speaking generally of the variation patterns of the parameters, the graphs indicate daily and unequal fluctuations of the parameters in every month as shown in the figures. The fluctuations in turn indicate daily changes in the atmospheric conditions causing the variations. It is observed that the reflectance, H_r/H_o and the cloudiness index, H_d/H, varied in the same manner everyday with only slight differences in their magnitudes, while they both varied oppositely to H/H_o. This result could mean that the reflection co-efficient can be interpreted to be a sort of cloudiness index as H_d/H is (Prado et al, 2005). Equations 3 and 4 above confirm this result.

The magnitude of the cloudiness index indicates the degree of cloudiness or turbidity in the sky and the magnitude of the diffuse radiation in the global, while the magnitude of reflection co-efficient indicates the degree of brightness of the surface and the amount of reflected radiation back to space.

Concerning the variation of the parameters in each of the sampled months, it is observed that, since H and H_r are each a fraction of the same quantity, H_o, H/H_o and H_r/H_o are comparable. In February, in Fig.1 below, the variations of H/H_o and H_r/H_o were observed not to be very significant; however the values of H/H_o were higher than those of H_r/H_o practically throughout the month. This implies that the global radiation H, received on the Earth's surface was more than the reflected radiation, H_r, lost to space in February at Ilorin. It further implies that the sky was relatively cloudless, albedo was relatively low and more radiation was available to the solar energy devices. On the other hand the variation of H_d/H was simultaneously significant; its variation was high in magnitude more than those of the others for the same changes in atmospheric conditions. It implies that it is more sensitive to the atmospheric condition changes responsible for the variations than the others.

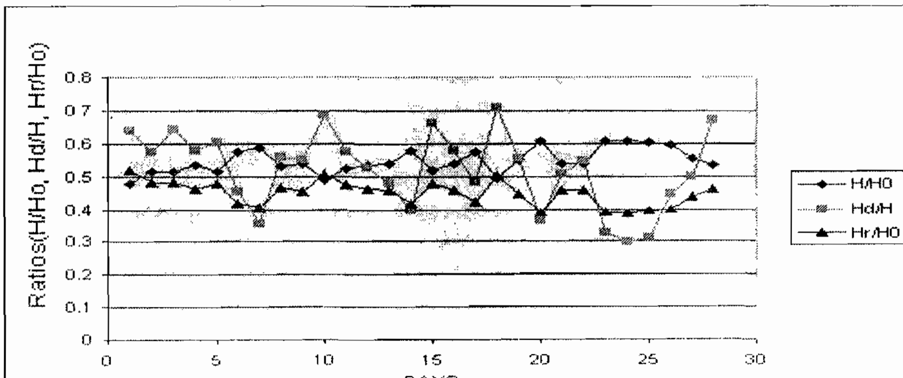

Fig 1 **H/H0, Hd/H, Hr/H0 FOR FEB 2000**

Fig.2 above, presenting the variations of the parameters in April, indicates very significant variations of the parameters. The high and frequent fluctuations of the parameters indicate dynamic changes in the atmospheric conditions in the month. Again, H/H_o was higher than H_r/H_o on many days in the month; indicating that more radiation was available than lost to space in reflection. The rise, however, in the value of albedo in this month was due to the presence of some clouds in the sky and heavy hygroscopic particles replacing the harmattan dust particles in the sky.

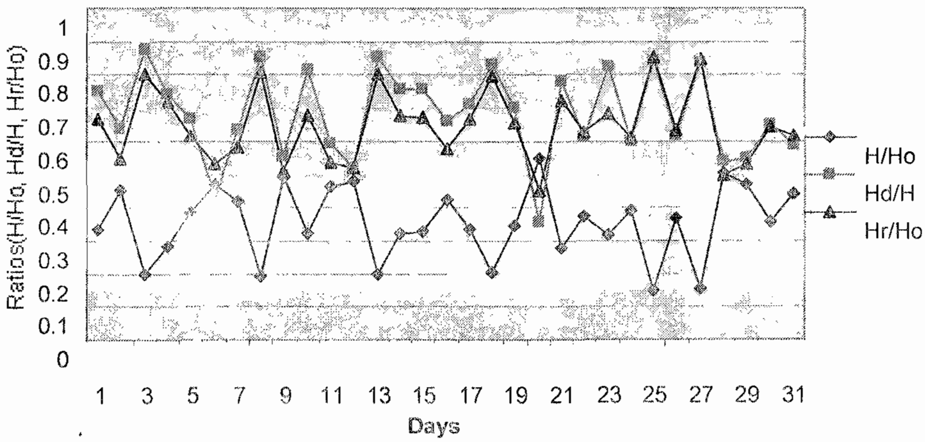

Fig. 3 H/Ho, Hd/H, Hr/Ho for August 2000

In August, in fig.3 above, the variations of the parameters were very significant with high values of fluctuation. However H_r/H_o and H_d/H were much higher than H/H_o for almost all the days in the month. This is a reversai ^f the case in February and November; it implies that more radiation was reflected back to space than received on the Earth's surface. The high values of H_d/H at the period indicate that the little global radiation received was mostly diffuse radiation. The high values of H_r/H_o, the reflectance or albedo, implies high brightness of the Earth's surface toward the space, and low surface temperature of the Earth.

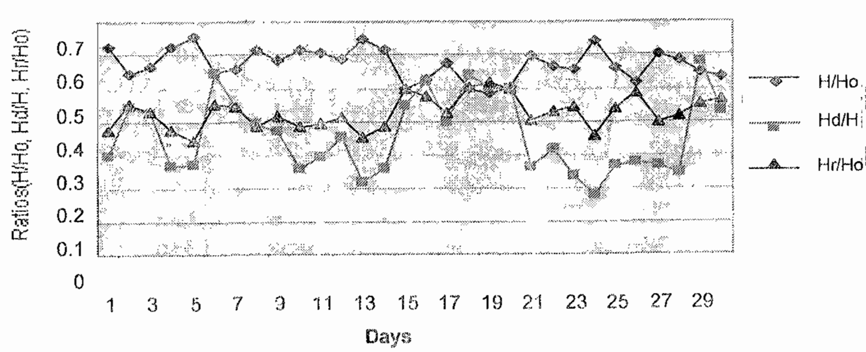

Fig. 4 H/Ho, Hd/H, Hr/Ho for November 2000

But in November (in Fig.4) above, the values of H/H_o were much higher than those of H_r/H_o and H_d/H for almost all the days in the month. The low values of H_r/H_o imply little amount of radiation was reflected to space, and large amount of radiation was received on the ground surface. They also imply low values of albedo, and therefore less brightness of the surface of the Earth but high surface temperature. All these, and the very low values of H_d/H indicate very little amount of diffuse radiation, little or no clouds and little or no dust particles in the sky.

(b) The Monthly Variation of H/H_o, H_d/H, H_r/H_o

The graphs of the monthly averages of H_r/H_o, H_d/H and H/H_o in Fig.5 below, indicate high values of H_r/H_o in July, August and September with the highest in August, and relatively low values in October, November, December and January with the lowest in November. Similarly the graphs indicate high values of H_d/H in June, July and August with the highest in August, and low values of it in November, December and January with the lowest in November. The result, that the parameters, H_d/H and H_r/H_o, have their highest and lowest values occurring in the same months respectively confirm that the two parameters are twins of the same physical quantity, cloudiness and turbidity, but in the opposite directions.

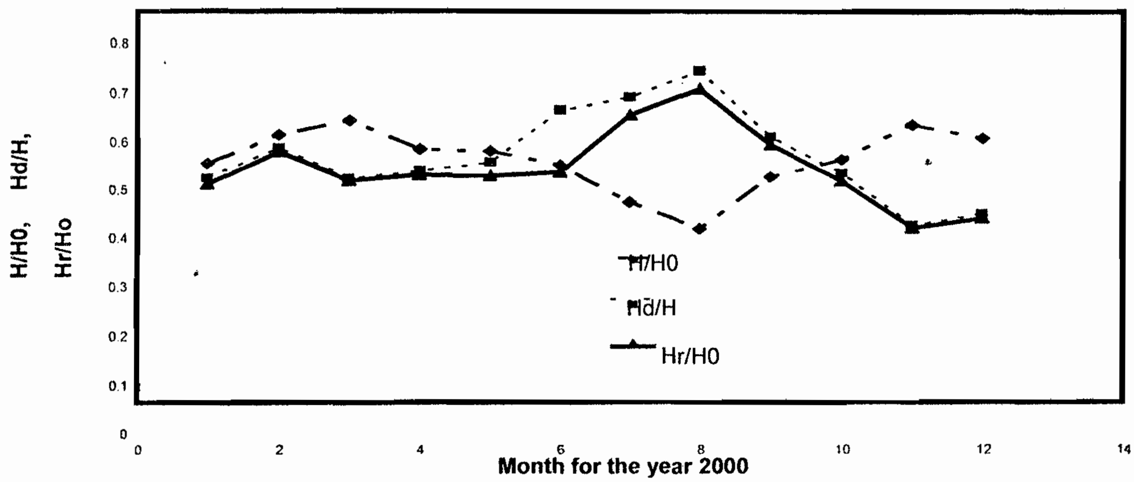

Fig 5. Monthly average variation of H/H0 , Hd/H, Hr/H0 for year 2000

The results further show that the high value of H_r/H_o in July, August and September, with the highest in August, the peak of rainy season and a predominantly cloudy month confirms the more, that the reflection of solar radiation by the planet Earth, in this region, is mostly by clouds. The lowest value of the parameter in November confirms also that November is relatively cloudless and dustless, that is, relatively clear and clean (Babatunde and Aro, 1990). A high value of reflectance observed in February, though a relatively cloudless month, shows that reflection of radiation at this period is by the dust particles in the atmosphere, and shows that the atmosphere in February of that year was heavily laden with harmattan dust.

Table 1: The Monthly Average of the Radiation coefficients and Fluxes in (MJ/m^2 day) for year 2000

Month	H_o	H	Hd	H/H_o	Hd/H	Hr/H_o	Hr
Jan	32.61	16.21	7.24	0.489	0.456	0.511	16.664
Feb.	34.85	19.14	9.83	0.549	0.522	0.451	15.717

Mar.	37.03	21 44	9.74	0.58	0.459	0.42	15.553
Apr	37.75	18 85	8.79	0.519	0.474	0.481	18.158
May	37 16	19.17	8.90	0.516	0.492	0.484	17.985
Jun	36.51	17.72	8.34	0.485	0.6	0.515	18.803
Jul	36.66	14.95	8.83	0.408	0.627	0.592	21.703
Aug.	37.29	13.14	8.46	0.353	0.68	0.647	24.127
Sep.	37.11	17 10	9.05	0.461	0.545	0.539	20.002
Oct.	35.44	17.67	8.01	0.498	0.47	0.502	17.791
Nov.	33.11	18.96	6.73	0.572	0.361	0.428	14.171
Dec.	31.18	17.26	6.47	0.543	0.384	0.457	14.537

Seasonal Variation and Sky Conditions by H_r/H_o

Table 1 and Fig.5 above; present the monthly average values of reflectivity, H_r/H_o, of the Earth and its atmosphere. It is seen from them that the reflectance or reflectivity varied from month to month. The seasonal values of reflectance at Ilorin can then be inferred from these monthly values, and that reflectance or albedo can be used as a radiation parameter to determine the sky conditions of a location or region, and may be used to estimate the surface temperature of the Earth at the location. The following expression, though not very accurate, relates the surface temperature, T of the Earth to the albedo, i.e.

$$T = [(1 - a)S/4\sigma]^{1/4} \text{ (McIlveen, 1992)}$$

where a is the albedo, S is the solar constant and σ is the universal Stefan-Boltzman constant. It indicates the temperature T decreases as albedo increases.

Nigeria being in the tropics experiences two main seasons: dry season and rainy season. While temporal demarcation between them is not rigid, the dry season is from about November to April and the rainy season is from about May to October. The two seasons may be divided into sub- seasons or periods with slightly different weather or atmospheric conditions (Falaiye et al, 2003). For the purpose of determining the sky conditions using seasonal variations of albedo in this work, the two seasons were sub- divided into four divisions. For each period, the average value of the albedo or reflectivity of the Earth was computed. The sub-divisions are presented in Table 2 below.

Table 2: Sub- Seasons with Albedo Values in Year 2000

Period	Albedo(H_r/H_o)	Sky Conditions
December-March	0.447 ± 0.049	Dry, Cloudless, Dusty
April–May	0.465 ± 0.001	Transition period: dry to rain, small cloudiness, dust clearing.
June-September	0.559 ± 0.065	Rains, cloudiness with low thick clouds, no dust.
October-November	0.404 ± 0.049	Transition period: rain to dry, little clouds, very little or no dust.

However for the two main seasons the sky conditions parameters are summarized as follow in Table 3.

Table 3: Seasonal sky conditions parameters for year 2000

Season	H/H_0(cloudiness index)	H_r/H_0(albedo)	H_d/H(cloudiness index)
*[1]DS(Nov-Apr.)	0.542 ± 0.031	0.435 ± 0.054	0.443 ± 0.055
*[2]RS(May-Oct)	0.454 ± 0.056	0.525 ± 0.071	0.569 ± 0.074

*[1]- Dry Season, *[2] - Rainy Season

For the dry season, the sky is generally and relatively cloudless as indicated by the relatively low value of albedo as seen in Table 3. More solar radiation is expected to be available at the Earth's surface, while in the rainy season the albedo is relatively high; it is attributed to high cloudiness at this period, see Table 3. Hence, relatively little amount of radiation is expected on the Earth's surface, the surface of the Earth-Atmosphere is expected to be brighter and cooler. A further analysis of these results shows that the sums of the ratios $H/H_0 + H_d/H$ and $H/H_0 + H_r/H_0$ are each approximately equal to unity in the two seasons. This confirms further that H_d/H and H_r/H_0 are mirror images of one another. They are the same atmospheric or sky condition parameter, cloudiness index.

Discussions

The results confirm that the atmospheric constituents responsible for reflecting solar radiation back to space are clouds, aerosols and dust particles of different sizes, of which cloud is the chief (Mcllveen,1992). When therefore an atmosphere is clear and clean, that is, cloudless and dustless, the values of H_r/H_o are expected to be relatively low and that of H/H_o to be relatively high. When the value of H/H_o is high, most of the radiation on such days is expected to reach the ground surface undeviated and unscattered. This will imply that reflection of radiation to space in such a situation is mostly from the surface of the Earth, because the atmosphere is cloudless. In general, it can be said that reflection of radiation back to space by the planet is mostly that of clouds and aerosol in the atmosphere. That is, the shortwave radiation reflection by the Earth's surface alone is comparatively small to that by its atmosphere. Thus it can be said that the atmospheric conditions influencing reflection of shortwave radiation back to space most are clouds and aerosol particles, particularly those of molecular size.

High values of reflectivity or reflectance indicate period of low level, thick clouds and rains dominating the sky. The high albedo values therefore at June to September must be mainly due to clouds. There is the possibility of poor performance of the solar energy systems, particularly solar concentrating devices, poor fruition of crops and plants and low surface temperature of the Earth during this period as most of the sun light is sent back to space by reflection. About 60%, according to the albedo value of this period, of the sunlight that strike the Earth-Atmosphere surface is reflected back, and was not available to such devices for use.

October to November, a transition period between rainy and dry seasons, had the lowest average value of albedo of 0.404 (Table 2 above). This indicates about 40% of sunlight being reflected away back to space. This does indicate a period of little or no clouds to reflect radiation, little or no dust to scatter radiation back to space but enhances more sunlight reaching the ground surface; hence performance of solar energy devices is expected to be high, fruition of crops and plants to be enhanced and the Earth's surface temperature is expected to rise.

April-May period is another transition period between the dry and rainy season. Changes in the sky conditions were dynamic during this period as the variations of all the parameters were very significant and frequent. It is therefore relatively cloudy and contained more of hygroscopic particles than dust. The next highest value of albedo of 0.465 (table 2 above) was in this period. This value indicates less than half or about half of the sunlight being reflected back. Its albedo was however higher than that of the period very dry, cloudless and with high concentration of the harmattan dust, December to March, a period with albedo of 0.447(Table 2 above). This analysis shows that an atmosphere with low level, thick clouds will reflect more radiation than the scattering by one which is concentrated with dust.

Since it is possible to use equation 3 to estimate the reflectance of a surface at any location, the values obtainable at Maceio, Brazil (9^0 40'S, 35^0 42'W), of coordinates almost similar to that of Ilorin (8^0 32'N, 4^0 34'E), are compared. It has a value of 0.53 for H/H_o in the rainy season and 0.59 in the dry season. These correspond to reflectance or albedo of 0.47 and 0.41 for the rainy and dry seasons respectively (De Sonsa et al, 2005). Brazil is covered with thick rain forest and also in the Tropics with clouds most of the time. These albedos are comparable to the ones obtained here at Ilorin. Hence this method of estimating albedo, though simple, may give a reasonable estimation of it word - wide.

Conclusion

The daily and monthly variation patterns of the simulated shortwave reflection co-efficient, H_r/H_o were compared with the corresponding cloudiness index, H_d/H and were both found to be mirror images of one another. While the shortwave diffuse radiation is toward the Earth's surface, its mirror image, the shortwave reflection radiation is back toward space.

The shortwave solar radiation reflection co-efficient was used to define the Earth's surface albedo which was found to vary daily and monthly in accordance with changes in the atmospheric conditions causing the variations.

The surface albedo according to the analysis, therefore, at Ilorin in year 2000 was found to range between 0.4 and 0.6. These values seem high when compared with the average value of 0.3 obtained for the Earth's surface albedo, but would be considered consistent with the acceptable ones since they fall within the many possible values averaged statistically to obtain the quoted value for the Earth. The values of albedo can vary from 0 for no reflection to 1 for complete reflection of light striking the surface. For a spot like Ilorin on the surface of the Earth to have between 0.4 and 0.6, is not unexpected. Ilorin, in Nigeria, is in the tropical region which is cloudy with different types of clouds most of the time in the year.

The atmospheric factors which are influencing radiation reflection and scattering in the Earth-Atmosphere system most are clouds and particles, clouds being chief. The Earth and its atmosphere, in this regard, were found most reflective in August and least reflective in November at Ilorin in year 2000.

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