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Research paper

Estimation of the earth's albedo over some selected area the Republic of Chad

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Abstract

Surface albedo is one parameter of the climate variables. It influences the surface radiation budget for a given site. The availability of surface albedo data at both temporally and spatially levels are needed. In the lack of ground recorded values of albedo, we have to estimate surface albedo from the climatic variables. The model generated in this study enables the continuous observation of land surface albedo through relative model established from the multivariate regression method. From satellite recorded data, we estimate the ground surface albedo for some selected sites. The result were satisfactory with the root mean square error (RMSE) is 0.035. The Mean Absolute Error (MAE) was computed and indicated to be as low as 0.027 and mean absolute percentage error (MAPE) is 7.58.

Keywords: *Albedo; Solar Radiation; Surface Temperature; Relative Humidity; Statistical Error Test; Chad.*

1. Introduction

Surface radiation is the driving force for the surface energy balance. It is the transportation and exchange of all matters at the interface between the surface and the atmosphere and significantly affects the climatic forming and change (Evans, 2017) [1]. In addition, as an important factor in global and regional climatic models, an accurate estimation of the Surface reflective radiation is required. Before reaching the earth, the radiation from the Sun will interact with the atmosphere and behave differently according to the contacted surface features. Albedo is regulated by the composition of the space between the earth atmosphere. Then surface albedo is highly variable temporally. It changes naturally with solar insolation angle, seasonally with vegetation changes and stochastically with rain or snowfall (Wang and Davidson, 2007) [2].The most significant factors affecting the soil albedo are surface, soil moisture content, organic matter content, particle size, iron-oxides, mineral composition, soluble salts, and parent material the type and condition of the vegetation covering the soil. It can also be changed directly via human activity or indirectly (Baumgardner, 1985) [3]. Surface albedo dynamics are closely related to ecosystem dynamics. Surface albedo is especially important for the global climate modelling (Dickinson, 1983) [6], as well as for surface fluxes estimation (Kustas et al., 1994) [7] (Olioso et al., 1999) [8]. Albedo varies diurnally and seasonally from place to place as well as from time to time in the same location due to theamount of cloud cover and particulate matter in the air plus the nature of the surface (K.N. Liou, 1980) [10]. Today, albedo is a major concern for humans worldwide. Albedo is very useful in the studies dealing with thermal balance in the atmosphere. It is an important input parameter or quantity in evaluating the total insolation on a building or a solar energy collector. Some research works on the albedo of the Earth's atmosphere for different location have been carried out. Some of the several reports on surface albedo estimation are from satellite data (M. Nunez and al., 2006) [11], (F.Robert and al., 1973) [12], (R.W. Saunders, 1990) [13]. Most of the estimated short-wave broadband albedo from satellite data are often corrected for geometric, atmospheric, spectral, topographic, and anisotropic effects in order to obtain accurate results (B. Pinty and ,al., 1987) [14], (W. Zhao et al, 2000) [15]. In Africa, there is no recorded measure of albedo. With the lack of recorded, we have to estimated. (Babatunde et al, 2005) [16], worked on the simulated reflected short-wave radiation and its characteristic variation at Ilorin, Nigeria. Their results showed among other things that the highest reflectance of 0.64 was recorded at the peak period of cloud activity in August, and the lowest reflectance of 0.36 was obtained in November when it was relatively cloudless and dustless. In this study, an empirical model for estimating the surface albedo for some selected site in the Republic of Chad was developed.

2. Materials and methods

2.1. Data gathering

The successful design and effective utilization of solar energy systems and devices for human
application largely depend on the availability of information on solar radiation characteristic of the location in which system and devices are to be used or situated (Falayi et al., 2008) [17].
The longer the period of record is, the more representative the result will be. The monthly mean of daily global and diffuse radiation on horizontal surface for twenty years (1985-2005) for five locations (Abéché, Ati, Faya-largeau, Moundou and N'Djamena) of Chad's displayed in figure1.

An information system, called HelioClim, is available for answering the needs for long-term time-series of solar radiation data. Daily irradiation values are available over Europe, Africa and Atlantic Ocean, from 1985 onwards. This database is accessible through the Soda Web service (http: //www.soda-pro.com)[18] on a free basis. Meteosat satellites images are used to produce this climatological database. In Africa, long-term energy measurements for solar energy applications have not been recorded, unlike others part of the world such as Europe and Northern America. This lake of recorded radiation data makes it necessary to resort to available databases to acquire data. Several assessments of the HelioClim-1 data against measurements made in meteorological-networks reveal that the HelioClim-1 database offers a reliable and accurate knowledge of thesolar radiation and its daily, seasonal and annual variations over recent years. Several published works benefited from the openness, availability and accuracy of the HelioClim-1 database in various domains: oceanography, climate, energy production, life cycle analysis, agriculture, forestry, architecture, health and air quality (Lefevre et al, 2014) [19] However, given the poor sampling in time of these images, it may be recommended to limit their use to the assessment of daily irradiation or to the irradiation for larger periods (CROS et al, 2004) [20].

2.2. Solar radiation zoning

Chad is a landlocked country in northern Central Africa. The country is situated between 7thand 24th degrees of latitude the North on one hand, and 13th and 24th degrees of longitude is on the other hand. Chad is a country globally very hot and very dry. The country includes four bioclimatic zones. In the North, is the desert (Sahara), the annual precipitation are lower than 200 mm with reach a minimum lower than 10 mm. The maximal temperatures reach (affect) regularly 43°C - 44°C during the hottest period of the year on average and low height. The number of months in the year when the average maximum temperature exceed 40°C increase gradually from the South to the North. Although, the altitude may modifies this standard. This translate to two months in N'djamena (298 m of height) in the South, four months in Abéché (549 m of altitude) in the center and up to six months in Faya-largeau in the desert in North (https ://fr.wikipedia.org) [21] . In our study, we choose ve locations as shown in Fig 1

Fig. 1: Select Stations of Chad Republic.

2.3. Albedo modelling

The conservation of energy requires that for radiation incident, Short wave solar energy balancing at the edge of the atmosphere can be computed using the relation given by (Audu et al.,(2014) [23] as :

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

where H_g is the global solar radiation and H_g/H_0 called clearness index, is the ratio of the global to the extra-terrestrial radiation transmitted through the atmosphere to the ground surface, Ha is the absorbed solar radiation and Ha /H0 is the fraction absorbed radiation, called the absorption coefficient or absorptance. Hr is the reflected radiation towards the space and Hr/H0 is the ratio of the short wave reflected radiation towards the space. H0 is the extra-terrestrial radiation, incident on the surface of the Earth at the edge of the Earth's atmosphere. Ha has been found very small compared to others ratios, hence negligible (Babatunde, 2003)[24] . Equation 1 then becomes:

$$\frac{H_g}{H_o}+\frac{H_r}{H_o}\approx 1 \quad (2)$$

Therefore, the reflectivity or albedo can be estimated using:

$$\frac{H_r}{H_o}=1-\frac{H_g}{H_o} \quad (3)$$

Albedo is the fraction of incident solar radiation reflected by a surface. Albedo determines the radiation balance of the surface and affects the surface temperature and boundary layer structure of the atmosphere. Albedo controls the microclimate conditions of plant canopies and their radiation absorption, which, in turn, affects ecosystem physical, physiological, and biogeochemical processes such as energy balance, evapotranspiration, photosynthesis, and respiration. It has long been recognized that surface albedo information is important for weather forecasting, climate projection and ecosystem modelling (Wang and Davidson, 2007) [2] . This parameter was also found to be an important modulator for regional climate characteristics such as natural droughts [1]. Several studies have shown that surface albedo has a negative effect on moisture flux convergences and rainfall, and desertification results generally in droughts by a positive feedback between land and atmosphere caused by high surface albedo (Charney et al. 1977 ; Chervin, 1979 ; Sud and Fennessy, 1982 ; Xue and Shukla, 1993 ; Dirmeyer and Shukla, 1996 ; Knorr et al., 2001)[25] - [30] . Changes in soil moisture content change the absorbance and reflectance characteristics of the soil. Increase in soil moisture content increases the portion of the incident solar radiation absorbed by the soil system [4]. The sun angle is also an important input for determination of surface albedo (Fricke et al, 2014) [5]. However, atmospheric turbidity and transmissivity, planetary boundary layer turbulence, cloud thickness, and temporal and spatial variations cause embedding of non-linear elements in the solar radiation phenomena. Hence, the use of simple linear models cannot be justified physically except statistically without thinking about obtaining the model parameter estimations (Zekai Sen, 2008) [31]. After all, Linear models have a number of advantages in the context of global data processing. A first and foremost advantage is that an y linear model can be inverted analytically through matrix in version for the system of equations obtained by setting the derivative of the error function to zero (Strahler, Muller, 1996) [32].
In order to get the best model for the study locations that takes in account some climatology parameters that influence the surface albedo, we proposed a multivariate (temperature (T) and relative humidity (HR)) linear relationship to determine albedo of the form:

$$A = \frac{H_r}{H_0} = b_0 + b_1 * HR + b_2 * T \quad (4)$$

where bi are empirical constant. We used data from 1985 to 2004 to evaluate and those of 2005 to validate.

2.4. Statistical evaluation

Several error indices are commonly used in model evaluation. The accuracy and performance of the derived relations in predicting of local albedo was evaluated on the basis of the following statistical error tests which are coefficient of determination R^2, root mean square error (RMSE), mean absolute error (MAE) and mean absolute percentage error (MAPE). Coefficient of determination (R^2) describes the degree of collinearity between simulated and measured data. R^2 ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable (Santhi et al., 2001, Van Liew et al., 2003)[33] - [34]. Mean absolute error (MAE) and root mean square error (RMSE). These indices are valuable because they indicate error in the units (or squared units) of the constituent of interest, which aids in analysis of the results. RMSE and MAE values of 0 indicate a perfect fit. (Singh et al. 2004)[35] state that RMSE and MAE values less than half the standard deviation of the measured data may be considered low and that either is appropriate for model evaluation. Mean absolute percentage error (MAPE) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta et al., 1999) [36]. The optimal value of MAPE is 0.0. These error indices are defined as:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(A_{m,i}-A_{e,i})^2}{\sum_{i=1}^{N}(A_{m,i}-\bar{A}_m)^2}$$

$$RMSE = \left(\frac{1}{N}\sum_{i=1}^{N}(A_{e,i}-A_{m,i})^2\right)^{\frac{1}{2}}$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|A_{e,i}-A_{m,i}\right|$$

$$MAPE = \frac{100}{N}\left(\sum_{i=1}^{N}\left|\frac{A_{e,i}-A_{m,i}}{A_{m,i}}\right|\right)$$

In the above relations, the subscript i refers to the ith value of the albedo and n is the number of the albedo data. The subscripts "e" and "m" refer to the estimated and measured albedo values, respectively Ae is the mean estimated albedo and Am is the mean measured albedo.

3. Results and discussion

Estimation of surface reflectance values of the study sites are presented in Table 1. The lack of concurrent field measurements of reflectance does not permit meaningful comparison between grounded and estimated values at this stage. It can be seen from this table that estimated values of albedo for the selected sites are by less than 0.05 in error from mean observed values.

Table 1: Analysis of Estimation (Proposed and Existing) Models Using Twenty-Year (1985-2005) Monthly Mean Daily Data Obtained for the Study Locations

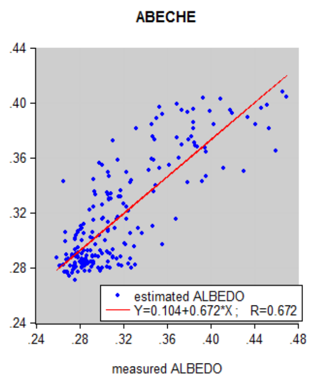
site	Estimated model	R	RMSE	MAE	MAPE
Abéché	-0.127+0.00183*HR+0.00123*T	0.671	0.027	0.0203	6.194
Ati	-0.338+0.0025*HR+0.002*T	0.709	0.033	0.0236	6.736
Faya-Largeau	-0.315+0.00326*HR+0.002*T	0.278	0.029	0.0232	7.242
Moundou	-2.37+0.0035*HR+0.0086*T	0.676	0.048	0.038	9.99
N'Djamena	-1.28+0.00265*HR+0.005*T	0.706	0.04	0.029	7.756

In these studies, we find albedo values in semi-arid regions vary between 0.27 to 0.60. Estimated albedo values appear reasonable and are in substantial agreement with published data for comparable surfaces and measurements in the similar region.

Although estimated albedo values, for a limited number of test sites, are well within the range of albedo values reported in other studies, questions need to be answered regarding the quality of the produced albedo map. (Sjoberg and Horn, 1983)[37] proposed three subjective criteria for evaluating the quality of albedo maps that can verify in those regions.

The dynamic range of the set of computed albedo values has also been respected. That is, every calculated value in the study area lies between 0.00 and 1.00. There is no the great difference between the low albedo value for these regions. The mean low value is around 0.28. But, there are significant differences between the high values of albedo. Their values depend on the geographic location. They are high in the southern zone which is Dry sandy soil zone (Moundou with 0.58) than the northern which are arid zone (Faya-largeau with 0.38). We have also N'Djamena site that is probably influence by the proximity of Lake Chad with a large spectre of values. The maxima value of albedo is around 0.55. We see that the albedo in the desert zone have a less variation. In the same observation, the empirical parameters are nearly the same in the site situated in the same geographical zone. One can use these regressions to determine albedo in the site that have the similar climate.

The accuracy of the albedo estimation depends on the quality of the climatological parameters collect. The uncertainty of the derived surface albedo is estimated as a combination of the uncertainty of the irradiance measurement and the impact of uncertainties in atmospheric parameters that are used in the extrapolation algorithm (Bierwirth et al., 2009)[38] . The mean absolute error (MAE) vary from 0.0203 to 0.038 Wm−2 and the mean absolute percentage error vary from 6.184 to 9.9 %. The scatter of the results from all regression t lie around the acceptance values, which is also reflected in the coefficients of determination (R^2) ranging from 0.671 to 0.706. Except the site of Faya-largeau where this coefficient is very bad. We can think that there are others phenomenon that influence the value of albedo.



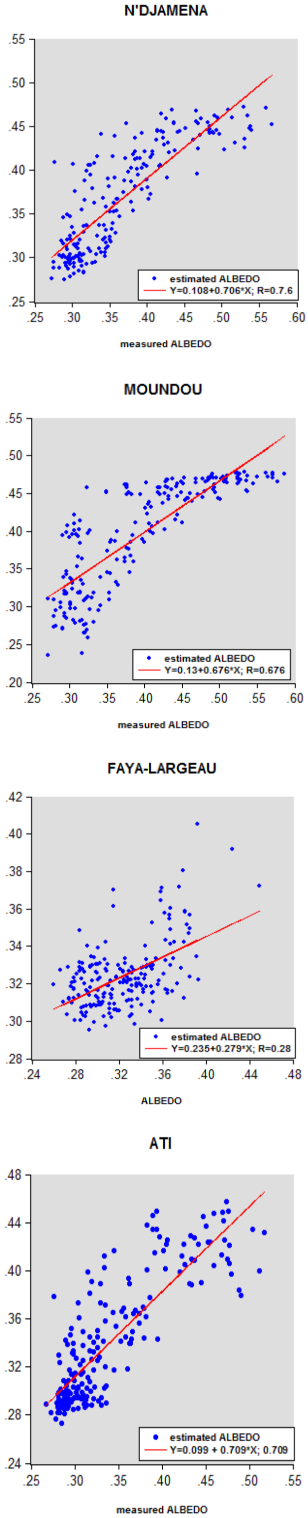
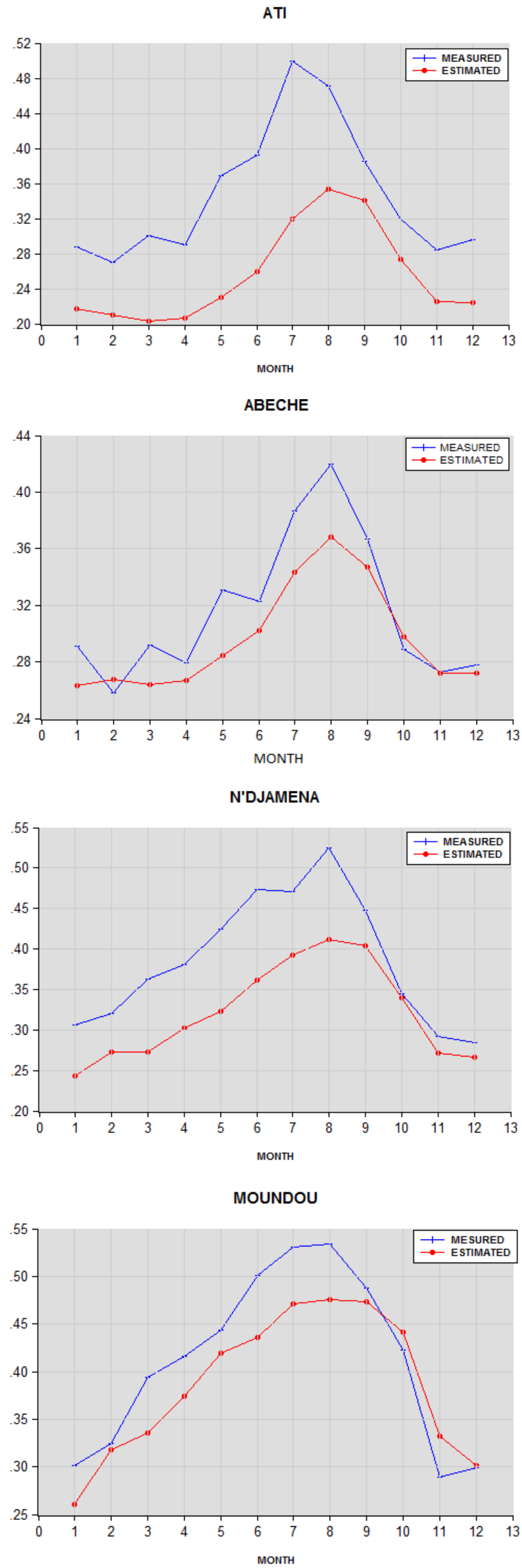


Fig. 2: Relationships between the Estimated and Measured Earth's Surface Albedo for Selected Stations.



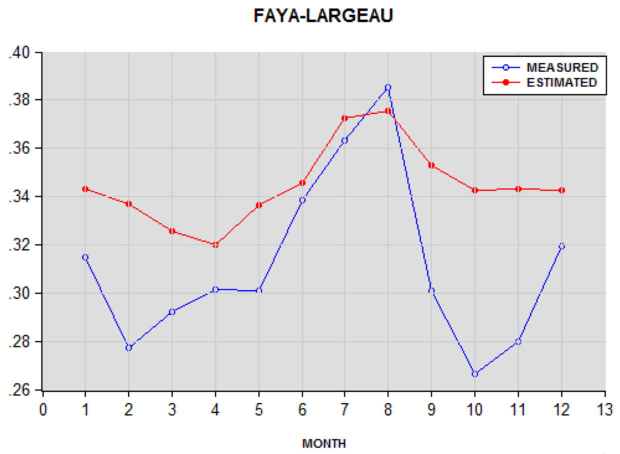


Fig. 3: Comparison between the Estimated and Measured Earth's Surface Albedo for Selected Stations.

4. Conclusion

In this study, we employed a multivariate (temperature and relative humidity) statistical fitting approach to develop the statistical relationship. From satellite data of irradiation, we deduce surface albedo for some selected region of republic of Chad. These regions do not have the recorded albedo. The statistical evaluation results show a better agreement measured and the estimated using the multivariate approach. Then, in the lack of ground recorded values of albedo, one can use the estimated regression to determine the ground albedo. Further studies using more climatological parameters (pressure, rainfall, wind speedy, etc..) and sun incident angle and cloud can improve the estimation of surface albedo because these parameters can influence the albedo [39](Dumont, 2010), [40] (Mueller, 2011) .

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