

*Full Length Research Paper*

# Characterization of the solar climate in Malawi using NASA's surface meteorology and solar energy (SSE) model

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This paper presents the characterization of global solar radiation (GSR) for Malawi using NASA's SSE model. The mean monthly daily GSR monthly variation in the three regions of Malawi has been investigated. It has been found that there is a general gradient in GSR in the north-south direction. This gradient correlates well with the variation of the clearness index in the same direction ( $r = 0.986$ ). It has been observed that the GSR is characteristic of each region. Simple analytic polynomials have been proposed for estimating solar radiation in the traditional Northern, Central and Southern regions of Malawi. There is a strong agreement between the polynomials and the SSE model with  $R^2$  values of 0.988, 0.989 and 0.989 and root mean square errors of 0.061, 0.057 and 0.062 kWh/m<sup>2</sup>.day for the regions, respectively.

**Key words:** Malawi, global solar radiation, solar climate, surface meteorology and solar energy (SSE) model.

## INTRODUCTION

Accurate global solar radiation (GSR) data for a particular location is an essential requirement for the design of efficient domestic and industrial solar based systems. Such data is used in project design, cost analysis and in system efficiency evaluation. In spite of the importance of GSR data, direct measurement is challenging due to high cost of maintenance and the need for calibration of the measuring instruments (Mubiru and Banda, 2008) as such models may be found to be handy to come up with GSR values for different locations. Many researchers have used models to estimate GSR. Sanusi and Abisoye (2013) and Oyeleke et al. (2014) used second order

quadratic models to estimate the diffuse solar radiation in Lagos and Ogbomoso respectively, and found that they were good enough to be used for the same. In their study, Safari and Gasore (2011) estimated GSR using Angstrom type polynomials of first and second order. Hassan and Ali (2013) used empirical regression models to predict daily and monthly average GSR for United Arab Emirates based on 9 year measured data. The surface meteorology and solar energy (SSE) section at NASA's Atmospheric Data Center provides GSR data that has been formulated specifically for the needs of photovoltaic and renewable energy system design (NASA, 2008). The

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**Figure 1.** Map of Malawi showing the longitudes used for data extraction.

SSE data used in this paper has a temporal extent of 22 years (July 1983 through June 2005). The validity of NASA's SSE model has been demonstrated elsewhere (Islam, 2009). Thus, the NASA's SSE model eliminates the need for actual GSR measurements for most applications.

Malawi is a tropical country that lies between the latitudes  $9^{\circ} 22' S$  and  $17^{\circ} 3' S$ . The country lies entirely in the earth's solar belt, a region of the earth that has an abundance of solar radiation flux ( $40^{\circ} N$  and  $40^{\circ} S$ ) (Islam, 2009). Som (1979) demonstrated the potential for utilization of solar energy in Malawi as early as 1979. Follow up studies by Diabate (2004) categorized Malawi as a solar climate II region without using any local data. This was confirmed by Madlopa (2006) using sunshine data from Chichiri meteorological station in Southern Malawi. Earlier Zingano (1986) found that there is a gradient in the GSR in the north-south direction using sunshine hours data. Tadros (2000) also used a similar approach to estimate GSR for Egypt. However, the accu-

racy of analytical results from sunshine hours data is inherently limited by the accuracy of the regression coefficients in the Angstrom equation (Amorox, 2004).

The aim of this study was to characterize the mean annual daily GSR flux in Malawi as a function of latitude and to analyse the variation of the mean monthly daily GSR over the year at different latitudes using SSE data. It was envisaged that use of SSE data could provide more accurate results as compared to those obtained using derived parameters such as the clearness index which can also be used to estimate GSR as is shown by Poudyal et al. (2012). The clearness index (which is the ratio of the global solar radiation measured at the surface to the total solar radiation at the top of the atmosphere) is a veritable tool in the characterization of sky conditions (or classification of sky types) over a particular locality (Okogbue et al., 2009). In this study, the clearness index which was empirically determined by Madlopa (2006) was compared.

#### DATA COLLECTION AND ANALYSIS

Malawi is divided into three administrative regions (north, central and south). Most of the land mass in Malawi lies along  $33^{\circ} 30' E$  longitude in the Northern and Central Regions and along  $35^{\circ} E$  longitude in the Southern region (Figure 1).

The GSR data extracted from the SSE model was obtained along longitude  $33^{\circ} 30' E$  for the Northern and Central Regions and  $35^{\circ} E$  for the Southern Region at latitude intervals of  $1^{\circ}$  from  $9^{\circ} 30' S$  through  $16^{\circ} 30' S$ . This was done by entering the particular geographical coordinates of interest into the model. The data is presented in Table 1 in which the mean monthly daily value of the GSR is given for each month for a particular latitude. The GSR values for each data point in Table 1 are for a  $1^{\circ} \times 1^{\circ}$  latitude-longitude cell (approximately 100 km by 90 km cells).

The data was then plotted to determine firstly the variation of mean annual daily flux with latitude, secondly the relationship between mean GSR and the clearness index  $K$ , and lastly the relation between GSR and altitude for Malawi to ascertain findings by Zingano (1986).

Monthly variation of the mean monthly daily flux at  $1^{\circ}$  latitude interval along the selected longitudes was analyzed to determine regional variations during the year. Simple analytical polynomials for estimating the GSR have been derived and presented for each of the three regions of Malawi.

#### RESULTS AND DISCUSSION

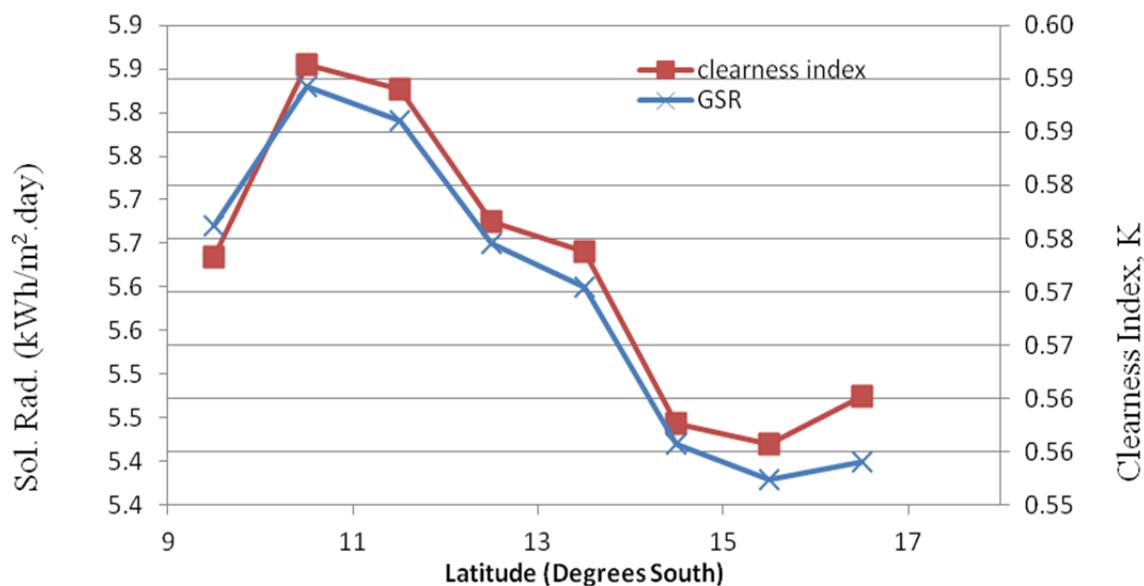
The following section presents results of variation of GSR with latitude, monthly variation of GSR and polynomials for estimating monthly GSR in northern, central and southern regions of Malawi in any month.

##### Global solar radiation and latitude

The insolation on the earth's surface is dependent on the clearness index,  $K$ , which is the fraction of the extra-terrestrial radiation transmitted through the earth's atmosphere to the surface. Figure 2 gives a plot of the mean

**Table 1.** Mean monthly daily global solar radiation (kWh/m<sup>2</sup>.day) for Malawi (the data was extracted from NASA's SSE model).

Latitude (degrees)	Month of the year											
	1	2	3	4	5	6	7	8	9	10	11	12
-9.5	4.93	5.11	5.31	5.21	5.33	5.45	5.68	6.23	6.77	6.8	6.01	5.21
-10.5	5.18	5.3	5.57	5.46	5.59	5.54	5.7	6.25	6.81	6.87	6.23	5.52
-11.5	5.22	5.41	5.59	5.52	5.48	5.3	5.43	6.02	6.71	6.87	6.33	5.58
-12.5	5.08	5.33	5.43	5.43	5.32	5.13	5.24	5.87	6.6	6.76	6.24	5.38
-13.5	5.17	5.35	5.53	5.48	5.25	4.96	5.07	5.67	6.48	6.67	6.24	5.38
-14.5	5.18	5.34	5.52	5.33	5.04	4.55	4.65	5.38	6.21	6.51	6.09	5.35
-15.5	5.32	5.46	5.43	5.19	4.84	4.34	4.48	5.26	6.21	6.49	6.12	5.43
-16.5	5.67	5.61	5.59	5.14	4.7	4.2	4.33	5.19	6.12	6.38	6.26	5.71

**Figure 2.** Latitude dependency of the global solar radiation and the clearness index.

annual daily GSR and K against latitude across Malawi in the north-south direction. The values of the clearness index used in the plot were empirically determined by Madhlopa (2006). There is a general gradient in the north-south direction with the maximum value (5.83 kWh/m<sup>2</sup>.day) at latitude 10° 30' S and the minimum value (5.38 kWh/m<sup>2</sup>.day) at 15° 30' S. The GSR closely matches the clearness index, as expected, since the top-of-atmosphere insolation is slowly varying as a function of latitude with the Pearson product-moment correlation coefficient  $r = 0.986$ .

Malawi has an altitude gradient in the north-south direction and it might be tempting to attribute the GSR gradient to the altitude. The GSR only drops from the peak by about 8% while the altitude drops by as much as 70% (Figure 3). This indicates that at a national scale, the dependency of GSR on altitude is weak.

### Monthly variation of the mean monthly daily GSR

An analysis of the dependence of GSR on the time of the year reveals two general patterns. The first is that there are two peaks in the insolation, a minor one in March a major one in October. The minimum amount of insolation occurs in June. In October, the atmospheric air is dry resulting in minimal attenuation. March is the end of the rainy season in Malawi resulting in reduced cloud cover. The dry air mass and reduced cloud cover account for the observed minor and major peaks, respectively. Malawi being a southern hemisphere country is farthest from the sun in June and has a high air mass and frequent cloudy days resulting in the observed minimum.

The difference between the yearly maximum and minimum of the mean monthly daily insolation values was seen to increase in the southern direction. For example,

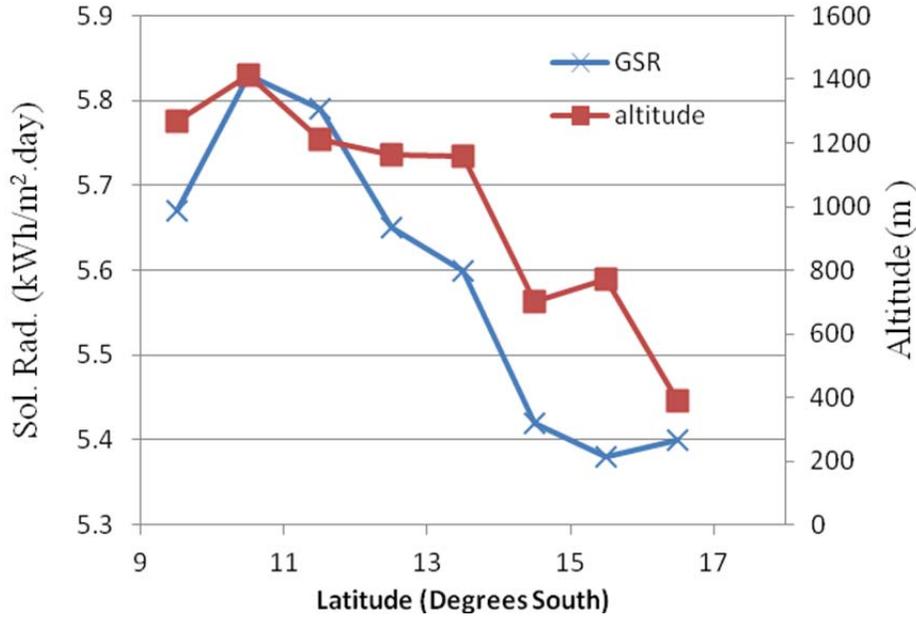


Figure 3. Global solar radiation and altitude.

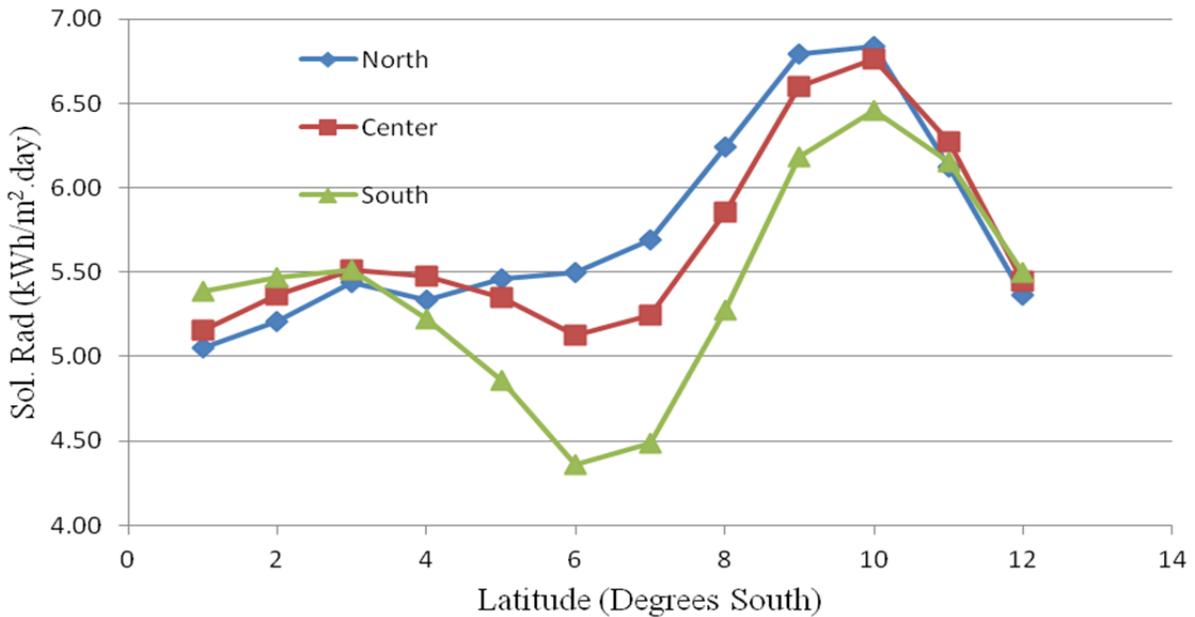


Figure 4. Region averages for mean monthly daily GSR.

the differences between the insolation for the months of October and June for latitudes 10° 30' S, 13° 30' S, and 16° 30' S are 1.33, 1.71 and 2.18 kWh/m<sup>2</sup>·day, respectively. This difference gives the variation in the amount of available GSR with the seasons in the Northern, Central and Southern regions. This means there is greater variation in the amount of solar radiation available in the Southern region as compared to the Central and

Northern Regions across the months. For some critical system designs applications like solar photovoltaics, this difference may become important and needs to be incorporated early enough at planning stage. Figure 4 gives the regional averages and their fits for the mean monthly daily GSR, highlighting the differences in the maximum and minimum flux during the year in the three regions.

**Table 2.** Polynomials for estimating GSR in the three regions of Malawi.

Region	Equation – GSR(n)	R <sup>2</sup>
North	$6.4115 - 2.8714n + 2.0732n^2 - 0.6362n^3 + 0.0939n^4 - 0.0065n^5 + 0.0002n^6$	0.9888
Central	$7.0154 - 3.8856n + 2.7698n^2 - 0.8394n^3 + 0.1209n^4 - 0.0081n^5 + 0.0002n^6$	0.989
South	$7.8074 - 4.9542n + 3.4757n^2 - 1.0706n^3 + 0.1559n^4 - 0.0106n^5 + 0.0003n^6$	0.989

### Polynomials for estimating global solar radiation in Malawi

Data from Table 2 and the plots in Figure 4 were used to generate empirical relationships between the time of the year in months ( $n$ ) and GSR. The resulting polynomial is of the form

$$GSR(n) = a_0 + a_1n + a_2n^2 + a_3n^3 + a_4n^4 + a_5n^5 + a_6n^6$$

Where,  $n$  an integer satisfying  $1 \leq n \leq 12$ .

The polynomials are given in Table 2. The R<sup>2</sup> value gives a measure of how close the polynomial agrees with SEE data and the agreement is good in all the three cases.

It was noticed that for the months October through April, including all the three polynomials give very close results indicating the insolation is similar throughout the country during this time. That is, it is only in the cold months of May through September that there are important regional variations in the amount of solar flux energy in Malawi.

### Conclusion

The SSE model was used to analyze solar insolation in Malawi. There is a north-south gradient in the GSR with an annual mean monthly daily peak of 5.83 kWh/m<sup>2</sup>.day at latitude 10° 30' S and an annual mean monthly daily minimum of 5.38 kWh/m<sup>2</sup>.day at latitude 15° 30' S. The radiation flux varies greatly over the course of the year with the mean monthly daily maximum of 6.87 kWh/m<sup>2</sup>.day and a mean monthly daily minimum of 4.20 kWh/m<sup>2</sup>.day. These spatial and temporal variations may need to be considered in critical applications. The dependence of the GSR data on altitude has also been shown to be weak.

An empirical polynomial model to estimate GSR in the three regions of Malawi has been presented. However, there is a need to assess the accuracy of the SSE model and the derived polynomials using real data to determine their accuracy.

### Conflict of interests

The authors did not declare any conflict of interest.

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