Correlation of Global Solar Irradiance with some Meteorological Parameters and Validation of some Existing Solar Radiation Models with Measured Data Over Selected Climatic Zones In Nigeria.

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Abstract

Fourteen models comprising of 12 existing and 2 parameterized models are evaluated for predicting the global solar irradiance on a horizontal surface at six different sites representative of six different climatic zones of Nigeria namely; Mangrove swamp forest (Calabar), Sahel Savannah (Nguru), Montane Vegetation (Yola), Sudan Savannah (Kano), Tropical rain forest (Ibadan) and Guinea Savannah (Minna). Results showed that the two models from this study performed well in predicting global solar irradiance over the six different zones with slight overestimation in some cases and slight underestimation in others. However, out of the two models, model 14 had a better predictive ability. For the 12 existing models, Glover and mcCulloch model was found to be most suitable for the Mangrove swamp forest, Sahel and Montane zones while Raja and Twidell , Rietveld and Annandale et al models are respectively the most suitable models in the Sudan, Tropical rainforest and Guinea zones.

Keywords: Global solar irradiance, sunshine duration, climatic zones, models, regression analysis.

"1.0 Introduction"

Solar radiation getting to the surface of the earth is naturally a fundamental renewable energy source. Data on global solar irradiance at a specific region is very germane in studies related to solar energy. In this sense, professionals such as architects, engineers, agriculturists and others that require the application of solar energy need to be acquainted about the daily, monthly and climatic pattern of global irradiance over any location. Architects, particularly need information on solar radiation over any location for the interior illumination of buildings. Despite the importance of solar radiation observations, this information is not readily available due to cost and the dearth of seasoned technologists or qualified personnel. This also holds for the six sites representative of the six different climatic zones under study which indicates the necessity to develop methods for estimating solar radiation.

In the past times, many models using some meteorological variables such as air temperature, sunshine hours, relative humidity e.t.c have been proposed for various locations, but models based on sunshine hours are the most commonly used. Besides the most popular Angstrom-Prescott model (1924) for estimating solar radiation from sunshine hours, some other scientists have developed many empirical equations that determine the relationship between radiation and several other meteorological, geographical and astronomical parameters.

The models have been developed in ways that combine one, two, three or more parameters. Models such as the ones developed by Glover and mcCulloch (1958), Dogniaux and Lemoine (1983) and Raja and Twidell (1990) combined the relative sunshine with the station's latitude, Swartman and Ogunlade (1967) developed a model that combined relative sunshine with the mean relative humidity, Gopinathan (1988) developed a model that combined the relative sunshine with the station's latitude in degrees and altitude in km, Abdalla (1994) made a combination of relative sunshine, mean air temperature and relative humidity in his model, Ododo et al. (1995) merged the maximum air temperature and mean relative humidity with relative sunshine in a model developed by him and co-scientists, Ojosu and Komolafe (1987) used a model that combined the sunshine ratio with temperature ratio and the ratio between the mean relative humidity and maximum relative humidity and Rehman and Halwani (1997) combined the sunshine ratio with the station's latitude and longitude in degrees and altitude in km. Bristow-Campbell (1984), Hargreaves et al. (1985), Allen (1997) and Chen et al. (2004) used only air temperature range in their models. Hargreaves and Samani (1982), developed a model that combined air temperature range with a factor of 0.16 for interior regions or 0.17 for coastal regions depending on the station. Annandale et al. (2002) did same but also incorporated the station's altitude in his model. Rietveld (1978) used a universally accepted regression constants in the Angstrom-Prescott type regression model. Skeiker (2006) produced a model with seven parameters while Ertekin and Yaldiz (1999) used nine parameters.

In Nigeria, a number of other studies have been conducted on the measurement and estimation of solar radiation from other meteorological variables and these include: Ezekwe and Ezeilo (1981), Awachie and Okeke (1982), Ideriah (1981, 1983, 1985), Bamiro (1983) and Okogbue and Adedokun (2002b). Ezekwe and Ezeilo (1981), presented empirical correlations for Nsukka a town located in the southeastern part of Nigeria (Lat 6^0 $40^|$ N, Long 7^0 $20^|$ E). On the other hand, Bamiro (1983), presented some empirical correlations for predicting global insolation for Ibadan (Nigeria).

Okogbue and Adedokun (2002b) in their attempt to improve on the estimation of global solar irradiance for Ondo, a city in south western Nigeria (latitude 7.08^0N, Longitude 4.92^0E), used daily global radiation, sunshine hours, minimum and maximum temperature and relative humidity data for the periods (1986-1990) have been used to produce seven additional correlation equations with the Angstrom type equation for estimating global solar irradiance in the location. The correlation equations performed better when long-term monthly average values of the meteorological parameters were used.

This paper has three main objectives, the first is to find a model based on the readily measured meteorological variables to calculate the monthly average global solar irradiance over six stations representative of the six climatic zones in Nigeria, the second is to validate existing models listed in table 2 with measured data over the climatic zones and the last is to find from the existing models, the most suitable using some statistical tests for the estimation of monthly averaged global solar irradiance over each of the six climatic zones.

2.0 The climatic zones and observational data.

Six climatic zones were selected from this study and a station representative of each namely: (Calabar: Mangrove swamp forest), (Nguru: Sahel), (Yola: Montane), (Kano: Sudan), (Ibadan: Tropical rain forest) and (Minna: Guinea).

Table.1 displays the characteristics particular to the six selected climatic zones with regards to their latitudes (ϕ), longitudes (Ψ) and altitudes (Z).

The data on mean monthly global solar irradiance on a horizontal surface, sunshine duration, minimum and maximum temperature and relative humidity for the following stations: Calabar, Nguru, Yola, Kano, Ibadan and Minna representative of the selected climatic zones for a thirty-year period, 1980-2009 were obtained from the Nigerian meteorological Agency Oshodi, Lagos. The radiation data obtained were measured using the Gunn-Bellani integrator. The Gunn-Bellani readings which were in ml had been calibrated with pyranometer readings after Folayan (1988) which gave 1ml=1.357±0.176MJm^{-2} for stations south of Ibadan and 1ml=1.286±0.176MJm^{-2} for stations north of Ibadan.

Figure.2 shows the monthly mean variations of the mean air temperature and relative humidity, the global solar irradiance and sunshine hours and the maximum and minimum air temperature for each of the climatic zones.

"2.1 Estimation Techniques".

The mean monthly values of parameters such as H, H_o, H/H_o, S/S_o, R_m, χ_{TR} , ΔT, T_m, lnΔT, sinδ, R_m/R_{max}, $T_{max}.S/S_o$ and $\Delta T^{0.5}$ which are respectively the global irradiance, extra terrestrial radiation, clearness index, relative sunshine, mean relative humidity, air temperature ratio (T_{min}/T_{max}), air temperature range (T_{max}-T_{min}), mean air temperature, natural logarithm of the air temperature range, sine of the solar declination angle, ratio of the mean relative humidity to the maximum relative humidity, product of the maximum air temperature and relative sunshine and square root of air temperature range were computed for the thirty-year period. Astronomical variables such as the daily extraterrestrial irradiance (H_o) in MJm^{-2}day^{-1} and the maximum sunshine (S_o) in hours were computed using familiar relationships in literature Iqbal (1983).

The mean monthly values of the above parameters have been used in validating the model equations and the estimation of global solar irradiance has been made for each of the climatic zones under study. For each of the two models used in this study, regression analysis has been carried out between the mean monthly global solar irradiance and the rest parameters to obtain the regression constants.

2.2 Statistical Tests of Performance.

To access the performance of the model equations, five statistical methods have been employed. These are the correlation coefficient (R), mean bias error (MBE) in MJ/m^2, root mean square error (RMSE) in MJ/m^2, Nash-Sutcliffe equation (NSE) and the chi-square (χ^2). These are defined as:

$$R = \frac{\sum_{i=1}^{N}\left(H_{cal}-\overline{H_{cal}}\right)\left(H_{meas}-\overline{H_{meas}}\right)}{\left\{\left[\sum_{i=1}^{N}\left(H_{cal}-\overline{H_{cal}}\right)^2\right]\left[\sum_{i=1}^{N}\left(H_{meas}-\overline{H_{meas}}\right)^2\right]\right\}^{1/2}} \quad \text{--------} \quad (2.2.1)$$

$$MBE = [\frac{1}{n}\sum_{i=1}^{n}(H_{cal} - H_{meas})] \quad \text{-------} \quad (2.2.2)$$

$$RMSE = [\frac{1}{n}\sum_{i=1}^{n}(H_{cal} - H_{meas})^2]^{1/2} \quad \text{---------} \quad (2.2.3)$$

$$NSE = 1 - \frac{\sum_{i=1}^{N}(H_{meas}-H_{cal})^2}{\sum_{i=1}^{N}(H_{meas}-H_{ma})^2} \quad \text{----------} \quad (2.2.4)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(H_{meas}-H_{cal}\right)^2}{H_{cal}} \quad \text{----------} \quad (2.2.5)$$

where:
H_{cal} represents the calculated value.
H_{meas}= the measured value.
$\overline{H_{cal}}$ = the calculated mean value.
$\overline{H}_{meas}$ = the measured mean value.
H_{ma} = the average of the measured values
N is the total number of observations.

The RMSE allows a term-by-term comparison of the actual deviation between the calculated and the measured values and therefore provides information on the short-term performance of studied models. The RMSE is always positive: however a zero value is ideal. On the other hand, the test on MBE provides information on the long-term performance of models. A positive MBE value gives the average amount of overestimation in the calculated values and vice versa. In general, a low MBE is desirable Iqbal (1983), Halouani et al, (1993). The correlation coefficient (R), is a test of the linear relationship between the calculated and measured values. The chi-square (χ^2) supplies a measure of the discrepancy between the observed and estimated. If χ^2 =0, the observed and the estimated values agree exactly. If χ^2 >0, they do not agree exactly. The larger the value of χ^2 ,the greater is the discrepancy between the observed and estimated. For better estimation, MBE, RMSE and χ^2 should be closer to zero, R and NSE should be closer to unity.

The above statistical analyses were performed for the models used in this study and the existing models in relation to the measured and estimated mean monthly values of the global solar irradiance.

3.0 Results and Discussion.

3.1 Parameterization using multiple regression.

Table 3 displays the results of the statistical tests carried out in the regression of measured global solar irradiance with some more readily measured meteorological variables for the estimation of global solar irradiance over the stations representative of the six different climatic zones of Nigeria.

From table 3, it is clear that model 14 performed better than model 13 in the estimation of global solar irradiance in all zones. This is seen in R values that showed a better correlation with the measured global solar irradiance and the closer values of NSE to unity in all cases. The table further shows that the model has lower RMSE and χ^2 values in all the zones. However, the two models, each slightly over estimated the global solar irradiance sometimes and slightly under estimated the global solar irradiance at other times , this is evident in figures 4, 5 and 6 for each of the climatic zones. In all cases, model 14 had a better performance and the models in general, slightly over estimated the global irradiance in some case and underestimated and underestimated some others.

3.2 Validation of existing models.

In this section, the predictive ability of some existing models from literature over the climatic zones is tested. The twelve models used are given in table 2.

Only one of the models (Rietveld model) has a form similar to the Angstrom-Prescott model. The rest models contain different variables.

The required variables were substituted into each model to estimate the global solar irradiance. The performance of each model in predicting global solar irradiance was assessed using some statistical tests as given in table 4. Clearly from the table, Glover and mcCulloch (model 2) gave the best performance in the Mangrove swamp forest with MBE(-0.03527), RMSE(0.639628), NSE(0.862028) and χ^2 (0.311112405), Sahel with MBE(0.520998), RMSE(1.709278), NSE(-0.06307) and χ^2 (1.579609) and Montane with MBE(0.481519), RMSE(1.937498), NSE(0.255371) and χ^2 (2.102207). Over the Sudan, Tropical rain forest and Guinea zones respectively, Raja and Twidell (model 5) with MBE(0.318932), RMSE(1.390925), NSE(0.194641) and χ^2 (1.030584), Rietveld (model 11) with MBE(1.238297), RMSE(1.422705), NSE(0.650121) and χ^2 (1.457569) and Annandale et al (model 10) with MBE(0.853369), RMSE(1.416949), NSE(0.652255) and χ^2 (1.269173) performed best. Most of the models overestimated global solar irradiance in each zone.

The time series of the monthly variation of global solar irradiance using the observed and estimated values from the model equations for all the climatic zones are as shown in figure 3 . A good inspection of these figures show that in all the climatic zones, global irradiance exhibit a bi-modal distribution with values received in the months of July, August and September generally being lower in comparison with other months with peak values in the months of February and November. This is due to the large cover of thick clouds like cumulonimbus, nimbostratus and other rain forming clouds in the wet months of July, August and September which deplete a large fraction of solar radiation from the sun. The situation during the dry months of November and February is a complete reversal of this. This is because during these months, there is the predominance of cirriform clouds with very little or no cumuliform or stratiform clouds in the sky thereby allowing much insolation from the sun to get to the earth's surface. Also considering the months of December, January and March, the sky is relatively clear or a bit cloudy and the insolation received is less than that of the months of November and February.

4.0 Conclusions.

Two models for calculating global solar irradiance over a horizontal surface have been established for six stations representative of the six climatic zones in Nigeria. In addition, the predictive ability of twelve existing models have been tested over the zones using measured data. Generally, the two models established in this study were found to sometimes slightly overestimate the global solar irradiance and sometimes, slightly underestimate it. Model 14 performed better in all zones as seen in the lower values of RMSE and χ^2 and higher values of R and NSE when compared with model 13. Glover and mcCulloch model is most suitable in the mangrove swamp forest, Sahel and Montane zones while in the Sudan, Tropical rain forest and Guinea zones, Ojosu and Komolafe, Rietveld and Annandale et al models are respectively the most appropriate models in each of these zones.

The depressions around July, August and September observed in the time series of global irradiance in all the zones is simply due to the availability of thick clouds in these months which deplete large quantity of incoming global solar radiation whereas, the peaks around November and February is a clear indication of the predominance of thin clouds and clear skies hence, there is high insolation in these months.

Appendix

Symbols, definitions and notations used

H – Global irradiance (MJ/m^2)

H_O – Extraterrestrial irradiance (MJ/m^2)

ml – Milliliter

S – Actual sunshine duration (h)

S_o– Theoretical sunshine duration (h)

R_m – Mean Relative humidity (%)

R_{max} – Maximum relative humidity (%)

R_{min} – Minimum relative humidity (%)

χ_{TR} – Temperature ratio (^{0})

T_{max} – Maximum temperature (^{0})

T_{min} – Minimum temperature (^{0})

ΔT – Temperature range (^{0})

T_m – Mean temperature (^{0})

Φ – Station latitude (^{0})

Z– Station altitude (m)

δ – Solar declination angle (^{0})

RMSE – Root mean square error (MJ/m^2)

MBE – Mean bias error (MJ/m^2)

R – Correlation coefficient

NSE – Nash-Sutcliffe equation

χ^2– Chi-square

a,b,c, d and e – Regression constants

1:1 – One by one line

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Table 1:
Details of the six selected climatic zones in Nigeria.

Station	Zone	Lat.(^{o}N)	Long.(^{o}E)	Altitude. (m)
Nguru	Sahel	$12^{o}\,53'$	$10^{o}\,28'$	343.1
Kano	Sudan	$12^{o}\,03'$	$8^{o}\,12'$	472.5
Yola	Montane	$9^{o}\,14'$	$12^{o}\,29'$	186.1
Minna	Guinea	$9^{o}\,37'$	$6^{o}\,32'$	256.4
Ibadan	Tropical Rain Forest	$7^{o}\,26'$	$3^{o}\,54'$	227.2
Calabar	Mangrove Swamp Forest	$4^{o}\,58'$	$8^{o}\,21'$	61.9

Table 2:
Models proposed in literature.

Model	The form	Author
1	$H=H_o[0.16(\Delta T)^{0.5}]$	Hargreaves and Samani (1982)
2	$H/H_o = 0.29\cos\Phi + 0.52(S/S_o)$	Glover and mcCulloch (1958)
3	$H/H_o = 0.153(\Delta T)^{0.5}-0.033$	Hargreaves and Hargreaves (1985)
4	$H/H_o = 0.484 + 0.274(S/S_o) - 0.0245(\chi TR)0.152(R_m/R_{max})$	Ojosu and Komolafe (1987)
5	$H/H_o = 0.388\cos\Phi + 0.407(S/S_o)$	Raja and Twidell (1990)
6	$H/H_o = 0.095 + 0.372\cos\Phi + 0.042Z$	Gopinathan (1988)
7	$H/H_o = 0.3702 + [0.00506(S/S_o) - 0.00313]\Phi + 0.32029(S/S_o)$	Dogniaux and M.Lemoine (1983)
8	$H/H_o = 0.264\ln(\Delta T) - 0.155$	Chen et al. (2004)
9	$H/H_o = 0.144(\Delta T)$	Allen (1997)
10	$H=H_o[0.16(1+2.7\times10^{-5}Z)(\Delta T)^{0.5}]$	Annandale et al. (2002)
11	$H/H_o = 0.18 + 0.62(S/S_o)$	Rietveld (1978)
12	$H/H_o = 0.335 + 0.368(S/S_o) - 0.00036T_{max} + 0.0005R_m - 0.0015T_{max}(S/S_o)$	Ododo et al. (1995)
13	$H = a + b(S/S_o) + c\sin\delta + dT_m$	This study model 13
14	$H = a + b\sin\delta + c(S/S_o) + dR_m + eT_m$	This study model 14

Table 3: Regression constants, R, MBE, RMSE, NSE and χ^2 for the models used in this study for the (a) Mangrove swamp forest (b) Sahel savannah (c) Montane vegetation (d) Sudan savannah (e) Tropical rain forest and (f) Guinea savannah.

(a)

MODEL	**a**	**b**	**c**	**d**	**e**	**R**	**MBE**	**RMSE**	**NSE**	χ^2
13	-21.99	3.28	0.47	1.38		0.9419	-9.5E-06	0.5786	0.8871	0.265717833
14	-58.51	-1.02	8.08	0.21	2.06	0.9745	3.69E-05	0.386131	0.949719	0.124923781

(b)

MODEL	a	b	c	d	e	R	MBE	RMSE	NSE	χ^2
13	7.15	-10.23	-8.63	0.82		0.8914	9.56E-06	0.751302	0.794617	0.297615
14	12.23	-4.64	-8.30	-0.05	0.65	0.9682	1.04E-05	0.415077	0.937311	0.090674

(c)

MODEL	a	b	c	d	e	R	MBE	RMSE	NSE	χ^2
13	-7.01	6.51	-5.40	0.88		0.9810	-9.7E-06	0.435116	0.962445	0.101842
14	-6.56	-5.30	6.45	-0.002	0.87	0.9811	0.000137	0.434516	0.962549	0.10165

(d)

MODEL	a	b	c	d	e	R	MBE	RMSE	NSE	χ^2
13	4.32	2.53	-3.59	0.64		0.8965	-7.1E-06	0.686598	0.80376	0.246315
14	12.73	0.29	0.30	-0.05	0.45	0.9563	0.000122	0.452981	0.914583	0.106679

(e)

MODEL	a	b	c	d	e	R	MBE	RMSE	NSE	χ^2
13	-15.96	12.01	1.58	1.04		0.9704	0.001017	0.581	0.94165	0.244605
14	-34.72	-0.14	9.82	0.09	1.53	0.9790	-1.4E-05	0.490166	0.958469	0.169755

(f)

MODEL	a	b	c	d	e	R	MBE	RMSE	NSE	χ^2
13	-11.47	14.03	0.96	0.84		0.9568	4.86E-05	0.698999	0.915373	0.306821
14	-23.81	-2.39	14.21	0.06	1.15	0.9769	-5.1E-06	0.512519	0.954504	0.16376

Table 4: MBE, RMSE, NSE and χ^2 for the existing models for the (a) Mangrove swamp forest (b) Sahel savannah (c) Montane vegetation (d) Sudan savannah (e) Tropical rain forest and (f) Guinea savannah.

(a)

MODEL	MBE	RMSE	NSE	χ^2
1	0.253779	0.70295	0.833358	0.386027002
2	-0.03527	0.639628	0.862028	0.311192405
3	2.128761	2.233145	-0.68178	4.257502131
4	-4.24423	4.37004	-5.44031	11.49564863
5	-2.30308	2.419281	-0.97382	3.964592861
6	2.940837	3.054346	-2.1461	8.388533135
7	-0.48991	1.000591	0.662364	0.780883203
8	2.560781	2.626215	-1.32593	6.294553199
9	1.831809	1.964735	-0.3018	3.209703259
10	0.253752	0.70294	0.833363	0.386016178
11	2.781517	2.882169	-1.8014	7.756335068
12	-0.51313	1.167399	0.540406	1.045283919

(b)

MODEL	MBE	RMSE	NSE	χ^2
1	2.087808	2.217313	-0.78891	2.909315
2	0.520998	1.709278	-0.06307	1.579609
3	4.165944	4.224056	-5.49223	11.54495
4	-0.4972	1.935946	-0.36371	1.854182
5	-0.08676	1.7353	-0.09568	1.548489
6	3.323335	3.472099	-3.38651	7.232031
7	2.134714	2.701118	-1.65474	4.288146
8	4.225619	4.276875	-5.65561	11.84268
9	4.188469	4.241353	-5.54551	11.60094
10	2.087613	2.217133	-0.78862	2.908824
11	1.696407	2.2973	-0.92031	3.031898
12	3.533255	4.058051	-4.99197	10.44208

(c)

MODEL	MBE	RMSE	NSE	χ^2
1	2.714166	2.775336	-2.20637	4.618035
2	1.123881	1.662333	-0.15032	1.540523
3	4.762143	4.801181	-8.59574	15.31984
4	-0.26827	1.532309	0.022593	1.189814
5	0.318932	1.390925	0.194641	1.030584
6	3.631814	3.708462	-4.72493	8.43134
7	2.558528	2.864784	-2.41638	4.911743
8	4.82399	4.874695	-8.89185	15.89691
9	4.737688	4.771817	-8.47873	15.06696
10	2.713908	2.775084	-2.20579	4.617145
11	2.497969	2.737928	-2.12052	4.42707
12	3.632335	4.008199	-5.68776	10.26924

(d)

MODEL	MBE	RMSE	NSE	χ^2
1	0.245175	1.448194	0.637471	1.566322
2	-1.05828	1.426991	0.64801	1.468592
3	2.167629	2.59888	-0.16751	5.29576
4	-4.18607	4.562545	-2.59834	11.89332
5	-2.783	3.088841	-0.64922	5.992576
6	2.008748	2.356015	0.040501	4.173971
7	-0.67417	1.602987	0.555831	1.856184
8	2.355721	2.661492	-0.22444	5.607148
9	1.945367	2.452905	-0.04004	4.66108
10	0.245071	1.448173	0.637482	1.566276

11	1.238297	1.422705	0.650121	1.457569
12	-0.49573	1.852264	0.406946	2.431532

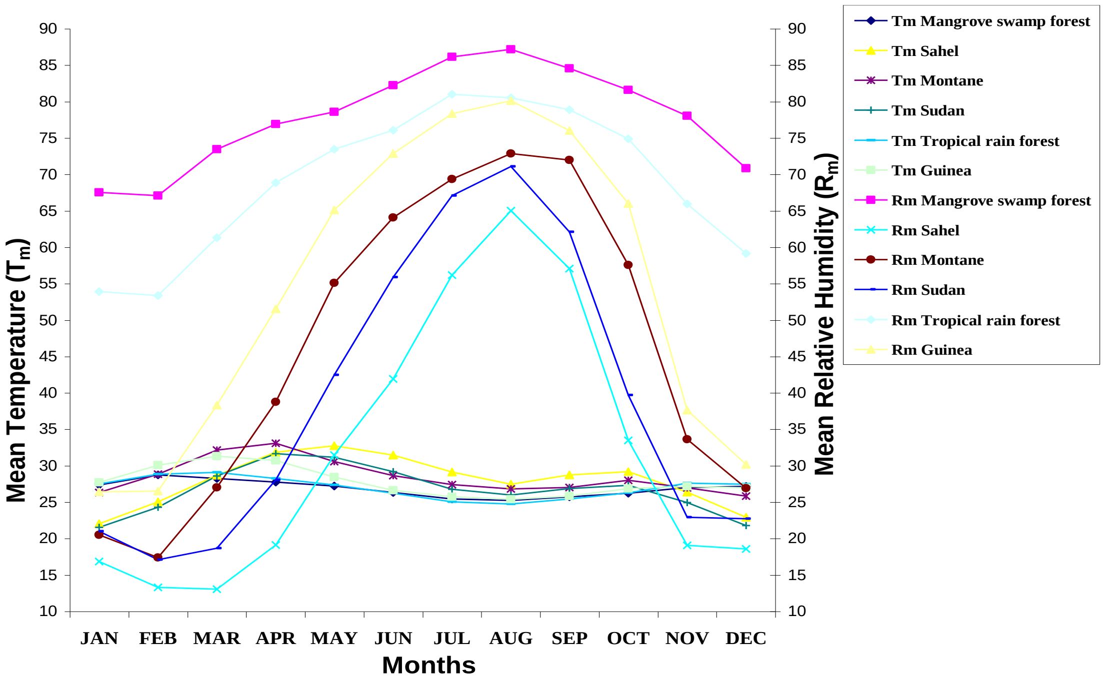
(e)

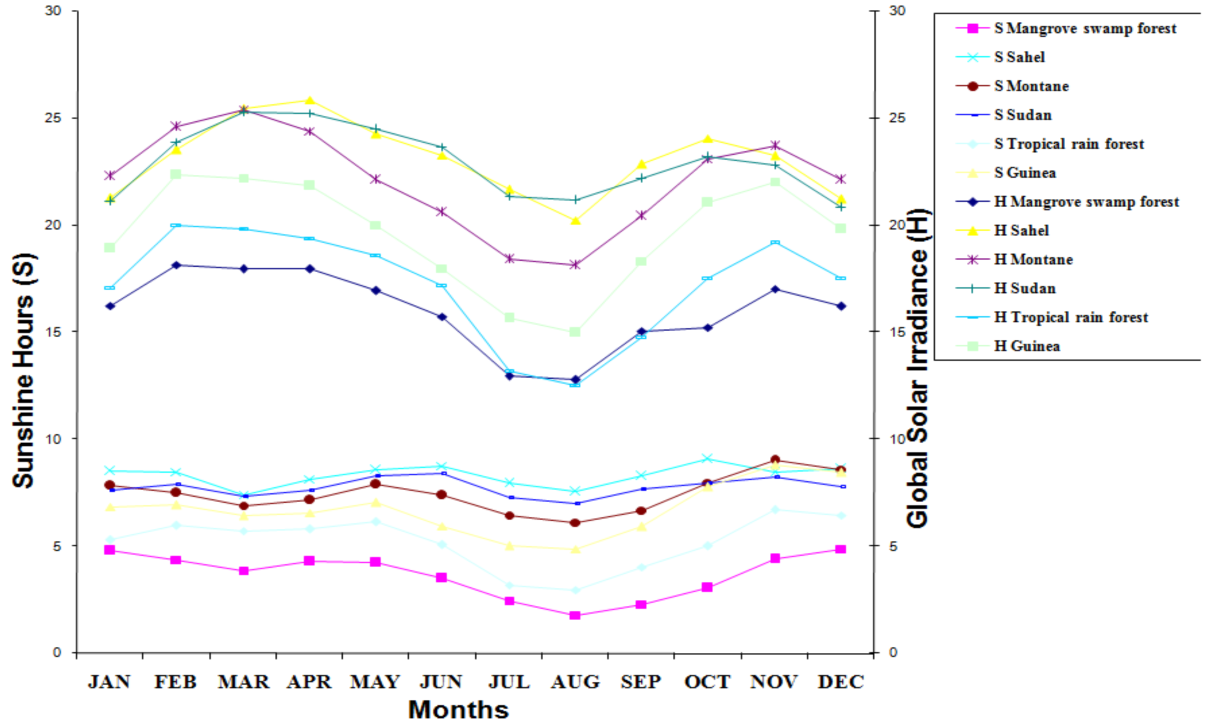
MODEL	MBE	RMSE	NSE	χ^2
1	2.183601	2.38648	-0.12973	3.491645
2	0.481519	1.937498	0.255371	2.102207
3	4.22925	4.342952	-2.74134	12.80933
4	-1.04028	2.533499	-0.27321	3.311103
5	-0.46578	2.11684	0.11114	2.404743
6	3.831573	4.076374	-2.29614	10.65661
7	1.897686	2.806249	-0.5621	4.682364
8	4.313293	4.406916	-2.85236	13.24087
9	4.177697	4.291118	-2.65257	12.36134
10	2.183501	2.386389	-0.12964	3.491364
11	2.05371	2.699468	-0.44549	4.339174
12	2.865935	3.844378	-1.93163	9.442991

(f)

MODEL	MBE	RMSE	NSE	χ^2
1	0.853499	1.417032	0.652214	1.269324
2	-0.83865	1.702925	0.497722	1.796427
3	2.846244	3.077325	-0.64021	6.630967
4	-2.91787	3.646193	-1.30267	7.130778
5	-2.03153	2.697314	-0.26013	4.169821
6	2.324803	2.665787	-0.23085	4.751735
7	0.228983	1.826727	0.422037	2.106613
8	2.903425	3.087233	-0.65079	6.718614
9	2.729656	2.990003	-0.54845	6.1879
10	0.853369	1.416949	0.652255	1.269173
11	0.94175	1.628416	0.540713	1.684122
12	0.877176	2.518539	-0.09863	4.135925

Figure 1: Map of Nigeria showing the six different climatic zones.
Adapted from Adejuwon, (2004).





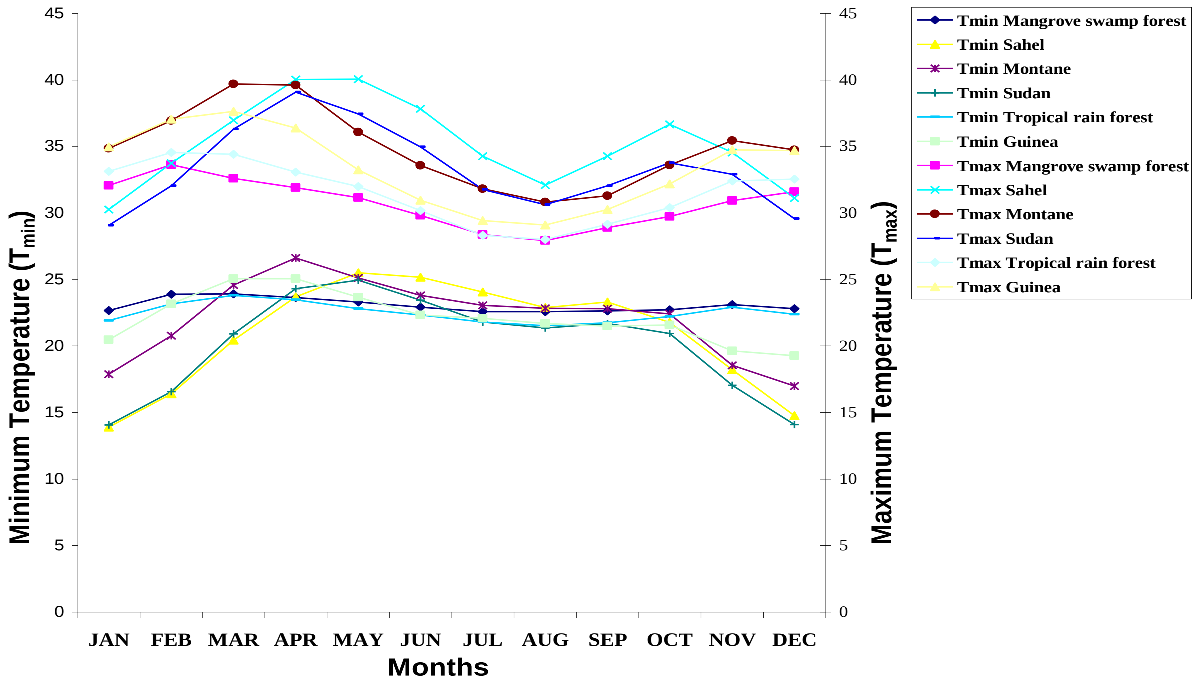
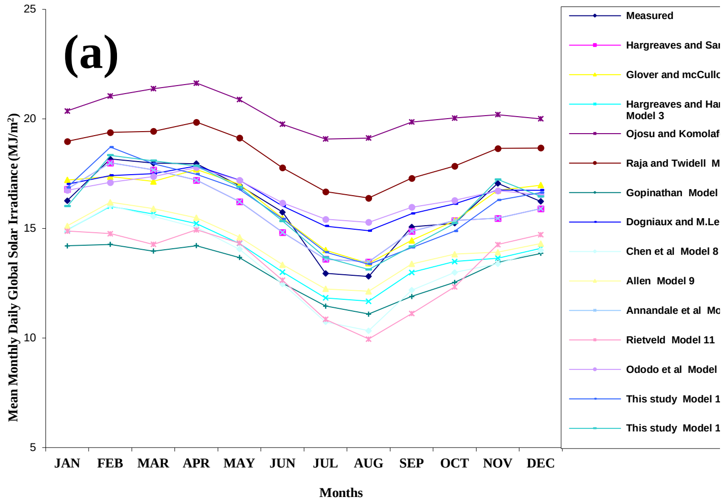
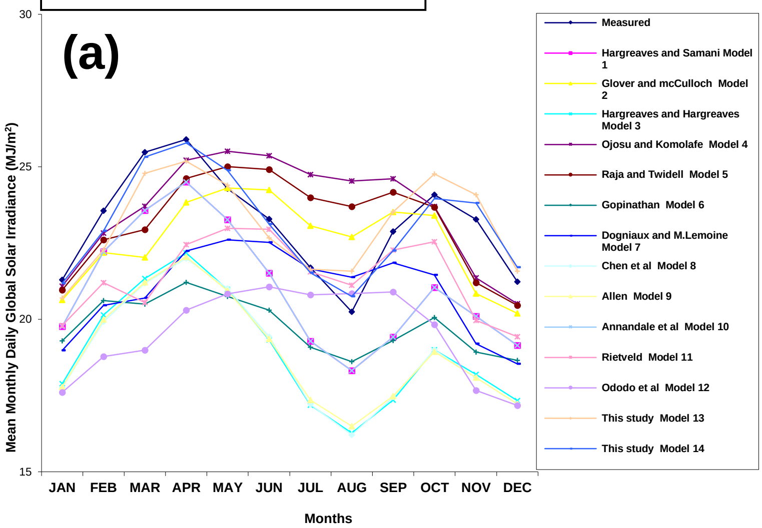


Figure 2: Monthly mean variations of the parameters (a) Mean Temperature (T_m) in ^{o}c and mean relative humidity (R_m) in % (b) Sunshine hours (S) in hours and global solar irradiance (H) in MJ/m^2/day on a horizontal surface and (c) Minimum (T_{min}) and Maximum (T_{max}) Temperature in ^{o}c over the six climatic zones of Nigeria for the period 1980-2009.

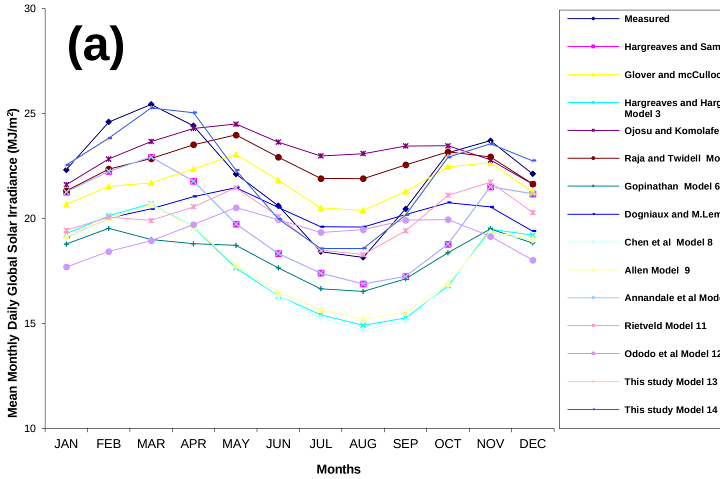
Mangrove swamp forest



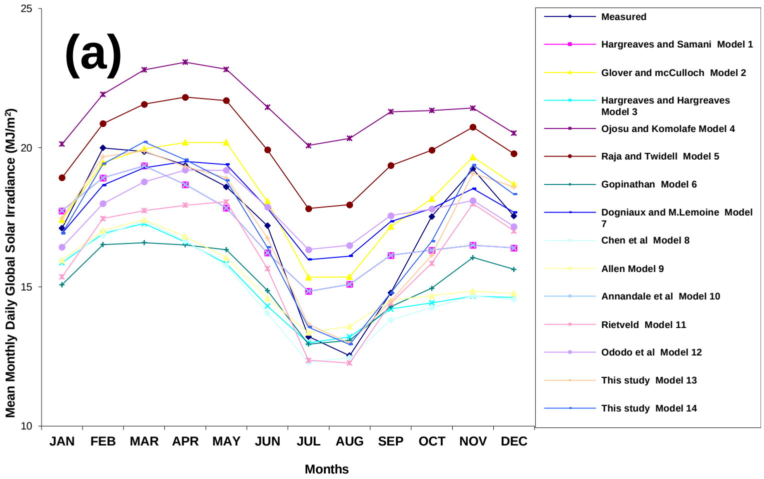
Sahel savannah



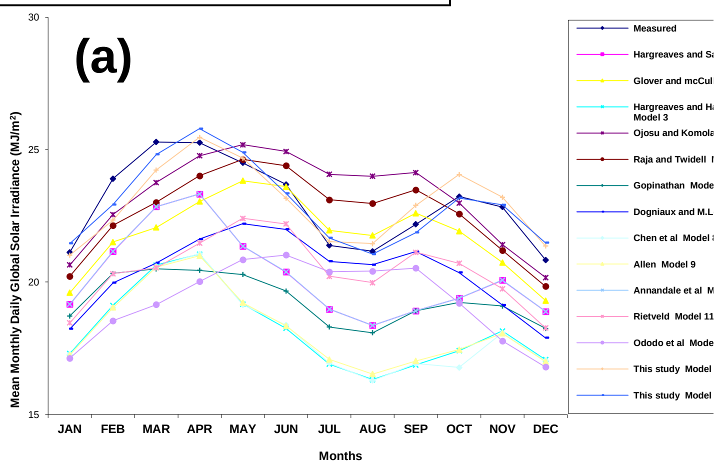
Montane Vegetation



Sudan Savannah



Tropical rain forest



Guinea savannah

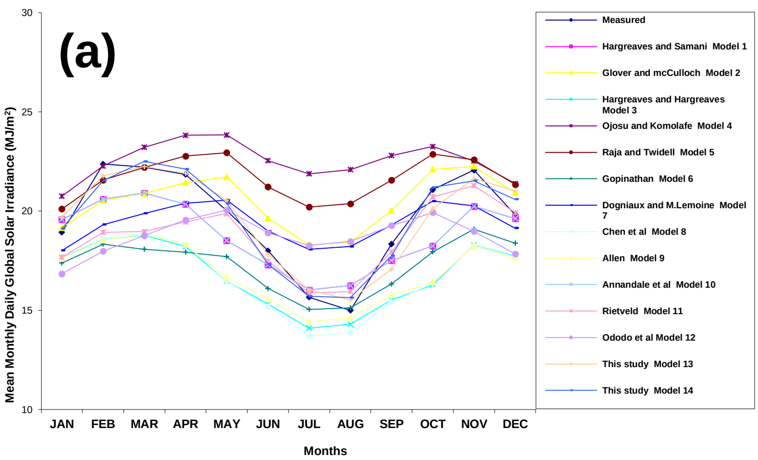


Figure 3: Plots of the measured and estimated monthly mean global solar irradiance for the six climatic zones.

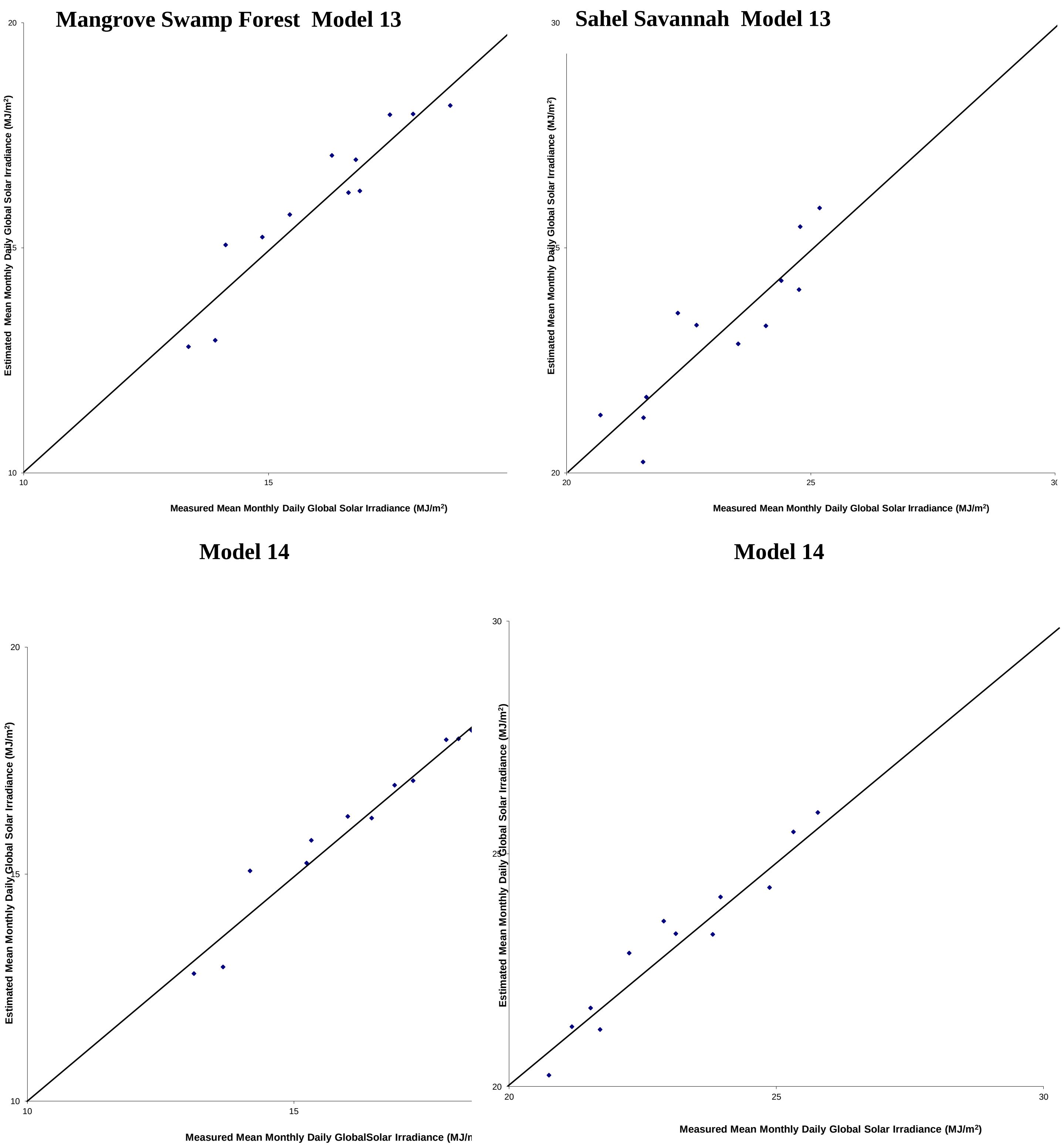
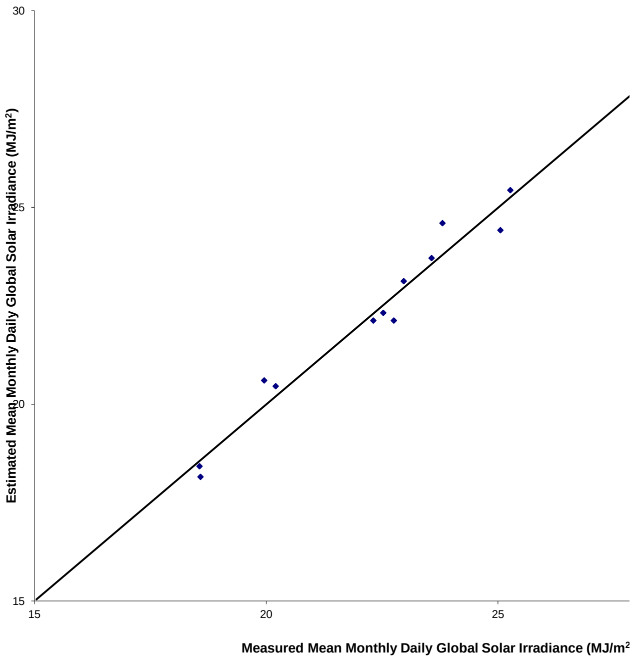
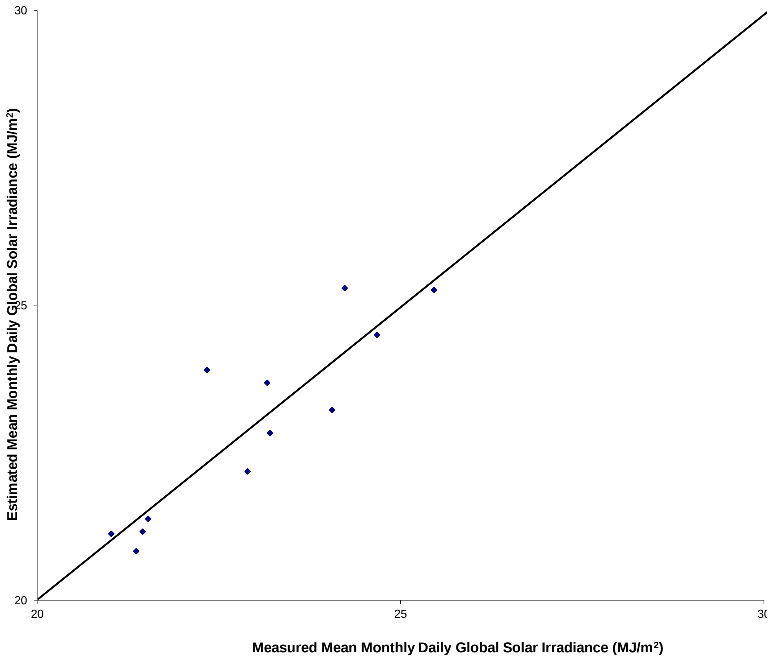
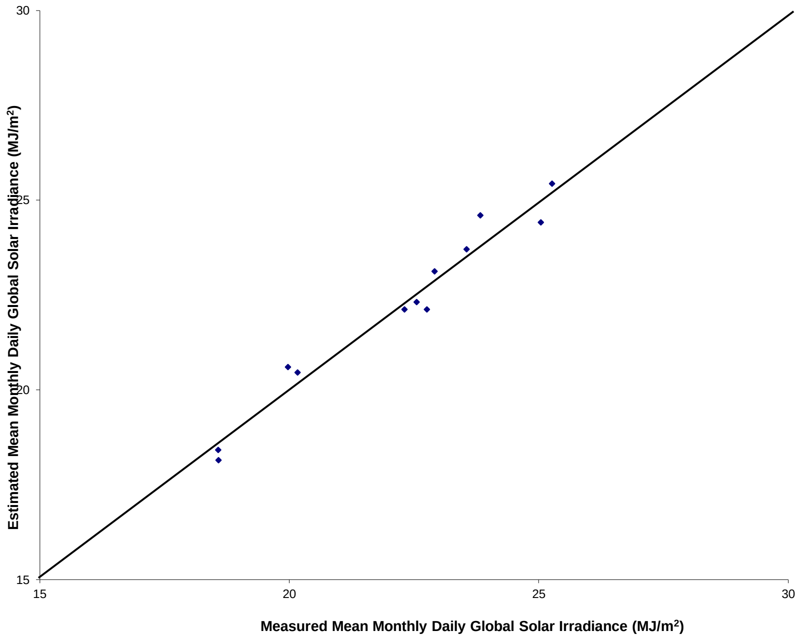


Figure 4: XY scattergrams for the Mangrove swamp forest and Sahel savannah using models 13 and 14 (the fitted 1:1 line on which the difference between the estimated and measured global solar irradiance is zero)





Model 14 **Model 14**



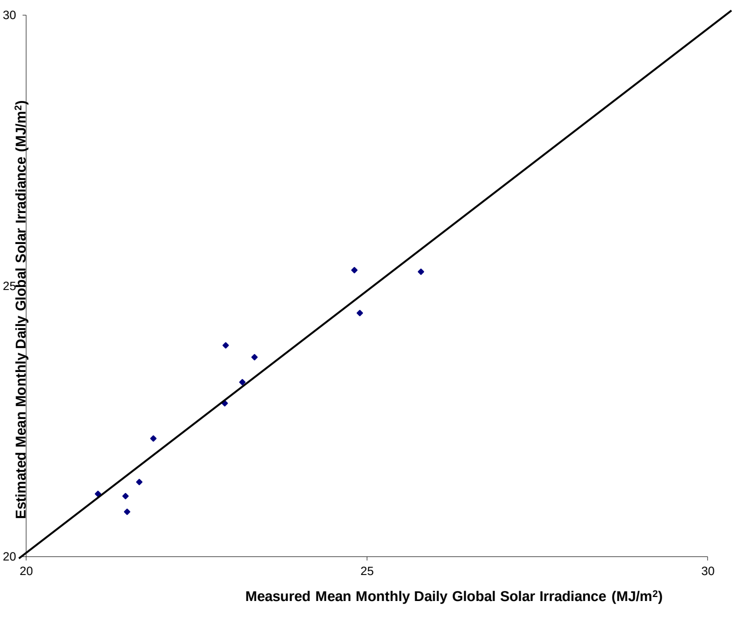


Figure 5: XY scattergrams for the Montane vegetation and Sudan savannah using models 13 and 14 (the fitted 1:1 line on which the difference between the estimated and measured global solar irradiance is zero).

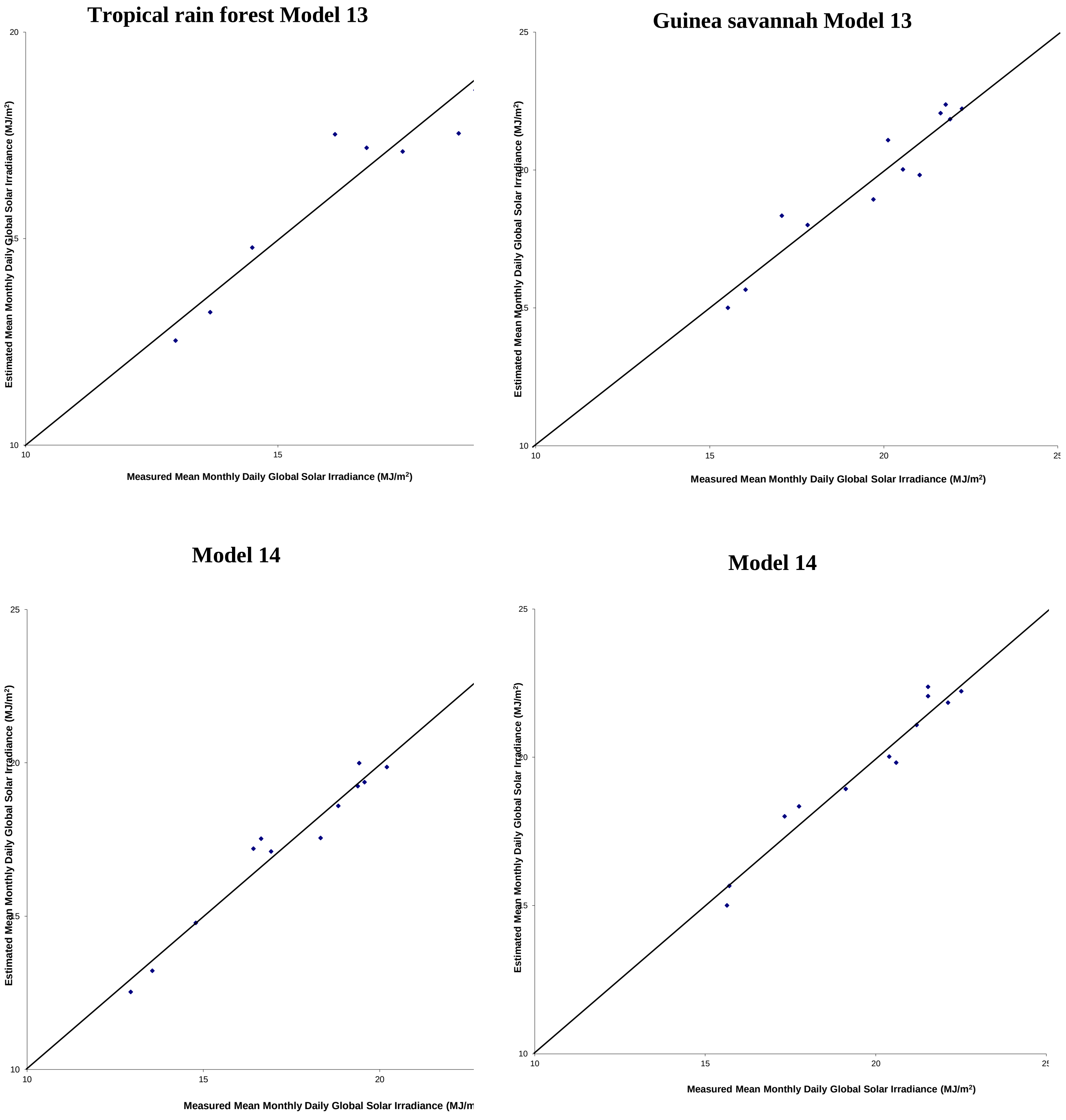


Figure 6: XY scattergrams for the Tropical rainforest and Guinea savannah using models 13 and 14 (the fitted 1:1 line on which the difference between the estimated and measured global solar irradiance is zero).