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Full Length Research Paper

Estimation of global solar radiation on horizontal surface in Erzincan, Turkey

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In the applications of solar energy, the solar radiation data and their components in a region must be known for the design of a system. In the locations where no solar radiation data is available, this parameter can be determined by performing a reasonable correlation. In the study, the models of global solar radiation on the horizontal surface in the literature are investigated, and new empirical models based on the sunshine hour data for Erzincan, Turkey are developed. In order to indicate the performance of the models, the statistical test methods of mean bias error (MBE), root mean square error (RMSE) and mean relative error (MRE) are used. The results obtained indicate that the correlations developed in the study predict the global solar radiation reasonably well for the future projections.

Key words: Solar energy, global solar radiation, sunshine hours, correlation, empirical models.

INTRODUCTION

The trends of energy indicate that world oil production will reach peak and start a long downward slide when the fossil fuel and gas would have been consumed (Augustine and Nnabuchi, 2009). The studies that have gained speed on the new and renewable energy sources, are encouraged because energy resources used today both rapidly decrease and cause environmental pollution. Solar radiation is the largest renewable energy source and it has been studied recently due to its importance (Falayi et al., 2008; Ugwu and Ugwuanyi, 2011). Turkey lies in a sunny belt between 36° and 42° N latitudes. The yearly average solar radiation is 3.6 kWhm^{-2}day^{-1} and the total yearly radiation period is approximately 2640 h, which is sufficient to provide adequate energy for solar thermal applications. In spite of this high potential, solar energy is not now widely used, except for flat-plate solar collectors (Karagoz and Bakirci, 2010).

The solar radiation data and their components in a region must be investigated for the design of a system in the applications of solar energy. Namely, a reasonably accurate knowledge of the availability of the solar resource at any place is required by solar engineers, architects and agriculturists for many applications of solar energy. The data are determined by developing correlations in the places where solar radiation data are not measured.

Scientists have developed many empirical equations which determine the relation between radiation and various climatological parameters (Iqbal, 1979; Newland, 1989; Jain, 1990; Tiris et al., 1995, 1996; Said et al., 1998; Rehman, 1998; Kaygusuz, 1999; Rehman, 1999; Ulgen and Hepbasli, 2004; Bakirci, 2008a; Falayi et al., 2008; Bakirci, 2009).

Page (1961) presented the coefficients of the Angström-type model, which is believed to be applicable anywhere in the world. Rietveld (1978) examined several published values of regression coefficient for Angström-type relations and suggested a correlation. Bahel et al. (1986) suggested the linear equation for the estimation of solar radiation of Dahran, Saudi Arabia. Louche et al. (1991) presented the linear model to predict global solar radiation for a French Mediterranean site. Tiris et al. (1996) proposed Angström-type equation with hours of bright sunshine in Gebze, Turkey. Togrul and Togrul (2002) developed the Angström-type equation for some provinces (Ankara, Antalya, Izmir, Yenihisar (Aydin), Yumurtalik (Adana) and Elazig) in Turkey. Ulgen and Hepbasli (2004) suggested the Angström-type for Ankara, Istanbul and Izmir in Turkey. Bakirci (2009) presented the linear model given in the work to estimate

Table 1. Yearly total N_{bin} values for the provinces of Erzincan.

Temperature bin (°C)	Yearly N_{bin} (h/year)
-7.5	121
-4.5	510
-1.5	902
1.5	952
4.5	704
7.5	732
10.5	755
13.5	779
16.5	832
19.5	781
22.5	642
25.5	502
28.5	335
31.5	211
34.5	2

the global solar radiation in general of Turkey. Bulut (2010) generated typical solar radiation years for seven provinces located in Aegean region of Turkey using the daily global solar radiation data measured during at least for 15 years. In Bulut's study, the typical daily global solar radiation data for the locations considered were presented throughout a year in a tabular form.

The objective of this study is to test the available models in the literature and to develop new empirical equations which correlate the monthly average daily horizontal global radiation by using the sunshine hour data for Erzincan, Turkey.

Climate properties

The latitude, longitude and altitude of Erzincan, Turkey are 39.30, 39.44 and 1215 m, respectively. The value of the yearly heating degree-days with the base temperatures of 18°C is 3020 (Bakirci et al., 2008).

Yearly total N_{bin} values for the provinces of Erzincan are shown in Table 1 (Ozyurt et al., 2009). The six time periods are: (1) 01 to 04 h, (2) 05 to 08 h, (3) 09 to 12 h, (4) 13 to 16 h, (5) 17 to 20 h, and (6) 21 to 24 h. Thus, bin data for dry-bulb temperature from -36 to 45°C with 3°C increments are calculated in six daily 4 h shifts (1 to 4, 5 to 8, 9 to 12, 13 to 16, 17 to 20 and 21 to 24 h) for Erzincan in the region of the East Anatolia of Turkey.

METHOD OF CALCULATION

The simple model used to estimate monthly average daily global solar radiation on horizontal surface is the modified form of the Angström-type equation. The original Angström-type regression equation is related with the monthly average daily radiation to the clear day radiation at the location and the average fraction of possible sunshine hours (Angström, 1924). Page (1961) and others have modified the method using the values of extraterrestrial radiation on a horizontal surface rather than that of clear day radiation (Duffie and Beckman, 1991):

$$\frac{H}{H_o} = a + b\left(\frac{S}{S_o}\right) \quad (1)$$

Where H is the monthly average daily global radiation, H_o is the monthly average daily extraterrestrial radiation, S is the day length, S_o is the maximum possible sunshine duration, and a and b are empirical coefficients.

The monthly average daily extraterrestrial radiation on a horizontal surface (H_o) can be computed by the Equation 2 (Howell et al., 1982; Duffie and Beckman, 1991):

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

Where I_{sc} is the solar constant (=1353 Wm^{-2}), φ the latitude of the site, δ the solar declination, ω_s the mean sunrise hour angle for the given month and D the number of days of the year starting from first January. The solar declination (δ) and the mean sunrise hour angle (ω_s) can be calculated by Equations 3 and 4, respectively (Duffie and Beckman, 1991):

$$\delta = 23.45\sin\left[\frac{360(D + 284)}{365}\right] \quad (3)$$

$$\omega_s = \cos^{-1}\left[-\tan(\delta)\tan(\varphi)\right] \quad (4)$$

For a given month, the maximum possible sunshine duration (S_o) can be computed by using Equation 5 (Duffie and Beckman, 1991):

$$S_o = \frac{2}{15}\omega_s \quad (5)$$

The values of the monthly average daily solar radiation (H) are calculated for the days giving average of each month offered by Klein (1977).

Used linear models

The simple model used to estimate monthly average daily global solar radiation on horizontal surface is the modified form of the Angström equation. There are eight types of the linear model equations in this study, as shown in Table 2.

The empirical coefficients of a and b shown in Equation 1 are obtained by using the least squares method. As shown in Table 2 and Equation 1, these empirical coefficients vary according to the climate conditions of the locations given. Additionally, the correlations obtained in the studies are generally chosen due to their simple and high determination coefficients.

Comparison of methods

In the literature, there are numerous statistical methods available

Table 2. Linear models in the literature and empirical coefficients in Equation 1.

Model	a	b	Referenecs
1	0.23	0.48	Page (1961)
2	0.18	0.62	Rietveld (1978)
3	0.175	0.552	Bahel et al. (1986)
4	0.206	0.546	Louche et al. (1991)
5	0.2262	0.418	Tiris et al. (1996)
6	0.318	0.449	Togrul and Togrul (2002)
7	0.2671	0.4754	Ulgen and Hepbasli (2004)
8	0.2786	0.4160	Bakirci (2009)

to compare solar radiation models (Ma and Iqbal, 1983; Tiris et al., 1996; Kaygusuz, 1999; Togrul and Togrul, 2002; Ulgen and Hepbasli, 2004; Bulut and Buyukalaca, 2007; Bakirci, 2008b). In the present study, the predictive efficiencies of the models are tested using the following terms: mean bias error (MBE), mean relative error (MRE) and root mean square error (RMSE). These terms are defined by Equations 6 and 7 as follows:

$$\mathrm{MBE} = \frac{1}{k}\sum_{i=1}^{k}(y_i - x_i) \qquad (6)$$

$$\mathrm{RMSE} = \left[\frac{1}{k}\sum_{i=1}^{k}(y_i - x_i)^2\right]^{1/2} \qquad (7)$$

Where x_i is the i-th measured value, y_i the i-th calculated value, and k the total number of observation. The MBE provides information on the long-term performance of an equation. A positive MBE represents an over-estimation while a negative MBE shows under-estimation. The RMSE provides information on the short-term performance of an equation. The value of RMSE is always positive, representing zero in the ideal case (Ma and Iqbal, 1983).

The MRE can be used to test for determining the linear relationship between measured and estimated values, which can be calculated from Equation 8 as follows (Bulut and Buyukalaca, 2007):

$$\mathrm{MRE} = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{y_i - x_i}{x_i}\right| \qquad (8)$$

In this study, the nine models are compared on the basis of the previously mentioned statistical error tests and, the accuracy of the estimated data for the models is determined by using these tests. For better data modeling, these statistics should be closer to zero.

RESULTS AND DISCUSSION

The data of the monthly average daily global solar radiation ($MJm^{-2}day^{-1}$) on horizontal surface and monthly average daily hours of bright sunshine (h) are taken from the Turkish State Meteorological Service over a 33-year period from 1975 to 2007. In this study, regression constants have been computed using observations of sunshine hours and monthly average daily global radiation for Erzincan, Turkey.

Some of the available models in the literature are tested to estimate the monthly average daily global solar radiation on horizontal surface with hours of bright sunshine for Erzincan, Turkey. Also, a modified Angström-type equation is developed (Model 9):

$$\frac{H}{H_o} = 0.3897 + 0.2066\left(\frac{S}{S_o}\right) \qquad (9)$$

The values of MBE, MRE and RMSE for Models (1 to 9) are shown in Table 3. The closer these statistics are to zero, the better the estimator is. A positive MBE represents an overestimation while a negative MBE shows an underestimation.

Comparing the results, it can be seen that some models give good results. Model 9 has the smallest errors than the other models. According to results, the Models 9 and 8 are proposed for the estimation of global solar radiation for Erzincan, Turkey.

The linear relationship between the monthly average values of H/H_o versus S/S_o is shown in Figure 1. The comparisons of the values of the monthly average global solar radiation measured and calculated from the Models (1 to 9) are shown in Figure 2. For the province of Erzincan, the following main results are obtained from the evaluation of the values in Table 3:

According to the results, the model shown in Equation 9, which is developed in the study, is found to be the most accurate model for the estimation of global solar radiation on a horizontal surface for Erzincan, Turkey. The MBE, MRE and RMSE are calculated to be 0.000, 0.025 and 0.321 MJ/m^2, respectively.

Among the other models in the literature, Model 8 (MBE = 0.166), Model 4 (MBE = 0.167) and Model 1 (MBE = -0.195) for values of MBE, Model 8 (MRE = 0.062), Model 7 (MRE = 0.083) and Model 1 (MRE = 0.084) for values of MRE and Model 8 (RMSE = 1.011), Model 1 (RMSE = 1.191) and Model 5 (RMSE = 1.489) for values of RMSE give the best results, respectively.

Table 3. The values of MBE, MRE and RMSE for Models (1 to 9).

Month	H	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
1	7.138	5.784	5.668	5.273	5.723	5.436	6.994	6.333	6.233	6.965
2	10.170	8.413	8.449	7.827	8.421	7.861	9.993	9.144	8.927	9.622
3	13.670	12.134	12.464	11.501	12.278	11.277	14.170	13.096	12.689	13.191
4	16.254	15.135	15.520	14.325	15.302	14.072	17.698	16.343	15.846	16.520
5	19.160	18.907	19.817	18.223	19.319	17.484	21.731	20.272	19.504	19.572
6	21.827	22.422	24.125	22.088	23.207	20.597	25.224	23.831	22.708	21.662
7	21.711	23.409	25.523	23.317	24.388	21.429	26.039	24.767	23.480	21.780
8	19.447	21.350	23.331	21.307	22.268	19.532	23.701	22.571	21.378	19.731
9	16.442	17.193	18.706	17.095	17.893	15.746	19.158	18.203	17.270	16.092
10	11.431	11.447	12.140	11.142	11.764	10.554	13.032	12.226	11.712	11.496
11	7.577	7.230	7.394	6.828	7.300	6.727	8.471	7.814	7.583	7.940
12	5.962	5.018	4.847	4.522	4.932	4.732	6.130	5.519	5.456	6.218
MBE		-0.195	0.600	-0.612	0.167	-1.279	1.796	0.778	0.166	0.000
MRE		0.084	0.120	0.117	0.100	0.114	0.110	0.083	0.062	0.025
RMSE		1.191	2.028	1.514	1.536	1.489	2.383	1.591	1.011	0.321

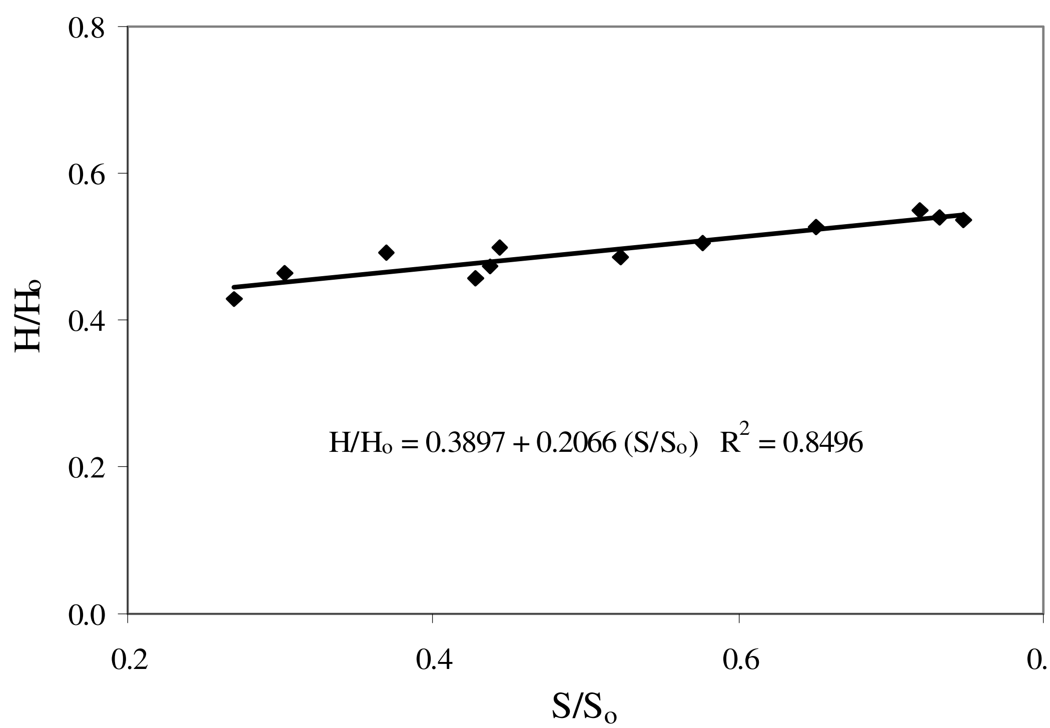


Figure 1. The linear relationships between the monthly average values (H/H_o versus S/S_o).

Conclusions

The sunshine based models are employed for the estimation of global solar radiation for Erzincan, Turkey and compared with the previously reported results on the basis of statistical error tests. The monthly linear equation (Model 9) developed in the study which is found to be the best overall according to MBE, MRE and RMSE, have the best performance based on the measured data at the station in Erzincan. Also, the correlation equations developed here will enable the solar energy researcher to use the estimated data with confidence because of its fine agreement with the observed data. Also, this correlation can be used elsewhere with similar climatic

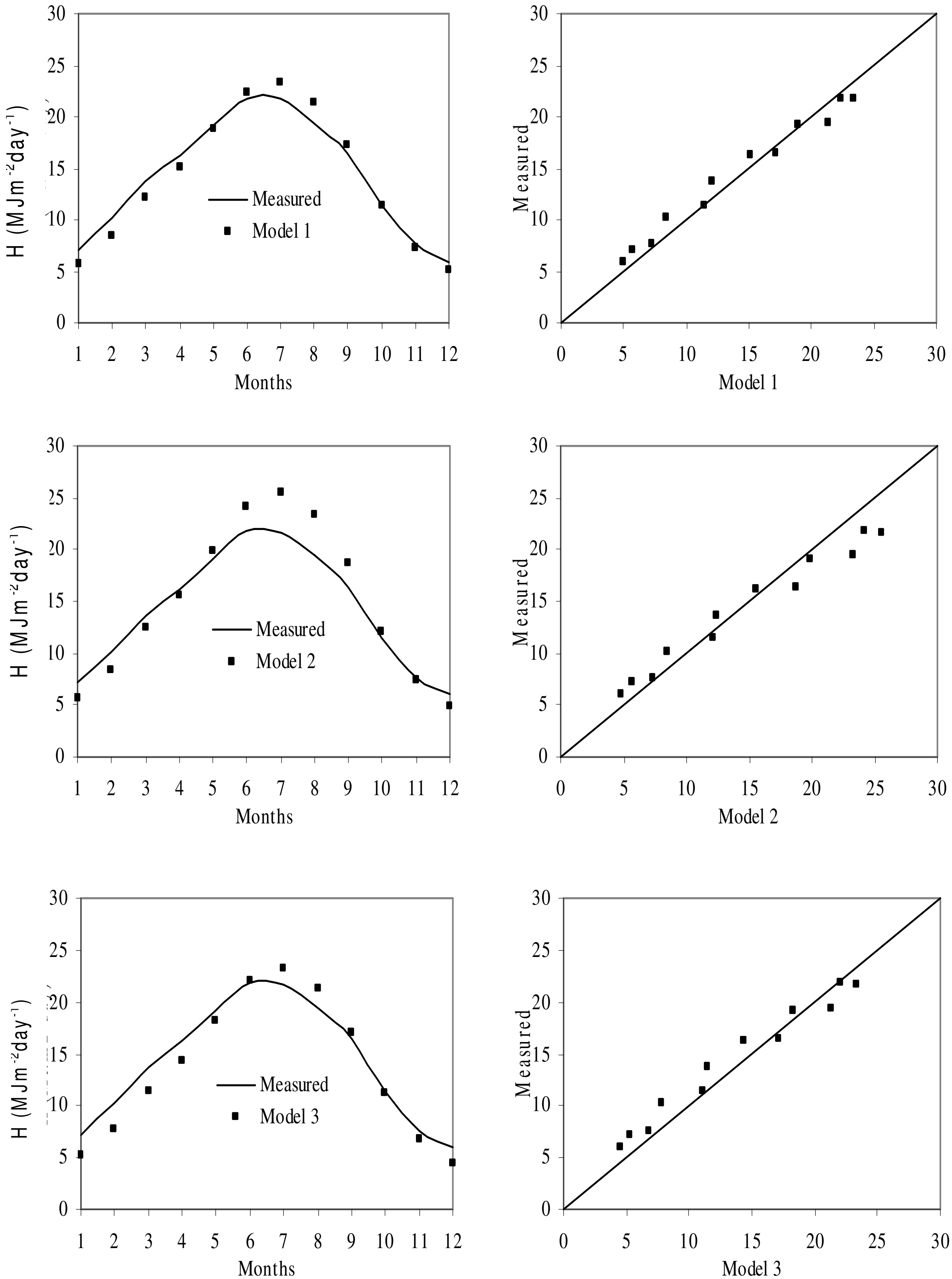
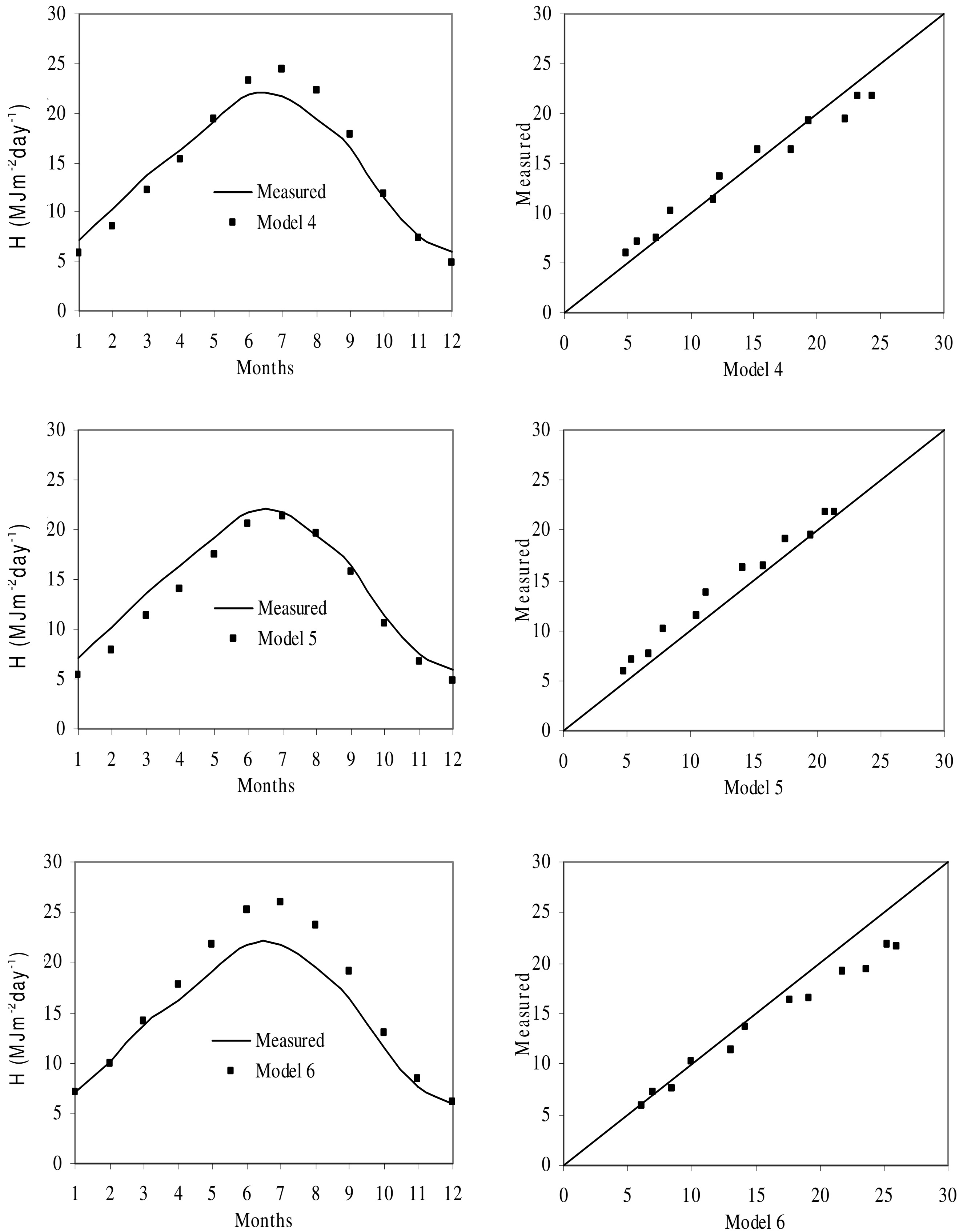


Figure 2. Comparisons of the values of the monthly average global solar radiation measured and calculated from the Models (1 to 9) (H, $MJm^{-2}day^{-1}$).



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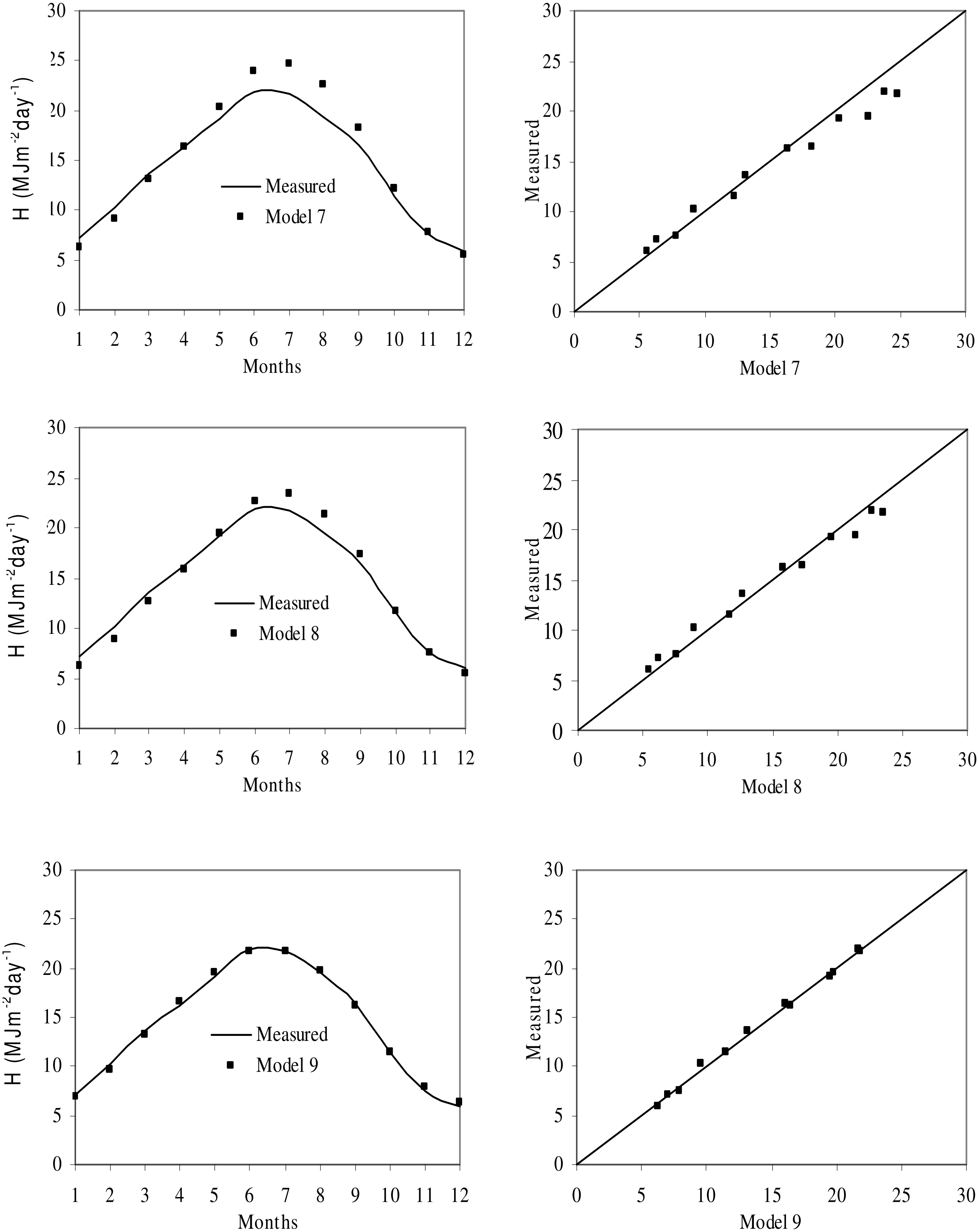

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conditions.

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Nomenclature: **a** and **b,** angstrom regression coefficients; **d,** the number of days of the year; **h,** monthly average daily global radiation on horizontal surface ($mjm^{-2}day^{-1}$); **h_o,** monthly average daily extraterrestrial radiation ($mjm^{-2}day^{-1}$); **i_{sc},** solar constant (wm^{-2}); **s,** monthly average daily hours of bright sunshine (h); **s_o,** monthly average day length (h); **δ,** solar declination (°); **φ,** latitude of site (°); **ω_s,** mean sunrise hour angle for the month (°).

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