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Technical note

Correlation of global solar radiation with meteorological parameters over Egypt

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Abstract

Global solar radiation measurements on a horizontal surface (G_m), mean daily maximum temperature (T), mean daily relative humidity (RH), mean daily sea level pressure (MSL), mean daily vapor pressure (V) and hours of bright sunshine (S) are presented, analyzed, arranged in tables and graphs and discussed for five selected locations over Egypt. The locations chosen represent the different weather conditions of Egypt. Matrough and Al Arish are in the north, Cairo in the middle and Kharga and Aswan in the south of Egypt. A correlation between the measurements of global solar radiation and the meteorological parameters were given for the considered locations. The common relationship for all Egypt was also estimated. The correlation and the regression coefficients and the standard errors of estimate are listed in Table 1. The values of correlation coefficients vary from 89% to 99% and the errors of estimation are between 0.01 and 0.04.

1. Introduction

Knowledge of the global solar radiation is of fundamental importance for all solar energy conversion system. The solar radiation data are not easily available for many countries. Many countries cannot afford the measuring equipment and

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Nomenclature

G	Total solar radiation (MJ/m^2/day).
G_o	The extraterrestrial radiation (MJ/m^2/day).
S/S_o	The sunshine duration.
T	The maximum temperature (°C).
V	The water vapor pressure (hpa).
R	The relative humidity (%).
MSL	The mean sea level pressure (hpa).
P	The ratio of MSL to V.

techniques involved [1]. Therefore, it is rather important to develop methods to estimate the solar radiation using whatever weather parameters are available.

Several empirical formulae have been developed to calculate the solar radiation using various parameters [2–5]. These parameters include the sunshine hours [6–9], the relation humidity and sunshine hours [10] and the sunshine duration, relative humidity, maximum temperature, water vapor pressure, mean sea level and the ratio of water vapor pressure to the mean sea level pressure [11].

This work tried to investigate the suite of empirical models used in the estimation of the global solar radiation from the meteorological parameters at some different zones in Egypt and over the whole of Egypt.

2. Computation techniques

A brief description of the mathematical expression of the various models examined are given below:

1. Gophanthan [12] introduced a multiple linear regression equation of the form:

$$G/G_o = a + b\ \cos\ \phi + ch + d(S/S_o) + eT + fR \tag{1}$$

Table 1
Geographic location of the selected stations and correlation, regression coefficients and standard errors of estimate for the model (5–9)

Location	Lat. N	Long. E	a	b	c	d	e	f	CC%	SE
Matrough	31° 20′	27° 13′	0.18	1.198	0.002	0.005	0.007	0.001	89	0.04
Al Arish	31° 07′	33° 45′	0.129	0.382	0.015	−0.009	−0.001	0.000	96	0.021
Cairo	30° 05′	32° 17′	0.179	0.021	0.008	0.01	−0.002	0.002	99	0.01
Kharga	25° 27′	30° 34′	1.35	−0.057	−0.01	0.007	−0.007	−0.001	94	0.014
Aswan	23° 58′	32° 47′	−0.776	0.034	0.02	0.01	0.01	0.003	86	0.018
All Egypt	28° 23′	31° 11′	−0.139	0.229	0.009	0.004	0.002	0.002	89	0.029

2. The model in Eq. (1) modified for Bahrain [11] is written as:

$$G/G_o = a + b(S/S_o) + cT + dR \tag{2}$$

and

$$G/G_o = a + b(S/S_o) + cT + dR + eP \tag{3}$$

where h is the elevation of the location in kilometers above sea level, T is the monthly mean daily maximum temperature, R is the daily mean relative humidity as a percentage, and P is the ratio between mean sea level pressure and mean daily vapour pressure.

3. In this paper, there is an addition of a new empirical model which takes the form:

$$G/G_o = a + b(S/S_o) + cT + dV + eR + fP \tag{4}$$

Where G_o is the extraterrestrial radiation calculated from [13] and V is the water vapor pressure (in hpa).

The measured data of global solar radiation and the meteorological parameters, listed in Tables 2–5, for the five selected locations in Egypt, have been processed and analyzed using an advanced computer program to obtain the correlation and the regression coefficients *a, b, c, d, e* and *f* in Eq. (4). The obtained values of correlation coefficients (CC) and the standard errors of estimation (SE) besides the regression coefficients are listed in Table 1.

Table 2
Monthly mean daily hours of global solar radiation (G), bright sunshine (s), maximum temperature (T), water vapor pressure, mean sea level and relative humidity (R) at Matrough station

Month	G	S (h)	T (°C)	V (hpa)	MSL (hpa)	R (%)
Jan	10.35	6.7	19.1	10.9	1020.1	67.0
Feb	13.80	7.6	18.0	10.1	1022.8	67.7
Mar	17.86	8.1	18.9	11.3	1016.8	65.7
Apr	21.87	9.0	21.3	11.9	1015.5	63.7
May	26.31	11.0	25.3	16.9	1015.6	73.0
Jun	27.19	12.2	28.8	21.7	1011.5	71.3
Jul	26.82	11.9	30.2	23.9	1011.8	69.7
Aug	24.64	11.7	29.4	24.2	1012.5	72.0
Sep	21.21	10.2	27.8	20.8	1014.7	67.7
Oct	15.59	8.3	26.5	16.3	1014.8	64.0
Nov	11.84	8.3	23.5	15.2	1016.4	73.0
Dec	9.71	6.8	19.9	11.4	1018.8	65.7
Mean	18.93	9.32	24.06	16.22	1015.94	68.38

Table 3
Monthly mean daily hours of global solar radiation (G), bright sunshine (s), maximum temperature (T), water vapor pressure, mean sea level and relative humidity (R) at Al Arish station

Month	G	S (h)	T (°C)	V (hpa)	MSL (hpa)	R (%)
Jan	11.4	7.6	20.1	11.4	1018.1	74.0
Feb	14.0	7.9	17.8	9.5	1021.0	67.3
Mar	19.8	8.5	19.7	10.6	1015.2	66.7
Apr	22.6	9.5	23.5	11.3	1015.2	59.3
May	27.0	11.3	27.0	16.5	1014.2	70.0
Jun	28.6	12.6	29.0	19.0	1012.0	70.0
Jul	27.2	12.0	32.2	23.8	1009.2	70.0
Aug	25.4	11.9	30.5	23.5	1010.2	71.7
Sep	21.5	10.7	29.8	20.8	1012.5	68.7
Oct	16.4	9.50	25.5	19.6	1013.2	73.5
Nov	12.4	8.50	21.1	15.4	1014.9	72.3
Dec	10.6	7.70	19.0	11.6	1018.8	71.0
Mean	19.75	9.81	24.6	16.08	1014.54	69.54

3. Results and discussions

3.1. The data used in this paper are listed in Tables 2–6. From these tables the following can be briefly summarized:

3.1.1. Global solar radiation measurements (G_m)

The maximum values of global solar radiation at all considered locations appear in June, while the minimum values are in December. The annual average

Table 4
Monthly mean daily hours of global solar radiation (G), bright sunshine (s), maximum temperature (T), water vapor pressure, mean sea level and relative humidity (R) at Cairo station

Month	G	S (h)	T (°C)	V (hpa)	MSL (hpa)	R (%)
Jan	11.2	7.6	20.1	10.8	1018.8	64.7
Feb	14.3	7.5	18.6	8.8	1021.9	59.0
Mar	17.8	8.4	20.8	10.0	1015.2	56.7
Apr	22.2	9.5	25.6	10.5	1014.1	48.0
May	25.9	11.0	32.6	14.2	1013.0	48.3
Jun	26.8	11.9	34.5	18.6	1009.2	52.7
Jul	25.9	11.6	35.0	22.3	1009.2	59.0
Aug	24.0	11.0	33.0	22.5	1011.0	62.3
Sep	21.2	10.0	32.0	20.0	1013.0	59.7
Oct	16.0	9.1	29.3	17.2	1013.8	60.0
Nov	12.2	8.3	25.1	14.2	1015.5	62.7
Dec	10.5	7.3	20.2	10.7	1018.8	62.3
Mean	19.00	9.43	27.23	14.98	1014.46	57.95

Table 5
Monthly mean daily hours of global solar radiation (G), bright sunshine (s), maximum temperature (T), water vapor pressure, mean sea level and relative humidity (R) at Kharga station

Month	G	S (h)	T (°C)	V (hpa)	MSL (hpa)	R (%)
Jan	15.8	9.6	23.3	8.7	1018.8	48.3
Feb	19.1	9.7	21.6	6.8	1021.0	41.3
Mar	22.2	9.6	26.9	8.3	1012.5	41.7
Apr	25.6	10.4	32.9	9.8	1012.4	34.0
May	27.0	10.9	38.8	12.3	1010.8	30.3
Jun	28.8	12.1	40.9	15.5	1007.0	32.7
Jul	28.2	11.0	41.5	17.2	1006.7	34.0
Aug	26.3	11.8	40.5	16.9	1008.3	34.0
Sep	23.1	10.8	37.8	16.7	1011.1	41.3
Oct	18.9	10.3	34.2	14.3	1010.8	46.0
Nov	16.2	9.8	29.1	11.9	1014.8	50.3
Dec	14.1	8.9	23.2	8.9	1018.5	54.0
Mean	22.11	10.41	32.56	12.28	1012.73	40.66

daily values for the global solar radiation on horizontal surface at Aswan is 22.76 MJ/m^2/day, at Kharga is 22.11 MJ/m^2/day, at Cairo is 19 MJ/m^2/day, at Matrough is 18.93 MJ/m^2/day and at Al Arish is 19.75 MJ/m^2/day. On the other hand, the values of global solar radiation at Aswan and Kharga (south Egypt) are higher than they are in Cairo (middle Egypt), Matrough and Al Arish (northern Egypt). This is due to the fact that weather in Aswan and Kharga is dry and clean if compared with other zones. And the daily mean hours of the bright sunshine

Table 6
Monthly mean daily hours of global solar radiation (G), bright sunshine (s), maximum temperature (T), water vapor pressure, mean sea level and relative humidity (R) at Aswan station

Month	G	S (h)	T (°C)	V (hpa)	MSL (hpa)	R (%)
Jan	16.3	10.0	25.0	8.4	1016.6	40.3
Feb	20.3	10.5	21.7	5.7	1020.5	34.0
Mar	22.3	9.6	26.9	6.6	1013.9	28.3
Apr	25.4	10.7	34.6	7.2	1011.0	20.7
May	29.0	11.0	39.2	8.4	1009.4	18.0
Jun	28.7	12.5	41.5	10.3	1006.0	19.3
Jul	27.8	12.2	42.2	10.1	1005.7	18.3
Aug	26.6	11.8	41.0	11.1	1007.9	21.3
Sep	23.8	10.8	39.5	10.7	1009.1	23.3
Oct	20.7	10.5	35.7	12.0	1010.8	31.0
Nov	16.9	10.1	29.9	9.4	1013.9	34.7
Dec	15.3	9.8	24.1	7.8	1017.3	40.3
Mean	22.76	10.79	33.44	8.98	1011.84	27.46

(S) in the south is higher than in the middle and the north. Where the values of annual mean of S in Aswan and Kharga are 10.79 and 10.41 h, in Cairo it is 9.43 h and in Matrough and Al Arish, 9.32 and 9.81 respectively. See Tables 2–6.

3.1.2. Maximum temperature (T)

The monthly daily mean of maximum temperatures has higher values in July and lower values in February at all locations. The annual mean values of the maximum temperatures decrease from the south toward the north, where these values are 33.44, 32.56, 27.23, 24.06 and 24.6°C at Aswan, Kharga, Cairo, Matrough and Al Arish respectively. This is because the sun is normal at Aswan

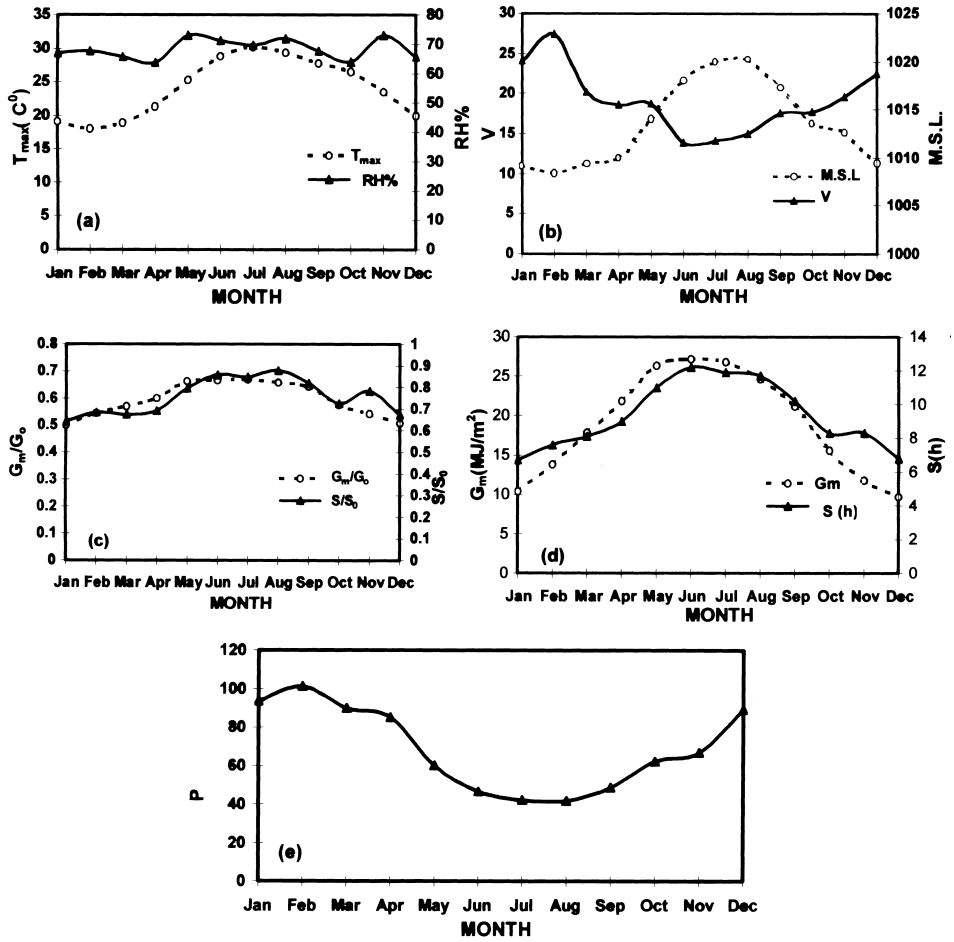

Fig. 1. Monthly mean variation of the considered parameters (a) T_{max} and RH, (b) V and MSL, (c) G/G_o and S/S_o, (d) G_m and S and (e) P at Matrough station.

and Kharga and also the solar declination at the south is smaller than at the middle and the north of Egypt.

3.1.3. The relative humidity as a percentage (R)

Because Matrough and Al Arish lie on the Mediterranean Sea, the amount of humidity is higher, but lower in the south. The annual means of R at Matrough and Al Arish are 68.38% and 69.54% and at Cairo is 57.95%, while at Kharga and Aswan are 40.66% and 27.46%.

3.1.4. Water vapor pressure V (hpa)

The monthly mean daily values of vapor pressure had the maximum value in

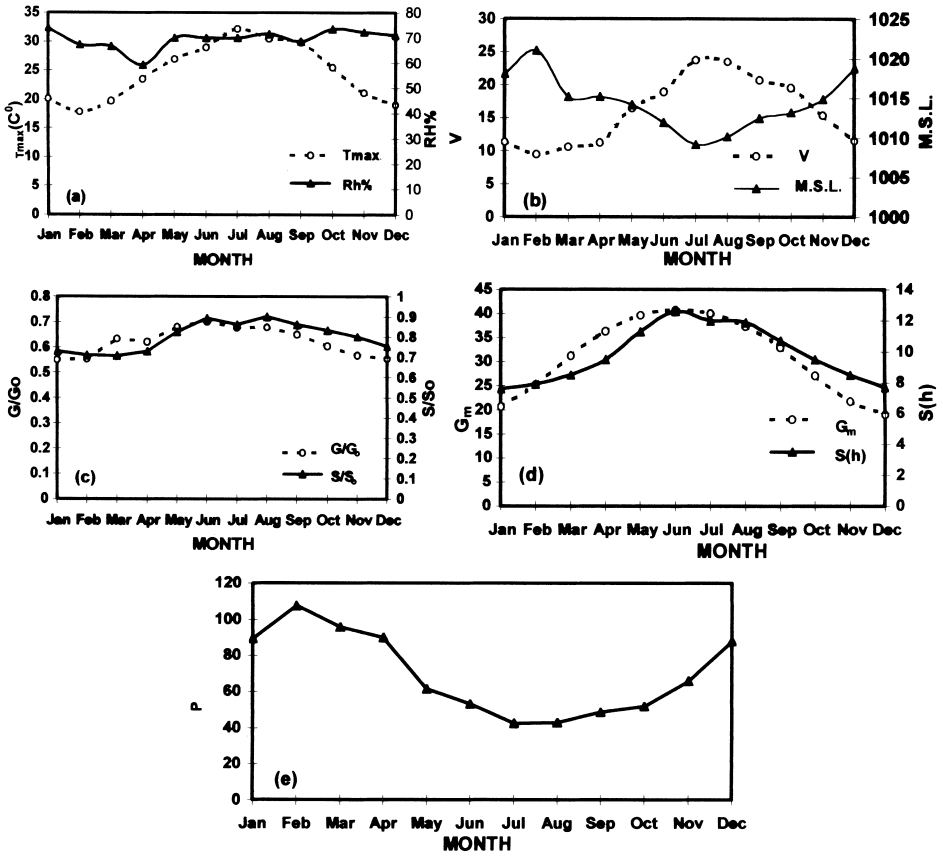

Fig. 2. Monthly mean variation of the considered parameters (a) T_{max} and RH, (b) V and MSL, (c) G/G_o and S/S_o, (d) G_m and S and (e) P at Al Arish station.

August at Matrough, Al Arish and Cairo, and in October at Aswan, and in July at Kharga. While they had the minimum values in February at all selected stations. The annual mean values were 16.22, 16.08, 14.98, 12.28 and 8.98 for Matrough, Al Arish, Cairo, Kharga and Aswan respectively.

The monthly variation of (T and R), (V and MSL), (G_m and S), (G/G_o and S/S_o) and (P) are illustrated by Figs. 1–5 for all considered locations. From the figures it is clear that:

- The monthly variation of T and R have opposite trend at Aswan, Kharga and Cairo, but have the same trend at Matrough and Al Arish. This is because Matrough and Al Arish lie on the sea.
- The monthly variation of V and MSL have the opposite trend, while G/G_o and S/S_o have the same trend for all locations.
- The monthly variation of G_m and S have the same trend, where the maximum values for each G_m and S were in June and the minimum values were in January and December.

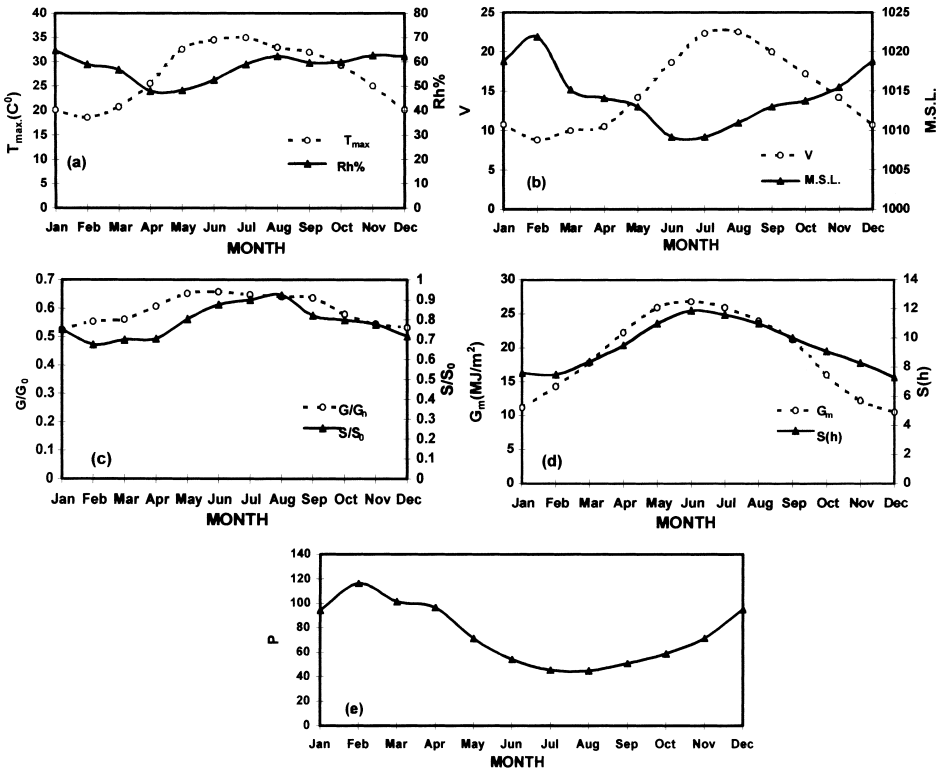

Fig. 3. Monthly mean variation of the considered parameters (a) T_{max} and RH, (b) V and MSL, (c) G/G_o and S/S_o, (d) G_m and S and (e) P at Cairo station.

- The monthly variation values of P were maximum in February at all locations, while the minimum values were in August at Matrough, Al Arish and Cairo, but the minimum values in October were at Aswan and Kharga.

3.2. Global solar radiation and the weather parameter's correlation

From Table 1, the formulae of empirical models investigated in this paper can be written as follows.

1. Matrough model

$$G/G_o = 0.18 + 1.198(S/S_o) + 0.002T - 0.005V - 0.007R + 0.001P \quad (5)$$

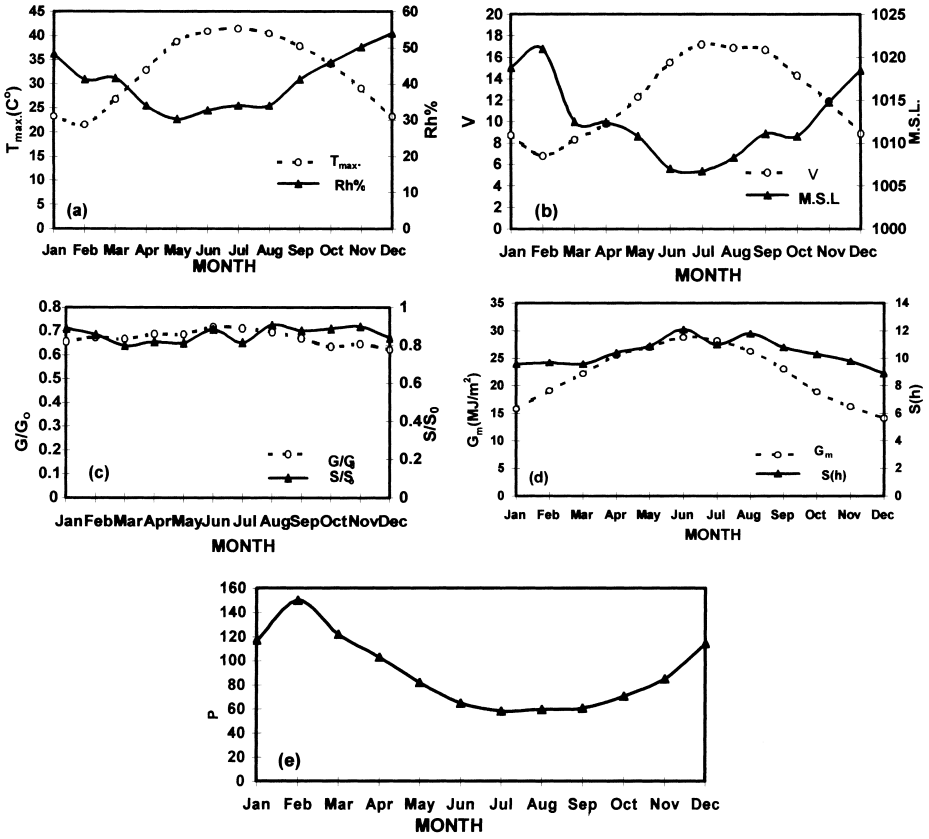

Fig. 4. Monthly mean variation of the considered parameters (a) T_{max} and RH, (b) V and MSL, (c) G/G_o and S/S_o, (d) G_m and S and (e) P at Kharga station.

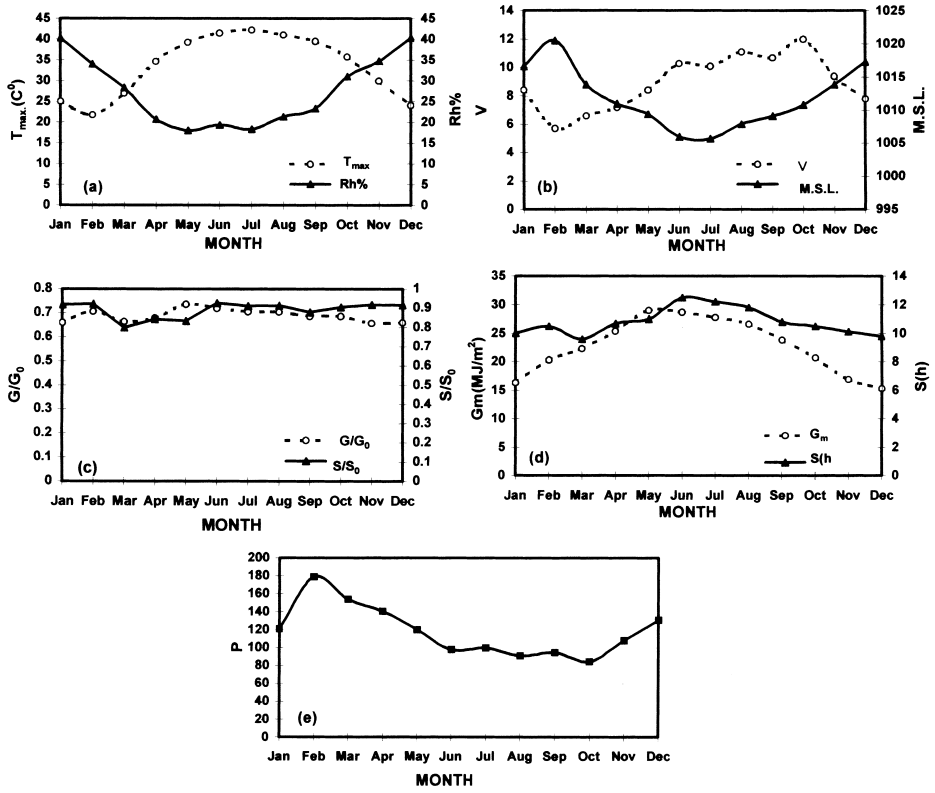

Fig. 5. Monthly mean variation of the considered parameters (a) T_{max} and RH, (b) V and MSL, (c) G/G_o and S/S_o, (d) G_m and S and (e) P at Aswan station.

2. Al Arish model

$$G/G_o = 0.129 + 0.382(S/S_o) + 0.015T - 0.009V - 0.001R \quad (6)$$

3. Cairo model

$$G/G_o = 0.179 + 0.021(S/S_o) + 0.008T + 0.01V - 0.002R + 0.002P \quad (7)$$

4. Kharga model

$$G/G_o = 1.35 - 0.057(S/S_o) - 0.01T + 0.007V - 0.007R - 0.001P \quad (8)$$

5. Aswan model

$$G/G_o = -0.776 + 0.034(S/S_o) + 0.02T + 0.01V + 0.01R + 0.003P \quad (9)$$

6. Egypt model

$$G/G_o = -0.139 + 0.229(S/S_o) + 0.009T + 0.004V + 0.002R + 0.002P \quad (10)$$

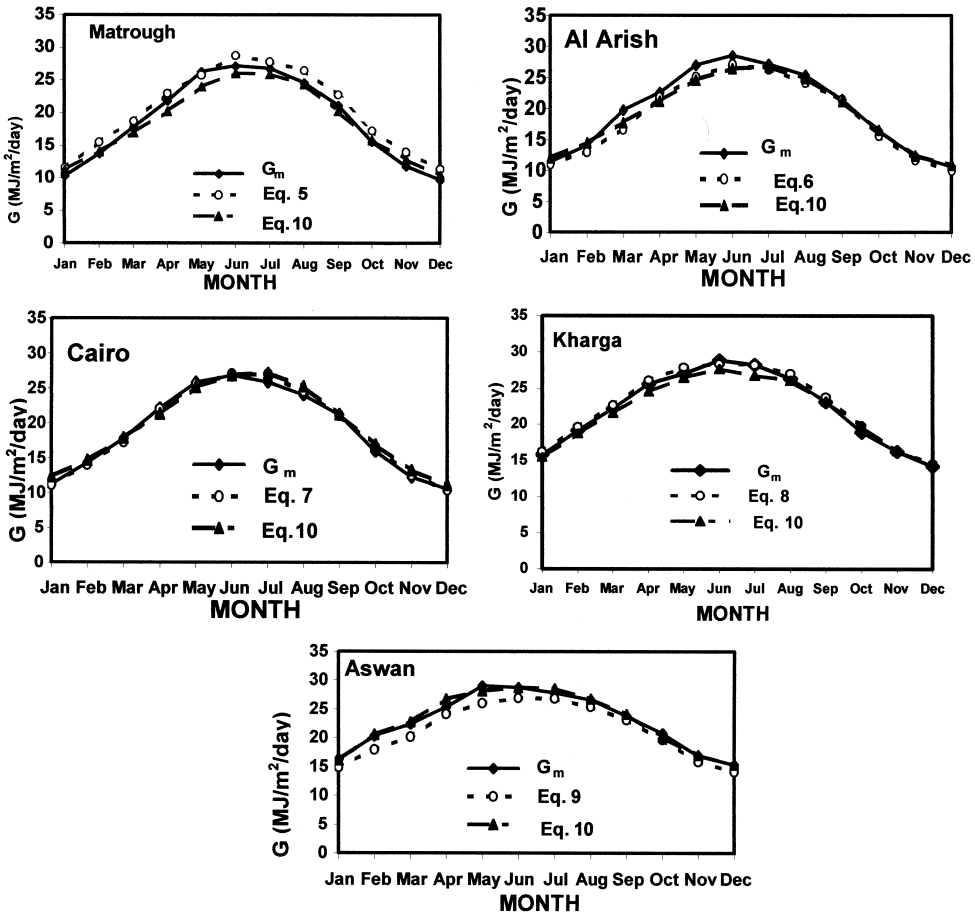

Fig. 6. Comparison between measured and estimated values of global solar radiation at the selected locations.

From Table 1, one can notice that the correlation coefficient (CC) at Cairo is the best, where its value is 99% and the standard error of estimation (SE) is 0.011. The lowest value of CC is 86% at Aswan and SE is 0.019. While R and SE have the values 90% and 0.001, 90% and 0.041, 96% and 0.021, 95% and 0.014 at Matrough, Al Arish and Kharga respectively. But for all Egypt CC is 89% and SE is 0.029.

3.3. Comparison between the measured and the estimated values of global solar radiation

The values of global solar radiation calculated in the models (Eqs. (5)–(10)) were compared with the corresponding measured values. The results are illustrated

in Fig. 6 for the considered stations. From this figure, the deviation between the measured and calculated values are very small during all months, and this means that these models are suitable to be used in calculating the global solar radiation at any location in Egypt.

4. Conclusion

The monthly variation of global solar radiation and different meteorological parameters such as sunshine duration, relative humidity as a percentage, maximum temperature, water vapor pressure, mean sea level and the ratio of MSL to water vapor pressure are presented and analyzed for five locations in Egypt. The correlation and regression coefficients for each location and also for all Egypt have been calculated. From the above results and considerations, the values of correlation coefficients vary between 99% at Cairo and 86% at Aswan and the error did not exceed 0.04. Eqs. (5)–(9) are used with high accuracy to estimate the global solar radiation at the selected locations and Eq. (10) for all Egypt.

References

[1] Said Ibrahim MA. Predicted and measured global solar radiation in Egypt. Solar Energy 1985;35(2):185–8.
[2] Moon P. Proposed standard radiation curves for engineering use. J Franklin Inst 1940;230:583–617.
[3] Fritz S, Mcdonald TH. Average solar radiation in the United States. Heat Ventil 1949;46(7):61–4.
[4] Fritz S. Solar energy on clear and cloudy days. Sci Monthly 1957;84:55–6.
[5] Drummond AJ, Vowinckel E. The distribution of solar radiation throughout Southern Africa. J Metro 1957;14(4):242–353.
[6] Angstrom. Solar and international radiation. Q J R Met Soc 1924;50:121–6.
[7] Black JN, Bonython CW, Prescott TA. Solar radiation and duration of sunshine. QR J Met Soc 1958;80(344):231–5.
[8] Smith GE. Solar radiation data base development based on bright sunshine data. Int and US Programs Solar flux Conf Winnipeg 1976;1:226–34.
[9] Swartman RK, Ogunlada O. Solar relation estimates from common parameters. Solar Energy 1967;11:170–2.
[10] Reddy SJ. An empirical method for the estimation of the total solar radiation. Solar Energy 1971;13.
[11] Abdalla YAG. New correlation of global solar radiation with meteorological parameters for Bahrain. Int J Solar Energy 1994;16:111–20.
[12] Gopinathan KK. A new model for estimating total solar radiation in Doha. Energy confers Mgmt 1988;28:63.
[13] Klein SA. Calculation of monthly average insolation on tilted surface. Solar Energy 1977;19:325–9.