MAUSAM, 51, 1 (January 2000), 75-80

551.521.1 : 551.501.721

Non-linear equation for estimation of the global solar radiation for any latitude in Egypt

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(Received 27 October 1998, Modified 9 June 1999)

सार - इस अध्ययन का उददेश्य सौर अभिलेखन उपकरणों के उपलब्ध न होने की स्थिति में मिस्त्र में किसी भी स्थान पर किसी भी अक्षांश के लिए मासिक सौर विकिरण के आकलन के लिए अरैखिक समीकरण का पता लगाना है। इस समीकरण से लगभग 7 प्रतिशत की घट-बढ़ के साथ मिस्त्र में किसी भी अक्षांश के किसी भी माह के प्रकाशित आँकड़ों (विश्व संजाल में) के अंतर सहित विश्वस्तरीय सौर विकिरण के मासिक मानों का आकलन किया जा सकता है।

ABSTRACT. The aim of this study is to obtain a nonlinear equation for computation of the monthly solar radiation for any latitude of any place in Egypt, when the recording solar instruments are not available. This equation allows to estimate the monthly values of the Global Solar Radiation for any latitude in Egypt with deviation from the published data (in the world net work), for any month, of about ±7%.

Key words - Global solar radiation, Egypt, Non-linear technique, Fourier-analysis, Solar radiation.

1. Introduction

The estimation of Global Solar Radiation (GSR) at a site is important for a large variety of applications, as the proper design of the solar systems, agriculture, hydrology, architecture, urban planning and many other projects [Khogali *et al.*, 1983, Atlas Arab Organization (1976)].

In many of the developing countries, as well as Egypt, the lack of the solar recording instruments is a barrier for many of the projects. Therefore, many of the projects have to depend, for determination of GSR, on the data published in the World Net Work (WNW). Actually, some projects can not be established in some sites because of the lack of the GSR data, even in the WNW. Therefore, this work is aiming to obtain a nonlinear equation of the fourth order for estimating the GSR with a higher accuracy than that obtained before by the author (Tadros, 1990) for second and third order of latitude. It was found that the published data with deviation of about ±7% is 77.6% for the linear equation (Tadros, 1990; Helwa *et al.*, 1988). The coincidence is about 86.4% and 87.6% for the equations of second and third order of latitude respectively.

The analysis of the global cloud fields show that the amounts of the clouds in the range of latitudes from 20°N to 30°N and longitudes from 20°E to 30°E are very small (Matveev and Titov, 1985; Matveev *et al.*, 1986). Therefore, it is possible to consider that the amounts of GSR are not much affected by the amounts of clouds in that region (Egypt territory) and can be considered as a function of latitude only.

2. Data base and method

The available daily Solar Radiation Data (SRD), in the period from 1981 to 1986 for different 9 stations related to different regions in Egypt, (7 stations of them were used to obtain the coefficients of the equation and the other 2 stations were used as a test for the equation), were published in the Solar Radiation and Radiation Balance Data (World Net Work 1981-87). Tadros and Shaltout (1990) applied Fourier analysis on 8 stations of these data and obtained the Typical Annual Time Function (TATF) for these different regions.

The suggested method in this work consists of 3 stages:

(*i*) The first stage is to obtain the TATF, as detailed in (Helwa *et al.*, 1988, Tadros and Shaltout, 1990, Alberto and Recio, 1984, Balling, 1983), from the averages of all the available years, day by day, for each station.

(*ii*) Second stage is to obtain the average for each month from TATF of each station.

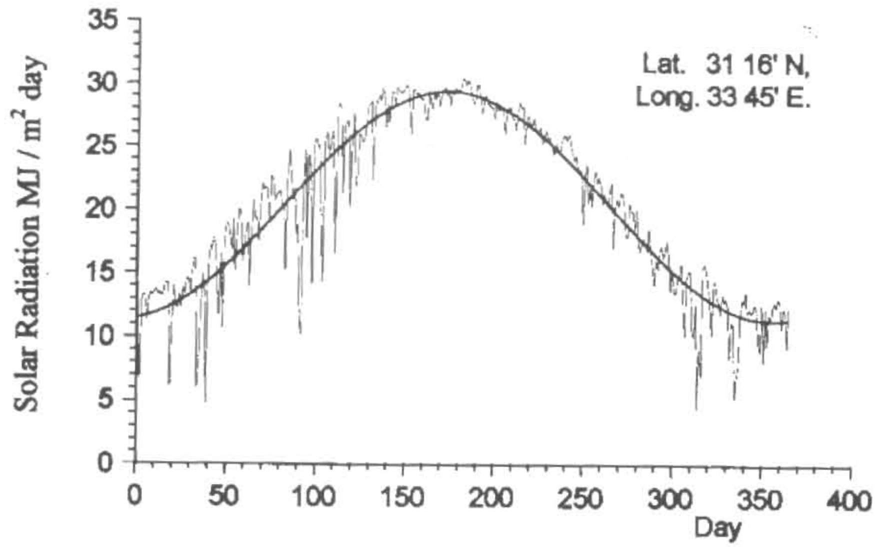

Fig. 1. Annual variation of daily solar radiation in El-Arish, 1986

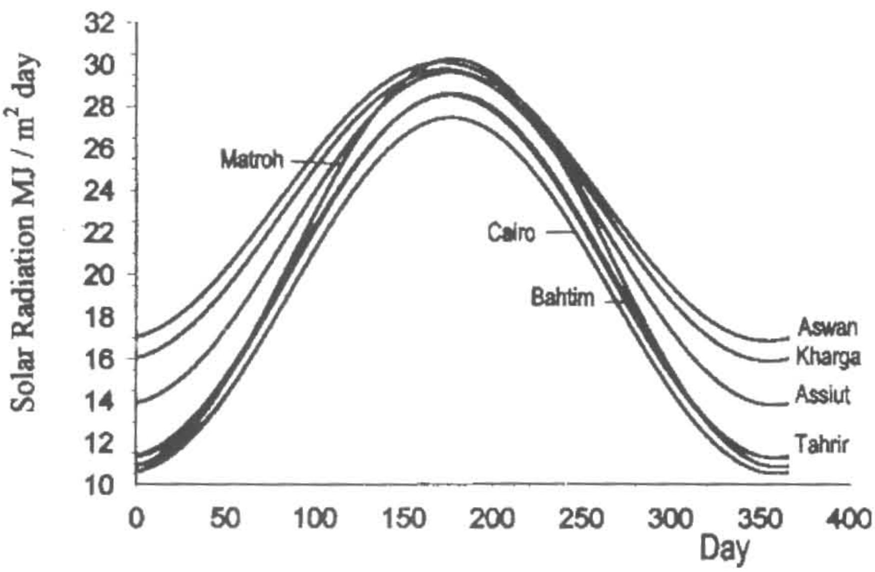

Fig. 2. Estimated representative equation for different stations

(*iii*) Third stage is applying the method of least squares approximation (Kouremenos *et al.*, 1985, Georald and Wheatley, 1984) between different latitudes and the corresponding monthly average obtained from the second stage to get the different monthly coefficients of the nonlinear equation.

For estimation the monthly average GSR, an equation is suggested in the following form:

$$G_M = A_{0M} + A_{1M}\phi + A_{2M}\phi^2 + A_{3M}\phi^3 + A_{4M}\phi^4 \qquad (1)$$

Where, G_M is the monthly average value of the estimated GSR in MJ/m² corresponding to the month M

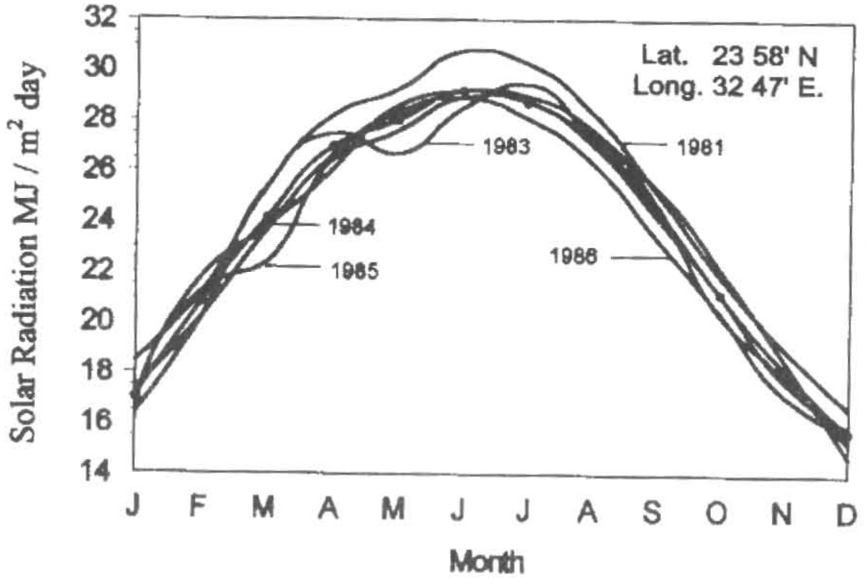

Fig. 3. Estimated solar radiation for Aswan

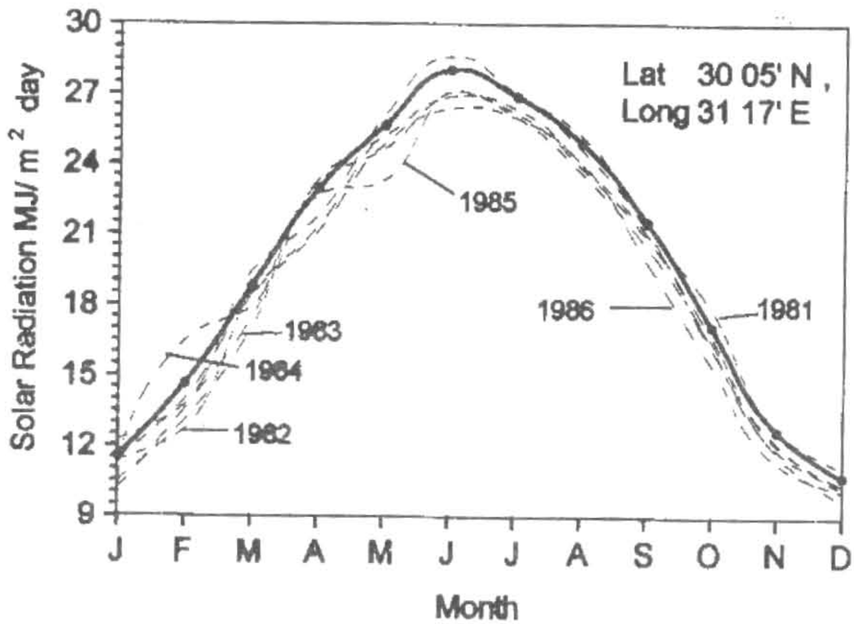

Fig. 4. Estimated solar radiation for Cairo

(M is January, February, ...), ϕ is the latitude in radian. A_{0M}, A_{1M}, A_{2M}, A_{3M} and A_{4M} are the monthly coefficients.

3. Results and discussion

Fourier analysis was applied, to the annual solar radiation in the period 1981-86 and for different latitudes in Egypt, to obtain the annual representative equation for each year and the TATF for each station (Tadros and Shaltout, 1990). Fig. 1 shows (as example) the published data and the corresponding representative equation for El-Arish station and for the year 1986. Fig. 2 shows the TATF for 7 stations in Egypt as obtained by Tadros and Shaltout (1990).

TABLE 1

The monthly coefficients of estimated equation

Month	A_{0M}	A_{1M}	A_{2M}	A_{3M}	A_{4M}
Jan	-138.4771	651.2980	401.6181	-4386.257	4371.313
Feb	-261.4302	1102.9000	884.0037	-7630.252	7338.980
Mar	-177.9979	824.6924	575.8751	-5677.960	5617.165
Apr	-311.7566	1316.2020	1064.8190	-9163.619	8901.320
May	-154.0047	703.3248	564.4849	-4831.505	4659.688
Jun	-169.7472	756.5549	614.3708	-5139.532	4935.850
Jul	-305.0124	1278.0650	1084.5680	-8976.324	8699.503
Aug	-336.5925	1381.2460	1170.0420	-9552.691	9163.659
Sep	-275.7087	1144.1960	961.9703	-7899.848	7562.862
Oct	-100.0840	475.5236	373.8110	-3236.057	3064.172
Nov	- 60.4486	368.7665	141.2527	-2423.100	2517.514
Dec	4.9595	111.7733	- 108.9469	- 519.251	688.676

TABLE 2

Comparison between monthly estimated and monthly published data (MJ/m²) for Sidi -Barrani

Month	Estimated value	1985		1986		1987	
		Publi-shed	Dev. %	Publi-shed	Dev. %	Publi-shed	Dev. %
Jan	11.51	11.35	1.41	11.52	-0.09	11.22	2.58
Feb	14.73	13.81	6.66	14.63	0.68	14.67	0.41
Mar	19.21	18.87	1.80	18.92	1.58	17.59	9.21
Apr	24.39	24.79	-1.61	23.13	5.45	23.69	2.95
May	26.22	24.44	7.28	26.81	-2.20	24.82	5.64
Jun	28.89	29.44	-1.87	26.98	7.08	28.64	0.87
Jul	28.87	29.40	-1.80	28.09	2.78	28.10	2.74
Aug	26.44	26.17	1.03	25.73	2.76	25.78	2.56
Sep	22.45	22.50	-0.22	21.43	4.76	--	--
Oct	16.50	16.30	1.23	15.40	7.14	17.19	-4.01
Nov	12.33	12.53	-1.60	11.16	10.48	12.72	-3.07
Dec	10.07	9.29	8.40	10.38	-2.99	--	--
Annual	20.13	19.91	1.10	19.52	3.13	20.44	-1.52

TABLE 3

Comparison between monthly estimated and monthly published data (MJ/m²) for El -Arish

Month	Estimated value	1986		1987	
		Published	dev. %	Published	dev. %
Jan	11.39	12.82	-11.15	12.31	-7.47
Feb	14.54	15.26	- 4.71	15.70	-7.39
Mar	18.96	20.09	- 5.65	18.73	1.23
Apr	23.83	22.50	5.91	24.88	-4.22
May	25.98	27.71	- 6.24	26.94	-3.56
Jun	28.57	28.92	- 1.21	28.86	-1.00
Jul	28.18	28.51	- 1.16	28.01	0.61
Aug	25.86	26.18	- 1.22	25.58	1.09
Sep	22.06	21.71	1.61	22.11	-0.23
Oct	16.58	16.84	- 1.54	16.13	2.79
Nov	12.34	12.40	- 0.48	13.23	-6.73
Dec	10.20	11.29	- 9.65	9.96	2.41
Annual	19.87	20.35	- 2.36	20.20	-1.63

TABLE 4

Coincidence percentage of the published SRD with that estimated from equation (1) for different stations

Stations	Location	Total months	No. of months ≤ ± 7%	Coincidence percentage
Aswan	Lat. 23°58' N, Long. 32° 47' E	60	60	100
Kharga	Lat. 25° 27' N, Long. 30° 32' E	72	70	97.2
Assiut	Lat. 27° 03' N, Long. 31° 03' E	60	57	95
Cairo	Lat. 30° 05' N, Long. 31° 17' E	72	59	82
Bahtim	Lat. 30° 08' N, Long. 31° 15' E	72	66	91.7
Tahrir	Lat. 30°39' N, Long. 30° 42' E	60	54	90
Matrouh	Lat. 31°20' N, Long. 27° 13' E	60	53	88.3

The application of the least square approximation (Kouremenos *et al.*, 1985, Georald and Wheatley, 1984) correlating the monthly averages (obtained from TATF) with the different latitudes, allows to obtain the monthly coefficients as in Table 1.

Fig.3 for Aswan and Fig.4 for Cairo, as an example, show the monthly average of the published data for different years (dotted lines) and the monthly estimated solar radiation according to equation (1) (marked solid line).

Also, to illustrate the validity of equation (1), the estimated solar radiation values for Sidi-Barrani of latitude 31° 38′ N (0.552 radian) and for El-Arish of latitude 31° 16′ N (0.5458 radian) are compared with the published data for the available years. Tables 2 and 3 give the estimated, published data and the deviation between them.

From Table 3 one can see that the coincidence, between the estimated values and the published data with deviation of accuracy about ± 7%, is about 91.2%. Also, from Table 3 the coincidence is about 91.7%.

Table 4 shows the percentage of coincidence for the real measured published monthly averages of SRD with that estimated from equation (1), with deviation less than ±7%, for different 7 stations.

From Table 4 it is clear that all published measured SRD for Aswan, occur within the accuracy ± 7%.

Also, the deviation for all months is about ± 7% for Kharga except for two months. For December 1981, it is –9% and for March 1985, it is 8%. This may be attributed to dust storms in the western desert in Egypt.

For Assiut, there are three months with deviation more than ± 7%. These months are February 1984 (-8.4%), December 1985 (8%) and November 1986 (8.8%).

Cairo has the lowermost coincidence percentage for SRD, of some months for different years, from the estimated values. Two months have deviations about 8.5% (April and September 1986), and six months have deviation about 10% (January 1985, 1986, March, May and December 1985, October 1986). Also, three months have about 11% (February 1984, 1985 and November 1986), one month has deviation about 13.5% (January 1983), and the last one has deviation about 15% (February 1982). Most of these months occur in the two years, 1985 and 1986, in the winter, spring and autumn seasons. This may be attributed to the increase of the pollution in Cairo in all seasons, and due to Khamasin wind in spring.

The pollution in Bahtim is lower than that in Cairo. Therefore only 6 months have deviations more than ± 7%. These months are May 1985 with deviation 8.2%, January, March 1981 and February 1982 have 10%. December 1985 has 11% and February 1984 has –15%.

Tahrir has 6 months with deviations greater than ± 7%. December 1983 and October 1986 have deviations about 8% and February 1981 has –9.4%, December 1981 has –12.5%, January 1981 has –14% and February 1984 has deviation –16%.

For Mersa Matrouh there are 7 months with deviations greater than ± 7%. These months are April 1984, which has –8.1%, October and December 1983 have –9.4%, October 1984 has –10.2%, April 1982 has 11.7%, January 1983 has 16.3% and February 1984 has –18.8%.

3. Conclusion

The GSR can be estimated by using the suggested nonlinear equation (1) and Table 1 in this work. From 514 months of different latitudes and years, in the period 1981-86, (stations of Sidi-Barrani in the period 1985-87 and El-Arish in 1986-87 were not used in determination of the equation coefficients but used to verify the estimated results of the nonlinear equation), there were 47 months which have a deviation greater than ± 7%, while the other 467 months have a deviation less than ± 7%, which indicates that the coincidence of the estimated values with the published SRD for all latitudes and over all the given period is about 90.8%. the large deviations noted are, in most of the cases, due to prevailing sky conditions being different from the normal conditions, due to natural and man-made pollution and unusual clouding activity.

The suggested equation can be used for any latitude in Egypt where cloud factor is not a dominant one. It is also recommended to obtain other monthly coefficients if data of a longer period is available. The presentation of a large number of latitudes and years allow to obtain different groups monthly coefficients depending on the climatic solar radiation regime of different regions in Egypt.

References

Alberto, C.S. and Recio, J.M., 1984, "Fourier analysis of meteorological data to obtain a Typical Annual Time Function", *Solar Energy*, **32**, 4, 479-488.

Atlas, Arab Organization for Agricultural Development, Agroclimatic study in the Arab countries, Khartoum (1976).

Balling, R.C., Jr., 1983, "Harmonic analysis of monthly insolation levels in United States", *Solar Energy*, **31**, 3, 293-298.

Georald, C.F. and Wheatley, P.O., 1984, "Applied Numerical Analysis", 3rd edition, Addison-Wesley publishing Company, 531-539.

Helwa, N.H., Tadros, M.T.Y. and Shaltout, M.A.M., 1988, "Simple method for computation of Solar Radiation for different latitudes in Egypt", *Indian Engineer (I) Journal-IDP*, **68**, 53-60.

Khogali, A., Ramadan, M.R.I., Ali, Z.E.H. and Fattah, Y.A., 1983, "Global and diffuse Solar irradiance in Yemen (Y.A.R.)", *Solar Energy*, **31**, 1, p5.

Kouremenos, D.A., Antonopoulos, K.A. and Domazakis, E.S., 1985, "Solar Radiation Correlation for the Athens, Greece area," *Solar Energy*, **35**, 3, 259-269.

Matveev, Yo.L. and Titov, V.I., 1985, "Data of structure and climatic changes of global cloud fields", Obninsk, 99 (in Russian).

Matveev, Yo. L., Matveev, L.T. and Soldatenko, S.A., 1986, "Global cloud fields", Leningrad, Hydrometeoizdat (in Russian).

Solar Radiation and Radiation Balance Data (1981-87), The World Net Work, Voeikov Main Geophysical Observatory, Leningrad, USSR.

Tadros, M.T.Y. and Shaltout, M.A.M., 1990, " Fourier analysis of daily solar radiation data in Egypt", Second Cairo International Symposium on Renewable Energy Sources, Cairo-Egypt, 1, 11-20.

Tadros, M.T.Y., 1990, "Comparison between linear and nonlinear equation for estimation of the solar radiation for different latitudes in Egypt", Second Cairo International Symposium on Renewable Energy Sources, Cairo-Egypt, 1, 45-55.