ROYAL OBSERVATORY, HONG KONG

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GLOBAL SOLAR RADIATION IN HONG KONG

by

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1. INTRODUCTION

Global solar radiation is the amount of direct and scattered solar energy that reaches the surface of the earth. An analysis of the daily measurements of global solar radiation and sunshine duration for the period 1958 - 1962 can be found in Sham (1964).

In recent years, the accurate determination of heating and cooling loads in buildings, and the design and evaluation of solar energy systems have become increasingly important. Solar radiation data are required for such calculations and have thus become increasingly useful to engineers. This report presents the results of an analysis of daily global solar radiation data for the period 1958 - 1983. Hourly solar radiation data which became available since December 1978 were also used. The variation of global solar radiation with the amount of cloud cover and sunshine was examined.

2. MEASUREMENTS OF GLOBAL SOLAR RADIATION AND SUNSHINE DURATION

(a) Global solar radiation

From 1 June to 31 December 1958, daily measurements of global solar radiation were made at the Royal Observatory using a bimetallic actinograph, British Meteorological Office Pattern Mark III. The actinograph was moved to King's Park Meteorological Office in January 1959. It was damaged during the passage of Typhoon Wanda in August 1962 and was replaced in December 1963. From January 1970 to November 1978, readings were taken from a thermo-electric pyranometer made by Lintronic Ltd. together with an integrating counter. Since then, the bimetallic actinograph has been used as a standby unit. From December 1978 onwards, a thermo-electric pyranometer manufactured by Kipp and Zonen together with an integrating counter has been employed to obtain both the daily and hourly global solar radiation measurements.

Details of instrument calibration and correction, estimation of missing data for days on which the instrument(s) in use at the time was unserviceable, can be found in the Royal Observatory "Meteorological Results, Part I, Surface Observations".

Solar radiation data are expressed in MJ m^{-2}. Hourly values are based on the local standard time, centred on the hour.

(b) Duration of sunshine

Since 1885, duration of sunshine was measured with a Campbell-Stokes recorder installed on the roof of the Royal Observatory 1883 Building. Another Campbell-Stokes recorder was installed on the roof of the existing radiosonde operation room at King's Park Meteorological Office in July 1957. Recording at the Royal Observatory continued until the end of 1960 when high-rise buildings in its vicinity made the recording no longer practicable. Starting from 1961, sunshine duration was obtained from the recorder at King's Park Meteorological Office. In 1968, owing to the installation of a radiosonde aerial system at King's Park which cut off some of the sunshine, the recorder was moved to the roof of the satellite workshop at King's Park Meteorological Office.

Based on apparent solar time, sunshine duration is expressed in fractions of an hour over a 60-minute interval centred on the hour.

3. DATA ANALYSIS

(a) Analysis of global solar radiation data

The daily global solar radiation data for the period 1958-1983 inclusive were analysed. The radiation data were classified into intervals of 2 MJ $m^{-2}day^{-1}$. The percentage and cumulative frequency distribution are presented in Table 1(a) and 1(b) respectively.

The percentage frequency distribution shows a maximum in the interval 14-18 MJm^{-2}. This is slightly less than that given by Sham (1964) for the period 1958 - 1962. From the distribution of the percentage frequency, one can easily infer that relatively strong insolation occasions are most frequent in July while weak insolation occasions occur in February.

The daily average shows a maximum in July and a minimum in February (Table 2).

The diurnal variation of global solar radiation for January to June and July to December are shown in Fig. 1(a) and Fig 1(b) respectively. Throughout the year, the daily maximum occurs at around 1300H. Maximum and minimum diurnal variation occur in July and February respectively.

(b) Correlation of global solar radiation with the cloud amount in different height ranges

With the availability of hourly global solar radiation data since December 1978, correlation of the amount of global solar radiation with the cloud amount in different height ranges was made. This analysis made use of the hourly global solar radiation measured at King's Park and the cloud cover observed at the Royal Observatory. Though there may be slight discrepancy in the cloud amount observed at the two sites, this discrepancy is expected to be small in view of the close proximity of the two stations (around 1 km).

Since low clouds generally absorb more radiation than high clouds (WMO 1981 pp. 133-134), the total amount of clouds below a certain height was correlated with the global solar radiation measured. Height increments of 2 000 ft and 5 000 ft intervals were used for cloud heights below 10 000 ft and between 10 000 ft and 25 000 ft respectively. The variation of correlation coefficients with cloud heights for some chosen time and months is presented in Fig. 2. The correlation increases with height up to 15 000 ft. Beyond this height, the correlation remains steady for cloud base heights up to 25 000 ft. However, in general, the correlation decreases when the total cloud amount, with high clouds included, was used. This indicates that as the high clouds absorb less radiation, a different regression relation exists between the cloud amount and the radiation.

The global solar radiation was fitted quadratically against the amount of cloud below 25 000 ft, which encompasses all low and medium clouds. In cases where there is some overlapping of low and medium clouds resulting in their sum being greater than the total cloud amount, the total cloud amount was used. The regression coefficients of the equation

$$G = A_0 + A_1N + A_2N^2$$

where N is the number of oktas of cloud cover, are given in Table 3. The correlation coefficient is highest around noon, with values generally greater than 0.80. On the other hand, the correlation may be as low as 0.60 at 0800H and 0.22 at 1800H.

The regression equations were used to predict the global solar radiation on some selected months in 1984. The percentage deviations from the measured value are given in Table 4. These values give the likely errors in estimating global solar radiation from low and medium cloud cover.

(c) Relationship between global solar radiation and sunshine

Statistics of mean monthly sunshine are presented in Table 2. On average, sunshine duration is longest in July and shortest in March. The percentage of possible sunshine was obtained by dividing the mean daily hours of sunshine by the maximum possible duration extracted from Smithsonian Meteorological Tables (1963). From July to December, the percentage exceeds 50%.

The regression equation relating the monthly sunshine duration with the global solar radiation given by Sham (1964) for the period 1958-1964, using 44 data points, was

$$Q/Q_A = 0.220 + 0.575\ S/S_O$$

where Q_A is the total radiation that would be received if the atmosphere were perfectly transparent and S_o the maximum possible duration of sunshine. The Q_A and S_o values for each month were adopted from Angot (Brunt 1963) and Smithsonian Meteorological Tables.

As more data are now available, the same procedure was repeated on a monthly basis for the period 1958-1983. Regression results and correlation coefficients are presented in Table 5. Note that in the calculation, Q_A was replaced by Q_o, the daily extraterrestrial radiation on a horizontal surface. Q_o was obtained by linear interpolating the values given in 5^o-latitude intervals in WMO (1981). From table 5, it can be seen that the correlation coefficient varies with the time of the year, from 0.9 in February to just 0.51 in July.

4. CONCLUSION

Analysis of daily global solar radiation for the period 1958 - 1983 and of hourly global solar radiation for the period 1979 - 1983 was carried out and results are presented in this report.

An attempt was made to correlate cloud amounts with measured global solar radiation. The dependence of global solar radiation on clouds with bases within different height ranges was investigated. The highest correlation was obtained with clouds of base heights below 25 000 ft. and the correlation was found to vary according to the time of the day.

Correlation was also made between global solar radiation and amount of sunshine on a monthly basis. The correlation coefficient ranges from 0.51 in July to 0.90 in February.

5. FUTURE WORK

Global solar radiation is composed of two parts: direct and diffuse radiation. The design of solar systems and air-conditioning loads in buildings often requires the estimation of direct and diffuse radiation on vertical and inclined surfaces. This necessitates the separation of global solar radiation into the two respective components by measuring either the diffuse or direct solar radiation. However, the necessary instruments are lacking at the Royal Observatory at present. So until a reasonably long period of such measurement is available, it is deemed necessary to compare the global solar radiation in Hong Kong with that of a neighbouring station, e.g. Macau, where either direct or diffuse radiation is measured. The comparison should be made with a view to transferring the data obtained from that station for use in Hong Kong.

REFERENCE

1.	Brunt, D.	1963	"Physical and Dynamical Meteorology", Cambridge University Press, p. 112.
2.	List, R.J.	1963	Smithsonian Meteorological Tables, Smithsonian Institution, p. 507.
3.	Sham, P.	1964	Total Solar and Sky radiation in Hong Kong, Royal Observatory Tech. Note No. 22.
4.	World Meteorological Organization	1981	Meteorological aspects of the utilization of solar radiation as an energy source, WMO Tech. Note No. 172.

TABLE 1(a) PERCENTAGE FREQUENCY DISTRIBUTION OF DAILY GLOBAL SOLAR RADIATION

Month $MJm^{-2}day^{-1}$	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0-2	1.7	5.2	3.3	1.3	1.3	1.1	0.8	1.4	4.9	5.3	5.4	5.4	3.1
2-4	6.7	12.2	9.5	5.5	2.9	1.6	1.4	2.0	2.5	3.4	3.3	3.9	4.6
4-6	9.5	10.1	10.7	8.9	4.6	4.1	3.8	3.0	2.9	3.7	3.5	6.9	6.0
6-8	10.0	9.9	10.2	7.6	5.2	6.5	3.6	4.6	4.9	4.7	5.4	7.8	6.7
8-10	9.4	8.8	10.0	8.2	7.1	5.7	2.8	6.0	5.3	6.3	4.9	8.1	6.9
10-12	9.1	6.9	7.5	8.3	7.1	8.1	5.3	4.0	6.0	5.6	7.5	9.1	7.0
12-14	12.3	7.0	7.4	7.3	7.3	5.7	4.2	4.5	7.5	6.6	8.9	18.0	8.1
14-16	13.6	9.7	9.3	9.5	8.8	8.5	6.6	7.7	8.4	10.0	19.0	21.1	11.0
16-18	13.3	10.4	8.9	10.8	8.5	10.3	8.5	11.7	10.6	13.3	21.8	13.6	11.8
18-20	8.7	7.3	7.4	9.3	10.0	10.5	8.9	11.0	11.6	14.8	12.0	4.3	9.7
20-22	4.4	5.6	6.8	7.1	9.5	8.9	9.0	11.9	12.8	11.3	5.8	1.8	7.9
22-24	0.9	5.4	5.2	5.2	8.8	9.2	11.9	10.9	9.9	8.6	2.4	0.0	6.5
24-26	0.4	1.2	2.2	4.8	8.2	7.6	11.0	8.9	8.4	4.9	0.1	0.0	4.8
26-28	0.0	0.3	1.1	4.5	5.5	6.3	13.0	8.1	3.5	1.4	0.0	0.0	3.6
28-30	0.0	0.0	0.2	0.9	3.1	3.4	6.1	3.5	0.7	0.0	0.0	0.0	1.5
30-32	0.0	0.0	0.2	0.7	1.4	1.4	2.5	0.8	0.1	0.0	0.0	0.0	0.6
32-34	0.0	0.0	0.0	0.1	0.3	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.1
34-36	0.0	0.0	0.1	0.0	0.4	0.5	0.0	0.0	0.0	0.1	0.0	0.0	0.1

TABLE 1(b) CUMULATIVE PERCENTAGE FREQUENCY TABLE OF DAILY GLOBAL SOLAR RADIATION

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$MJm^{-2}day^{-1}$												
< 2	1.7	5.2	3.3	1.3	1.3	21.1	0.8	1.4	4.9	5.3	5.4	5.4
< 4	8.4	17.4	12.8	6.8	4.2	2.7	2.2	3.4	7.4	8.7	8.7	9.3
< 6	17.9	27.5	23.5	15.7	8.8	6.8	6.0	6.4	10.3	12.4	12.2	16.2
< 8	27.9	37.4	33.7	23.3	14.0	13.3	9.6	11.0	15.2	17.1	17.6	24.0
< 10	37.3	46.2	43.7	31.5	21.1	19.0	12.4	17.0	20.5	23.4	22.5	32.1
< 12	46.4	53.1	51.2	39.8	28.2	27.1	17.7	21.0	26.5	29.0	30.0	41.2
< 14	58.7	60.1	58.6	47.1	35.5	32.8	21.9	25.5	34.0	35.6	38.9	59.2
< 16	72.3	69.8	67.9	56.6	44.3	41.3	28.5	33.2	42.4	45.6	57.9	80.3
< 18	85.6	80.2	76.8	67.4	52.8	51.6	37.0	44.9	53.0	58.9	79.7	93.9
< 20	94.3	87.5	84.2	76.7	62.8	62.1	45.9	55.9	64.6	73.7	91.7	98.2
< 22	98.7	93.1	91.0	83.8	72.3	71.0	54.9	67.8	77.4	85.0	97.5	100.0
< 24	99.6	98.5	96.2	89.0	81.1	80.2	66.8	78.7	87.3	93.6	99.9	100.0
< 26	100.0	99.7	98.4	93.8	89.3	87.8	77.8	87.6	95.7	98.5	100.0	100.0
< 28	100.0	100.0	99.5	98.3	94.8	94.1	90.8	95.7	99.2	99.9	100.0	100.0
< 30	100.0	100.0	99.7	99.2	97.9	97.5	96.9	99.2	99.9	99.9	100.0	100.0
< 32	100.0	100.0	99.9	99.9	99.3	98.9	99.4	100.0	100.0	99.9	100.0	100.0
< 34	100.0	100.0	99.9	100.0	99.6	99.5	100.0	100.0	100.0	99.9	100.0	100.0
< 36	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE 2 MONTHLY STATISTICS OF DAILY SUNSHINE, GLOBAL SOLAR RADIATION AND CLOUD COVER

Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Global solar radiation (MJ/M^2)	mean	12.12	11.49	11.96	14.43	17.04	17.33	19.88	18.21	17.20	16.28	14.06	12.43
	maximum	24.47	26.63	30.34	33.07	34.50	35.63	33.77	31.45	30.33	27.71	24.48	21.99
	minimum	0.61	0.43	0.32	1.07	0.34	0.24	0.93	0.48	0.48	0.55	0.54	1.39
	Q_o	25.78	29.73	34.29	37.79	39.51	39.95	39.58	28.23	35.43	31.21	28.64	24.52
Sunshine Duration (hr)	mean	4.8	3.6	3.1	3.9	5.1	5.3	7.0	6.6	6.5	6.9	6.2	5.6
	possible	10.9	11.4	12.0	12.6	13.2	13.5	13.4	12.9	12.3	11.7	11.1	10.8
	percent	44.0	31.6	25.8	31.0	38.6	39.3	52.2	51.2	52.8	59.0	55.9	51.9
Mean percentage of cloud cover at R.O.		59	71	76	76	73	75	66	66	62	52	52	52

TABLE 3 REGRESSION AND CORRELATION COEFFICIENTS OF EQUATION $G = A_o + A_1N + A_2N^2$

Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0800H	A_o	0.086	0.129	0.307	0.601	0.838	0.751	0.681	0.546	0.735	0.564	0.269	0.128
	A_1	0.011	0.024	0.016	0.046	0.014	0.074	0.071	0.109	-0.051	-0.034	0.022	0.005
	A_2	-0.003	-0.005	-0.006	-0.014	-0.012	-0.018	-0.017	-0.021	-0.002	-0.003	-0.006	-0.002
	r	-0.601	-0.730	-0.739	-0.756	-0.760	-0.684	-0.673	-0.649	-0.626	-0.738	-0.686	-0.626
0900H	A_o	0.566	0.619	0.797	1.034	1.505	1.429	1.370	1.217	1.354	1.283	0.946	0.577
	A_1	0.053	0.081	0.093	0.159	0.053	0.057	0.103	0.123	0.052	-0.011	0.026	0.003
	A_2	-0.014	-0.018	-0.021	-0.032	-0.024	-0.023	-0.030	-0.030	-0.023	-0.015	-0.015	-0.008
	r	-0.799	-0.809	-0.708	-0.719	-0.798	-0.672	-0.695	-0.712	-0.677	-0.805	-0.825	-0.787
1000H	A_o	1.186	1.222	0.991	1.767	2.097	2.259	2.091	1.831	1.972	1.979	1.599	1.310
	A_1	0.091	0.162	0.299	0.159	0.138	0.006	0.111	0.176	0.047	0.023	0.039	0.027
	A_2	-0.026	-0.036	-0.048	-0.032	-0.041	-0.027	-0.039	-0.046	-0.027	-0.027	-0.024	-0.018
	r	-0.838	-0.797	-0.731	-0.795	-0.800	-0.778	-0.757	-0.728	-0.669	-0.825	-0.841	-0.805
1100H	A_0	1.725	1.732	1.970	2.433	2.756	2.473	2.595	2.409	2.577	2.584	2.100	1.829
	A_1	0.162	0.227	0.189	0.233	-0.093	0.214	0.149	0.246	0.034	-0.052	0.065	0.033
	A_2	-0.040	-0.050	-0.047	-0.059	-0.045	-0.055	-0.051	-0.062	-0.031	-0.024	-0.033	-0.024
	r	-0.823	-0.825	-0.814	-0.801	-0.818	-0.754	-0.783	-0.780	-0.675	-0.849	-0.841	-0.805
1200H	A_0	2.126	2.414	2.345	2.860	3.098	3.007	2.744	3.118	2.813	2.889	2.385	2.111
	A_1	0.125	0.108	0.296	0.207	0.139	0.090	0.270	0.075	0.120	0.010	0.061	0.092
	A_2	-0.039	-0.044	-0.064	-0.060	-0.054	-0.044	-0.069	-0.047	-0.048	-0.036	-0.036	-0.033
	r	-0.816	-0.886	-0.804	-0.793	-0.778	-0.727	-0.774	-0.770	-0.721	-0.852	-0.850	-0.822
1300H	A_0	2.259	2.384	2.604	2.936	3.091	2.850	3.047	3.170	2.916	2.931	2.399	2.189
	A_1	0.142	0.275	0.229	0.239	0.140	0.223	0.179	0.107	0.124	-0.011	0.130	0.122
	A_2	-0.042	-0.063	-0.059	-0.065	-0.052	-0.061	-0.061	-0.053	-0.050	-0.033	-0.047	-0.038
	r	-0.794	-0.819	-0.840	-0.856	-0.752	-0.751	-0.787	-0.777	-0.757	-0.869	-0.855	-0.820
1400H	A_0	2.094	2.174	2.610	2.598	2.858	2.800	2.734	2.708	2.903	2.697	2.182	2.034
	A_1	0.189	0.381	0.185	0.286	0.179	0.217	0.260	0.238	-0.002	-0.029	0.095	0.070
	A_2	-0.047	-0.074	-0.054	-0.067	-0.056	-0.060	-0.066	-0.061	-0.034	-0.030	-0.038	-0.030
	r	-0.811	-0.795	-0.788	-0.818	-0.789	-0.810	-0.794	-0.731	-0.773	-0.862	-0.838	-0.837
1500H	A_0	1.767	1.868	2.259	2.349	2.264	2.636	2.577	2.487	2.335	2.193	1.785	1.623
	A_1	0.148	0.304	0.160	0.190	0.289	0.169	0.170	0.195	0.047	-0.053	0.045	0.101
	A_2	-0.039	-0.061	-0.047	-0.053	-0.063	-0.053	-0.053	-0.055	-0.034	-0.020	-0.027	-0.031
	r	-0.780	-0.790	-0.828	-0.825	-0.760	-0.827	-0.808	-0.803	-0.800	-0.864	-0.831	-0.808
1600H	A_0	1.259	1.507	1.620	1.770	1.794	2.015	1.916	2.003	1.635	1.480	1.151	1.067
	A_1	0.104	0.140	0.142	0.171	0.154	0.139	0.218	0.087	0.078	-0.006	0.029	0.045
	A_2	-0.027	-0.037	-0.037	-0.044	-0.040	-0.041	-0.050	-0.033	-0.030	-0.018	-0.018	-0.018
	r	-0.758	-0.863	-0.839	-0.808	-0.739	-0.777	-0.814	-0.712	-0.749	-0.863	-0.843	-0.798
1700H	A_0	0.631	0.863	0.973	1.196	1.239	1.316	1.371	1.219	0.987	0.694	0.448	0.438
	A_1	0.048	0.083	0.059	0.054	0.083	0.143	0.156	0.093	0.007	-0.001	0.003	0.019
	A_2	-0.014	-0.022	-0.020	-0.023	-0.025	-0.034	-0.036	-0.025	-0.013	-0.009	-0.006	-0.008
	r	-0.741	-0.846	-0.825	-0.845	-0.784	-0.785	-0.755	-0.656	-0.724	-0.788	-0.776	-0.786
1800H	A_0	0.106	0.240	0.345	0.504	0.542	0.782	0.665	0.561	0.243	0.114	0.019	0.028
	A_1	0.018	0.026	0.005	0.021	0.034	0.023	0.115	0.031	0.021	-0.016	0.003	-0.002
	A_2	-0.004	-0.007	-0.005	-0.010	-0.011	-0.013	-0.023	-0.010	-0.006	0.000	0.000	0.000
	r	-0.518	-0.773	-0.818	-0.819	-0.689	-0.838	-0.680	-0.581	-0.542	-0.476	-0.223	-0.444

TABLE 4 PERCENTAGE DEVIATION OF CALCULATED GLOBAL SOLAR RADIATION FROM MEASURED VALUES USING REGRESSION EQUATION IN TABLE 3

Month		Jan	Apr	Jul
Hourly	0900H	23.2	25.1	32.4
	1200H	17.1	30.6	23.6
	1500H	16.1	33.2	24.2
Daily		14.2	16.5	16.5

TABLE 5 MONTHLY REGRESSION AND CORRELATION COEFFICIENTS FOR THE EQUATION

$$G = a S + b$$

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
a	.5839	.7611	.6848	.6251	.5991	.4663	.4220	.4691	.6433	.4035	.4411	.3560
b	.2081	.1430	1689	.1882	.1993	.2433	.2623	.2303	.1600	.2880	.2437	.3148
r	.8651	.8986	.8405	.7326	.8465	.7094	.5061	.7851	.7857	.5789	.7111	.6829

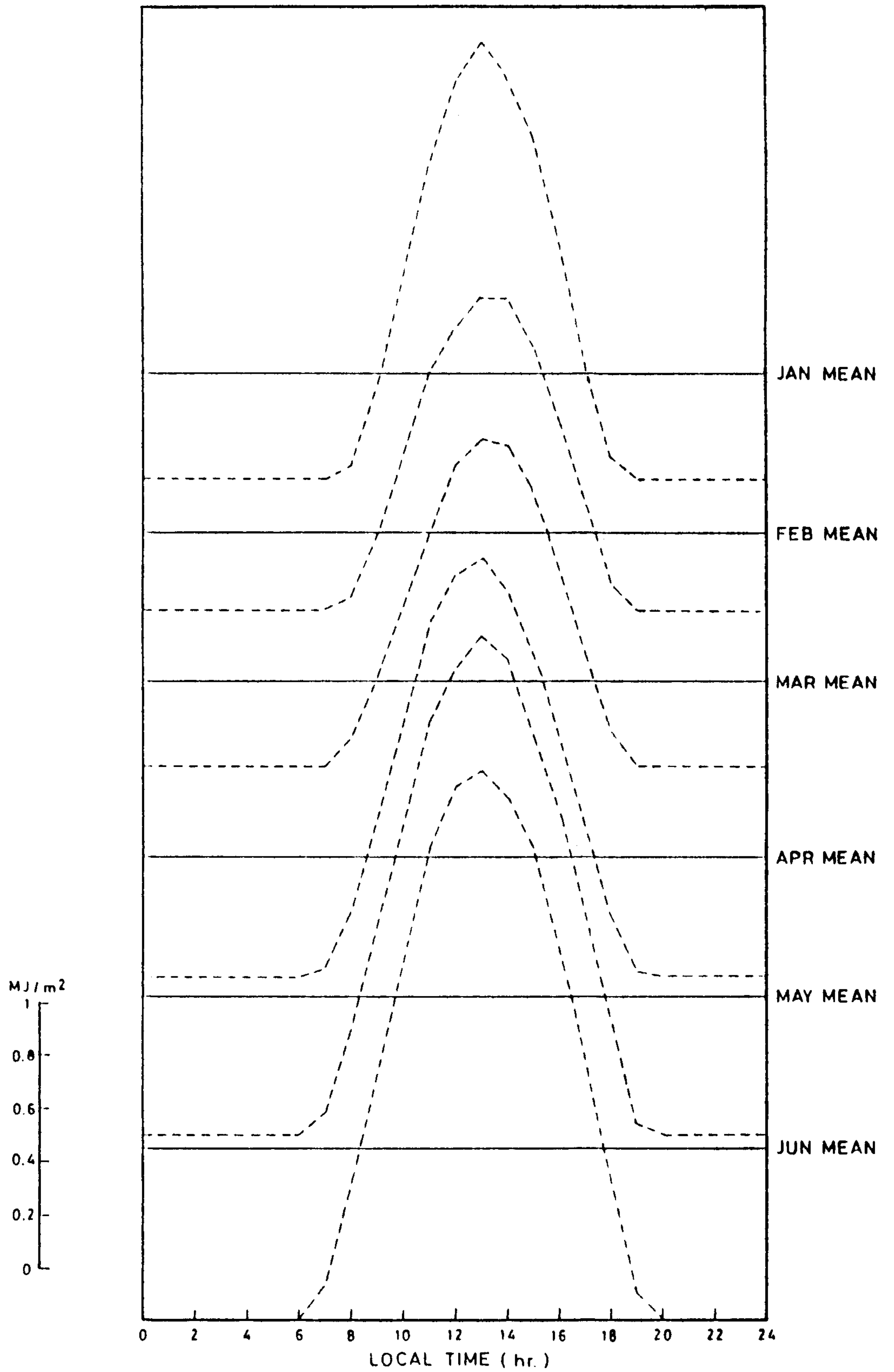

Fig 1a. Diurnal variation of global solar radiation of Hong Kong (January - June).

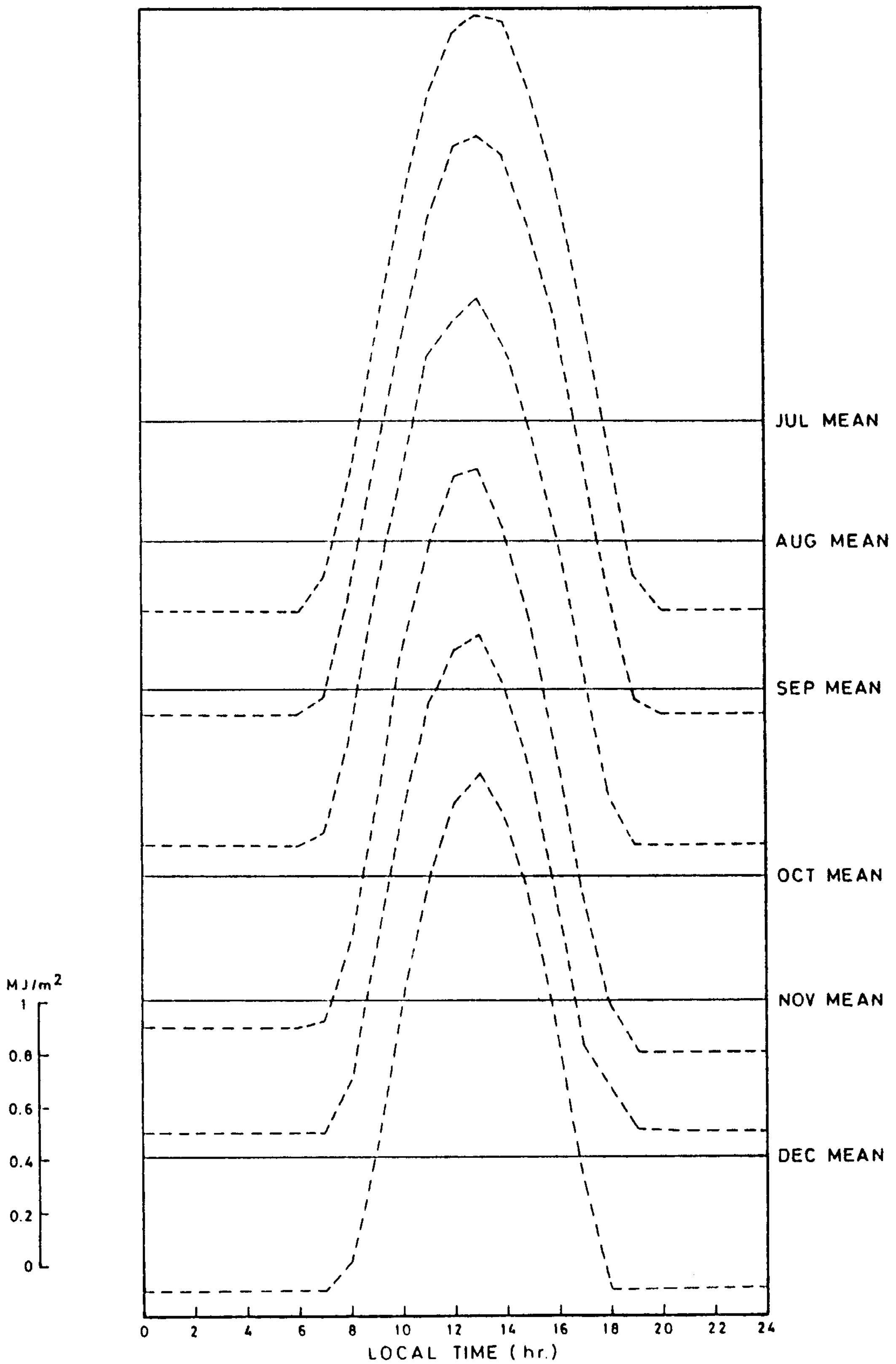

Fig 1b. Diurnal variation of global solar radiation of Hong Kong (July - December).

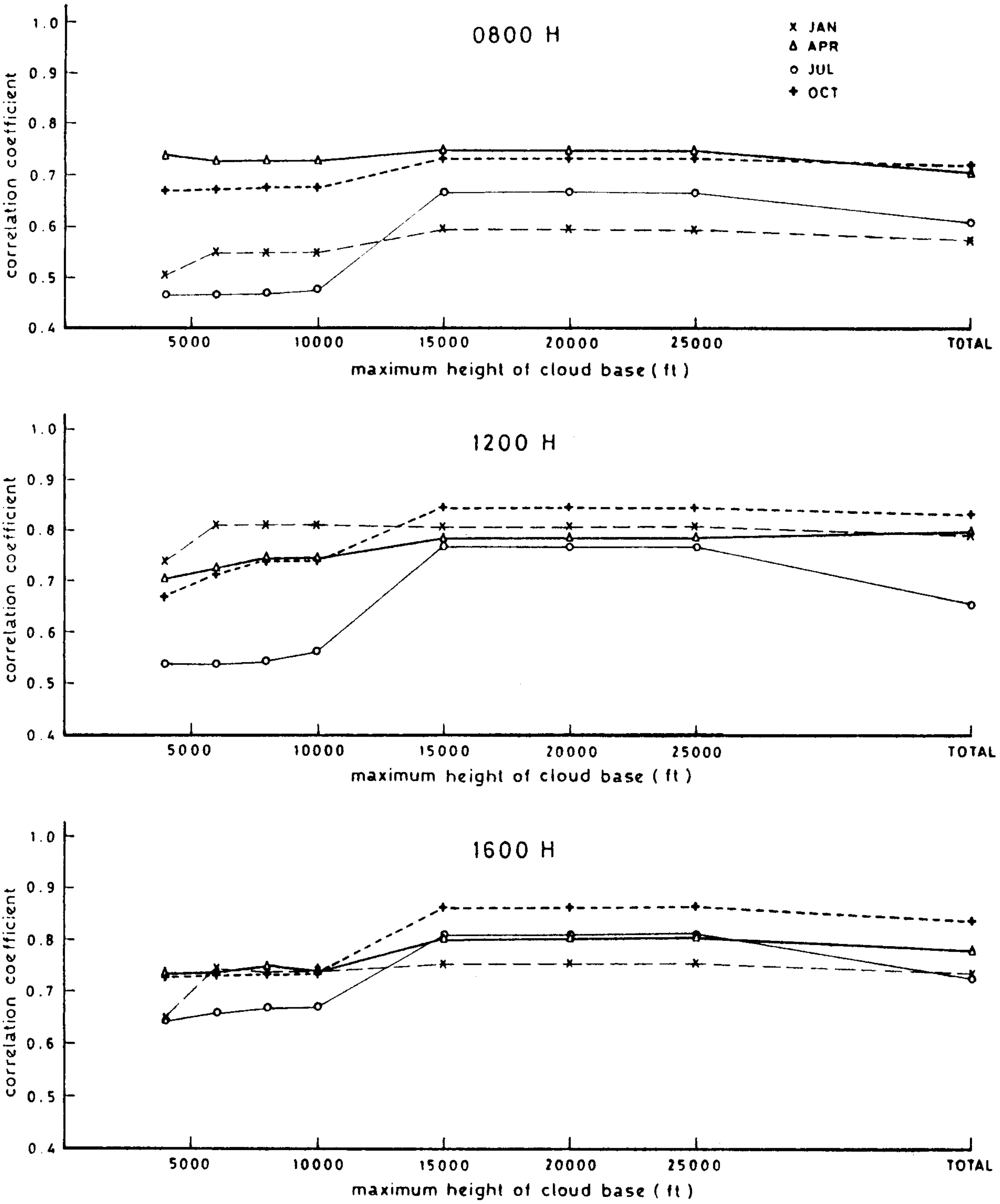

Fig 2. Variation of correlation coefficient with the maximum height of cloud base at some chosen hours and months.