SIMULATION OF HOURLY CLOUD COVER, SUNSHINE RATIO, AND SOLAR RADIATION THROUGHOUT A YEAR USING STATISTICAL QUANTITIES DERIVED FROM OBSERVED WEATHER DATA

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ABSTRACT

Using a statistical method, the relation between the hourly solar radiation TH and the hourly cloud cover CC, sunshine ratio SH, and rain and snow index RS was studied. On the basis of the results, a formula for predicting the value of TH as a function of CC, SH, and RS was drawn out.

A simulation program was also developed which can estimate the hourly values of CC, SH, and RS, throughout a year , if several statistical quantities indicating the characteristics of CC, SH, and RS and the relations among them are given as input data. In addition, the program numerically determines the indefinite parts of CC, SH, and RS by the Monte Carlo method as probability problems.

If the simulated CC, SH, and RS values are put in the formula for TH, then the TH value can be calculated. By the procedure stated above, CC, SH, and TH values were generated throughout a year by inputting statistical quantities picked out of the hourly weather observations at Kagoshima City in 1975.

The calculations were compared with the observations from several viewpoints of statistical characteristics, and the statistical characteristics of the calculations were found to correspond well with those actually observed.

1. INTRODUCTION

The hourly cloud cover CC, sunshine ratio SH, and rain and snow index RS can be simulated by the Monte Carlo method if several pieces of the statistical quantity indicating the respective characteristics and the relations among them are given[1,2]. In addition, the value of the hourly solar radiation TH can be calculated to a considerable accuracy using a prediction formula containing CC, SH, and RS[3]. Accordingly, if the value of TH is calculated using simulated CC, SH, and RS values, then the four hourly climate element values can be obtained on the basis of input statistical quantity. This paper explains the procedure for simulating the four climate elements and discusses the characteristics of the calculated four climate element values through out a year.

2. DEFINITION OF TERMINOLOGY AND SYMBOL

2. 1 TERMINOLOGY

(1) Appearance ratio for each rank

For the values of hourly cloud cover CC, hourly sunshine ratio SH, and rain and snow index RS, if the same value appears consecutively, we call the amount of hours 'continuation hours' here, and also call a group of the amounts in a range a 'rank'. The values of CC and RS are provided with 17 ranks and the value of SH, with 7 ranks. For the values of CC and RS, the ranges of continuation hours are 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 to 15, 16 to 20, 21 to 30, 31 to 40, 41 to 60, 61 to 100, and 101 or more and, for the value of SH, 1, 2, 3, 4, 5, and 6 or more. We call the ratios (%) of the hours of CC, SH, and RS belonging to their respective ranks to the total time an 'appearance ratio for each rank'.

(2) Block

For the values of hourly cloud cover CC, sunshine ratio SH and rain and snow index RS, we call their respective groups of data with specific continuation hours a 'block'.

2. 2 SYMBOL

CC : hourly cloud cover or block of cloud cover (CC=0: clear sky; CC=1 to 9: partly cloudy sky; CC=10: overcast sky)

SH : hourly sunshine ratio or block of sunshine ratio (SH=0: no sunshine for one hour; SH=0.1 to 0.9: sunshine for 10 to 90 % of one hour: SH= 1.0: sunshine for one hour)

RS : rain and snow index or block of rain and snow index (RS = 1: rainfall; RS = 2: snowfall; RS=3: snowfall without snowcover; RS= 4: no precipitation)

TH : hourly solar radiation measured on a horizontal plane (Kcal/(m^2h))

TH(SH, CC, RS) : TH as a function of SH, CC, and RS

THO : hourly solar radiation outside the atmosphere measured on a horizontal plane (Kcal/(m^2h))

CFN : correction coefficient for normalization (=0.95)

CFM : correction coefficient of scale (=1.022)

CFSF : correction coefficient of snowfall (=0.82)

CFSC(SH) : correction coefficient of snowcover at given SH (CFSC(SH=0)=1.48, CFSC(S=1.0)=1.04)

$\overline{CC}$(m) : mean value of cloud cover for month m

R(m, CC=0) : ratio (%) of the amount of cloud cover 10 arrearance hours for month m

WF1(CC) : ratio of the amount of cloud cover 1 to 9 appearance hours

RANK(CC,r) : ratio (%) of the amount of cloud cover CC appearance hours for each rank

WF2(CC_j/CC_i) : correction factor of the probability of the next block of cloud cover CC_j appearance predicted from present block of cloud cover CC_i

α(CC=0, t) : ratio (%) of the amount of cloud cover 0 appearance hours for each hour

$\overline{SH}$(m) : mean value of sunshine ratio for month m

R(m, SH=1.0) : ratio (%) of the amount of sunshine ratio 1.0 appearance hours for month m

WF1(SH) : ratio of the amount of sunshine ratio 0.1 to 0.9 appearance hours

RANK(SH, r) : ratio (%) of the amount of sunshine ratio SH appearance hours for each rank

WF2(SH_j/SH_i) : correction factor of the probability of the next block of sunshine ratio SH_j appearance predicted from present block of sunshine ratio SH_i

R(m, RS=1,2) : ratio (%) of the amount of snowfall and rainfall hours for month m

RANK(RS=1,2, r): ratio(%) of the amount of rainfall and snowfall appearance hours for each rank

N1 : ratio (%) of the amount of sunshine ratio 0 and cloud cover 10 appearance hours to the total time of sunshine ratio 0

N2(CC) : ratio (%) of the amount of sunshine ratio 1.0 appearance hours to the total time of

	each cloud cover value appearance
RNO	: initial value for generating a random number series
LA, LO	: latitude and longitude
HT	: height from sea level
N	: distribution of land and sea

3. FORMULA FOR CALCULATING THE HOURLY SOLAR RADIATION TH

The value of TH(SH, CC, RS) predicted from SH, CC, and RS values can be expressed by the following equation[3].

$$TH(SH,CC,RS)=CFN \cdot CFM \cdot \{TH(SH=0, CC, RS) \cdot (1-SH)+TH(SH=1.0, CC, RS) \cdot SH\} \quad \cdots\cdots(1)$$

The values of TH(SH = 0, CC, RS) and TH(SH = 1.0, CC, RS) in Eq. (1) can be calculated from the following equations.

$$TH(SH=0, CC, RS=1)=0.1339\ THO-17.2 \quad (TH \geq 300)\cdots\cdots(2)$$
$$TH(SH=0, CC, RS=1)=0.0766\ THO \quad (THO<300)\ldots\ldots(3)$$
$$TH(SH=0, CC, RS=4)=0.2229\ THO-24.4 \quad (TH \geq 300)\cdots\cdots(4)$$
$$TH(SH=0, CC, RS=4)=0.1416\ THO \quad (THO<300)\cdots\cdots(5)$$
$$TH(SH=0, CC, RS=2)=CFSF \cdot TH(SH=0, CC, RS=4) \quad \cdots\cdots(6)$$
$$TH(SH=0, CC, RS=3)=CFSC(SH=0) \cdot TH(SH=0, CC, RS=4) \quad \cdots\cdots(7)$$
$$TH(SH=1.0, CC, RS\neq 3)=A(CC) \cdot THO-98.9 \quad (TH \geq 300)\cdots\cdots(8)$$
$$TH(SH=1.0, CC, RS\neq 3)=(300\ A(CC)-98.9) \cdot THO/300 \quad (THO<300)\cdots\cdots(9)$$
$$TH(SH=1.0, CC, RS=3)=CFSC(SH=1.0) \cdot TH(SH=1.0, CC, RS\neq 3) \quad \cdots\cdots(10)$$

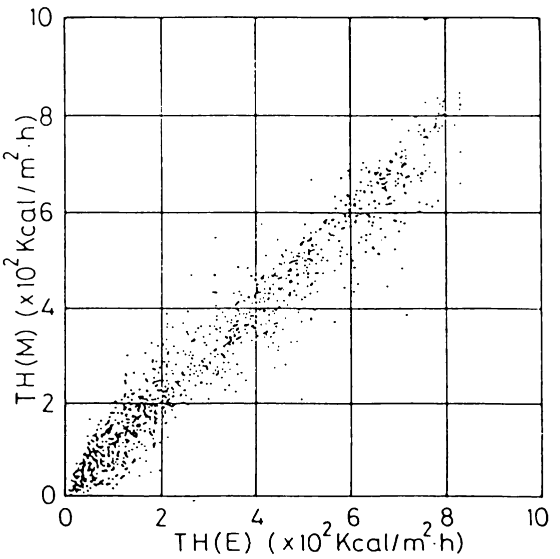

Fig. 1 Relationship between measured TH (TH(M)) and estimated TH (TH(E)) (TH(M)) were measured at Kagoshima in 1982. Number of dots is 1323. Correlation coefficient is 0.971, Ref. (3)).

$$A(CC)=0.8728-0.01617\ CC+0.003167\ CC^2-0.0002649\ CC^3 \qquad \cdots\cdots(11)$$

Fig. 1 shows an example of the comparison of the values of TH(SH, CC, RS) predicted using Eq. (1) with the observations. We can conclude that predicted values have a high accuracy.

4. INPUT STATISTICAL QUANTITY FOR GENERATING THE VALUES OF CC, SH, AND RS

The three elements CC, SH, and RS have their proper characteristics and relate to one another. To generate the three climate elements by simulation, the characteristics and relations among them must be reserved. The characteristics and mutual relations can probably be expressed in terms of various pieces of statistical quantity which are obtained from observations. The simulation must be carried out as to reserve several pieces of statistical quantity. To make the simulation useful, important and as least an amount of data as possible must be input. As to what kinds of statistical quantity to choose, the hourly observations at Kagoshima City for 10 years from 1966 to 1975 and of the standard weater data at various sites in Japan, has been studied and concluded that the statistical quantity as listed in table−1 was necessary[1),2)]. In addition, as an example, the input data columns in Table−1 are filled with various pieces of statistical quantity obtained from hourly observations at Kagoshima City in 1975.

5. THE METHOD OF CALCULATION OF INPUT DATA IN TABLE−1

Here, the methods of calculation of the values listed in Table−1 are discribed. The values in Table−1, except for the values in column 2, are calculated from hourly observations at Kagoshima City in 1975.

(1) $\overline{CC}(m)$, R(m, CC=10), WF1(CC)

The monthly ratios of the amount of each cloud cover appearance hours, and monthly mean values of cloud cover are given in Table−2. Table−2 indicates the ratios of cloud cover 10 are considerably high. Selected $\overline{CC}(m)$, R(m, CC=10) and calculated WF1(CC) from Table−2 are listed in column 1,3 and 4, Table−1, respectively.

(2) The minimum ratio of the amount of cloud cover 0 appearance hours

The ratio was calculated using the hourly observations at Kagoshima City from 1966 to 1975 and is listed in column 2, Table−1.

(3) RANK(CC, r)

The ratios of the amount of each cloud cover appearance hours for each rank through the year are shown in Table−3. The values in higher rank column of CC 0 and 10 comparatively large. This indicates that CC 0 and 10 tend to continue. RANK(CC=0, r), RANK(CC=10, r) selected from Table−3 are shown in column 5, 7. The mean values of RANK (CC=1～9, r) are listed in column 6.

(4) WF2(CC_j/CC_i)

The appearance probability of cloud cover block CC_j is affected by the former cloud cover block CC_i. This probability process is considered to be the Marcov process. If we assume that CC_j is not affected by CC_i, then $\overline{P}(CC_j/CC_i)$, the appearance probability of CC_j after CC_i, is written by:

$$\overline{P}(CC_j/CC_i)=M(CC_j)\ /\ \sum_{\substack{k=0\\k\neq i}}^{10} M(CC_k) \qquad \cdots\cdots(12)$$

Where $M(CC_j)$, $M(CC_k)$ are the total frequencies of the cloud cover block CC_j, CC_k in a certain

Table–1 Statistical quantity and its parameter for hourly cloud cover (CC), sunshine ratio (SH) and rain and snow index (RS), followed by input data obtained from the hourly measured data of Kagoshima in 1975.

Elements	Column number	Statistical quantity		Parameter	Input data
CC	1	$\overline{CC}(m)$		m = 1 ∿ 12	6.7 6.7 5.7 8.0 8.0 8.1 7.1 7.2 6.2 6.7 4.3 6.0
	2	Minimum ratio of cloud cover 0 appearance hours			3.6
	3	R(m, CC=10)		m = 1 ∿ 12	47 53 40 66 65 65 45 45 39 52 26 43
	4	WF1(CC)		CC= 1 ∿ 9	0.78 1.04 0.89 1.02 0.63 0.97 1.04 1.41 1.22
	5	RANK(CC, r)	CC = 0	r = 1 ∿ 12, 13 ∿ 17	7.8 7.4 6.4 7.7 7.5 3.7 3.8 8.8 6.2 4.1 14.9 14.6 7.1 0 0 0 0
	6		CC = 1∿9		67 25 5 2 1 0 0 0 0 0 0 0 0 0 0 0 0
	7		CC = 10		3.6 4.4 4.0 2.3 1.9 2.8 1.6 1.9 0.8 3.0 7.9 13.5 16.4 6.4 11.4 7.3 10.7
	8	$WF2(CC_j/CC_i)$	CC_i=0∿2,8∿10	CC_j a)	2.8 2.0 1.4 1.3 0.7 0.7 0.6 0.4 0.2 0.3
	9		CC_i = 3∿7		1.4 1.0 0.6 b)
	10	α(CC=0, t)		t = 1 ∿ 12, 13 ∿ 24	6.2 6.0 6.3 6.3 6.1 4.7 4.0 3.6 3.2 2.4 2.7 2.1 1.9 1.6 1.7 2.5 3.2 3.4 4.1 4.9 5.6 5.6 5.7 6.2
	11	High-cloud cover period, low-cloud cover period			6/16 7/13, 9/20 9/30 (High-cloud cover period)
SH	12	$\overline{SH}(m)$		m = 1 ∿ 12	0.48 0.48 0.61 0.42 0.49 0.40 0.60 0.60 0.56 0.53 0.68 0.54
	13	R(m, SH=1.0)		m = 1 ∿ 12	31 34 45 26 28 27 35 35 34 34 51 32
	14	WF1(SH)		SH=0.1∿0.9	0.94 0.96 0.73 0.91 0.86 0.91 0.94 1.21 1.54
	15	RANK(SH,r)	SH = 0	r = 1 ∿ 6	9.5 8.3 9.6 6.4 2.7 63.5
	16		SH = 1.0		8.3 9.1 7.4 11.1 8.0 56.1
	17	$WF2(SH_j/SH_i)$	SH_i= 0∿0.2, 0.8∿1.0	SH_j c)	2.68 1.95 1.55 1.07 1.15 0.82 0.36 0.43 0.27 0.11
	18		SH_i=0.3∿0.7		0.96 1.03 0.66 d)
	19		SH_i=0.1∿0.9		1.26 0.99 e)
CC f) & SH	20	N1			97
	21	N2(CC)		CC= 0 ∿ 10	91 86 82 75 60 57 51 47 45 25 8
RS	22	R(m, RS=1,2)		m = 1 ∿ 12	21 26 15 28 16 23 11 10 12 21 11 14
	23	RANK(RS=1,2, r)		r = 1 ∿ 12, 13 ∿ 17	15 10 9 6 5 4 5 3 6 5 18 7 2 2 3 0 0

a) CC_j = 0, 1, ..., 10 for 0 ≤CC_i≤ 2, CC_j = 10, 9, ..., 0 for 8 ≤CC_i≤ 10, (CC_j ≠ CC_i)
b) 1.4, 1.0 and 0.6 are the averages of the values in three classifications set in the range of 3 ≤CC_j ≤7 in Table-4
c) SH_j = 0, 0.1, ..., 1.0 for 0 ≤SH_i ≤0.2, SH_j = 1.0, 0.9, ..., 0 for 0.8 ≤SH_j ≤1.0, (SH_j ≠SH_i)
d) 0.96, 1.03 and 0.66 are the averages of the values in three classifications set in the range of 0.3 ≤SH_j ≤0.7 in Table-7
e) 1.26 and 0.99 are the averages of diagonal elements for i=0.1, 0.2, 0.8, 0.9 and 0.3 ≤i ≤0.7 in Table-7
f) Column 20 and 21 refer to the statistical quantity representing the correlation between CC and SH

Table–2 R(m, CC) and $\overline{CC}$(m)

m	CC 0	1	2	3	4	5	6	7	8	9	10	$\overline{CC}$(m)
1	19.8	2.2	2.7	2.7	2.6	1.7	4.7	4.4	6.7	5.5	47.4	6.72
2	19.0	2.5	3.3	4.0	2.8	1.8	3.3	3.3	3.3	3.9	52.8	6.73
3	25.9	3.4	5.0	3.4	4.3	2.6	2.7	3.2	5.5	4.6	39.5	5.72
4	9.2	1.9	2.2	2.1	2.9	2.2	2.9	2.8	4.2	3.7	65.8	7.98
5	7.9	1.9	2.6	2.6	3.4	0.9	2.8	4.3	3.9	4.4	65.3	8.04
6	8.1	1.9	2.6	2.4	2.9	2.1	2.5	2.6	3.7	6.4	64.7	8.05
7	8.5	2.7	5.0	3.9	5.4	3.6	4.7	5.8	8.3	7.4	44.8	7.13
8	7.3	3.6	4.8	3.5	6.0	3.2	4.3	6.6	8.3	6.9	45.4	7.19
9	15.8	3.5	6.7	6.1	4.7	3.9	4.4	6.0	5.3	4.2	39.4	6.16
10	16.1	4.3	4.6	3.4	3.1	2.3	3.6	2.7	4.8	3.5	51.6	6.74
11	39.3	4.7	4.6	3.5	4.3	2.2	3.5	2.8	6.9	2.2	26.0	4.28
12	23.7	3.9	3.9	3.1	4.0	2.3	4.3	3.6	4.0	4.0	43.1	6.00
Ave.	16.6	3.0	4.0	3.4	3.9	2.4	3.7	4.0	5.4	4.7	48.8	6.73

Table−3　RANK(CC, r)

r	CC 0	1	2	3	4	5	6	7	8	9	10
1	7.8	64.0	60.3	69.5	67.6	83.9	73.1	69.3	57.0	58.6	3.6
2	7.4	27.7	29.7	25.1	25.9	13.3	23.7	21.0	29.4	24.6	4.4
3	6.4	6.7	5.1	4.1	3.5	2.8	1.9	6.0	6.9	10.1	4.0
4	7.7	1.5	3.4	1.4	1.2	0	1.2	2.3	4.2	3.9	2.3
5	7.5	0	1.4	0	0	0	0	1.4	0	1.2	1.9
6	3.7	0	0	0	1.8	0	0	0	2.5	0	2.8
7	3.8	0	0	0	0	0	0	0	0	1.7	1.6
8	8.8	0	0	0	0	0	0	0	0	0	1.9
9	6.2	0	0	0	0	0	0	0	0	0	0.8
10	4.1	0	0	0	0	0	0	0	0	0	3.0
11	14.9	0	0	0	0	0	0	0	0	0	7.9
12	14.6	0	0	0	0	0	0	0	0	0	13.5
13	7.1	0	0	0	0	0	0	0	0	0	16.4
14	0	0	0	0	0	0	0	0	0	0	6.4
15	0	0	0	0	0	0	0	0	0	0	11.4
16	0	0	0	0	0	0	0	0	0	0	7.3
17	0	0	0	0	0	0	0	0	0	0	10.7

Table−4　WF2(CC_j/CC_i)

CC_i	CC_j 0	1	2	3	4	5	6	7	8	9	10
0		2.94	2.25	1.75	1.29	0.75	0.72	0.84	0.38	0.17	0.28
1	3.75		1.62	1.85	1.07	0.59	0.62	0.20	0.32	0.14	0.28
2	3.00	1.80		1.07	1.22	1.03	1.00	0.65	0.43	0.21	0.30
3	1.80	1.95	1.62		0.97	1.15	0.72	1.19	0.41	0.43	0.53
4	1.05	0.95	2.05	1.39		1.34	0.94	0.70	0.84	0.51	0.73
5	0.88	1.04	0.82	1.43	1.43		1.17	1.21	1.25	0.46	0.66
6	0.67	0.61	0.76	1.02	0.98	1.53		1.43	1.31	0.73	1.00
7	0.35	0.34	0.72	0.83	1.10	1.71	1.20		1.00	1.25	1.34
8	0.17	0.42	0.39	0.56	0.93	0.93	1.24	1.12		1.43	1.92
9	0.06	0.18	0.17	0.31	0.68	0.29	0.62	1.17	1.45		2.95
10	0.26	0.23	0.32	0.46	0.66	0.62	1.26	1.11	1.83	2.58	

period, respectively. Practically, we can calculate $n(CC_j/CC_i)$ from the CC observations. Where $n(CC_j/CC_i)$ is the frequency of CC_j appearance after CC_i in the period. Then $P(CC_j/CC_i)$ can be expressed by:

$$P(CC_j/CC_i)=n(CC_j/CC_i)/M(CC_i) \qquad \cdots\cdots(13)$$

Where $P(CC_j/CC_i)$ is the appearance probability of CC_j influenced by CC_i. We define $WF2(CC_j/CC_i)$ as following:

$$WF2(CC_j/CC_i)=P(CCj/CCi)/\overline{P}(CC_j/CC_i) \qquad \cdots\cdots(14)$$

The calculations of $WF2(CC_j/CC_i)$ are indicated in Table−4. The mean values of $WF2(CC_j/CC_i)$ are shown in column 8,9,Table−1.

(5)　α (CC=0,t)

The probability of the CC 0 apprearance in the nighttime is higher than in the daytime. This tendency can't be observed in the other CC. α (CC=0, t) is shown in column 10, Table–1.

(6) High–cloud cover period, low–cloud cover period

The simulation program described in the next paragraph was so composed as to generate hourly CC on the assumption that the statistical properties are constant during each month. However, it is considered that a high or low CC period may tend to occur during a shorter or longer period than a month in some cases.These input data enables to designate these periods.

(7) $\overline{SH}$(m), R(m,SH=1.0), WF1(SH)

The monthly ratios of the amount of each sunshine appearance hours, and monthly mean values of sunshine ratio are given in Table–5. Selected $\overline{SH}$(m), R(m,SH = 1.0) and calculated WF1(SH) from Table–5 are listed in column 12, 13 and 14, Table–1, respectively.

Table–5 R(m, SH) and $\overline{SH}$(m)

m	SH 0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	$\overline{SH}$(m)
1	32.3	4.8	5.2	4.0	3.6	4.4	3.6	3.2	3.2	4.8	30.6	0.48
2	37.1	4.4	2.4	3.2	2.0	2.8	3.2	1.6	4.8	4.8	33.9	0.48
3	26.8	3.5	3.2	0.6	1.9	1.9	3.5	3.2	4.5	5.5	45.2	0.61
4	46.6	3.1	1.9	1.5	1.9	2.8	3.1	3.4	4.9	4.9	25.9	0.42
5	35.6	3.8	2.2	2.5	4.4	2.2	3.6	4.7	6.0	7.1	27.9	0.49
6	48.1	2.8	1.9	1.9	3.3	3.3	2.2	1.9	3.3	4.2	26.9	0.40
7	17.7	4.8	6.5	4.6	4.3	4.6	5.4	3.2	4.8	9.1	34.9	0.60
8	21.4	3.9	5.0	3.1	4.2	4.5	2.8	4.7	6.7	8.9	34.8	0.60
9	23.4	3.8	4.4	4.1	6.0	4.1	6.0	4.1	4.7	5.4	33.9	0.56
10	31.7	3.2	4.6	2.1	3.9	2.5	2.5	3.5	5.3	7.0	33.8	0.53
11	19.3	1.1	3.4	3.0	1.9	3.4	3.4	5.3	3.8	4.2	51.1	0.68
12	23.8	5.6	5.2	4.4	6.0	3.6	4.0	5.2	4.4	5.2	32.3	0.54
Ave.	30.5	3.7	3.8	2.9	3.6	3.4	3.6	3.7	4.8	6.1	34.0	0.53

(8) RANK(SH,r)

The ratios of the amount of each sunshine appearance hours for each rank through the year are shown in table–6. RANK(SH=0, r), RANK(SH=1.0, r) selected from Table–6 are shown in column 15, 16, Table–1, respectively.

Table–6 RANK(SH, r)

r	SH 0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
1	9.5	74.6	79.4	86.9	86.7	90.3	94.0	75.0	84.2	76.0	8.3
2	8.3	18.8	18.4	13.1	13.3	9.7	6.0	17.6	15.8	15.1	9.1
3	9.6	6.5	2.1	0	0	0	0	4.4	0	5.3	7.4
4	6.4	0	0	0	0	0	0	2.9	0	3.6	11.1
5	2.7	0	0	0	0	0	0	0	0	0	8.0
6	63.5	0	0	0	0	0	0	0	0	0	56.1

(9) WF2(SH_j/SH_i)

The definition of WF2(SH_j/SH_i) is the same as WF2(CC_j/CC_i). The calculations of WF2(SH_j/SH_i) are indicated in Table–7. The mean values of WF2(SH_j/SH_i) are shown in column 17, 18 and 19, table–1.

Table–7 WF2(SH_j/SH_i)

SH_i	SH_j 0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0		2.87	2.09	2.05	1.34	1.24	1.07	0.42	0.39	0.36	0
0.1	3.01	1.69	1.23	1.36	1.35	0.84	0.49	0.54	0.28	0.23	0.05
0.2	2.31	1.15	1.53	1.20	1.35	1.01	0.73	0.58	0.46	0.42	0.25
0.3	1.63	1.65	0.81	1.24	1.02	1.64	0.69	0.90	0.50	0.48	0.53
0.4	1.52	0.63	1.05	1.12	0.81	1.05	1.37	0.81	1.00	0.34	0.80
0.5	1.02	1.27	0.90	0.88	0.43	0.75	0.35	1.07	0.76	0.87	1.44
0.6	0.63	0.39	1.05	0.82	0.59	1.04	0.43	0.99	1.01	0.93	1.65
0.7	0.87	0.54	0.38	0.87	0.81	0.95	0.88	1.72	0.86	0.51	1.46
0.8	0.28	0.41	0.89	0.77	0.63	0.32	1.36	0.91	0.77	0.83	1.92
0.9	0.09	0.11	0.23	0.37	0.65	0.31	1.00	0.54	1.06	1.05	2.50
1.0	0.21	0.17	0.46	0.30	0.56	1.06	0.80	1.04	1.81	2.48	

(10) N1, N2(CC)

The calculations of two–dimentional histogram between CC and SH are shown in Table–8. Table–8 indicates that the greater portion of SH 0 correspondingly occurs with CC 10. Furthermore, the ratio of SH 1.0 is important for the estimation of TH because TH is larger when SH is 1.0. N1, N2(CC), in column 20, 21, Table–1 are the statistical quantity representing these characteristics.

Table–8 2–dimentional frequency distribution between CC and SH.

CC	SH 0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	Total
0	2	0	1	1	2	4	5	4	3	7	308	337
1	0	0	1	0	1	0	3	2	5	5	101	118
2	1	0	0	1	1	1	2	3	7	10	115	141
3	1	0	1	1	2	1	3	6	5	16	106	142
4	0	0	1	1	2	3	9	9	13	22	90	150
5	0	0	1	0	2	5	7	10	7	9	55	96
6	4	0	2	1	5	6	9	9	17	19	74	146
7	3	2	3	5	4	6	8	17	15	34	87	184
8	7	3	6	11	11	13	17	18	25	22	110	243
9	17	8	13	16	23	16	16	16	18	28	56	227
10	1092	125	112	70	82	69	55	42	62	53	155	1917
Total	1127	138	141	107	135	124	134	136	177	225	1257	3701

(11) R(m, RS=1,2), RANK(RS=1,2, r)

The calculations of R(m, RS=1,2), RANK(RS=1,2, r) are indicated in column 22, 23, Table–1, respectively.

6. METHOD OF SIMULATION

The procedure for simulation is listed below[1,2]. Steps with an asterisk(*) refer to simulation using random numbers. In addition, codes or simbols, enclosed in parentheses at the ends of some steps refer to data to be input in the respective steps. Steps 1 to 4 are for CC generation, steps 5 to 10 for RS generation, and steps 11 to 18 for SH generation. Then , using generated CC, RS, and SH, TH is calculated from Eq. (1) to Eq. (11).

(1) Calculation of the amount of appearance hours for each month and for each cloud cover ($\overline{CC}$(m),

R(m,CC=10), WF1(CC), minimum ratio of cloud cover 0 appearance hours)

(2) Calculation of the amount of appearance hours for each cloud cover and for each rank (RANK(CC, r))

(3) * Determination of the blocks of cloud covers 0 and 10 for ranks 11 or more

(4) * Sequential determination of occurence order of blocks for each cloud cover (WF2(CC_j/CC_i), α (CC=0, t), high–cloud cover period, low–cloud cover period)

(5) Calculation of amount of precipitation hours for each month (R(m,RS=1,2))

(6) Calculation of the amount of precipitation hours for each month and for each rank (RANK(RS=1,2, r))

(7) * Determination of precipitation blocks for ranks 11 or more

(8) * Fitting precipitation blocks in cloud cover 10 occurence hours

(9) Calculation of approximate daily standard atmospheric temperature at the place[4)] (LA, LO, HT, and N)

(10) Judgement of snowfall and snowcover using the temperature stated above

(11) Calculation of the amount of appearance hours for each month and for each sunshine ratio ($\overline{SH}$(m), R(m, SH=1.0), WF1(SH))

(12) Calculation of the amount of appearance hours for each sunshine ratio and for each rank (RANK(SH, r))

(13) * Determination of the blocks of sunshine ratios 0 and 1.0 for rank 6

(14) * Determination of the appearance time of the blocks of sunshine ratio 0 so that the amount of hours for cloud cover 10 and rain and snow indexes 1 and 2 can be contained in the hours of sunshine ratio 0

(15) Determination of the appearance time of the blocks of sunshine ratio so that the N1 (%) of the total amount of hours of sunshine ratio 0 will fit the appearance hours of cloud cover 10 (N1)

(16) * Determination of the appearance time of blocks of sunshine ratio 1.0 so that the N2(CC) (%) of the respective hours of cloud covers 0 to 10 will fit the appearance hour of sunshine ratio 1.0 (N2(CC))

(17) * Sequential determination of the undetermined appearance hours of sunshine ratio (WF2(SH_j/SH_i))

(18) * Determination of the fraction parts of the hours of sunshine ratio at sunrise and at sunset

According to the procedure stated above, the author wrote the computer program.

7. DISCUSSION OF THE RESULTS OF SIMULATION

The simulation program the author has developed needs uniform random number numerous times. The author chose 1 and 500 as the two initial numbers of uniform random number series and carried out simulation with input data in Table–1. We let the rounds of simulation be SIMU–A and SIMU–B.

Table–9 lists the same items as Table–1. The column of Table–9 are filled with the calculated statistical values obtained using the hourly values of CC, SH, and RS by SIMU–A, SIMU–B. From the comparison of the values in Table–9 with those in Table–1, it is evident that calculated statistical quantity can show high repeatability with the input one.

Fig. 2, 3 and 4 compare the calculations with the observations for July. It is obvious that the pattern of variation for each hour and the relations among CC, SH, and TH are nearly repeated.

Fig. 5 to 10 show the comparison of the power spectra (Fig. 5 to 7) and the coherences (Fig. 8 to 10) of the observed CC_d, SH_d, and TH_d at Kagoshima City in 1974 and 1975 with those of CC_d, SH_d, Table−9 Statistical quantity, corresponding to that in the same column number in Table−1, calculated using the hourly values of CC, SH and RS obtained as the output of SIMU−A and SIMU−B.

Column number	SIMU-A	SIMU-B
1	6.7 6.6 5.8 8.0 7.9 8.1 7.1 7.2 6.2 6.7 4.3 6.0	6.7 6.7 5.7 8.0 8.0 8.1 7.1 7.2 6.1 6.7 4.4 5.9
3	47 53 41 66 64 65 46 45 39 52 27 43	47 53 40 65 65 65 45 45 39 52 27 42
4	.78 1.0 .88 1.0 .62 .96 1.0 1.4 1.2	.78 1.0 .88 1.0 .62 .96 1.0 1.4 1.2
5	7.4 6.4 6.0 6.0 6.8 3.7 1.9 9.3 5.5 4.1 12 10 7.1 4.4 3.8 5.7 0	7.4 6.6 5.5 6.8 7.2 4.1 2.4 9.3 5.5 3.4 17 10 7.1 0 3.1 4.8 0
6	69 24 5 2 0 0 0 0 0 0 0 0 0 0 0 0 0	69 24 5 2 0 0 0 0 0 0 0 0 0 0 0 0 0
7	3.8 4.1 3.7 2.2 2.0 2.8 1.5 2.1 0.6 2.8 8.3 14 16 7.3 11 8.9 9.8	3.7 4.1 3.8 2.0 1.9 2.4 1.6 1.7 0.8 2.8 7.5 13 16 9.0 13 6.3 11
8	2.6 2.1 1.1 1.0 0.8 0.7 0.6 0.5 0.3 0.5	2.5 1.9 1.3 1.1 0.9 0.8 0.6 0.4 0.2 0.6
9	1.3 1.1 0.6	1.3 1.0 0.6
10	5.8 5.6 5.7 5.8 5.3 4.2 4.0 3.8 3.6 2.8 3.0 2.3 2.9 2.1 2.3 3.2 3.7 3.8 4.2 4.8 5.7 5.0 4.5 6.0	5.4 4.7 5.3 5.4 5.6 4.6 4.2 3.8 3.4 2.9 3.3 2.7 2.7 2.5 2.9 3.4 3.9 4.0 4.4 5.0 5.1 5.1 5.1 4.8
12	.48 .48 .61 .42 .49 .40 .60 .60 .56 .53 .68 .54	.48 .49 .61 .42 .49 .40 .60 .60 .56 .53 .68 .54
13	31 34 45 26 28 27 36 35 34 34 51 32	31 35 45 26 28 27 36 35 34 34 51 32
14	.94 .97 .71 .89 .87 .89 .94 1.2 1.6	.94 .97 .71 .89 .87 .89 .94 1.2 1.6
15	11 7.4 7.8 7.7 3.7 63	8.6 6.6 8.5 6.3 3.7 66
16	8.9 9.2 8.0 11 8.7 54	8.8 9.6 7.8 12 7.0 55
17	2.3 1.4 1.4 .98 .89 .75 .43 .42 .38 .96	2.2 1.5 1.4 1.3 1.3 .89 .41 .50 .18 .64
18	.95 1.1 .73	1.0 1.1 .63
19	.85 .86	1.2 .94
20	97	99
21	91 83 80 74 61 59 54 49 43 30 4	92 81 81 80 63 61 52 55 46 26 2
22	22 27 16 29 17 24 11 10 12 22 11 14	22 27 16 29 17 24 11 10 12 22 11 14
23	11 9 10 6 6 4 5 3 5 5 19 7 5 2 3 0 0	12 10 8 7 4 3 6 3 4 6 20 8 1 4 3 0 0

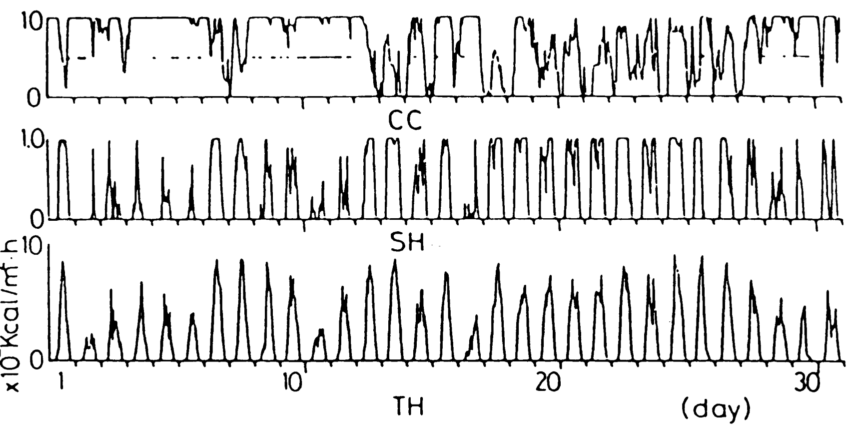

Fig. 2 CC, SH, and TH measured at Kagoshima for July 1975 (Dotted line in the upper graph refers to rainfall hours. Note also Fig. 3 and Fig. 4).

and TH_d calculated from CC, SH, and TH by SIMU−A, SIMU−B. Where CC_d, SH_d, TH_d are dayly average of cloud cover, dayly integrated sunshine hours, and dayly integrated solar radiation, respectively. (a) of Fig. 5 to 10 compares the power spectra and coherences of the calculations by SIMU−A and SIMU−B with those of the observations in 1975 and (b) compares those of the observations in 1975 with those in 1974. All curves in Fig. 5 to 10 are smoothed by Parzen Window. In Fig. 7 (a), the power spectrum of TH_d calculated from observed CC and SH is also illustrated. Judging from these figures, it can be safely said that power spectra and coherences obtained from the results of SIMU−A , SIMU−B are similar to those obtained from observations. Furthermore, there are no significant dif-

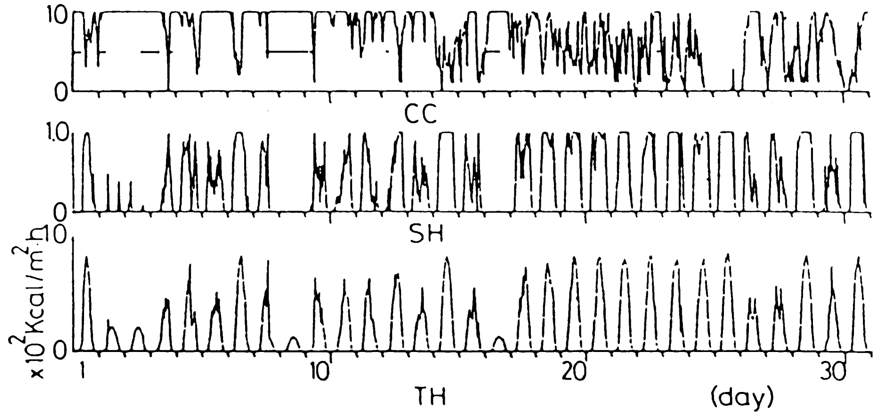

Fig. 3 CC, SH, and TH for July obtained by SIMU–A.

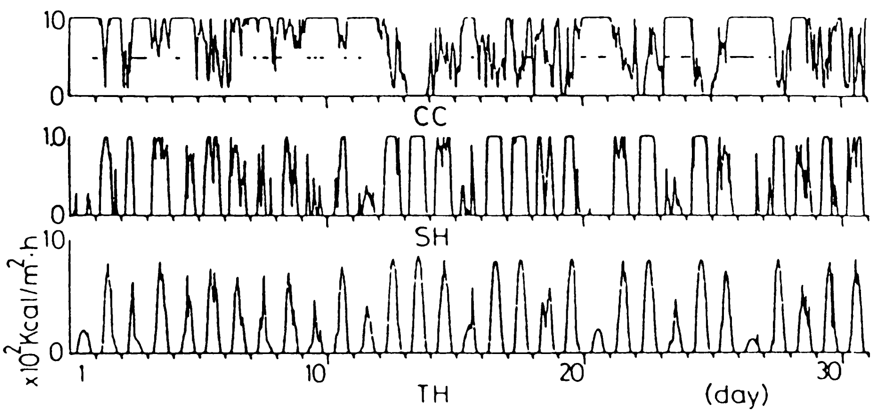

Fig. 4 CC, SH, and TH for July obtained by SIMU–B.

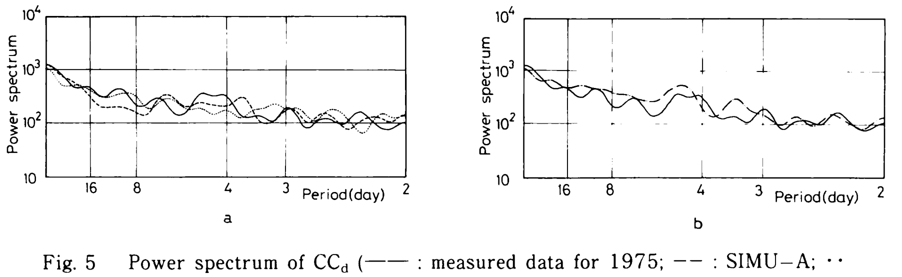

Fig. 5 Power spectrum of CC_d (—— : measured data for 1975; – – : SIMU–A; ·· ·· : SIMU–B; —··— : measured data for 1974. Note also Fig. 6 to Fig. 10).

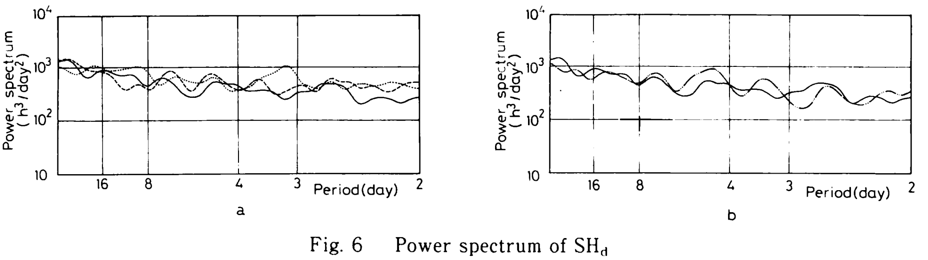

Fig. 6 Power spectrum of SH_d

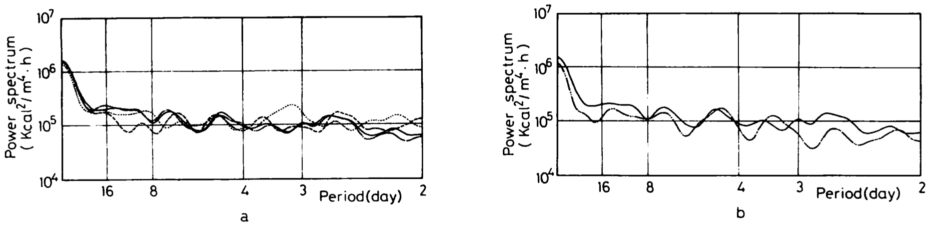

Fig. 7 Power spectrum of TH_d (—・— : calculated TH_d using measured CC and SH for 1975).

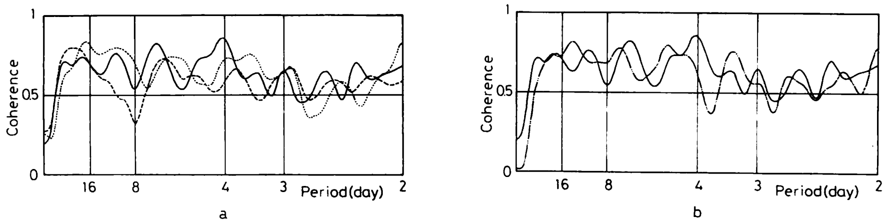

Fig. 8 Coherence between CC_d and SH_d

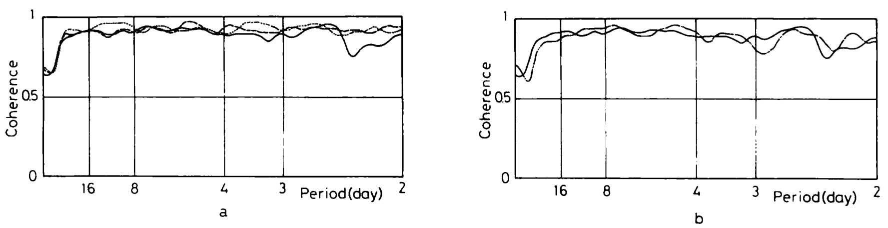

Fig. 9 Coherence between CC_d and TH_d

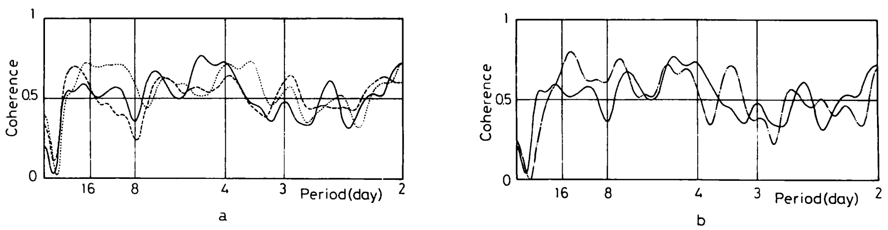

Fig. 10 Coherence between SH_d and TH_d

ferences between (a) and (b) of each figure.

For the values of TH, Fig. 11 shows the comparison of the frequency distribution of observation with that of the calculations. In a range of $400 \leq TH \leq 800$, the observations well agree with the calculations. In range of $TH < 200$ and $800 < TH$, however, a deflection appears. The comparison of the values with an open circle (○) with those with a dark (●) proves that the deflection results from the properties of Eq. (1) to (11), not from the properties of simulation.

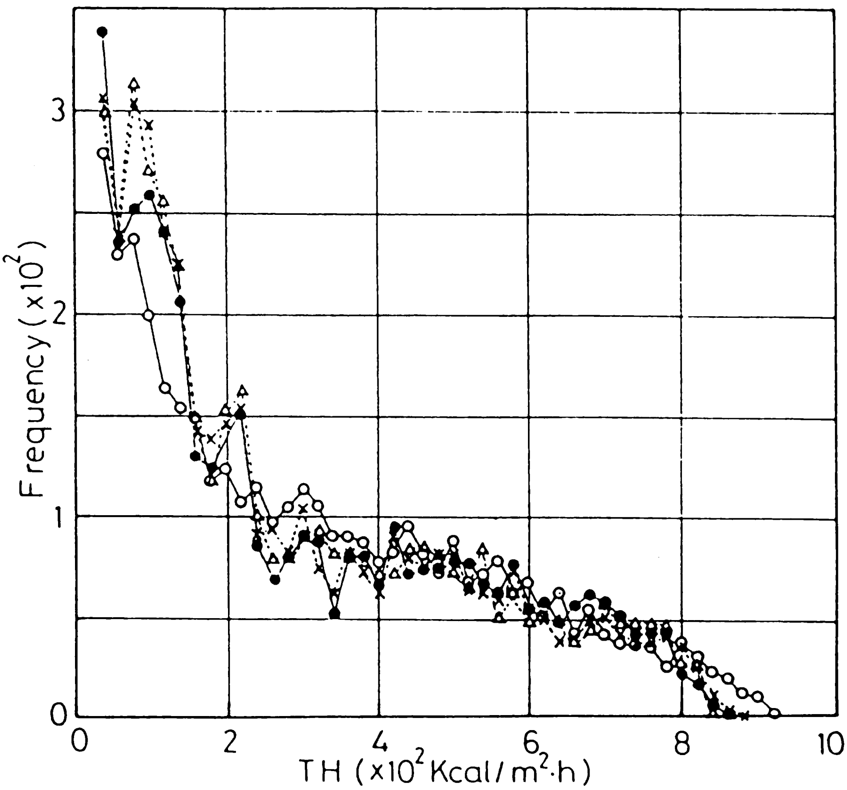

Fig. 11 Frequency distribution of TH (—O— : measured data; —●— : calculated values using measured CC and SH; ···△··· : calculated values by SIMU–A; ···×··· : calculated values by SIMU–B).

8. CONCLUSION

(1) If the values of hourly cloud cover, sunshine ratio, and rain and snow index are given, the values of hourly solar radiation can be obtained from Eq. (1) to (11). In addition, it has been confirmed that the calculations considerably well agree with the observations. The method is useful for projecting the value of solar radiation when we have the values of observed cloud cover and sunshine ratio and do not have the value of solar radiation. In this case, however, the observations of sunshine ratio are obtained with a Jordan sunshine meter. If sunshine ratio is measured by other sunshine meters, Eq.(1) to (11) probably need kind of alteration. The problem will be taken into consideration later.

(2) The author has developed a computer program which , if several pieces of statistical quantity are given , can generate the values of hourly cloud cover, sunshine ratio, and snow index, thereby compute the value of hourly solar radiation. It has been confirmed that variation pattern and power spectrum in solar radiation calculated by the computer and those in observed solar radiation are similar and the frequency distribution of observations well agree with that of the calculations. Consequently, it can be concluded that the computer program can simulate the value of hourly solar radiation for each hour including a cloudy sky.

9. SUBJECT IN FUTURE

(1) The simulation was carried out using the statistical quantity calculated from climate data at Kagoshima City in 1975. If the statistical quantities are collected from lots of sites, the program can simulate the values of cloud cover, sunshine ratio, rain and snow index, and solar radiation for the sites.

(2) The computer program will be supplemented with a subroutine to calculate atmospheric temperature and humidity ratio. Accordingly, the output values of this program would be adaptable to the calculation of air—conditioning load or natural energy utilization problems in simulation.

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