SPATIAL AND TEMPORAL DIFFERENCES OF GLOBAL SOLAR RADIATION : APPLICABILITY OF MEAN DAILY CLEARNESS INDEX

Mika ICHINO and Takehiko MIKAMI

Abstract In order to reconstruct historical climate from daily weather records in old diaries, the method for estimating global solar radiation based on daily weather condition was constructed by Ichino *et al.* (2001). The most important variable in the formula is the mean daily clearness index (MDCI), which is a quantitative measure of weather condition. This study aims to investigate the spatial range where the same value is used for MDCI, because the method must be applicable for estimation all over Japan. This paper presents an attempt to investigate interchangeability and generality of MDCI at 8 points in Japan where historical daily weather records are available in the neighborhood. This paper indicates that the spatial applicability of the MDCI is affected by climatic characteristics of solar radiation rather than distance. The estimated relative error is less than 10% at almost all the points in the same climatic division classified by Japan Weather Association (1986), which was based on the climate characteristics of the solar radiation. As a result, the MDCI used for estimating monthly mean solar radiation from historical daily weather records can be calculated by using the data from neighboring observatory.

Key words: monthly mean solar radiation (MMSR), weather condition, climatic division, historical daily weather records, mean daily clearness index (MDCI)

1. Introduction

Historical documents that include weather descriptions are very useful for climatic reconstruction before the instrumental period. Very precious documents exist in Japan because they include daily records and have been continued for several hundred years. Various studies have been conducted on the climatic reconstruction using these descriptions (*e.g.*, Mikami 1999). Previous studies have produced various statistical methods for reconstructing temperature and precipitation in Japan. Most of investigations adopt statistical approaches.

Ichino *et al.* (2001) have developed a method for estimating monthly mean solar radiation (MMSR) from the daily weather descriptions aiming at reconstructing the global solar radiation in historical periods. They suggested that the global solar radiation was highly related to the weather condition. They used a daily clearness index, K_T, defined as Q_d/Q_s (Q_d: direct plus diffuse solar radiation observed at the surface, Q_s: solar radiation arriving at the top of the atmosphere), which was firstly introduced by Liu and Jordan (1960). In Ichino *et al.* (2001), the relationship between K_T and the weather condition was examined. The weather condition, which was obtained in the daily reports of Japan Meteorological Agency (JMA), was classified into N categories (Table 1). N is the number of categories (N is 3, 5, or 9). Category class number is represented by (N,k), where k is from 1 to N. The mean daily clearness index (MDCI) represents an average of monthly mean K_T for each k and each observatory for the period when the data are available. Ichino *et al.* (2001) showed the method applicable at 8 points where the data are available (see Section 2).

However, the spatial applicability of this method has not been sufficiently made clear. The MDCI values used in the formula of this method were different among the observatories. In fact, any observatories do not exist at the places where historical daily weather records are available. In order to apply the method to estimate MMSR from the historical daily weather records all over Japan, this paper examined the spatial applicability of MDCI.

2. Data and Method

The data used for this study were the daily-accumulated solar radiation (Q_d) and daily weather condition from 1995 to 1999 at 8 local observatories of JMA (Fig. 1 and Table 2: Aomori, Hachinohe, Yamagata, Sendai, Takada, Tokyo, Saga and Nagasaki). "Weather condition" is a qualitative variable expressed in several standardized words. The weather condition data had been already digitized for this period, and used in Ichino *et al.* (2001).

Following the method of Ichino *et al.* (2001), K_T was calculated from Q_d and daily total insolation Q_0 by the following equation:

Table 1 Weather categories into which weather condition is classified

<table>
<tr><th></th><th>N=3</th><th>N=5</th><th>N=9</th><th></th></tr>
<tr><td rowspan="9">(N,k)</td><td rowspan="4">(3,1)</td><td>(5,1)</td><td>(9,1)</td><td>fine</td></tr>
<tr><td rowspan="3">(5,2)</td><td>(9,2)</td><td>fine partly cloudy</td></tr>
<tr><td>(9,3)</td><td>half fine, half cloudy</td></tr>
<tr><td>(9,4)</td><td>cloudy partly fine</td></tr>
<tr><td>(3,2)</td><td>(5,3)</td><td>(9,5)</td><td>cloudy, or half fine half rainy</td></tr>
<tr><td rowspan="4">(3,3)</td><td rowspan="3">(5,4)</td><td>(9,6)</td><td>cloudy partly rainy</td></tr>
<tr><td>(9,7)</td><td>half cloudy, half rainy</td></tr>
<tr><td>(9,8)</td><td>rainy partly cloudy</td></tr>
<tr><td>(5,5)</td><td>(9,9)</td><td>rainy</td></tr>
</table>

Each grade is expressed as (N,k). N is a number of categories (N is 3, 5 or 9), where k is a grade number of weather categories from 1 to 9. For example, (3,1) means N=3 and k=1.

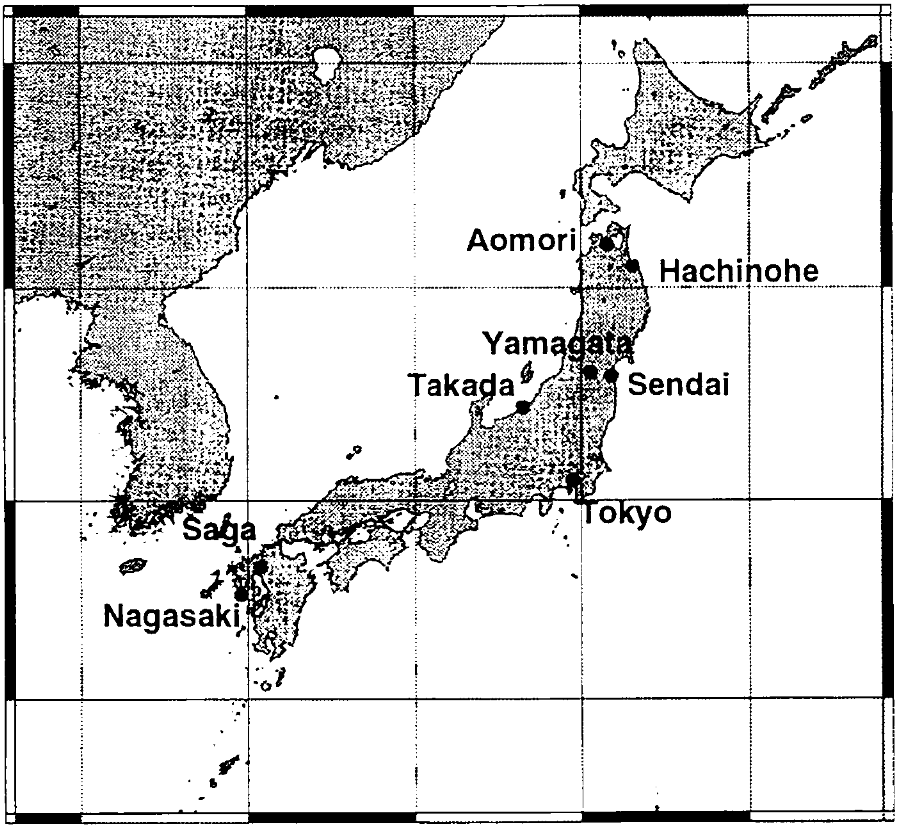

Fig. 1 Eight observatories where global solar radiation and daily weather condition in daytime are available.

Table 2 Eight observatories where global solar radiation and daily weather condition in daytime are available

point No	point	latitude (°N)	longitude (°E)	altitude (m)	climatic division
575	Aomori	40.82	140.77	2.8	I
581	Hachinohe	40.52	141.53	27.1	I
588	Yamagata	38.25	140.35	152.5	I
590	Sendai	38.26	140.90	38.9	III
612	Takada	37.10	138.25	12.9	I
662	Tokyo	35.68	139.76	6.5	III
813	Saga	33.26	130.31	3.6	IV
817	Nagasaki	32.73	129.87	26.9	IV

This climatic division is created, based on the climate characteristics of the solar radiation by Japan Weather Association (1986). These numbers correspond to the classes of the division.

$$K_T = Q_d / Q_s \quad (1)$$

Q_s was calculated from the orbital factor of the earth in its revolution around the sun by the formula of Kondo (1994). The weather condition was classified into 3 categories as in Table 1. N is 3 and k is 1,2,or 3, where k is a grade number of weather categories. The MDCI was calculated for each month, each k and each observatory for 5 years (1995-1999).

$Q_{e(x)}$ at point y is calculated from the MDCI at point x and weather condition data at point y by the following formula :

$$Q_{e(x)} = \frac{1}{n}\sum_{j=1}^{n}\left\{\overline{K_{T(x)}}(N,k_{j(y)}) \bullet Q_{sj(y)}\right\} \quad (2)$$

Where j is a day of a month, n is the number of days in a month, but the day of missing data is not accounted, x and y are point names. $\overline{K_{T(x)}}(N,k_{j(y)})$ is the MDCI of weather category $k_{j(y)}$ at point x. $k_{j(y)}$ is the category of weather condition in the day of j at point y, $Q_{sj(y)}$ is the daily total insolation in the day of j at point y. For example, the estimated MMSR by using MDCI of Tokyo at each point is shown as $Q_{e(Tokyo)}$. The estimations of solar radiation were made for all combinations of points x and y.

To clarify the spatial applicability of MDCI, MMSR at all points ($x \neq y$) were estimated and compared with the case ($x = y$). The errors of 64 (8 × 8) estimations that included the 8 values ($x = y$) were calculated. The accuracy was discussed by calculating root mean square relative error (RMSRE) between Q_e and observed monthly mean solar radiation. In order to verify the estimations more precisely, seasonal variability was eliminated. Scatter diagrams were prepared by using monthly mean K_T (referred to as $\overline{K_{To}}$) and estimated monthly mean K_T (referred to as $\overline{K_{Te}}$) as follows.

$$\overline{K_{To}} = \frac{1}{n}\sum_{j=1}^{n}\{K_T\} \quad (3)$$

$$\overline{K_{Te}} = \frac{1}{n}\sum_{j=1}^{n}\left\{\overline{K_T}(N,k_j)\right\} \quad (4)$$

3. Results and Discussion

The spatial applicability (*e.g.*, the interchangeability and the generality) discussed here was derived from all 64 results of estimations available. For example, the relationship between MDCI at Takada and the errors of estimations in other points are illustrated (Fig.2). A scatter diagram of estimations $\overline{K_{Te(Takada)}}$ and observations $\overline{K_{To}}$ at Aomori and Tokyo, based on the MDCI at Takada, is presented.

As illustrated in Table 3, RMSRE of $Q_{e(Takada)}$ at Tokyo was 16.0%, while that at Aomori was 7.0%, however, the distance between Aomori and Takada is larger than that between Tokyo and Takada. The errors of estimations at Yamagata and Hachinohe with MDCI at Takada were small (7.0% and 7.4%, respectively, Table 3). The values with gray shade are larger than 10%.

The results indicate that the spatial applicability of MDCI is not determined by distance

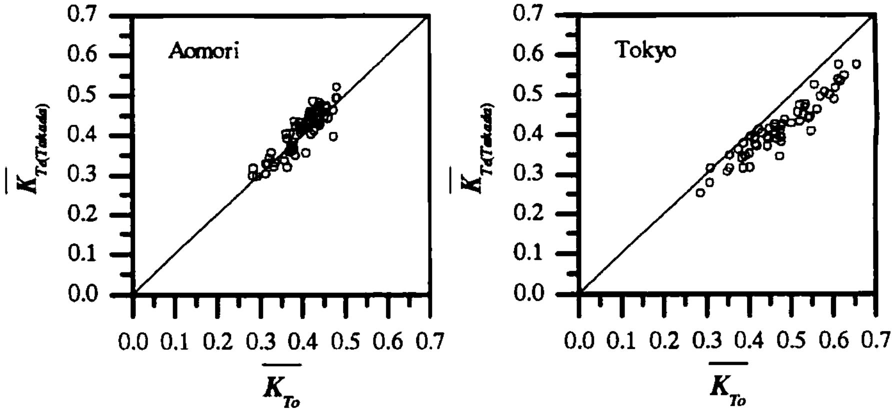

Fig. 2 Scatter diagram of estimations $\overline{K_{T(Takada)}}$ and observations $\overline{K_{To}}$ at Aomori and Tokyo for the period from 1995 to 1999, based on the MDCI at Takada.

Table 3 The RMSRE of MMSR estimated by replacing MDCI at 8 points

Point *y*			Point *x*							
			Climatic division I				Climatic division II		Climatic division IV	
			581	588	575	612	590	662	813	817
			Hachinohe	Yamagata	Aomori	Takada	Sendai	Tokyo	Saga	Nagasaki
I	581	Hachinohe	4.1	7.3	5.3	7.4	11.9	16.8	11.9	8.4
	588	Yamagata	9.4	4.9	8.6	7.0	10.6	19.1	13.1	12.7
	575	Aomori	5.8	9.1	4.5	7.0	12.0	21.2	13.4	11.3
	612	Takada	8.9	8.3	7.7	5.6	9.8	18.5	11.6	10.9
II	590	Sendai	15.4	10.9	14.4	11.5	6.0	10.4	10.1	14.9
	662	Tokyo	18.0	14.0	17.7	16.0	8.4	4.5	9.3	15.7
IV	813	Saga	12.7	11.7	12.1	12.2	7.3	8.0	3.7	8.7
	817	Nagasaki	8.3	10.9	7.9	10.4	10.3	13.4	7.5	3.7

The RMSRE at point *y* is calculated by using MDCI at point *x*. These points are put into three groups, based on the climatic division of JWA (1986). The values with gray shade is larger than 10%. Values in thick solid rectangles are errors when point *x* and point *y* are included in the same division.

alone. Figure 3 shows the relationship between RMSRE and distance from Takada.

Japan Weather Association (JWA) (1986) created a climatic division based on the climate characteristics of the solar radiation by cluster analysis (maximum-distance method with the use of Euclid distance). The results of this study were discussed by using this climatic division. In their climatic division, Aomori, Hachinohe, Yamagata and Takada belong to climatic division Ⅰ. Tokyo and Sendai belong to Ⅲ, while Nagasaki and Saga belong to Ⅳ (Table 3). When points x and y are included in the same division. RMSRE of estimated MMSR were almost smaller than 10% (Table 3). We consider that the estimated errors are small when the characteristic of solar radiation at point y is similar to that at x. Namely, MDCI

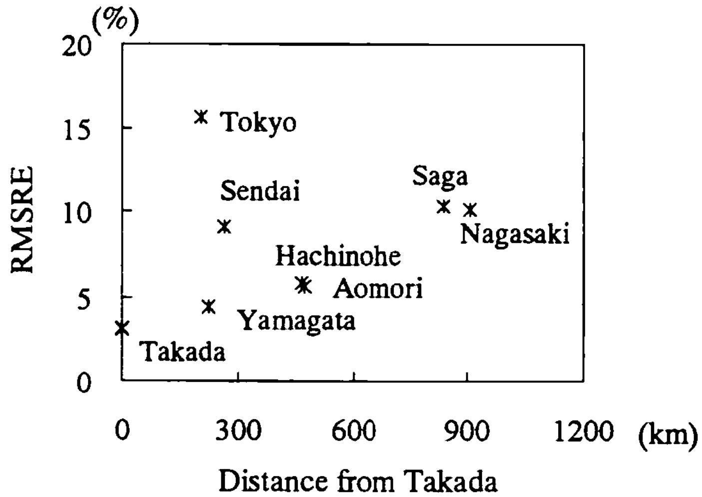

Fig. 3 Relationship between RMSRE and distance from Takada.

that is obtained at a certain point can be applied within the same climatic division of JWA (1986). If the same MDCI is available in a certain area, this method is applicable in this area.

Therefore, it is appropriate that the MDCI at Tokyo will be used for estimating MMSR from historical daily weather records in and around Tokyo. However, this investigation is conducted at only 8 point all over Japan. Before concluding that the climatic division of JWA (1986) is useful for this method, we must investigate the spatial applicability of MDCI at all points available.

4. Conclusion

The primary aim of this study is to estimate MMSR from the historical daily weather records. It was clarified earlier that the method could be applied at the observatories where both Q_d and daily weather condition are observed by JMA. The estimations calculated by replacing the MDCI of other stations revealed that the method could be used at points wherever they belong to the same climatic division of JWA (1986). The result indicated that this method is applicable as long as the values of MDCI are similar. The results can be employed to estimate MMSR from historical daily weather records in suburbs of Tokyo. Our future work will be to create a climatic division for estimating MMSR based on the method of Ichino *et al.* (2001).

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