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Estimation of daily solar radiation from sunshine duration in Ningxia region, China

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For the estimation of daily solar radiation from sunshine duration, observation data of Yinchuan station in Ningxia, China was used. Using a linear relationship between solar radiation and extraterrestrial radiation including relative sunshine duration and daylength, we obtained local coefficients a_s =0.18, b_s =0.62 from past five years data(1981-1985). Using the same method, coefficients for Guyuan region were confirmed too as a representative of south part of Ningxia province. Applying the local coefficients and calculation formula of solar radiation, we validated daily solar radiation of two years(1986-1987) of Yinchuan station and four years(1991-1994) of Guyuan station. The results showed high correlation coefficients of R^2=0.94 in Yinchuan and R^2=0.85 in Guyuan. Error analysis was applied using mean bias error(MBE), mean absolute bias error(MABE), root mean square error(RMSE), mean absolute percentage error(MAPE) on solar radiation of Yinchuan(1973-2006) and Guyuan(1986-2006) stations. Results showed that mean absolute bias error(MABE) was less than 13% and 17% in Yinchuan station and Guyuan station respectively.

Then we have applied this method to the estimation of daily solar radiation at ‘Yongning’ station(near Yinchan) with the sunshine duration data at ‘Yongning’. The estimated values were compared with observed daily solar radiation at Yinchuan as past twelve years data(1989-2000). The results showed good linear relationship with high correlation coefficient of R^2= 0.88.

Key words: Daily solar radiation, Extraterrestrial radiation Relative sunshine duration, Local coefficient,

1. Introduction

In the surface energy budget, solar radiation is the most important parameter controlling the surface heat budget. And it is applied in a lot of crop modeling[1-4] However, most of the weather station data do not include the solar radiation flux in China as well as in Japan.

Alternatively, sunshine duration is rather popular parameter observed in China weather station and AMeDAS in Japan. Actually in Ningxia region in China, there are 26 weather stations, but only two stations (Yinchuan and Guyuan) include solar radiation measurements. In order to convert the sunshine duration data to daily solar radiation data, we should establish a applicable formula including some local coefficients.

In the present paper, using a experimental formula between daily solar radiation and sunshine duration, local coefficients were obtained to estimate daily solar radiation in Ningxia region, and then applied to daily solar radiation of Yongning station in Ningxia for past twelve years(1989-2000). This simulation method is expected to be able to apply in other stations.

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2. Estimation method and data

Yinchuan city is in situated in Ningxia province at the northwest of China. The latitude is 38.48° N, longitude is 106.22° E, altitude is 1111 m. Fig.1

shows the regional map in Ningxia region. Dots in this map are meteorological stations of Ningxia region. The two stations including solar radiation are Yinchuan and Guyuan situated in north and south part in this region. The target station 'Yongning', which does not include solar radiation measurement, is located near Yinchuan.

Fig.1 Regional map of Ningxia province, China

According to DeBoer et. al (2005), daily solar radiation(R_s) is estimated as follows using two local coefficients, "a_s" and "b_s".

$$R_s = (a_s + b_s \frac{n}{N}) R_a \qquad (1)$$

Where

R_s : daily solar radiation [MJ m^{-2} day^{-1}];

n : actual sunshine duration [hour] observed at each weather station

N : maximum possible sunshine duration or daylight hours [hour] calculated in Eq(6).

n/N : relative sunshine duration

R_a : extra-terrestrial radiation [MJ m^{-2} day^{-1}] calculated in Eq(2)

a_s : local coefficient, expressing the fraction of Rs/Ra on overcast days (n = 0);

$a_s + b_s$: fraction of R_s / R_a on clear days ($n = N$).

The extra-terrestrial radiation, Ra is calculated as follows.

$$R_a = \frac{24 \times 60}{\pi} \times G_{sc}\, d_r \times \left[\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)\right] \qquad (2)$$

G_{sc} : solar constant = 0.0820 [MJ m^{-2} min^{-1}]

d_r : inverse relative distance between Earth and Sun calculated as follows.

$$d_r = 1 + 0.033 \cos(\frac{2\pi}{365} \times J) \qquad (3)$$

J is the Julian day ranging 1 (1 January) and 365 or 366(31 December).

ω_s :sunset hour angle calculated with φ and δ

$$\omega_s = arc\cos\left[-\tan(\varphi)\tan(\delta)\right] \qquad (4)$$

φ :latitude[radians]

δ :celestial declination[radians] given by Eq. (5);

$$\delta = 0.409 \sin\left[\frac{2\pi}{365} \times J - 1.39\right] \quad (5)$$

The maximum possible sunshine duration, N in Eq(1) is calculated as follows.

$$N = \frac{24}{\pi} \times \omega_s \quad (6)$$

Local coefficients a_s and b_s in Eq.(1) were decided based on sunshine duration (n) and daily solar radiation(R_s) at Yinchuan and Guyuan stations in Ningxia. We have used 5 year(1981-1985) radiation data in Yinchuan. Fig.2 shows a linear relation between observed daily solar radiation (R_s) and the formula including extraterrestrial radiation (R_a), sunshine duration(n) and maximum possible sunshine duration (N) in Yinchuan. Based on the linear regression equation, we can calculate as a_s=0.18 and b_s=0.62.

Kondo et al.(1991) have obtained the local coefficients based on Sendai weather station data in Japan. They have evaluated as a_s =0.179 and b_s=0.550 for Jordan sunshine meter. They also report that the value depends on the type of sunshine meter and also depends on region and data duration.

Using the local coefficients, we have validated for other two-year(1986 and 1987) data comparing the calculated value with the observed daily solar radiation value. Fig.3 shows a good agreement between calculated and observed values and approached 1:1 line.

So we can consider that the local coefficients(a_s and b_s)values are useful to calculate solar radiation at other regions near Yinchuan station in north part in Ningxia province.

Using the same method, the local coefficients of Guyuan station(south part in Ningxia) were evaluated as a_s=0.16 and b_s=0.58, and the calculated values were compared with observation data of daily solar radiation for four years(1991～1994). Results were showed in Fig.4.

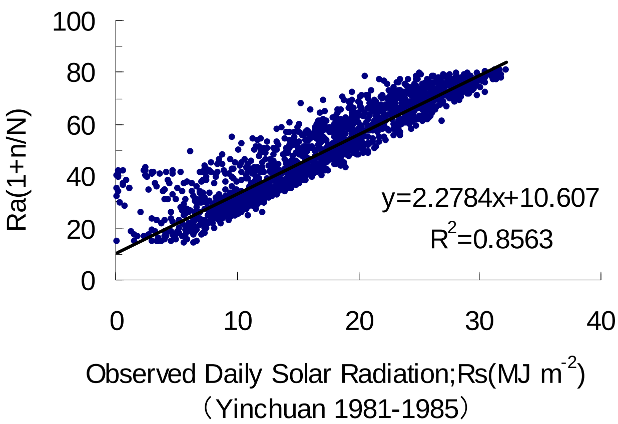

Fig.2 Relationship between observed solar radiation(Rs) and formula of extra- terrestrial radiation(Ra), sunshine duration(n) and maximum possible sunshine duration (N).

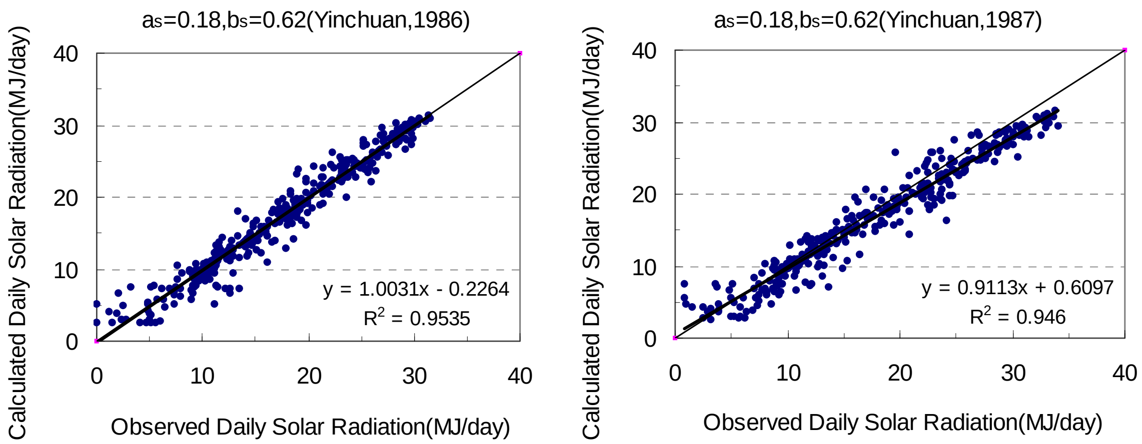

Fig.3 Comparison of observed daily solar radiation and calculated daily solar radiation at Yinchuan(1986,1987

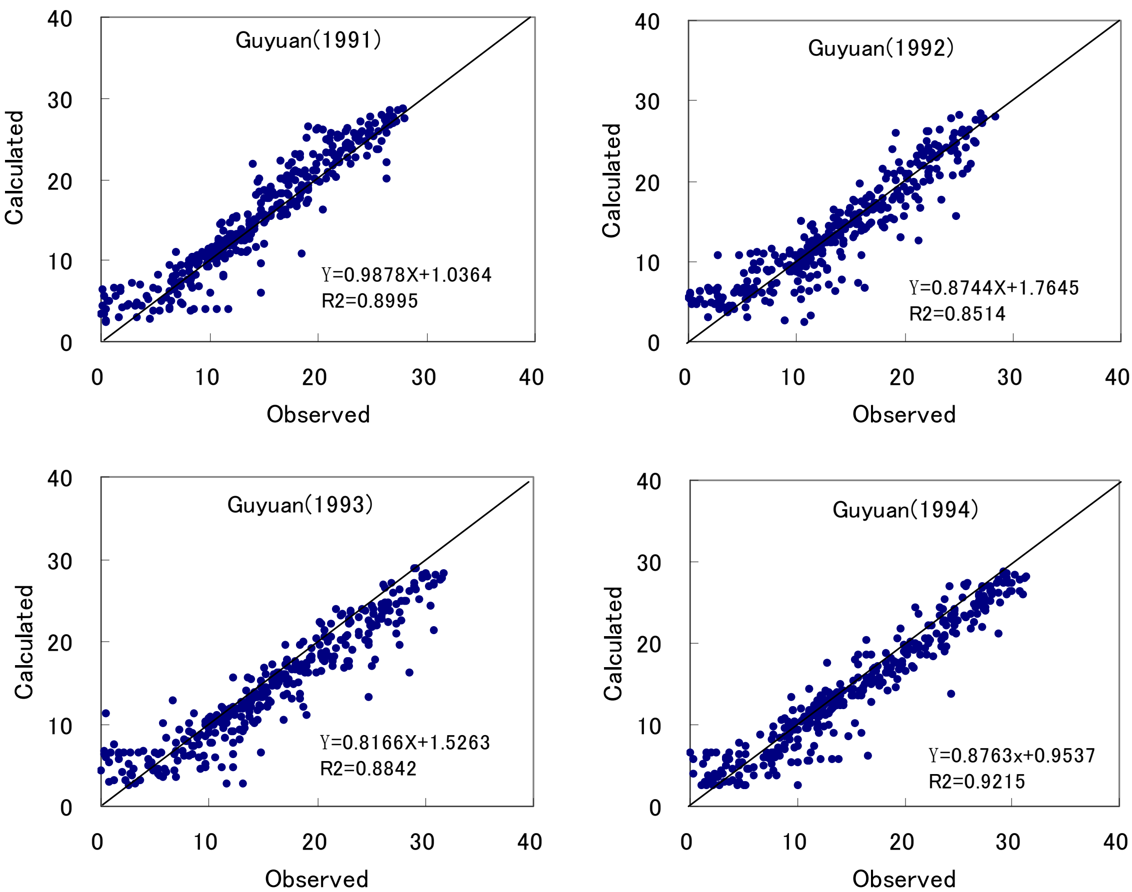

Fig.4 Comparison of observed daily solar radiation and calculated daily solar radiation at Guyuan(1991-1994)

3. Error and Confidence level analysis

3.1 Error analysis

Now we have obtained the local coefficients of as and bs for the north and south part in Ningxia region. In the north and middle regions of Ningxia, Eq.(7) can be used for the estimation of daily solar radiation. And in the south part of Ningxia region around Guyuan, Eq.(8) can be used.

$$Rs = (0.18 + 0.62\frac{n}{N})\ Ra \quad (7)$$

$$Rs = (0.16 + 0.58\frac{n}{N})\ Ra \quad (8)$$

Before, applying the two equations, we have simulated solar radiation values and compared with the measurements based on historic value of daily solar radiation of Yinchuan(1973-2006) and Guyuan(1986-2006). Yinchuan and Guyuan stations were set up in 1973 and 1986respectively. As the error analysis, mean bias error(MBE; MJ m^{-2} d^{-1}), mean absolute bias error(MABE; MJ m^{-2} d^{-1}), root mean square error(RMSE; MJ m^{-2} d^{-1}), mean absolute percentage error(MAPE; %) were calculated as shown in Table 1 using Eqs.(9)-(12). Here, R_{sim} and R_{obs} express simulation and observation value, *n* is the number of sample years.

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(R_{sim} - R_{obs}) \quad (9)$$

$$MABE = \frac{1}{n}\sum_{i=1}^{n}\left|\ (R_{sim} - R_{obs})\ \right| \quad (10)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(R_{sim} - R_{obs})^2} \quad (11)$$

$$MAPE = \frac{\frac{1}{n}\sum_{i=1}^{n}\left|\ R_{sim} - R_{obs}\ \right|}{\frac{1}{n}\sum_{i=1}^{n}R_{obs}} \times 100 \quad (12)$$

Mean bias error(MBE) in Yinchuan station is mostly positive and mostly negative in Guyuan station. This means estimated values at Yinchuan station are a little higher than observation values, and those at Guyuan station are a little lower. Mean absolute bias error(MABE) are 1.5 and 1.7. This is almost same as the results of Kondo et al.(1991). Mean absolute percentage error(MAPE) at Yinchuan is lower than Guyuan, the maximum value is13% and 17% in Yinchuan and Guyuan stations respectively.

3.2 Confidence level test

As a confidence level test, “t-test” was applied on estimated and observed value of daily solar radiation for five years(1986-1990) in Guyuan station as shown in Table 2. When confidence level was set at α= 0.05(5%), t-value of infinitesimal freedom is 1.96. According to the five year t-test results, t-value is calculated as lower than 1.96. This means that estimated values and observed values are not different statistically.

Table 1 Various error test of daily solar radiation in Yinchuan(1973～2006) and Guyuan(1986～2006) stations

Yinchuan	MBE	MABE	RMSE	MAPE(%)	Guyuan	MBE	MABE	RMSE	MAPE(%)
1973	1.4	1.8	2.5	10.7					
1974	1.4	1.7	2.3	9.9					
1975	0.7	1.4	1.9	8.6					
1976	0.5	1.4	2.3	8.4					
1977	0.3	1.3	1.8	7.7					
1978	0.8	1.3	1.9	7.8					
1979	0.2	1.4	1.9	8.2					
1980	1.5	1.9	2.8	11.9					
1981	1.3	1.8	2.5	11.5					
1982	0.7	1.5	2.1	9.1					
1983	0.8	1.5	2.2	9.6					
1984	0.3	1.3	1.8	7.6					
1985	-0.2	1.7	2.2	8.3					
1986	-0.3	1.2	1.7	7.2	1986	-0.2	2.5	3.9	16.5
1987	-1.0	1.7	2.2	9.9	1987	-0.4	1.9	2.4	11.9
1988	-0.1	1.6	2.1	9.5	1988	0.3	1.9	2.5	13.5
1989	0.6	1.4	1.9	9.1	1989	0.2	2.0	2.6	14.2
1990	1.6	1.9	2.6	12.1	1990	0.0	1.7	2.4	11.5
1991	0.3	1.4	2.0	8.4	1991	1.0	1.8	2.4	12.4
1992	0.4	1.8	3.1	11.6	1992	0.3	2.0	2.8	14.5
1993	-0.1	1.4	2.3	8.5	1993	-1.0	2.3	3.3	15.1
1994	1.4	1.8	2.5	10.7	1994	-0.8	1.8	2.4	11.8
1995	1.3	1.7	2.3	9.9	1995	-0.3	1.4	1.7	8.6
1996	0.7	1.4	1.9	8.5	1996	-0.4	1.4	1.8	8.8
1997	0.5	1.4	2.3	8.5	1997	-0.8	1.5	1.9	9.5
1998	0.4	1.3	1.8	7.7	1998	-0.9	1.8	2.0	9.1
1999	0.8	1.3	1.9	7.8	1999	-0.5	1.5	2.0	9.7
2000	0.1	1.4	1.9	8.2	2000	-0.9	1.6	2.2	10.3
2001	1.5	2.0	2.8	12.1	2001	-0.6	1.6	2.3	10.6
2002	1.3	1.8	2.5	11.3	2002	-0.3	1.3	1.8	8.6
2003	0.7	1.5	2.1	9.3	2003	-0.4	1.6	2.1	11.0
2004	0.8	1.5	2.1	9.5	2004	-0.4	1.6	2.1	10.4
2005	0.2	1.3	1.8	7.6	2005	-0.9	1.7	2.1	11.0
2006	-0.2	1.7	2.3	8.3	2006	-1.0	1.5	2.2	11.7
Average	0.6	1.5	2.2	9.3	Average	-0.4	1.7	2.3	11.5

Table 2 't-test' value of daily solar radiation for five years in Guyuan station (1986～1990)

	1986	1987	1988	1989	1990
freedom	728	728	730	728	728
Sample size	365	365	366	365	365
t-value	0.335	0.683	-0.624	-0.328	0.014

4. Application to other station

As a practical application based on Yinchuan station, daily solar radiation at Yongning station was estimated for twelve years(1989-2000). Results were compared with the same time series observation value of Yinchuan as reference as shown in Fig. 5. There is a good linear relationship between estimation results at Yongning station and observation at Yinchuan station. Minimum value of the regression error R^2 is 0.88, and maximum R^2 reached 0.93. It is considered this method is applicable to estimate daily solar radiation in Ningxia region.

5. Summary

In order to estimate daily solar radiation, a method of calculation based on daily sunshine duration was proposed to be applicable in Ningxia region, China. For the calculation using Eq.(1), local coefficients are determined based on two weather station data in Ningxia region. The local coefficient values are evaluated as as=0.18, bs=0.62 for the north and middle part of Ningxia region, and as=0.16, bs=0.58 for the south part of Ningxia region. The results of the application were checked against referenced observation of daily solar radiation and statistical error analysis and confidence check was used. And finally, the method was applied to other station in Ningxia region with satisfactory results. This estimated daily solar radiation can be usefully included in crop model for agricultural meteorology.

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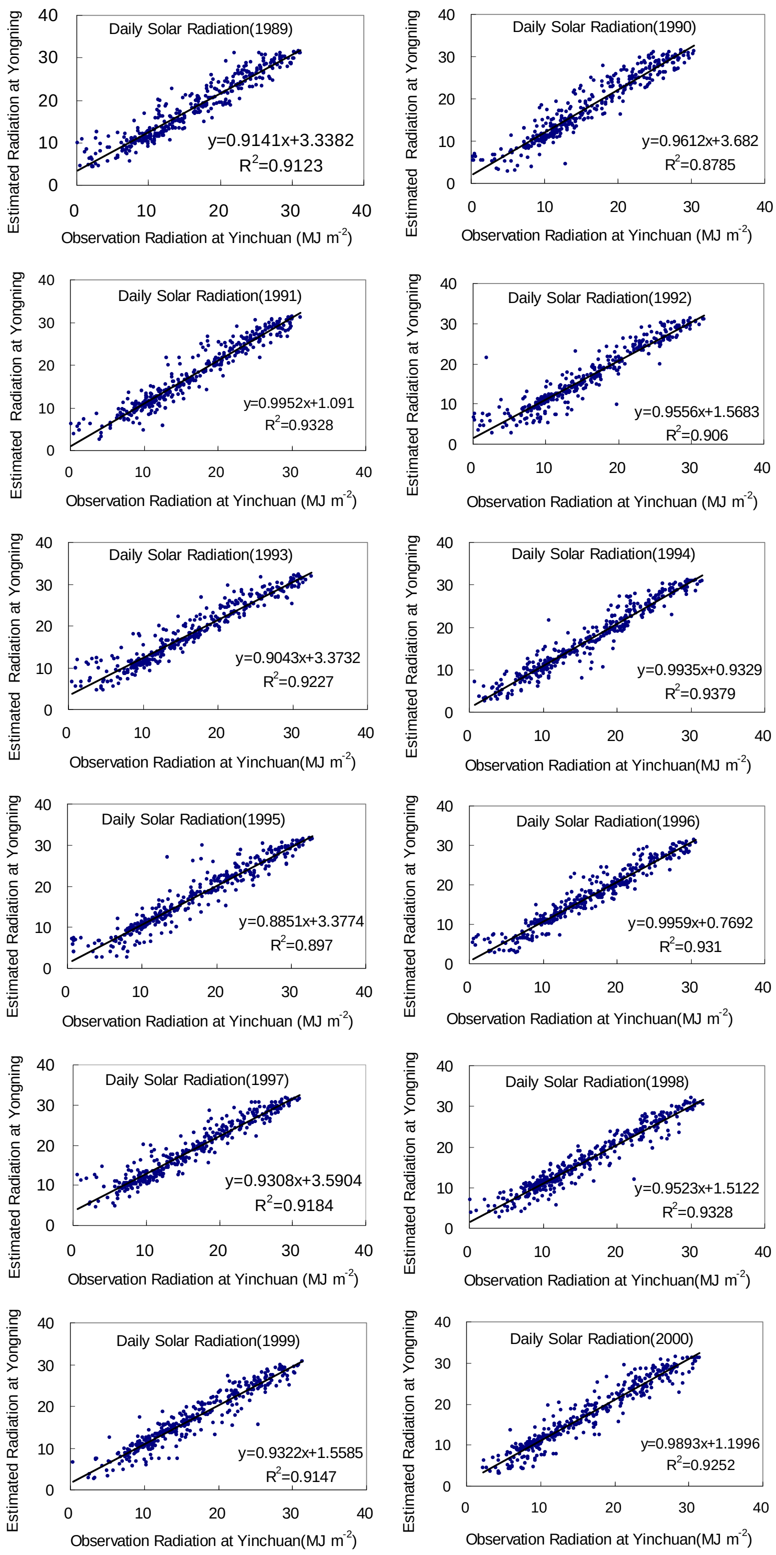

Fig.5 Comparison of estimated daily solar radiation at Yongning with observed values at Yinchuan for twelve years