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Validation of five global radiation models with measured daily data in China

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Abstract

Two sunshine based and three air temperature based global radiation models are calibrated using daily data in Jan. 1 1994–Dec. 31 1998 at 48 stations all over China. The Nash–Sutcliffe equation (NSE) is used as the model evaluation criterion. The sunshine based models are suitable for daily global radiation estimation. The averaged NSE value of the Angström model is 0.83, and the maximum value is 0.91. The maximum NSE value of the Bahel model is 0.92 with an averaged value of 0.84. The models that use air temperature as the input variable are not suitable for daily global radiation estimation in China. The averaged NSE values of the three air temperature based models (Bristow–Campbell model, Allen model and Hargreaves model) are not larger than 0.47. A logarithmic relationship between the daily global radiation/daily extra-terrestrial solar radiation (R_G/R_A) and the temperature difference between the maximum and minimum daily air temperature ($T_M - T_m$) is found in the present study. A new daily global radiation model that is a function of R_A, sunshine hours and $T_M - T_m$ is designed, which gives an averaged NSE value of 0.85 and a maximum value of 0.92.
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Keywords: Model validation; Daily global radiation; Sunshine hours; Air temperature; China

1. Introduction

Solar radiation is the principal energy source for physical, biological and chemical processes, such as, snow melt, plant photosynthesis, evapotranspiration and crop growth and is also a

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variable needed for biophysical models to evaluate the risk of forest fires, hydrological simulation models and mathematical models of natural processes [1]. Accurate knowledge of the solar radiation data at a particular geographical location is of vital importance [2]. As in many parts of the world, there have been a large number of stations measuring basic meteorological variables, while few stations measure global radiation. Therefore, many empirical global radiation models are discussed in the literature, which are based on basic climatic variables, such as sunshine hours, air temperature and so on [1,3–5]. However, since Wenxian et al. [4] reported the parameters of eight sunshine based monthly global radiation models in Yunan province in 1999, there has rarely been any papers using the data from China in the present literature.

There are about 726 long term and stationary meteorological stations in China Mainland that measure sunshine hours, air temperature, precipitation etc. However, there have been only 98 stations measuring global radiation from 1993, 50 stations measure net radiation and only 17 stations measure diffuse radiation, direct radiation and albedo [6]. Hence, knowing about the relationship between global radiation and some basic climatic variables is necessary in China. In the following text, two sunshine based models and three air temperature based models are validated using the daily data coming from 48 stations in China.

2. Models and data

2.1. Angström model

Angström [7] suggested a simple linear relationship to estimate global solar radiation (R_G, $\mathrm{MJ\,m^{-2}\,day^{-1}}$) as a function of extra-terrestrial solar radiation (R_A, $\mathrm{MJ\,m^{-2}\,day^{-1}}$), actual sunshine hours (n) and potential sunshine hours (N).

$$\frac{R_G}{R_A} = a + b\frac{n}{N} \tag{1}$$

The methods that calculate extra-terrestrial solar radiation R_A and potential sunshine hours N can be found in many reports, for example, in Francisco et al. [1], Romo and Arteaga [8] and Michael et al. [9].

Angström suggested values of 0.2 and 0.5 for the empirical coefficients a and b, respectively. Many authors have calibrated this model for different places [1,4,9–14].

2.2. Bahel model

In Ref. [15], Bahel developed a worldwide correlation based on bright sunshine hours and global radiation data of 48 stations around the world:

$$R_G/R_A a + b(n/N) + c(n/N)^2 + d(n/N)^3 \tag{2}$$

The parameter values are 0.16, 0.87, −0.16 and 0.34 for a, b, c and d, respectively [15].

2.3. Bristow–Campbell model

Bristow and Campbell [16] suggested the following relationship for daily R_G, as a function of daily R_A and the difference between maximum and minimum temperatures (ΔT, °C):

$$\frac{R_G}{R_A} = a[1 - \exp(-b\Delta T^c)] \tag{3}$$

Although coefficients a, b and c are empirical, they have some physical meaning. Coefficient a represents the maximum radiation that can be expected on a clear day. Coefficients b and c control the rate at which a is approached as the temperature difference increases [1].

2.4. Allen model

Allen [17] suggested a self calibrating global solar radiation model that is a function of R_A mean monthly maximum (T_M, °C) and minimum temperatures (T_m, °C). Here, we use daily data instead.

$$\frac{R_G}{R_A} = a(T_M - T_m)^{0.5} \tag{4}$$

2.5. Hargreaves model

Hargreaves et al. [18] report a simple method to estimate daily global radiation that has an expression like the Allen model [17]:

$$\frac{R_G}{R_A} = a(T_M - T_m)^{0.5} + b \tag{5}$$

2.6. Parameters calculation and model evaluation

Model parameters are obtained by numerical iteration methods [19], and the famous Nash–Sutcliffe equation (NSE) [20] is selected as the evaluation criterion:

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{n}(R_{Gi\mathrm{obs}} - R_{Gi\mathrm{mod}})^2}{\sum_{i=1}^{n}(R_{Gi\mathrm{obs}} - \overline{R_{G\mathrm{obs}}})^2} \tag{6}$$

where $R_{Gi\mathrm{obs}}$ is the measured global radiation in time i, $R_{Gi\mathrm{mod}}$ is the calculated R_G, $\overline{R_{G\mathrm{obs}}}$ is the mean measured R_G and n is the length of the series. A model is more efficient when NSE is closer to 1 [21].

2.7. Climatic data

The daily climatic data come from 48 meteorological stations all over China in Jan. 1 1994–Dec. 31 1998. The data were provided by the Chinese National Climate Center. Fig. 1 shows the distribution of the selected stations. Table 1 lists the detail information of these stations.

Fig. 1. Distribution of the selected climatic stations in China.

3. Results and discussion

3.1. Angström model

The parameters of the Angström model are listed in Table 1. The maximum NSE value is 0.91 and the averaged value is 0.83. This means that the model runs well. The averaged values of coefficients a and b are 0.19 and 0.53, respectively, and a varies as 0.12–0.3, while b varies as 0.45–0.68.

The averaged value of a is less while the averaged value of b is larger than the values of Angström [7] and Castillo [1]. Rietveld reported that the a and b values were 0.18 and 0.62, respectively [22].

Table 1
Coefficients *a* and *b* of Angström model

Stations	*a*	*b*	NSE	Latitude (N)	Longitude (E)	Altitude (m)	Stations	*a*	*b*	NSE	Latitude (N)	Longitude (E)	Altitude (m)
Heihe	0.21	0.49	0.86	50°15′	127°27′	166.4	Zhengzhou	0.17	0.52	0.88	34°43	113°39′	110.4
Hailaer	0.24	0.50	0.80	49°13′	119°45′	610.2	Xian	0.23	0.48	0.71	34°18′	108°56′	397.5
Alatai	0.19	0.57	0.78	47°44′	88°05′	735.3	Geer	0.21	0.68	0.58	32°30′	80°05′	4278
Tacheng	0.24	0.51	0.83	46°44	83°00′	534.9	Nanjing	0.14	0.53	0.90	32°00′	118°48′	8.9
Haerbin	0.25	0.46	0.78	45°45′	126°46′	142.3	Hefei	0.16	0.54	0.85	31°52′	117°14′	27.9
Yining	0.12	0.60	0.86	43°57′	81°20′	662.5	Shanghai	0.17	0.54	0.86	31°24′	121°29′	3.5
Changchun	0.16	0.57	0.87	43°54′	125°13′	236.8	Changdu	0.22	0.58	0.85	31°09	97°10′	3306
Urumqi	0.21	0.52	0.80	43°47′	87°37′	917.9	Chengdu	0.15	0.55	0.81	30°40′	104°01′	506.1
Erlianhaote	0.26	0.52	0.83	43°39	111°58′	964.7	Wuhan	0.13	0.52	0.84	30°37′	114°08′	23.3
Hami	0.19	0.58	0.85	42°49′	93°31′	737.2	Hangzhou	0.13	0.62	0.89	30°14′	120°10′	41.7
Erjinaqi	0.26	0.51	0.85	41°57′	101°04′	940.5	Lasa	0.30	0.54	0.80	29°40′	91°08′	3648.7
Shenyang	0.19	0.50	0.83	41°44′	123°27′	42.8	Chongqing	0.14	0.57	0.83	29°35′	106°28′	259.1
Tunhang	0.20	0.53	0.85	40°09′	94°41′	1139	Nanchang	0.14	0.57	0.89	28°36′	115°55′	46.7
Peking	0.17	0.53	0.88	39°56′	116°17′	54	Changsha	0.16	0.57	0.84	28°13	112°55′	68
Kashi	0.25	0.46	0.74	39°28′	75°59′	1288.7	Guiyang	0.18	0.58	0.76	26°35′	106°43′	1074.3
Leting	0.19	0.53	0.86	39°25′	118°54′	10.5	Fuzhou	0.19	0.55	0.74	26°05′	119°17′	84
Tianjin	0.18	0.46	0.79	39°05′	117°04′	2.5	Guilin	0.15	0.57	0.88	25°19′	110°18′	194.4
Yinchuan	0.19	0.56	0.88	38°29′	106°13′	1111.4	Kunming	0.19	0.59	0.91	25°01′	102°41′	1891.4
Taiyuan	0.20	0.48	0.80	37°47	112°33′	778.3	Shantou	0.19	0.52	0.90	23°24′	116°41′	1.1
Hetian	0.25	0.48	0.88	37°08′	79°56′	1374.6	Guangzhou	0.16	0.48	0.80	23°08′	113°19′	6.6
Jinan	0.16	0.51	0.85	36°41′	116°59′	51.6	Nanning	0.16	0.58	0.85	22°49′	108°21′	73.1
Xining	0.21	0.53	0.88	36°37′	101°46′	2261.2	Jinghong	0.23	0.45	0.75	22°00′	100°48′	552.7
Geermu	0.25	0.55	0.87	36°25′	94°54′	2807.6	Haikou	0.16	0.56	0.88	20°02′	110°21′	13.9
Lanzhou	0.16	0.53	0.87	36°03′	103°53′	1517.2	Sanya	0.24	0.48	0.81	18°14′	109°31′	5.5

Table 2
Bahel model coefficients

Stations	*a*	*b*	*c*	*d*	NSE	Stations	*a*	*b*	*c*	*d*	NSE
Heihe	0.19	0.83	−0.68	0.38	0.87	Zhengzhou	0.15	1.15	−1.69	1.15	0.90
Hailaer	0.24	0.45	0.22	−0.19	0.80	Xian	0.21	1.15	−1.80	1.20	0.73
Alatai	0.17	0.67	−0.04	−0.07	0.78	Geer	0.20	1.01	−0.85	0.55	0.58
Tacheng	0.24	0.59	−0.29	0.23	0.83	Nanjing	0.11	1.11	−1.50	0.98	0.91
Haerbin	0.22	0.77	−0.66	0.37	0.79	Hefei	0.13	1.23	−1.69	1.05	0.87
Yining	0.10	0.80	−0.42	0.23	0.86	Shanghai	0.14	1.28	−1.74	1.04	0.89
Chang-chun	0.14	0.86	−0.67	0.41	0.87	Changdu	0.24	0.59	−0.32	0.37	0.86
Urumqi	0.19	0.92	−1.06	0.72	0.80	Chengdu	0.13	1.19	−1.93	1.40	0.83
Erlian-haote	0.25	0.61	−0.19	0.10	0.83	Wuhan	0.11	1.07	−1.34	0.83	0.85
Hami	0.21	0.70	−0.58	0.50	0.85	Hangzhou	0.11	1.30	−1.82	1.23	0.90
Erjinaqi	0.26	0.57	−0.18	0.13	0.85	Lasa	0.30	0.58	−0.15	0.12	0.80
Shenyang	0.18	0.77	−0.67	0.43	0.83	Chongqing	0.13	0.39	−2.23	1.47	0.85
Tunhang	0.22	0.55	−0.31	0.29	0.86	Nanchang	0.12	1.39	−2.03	1.27	0.91
Peking	0.16	0.98	−1.36	0.99	0.89	Changsha	0.14	1.29	−1.69	0.97	0.87
Kashi	0.25	0.42	0.12	−0.09	0.74	Guiyang	0.16	1.38	−2.19	1.44	0.79
Leting	0.17	1.01	−1.24	0.82	0.87	Fuzhou	0.16	1.48	−2.39	1.54	0.78
Tianjin	0.16	0.88	−1.12	0.77	0.80	Guilin	0.13	1.21	−1.62	1.01	0.90
Yinchuan	0.17	0.94	−0.94	0.62	0.89	Kunming	0.15	1.15	−1.30	0.79	0.92
Taiyuan	0.18	0.84	−1.00	1.71	0.80	Shantou	0.16	1.08	−1.37	0.85	0.91
Hetian	0.25	0.59	−0.38	0.30	0.88	Guang-zhou	0.13	1.16	−1.71	1.09	0.84
Jinan	0.13	1.09	−1.56	1.08	0.86	Nanning	0.11	1.11	−1.50	0.98	0.91
Xining	0.19	0.81	−0.70	0.47	0.88	Jinghong	0.19	0.79	−0.63	0.29	0.77
Geermu	0.22	0.81	−0.59	0.38	0.87	Haikou	0.13	1.23	−1.71	1.12	0.90
Lanzhou	0.14	0.95	−1.18	0.83	0.88	Sanya	0.21	0.99	−1.20	0.74	0.82

3.2. Bahel model

Table 2 shows the results of the Bahel model. The averaged and maximum NSE values are 0.84 and 0.92, respectively. The Angström model NSE value is less than the Bahel model NSE value at 31 stations, and equal at the other 17 stations. That is to say, the Bahel model is more suitable to calculate the daily global radiation in China.

The averaged value for a, b, c and d is 0.17, 0.93, −1.08 and 0.73, respectively, which is largely different from the values that were suggested by Bahel (0.16, 0.87, −0.16 and 0.34, respectively) [15].

3.3. Bristow–Campbell model

The Bristow–Campbell model results are shown in Table 3. The computational program did not converge when the data at Xian and Chongqing stations were used. Therefore, the Bristow–Campbell model results are unreliable at these two stations. The averaged NSE value is 0.47,

Table 3
Bristow–Campbell model results

Stations	*a*	*b*	*c*	NSE	Stations	*a*	*b*	*c*	NSE
Heihe	0.60	0.07	1.47	0.28	Zhengzhou	0.56	0.03	1.69	0.56
Hailaer	0.61	0.04	1.70	0.27	Xian	2.35	0.08	0.28	0.09
Alatai	0.70	0.04	1.56	0.34	Geer	1.02	0.11	0.96	0.31
Tacheng	0.75	0.12	1.04	0.34	Nanjing	0.52	0.01	2.28	0.61
Haerbin	0.63	0.14	1.07	0.25	Hefei	0.55	0.01	2.32	0.61
Yining	0.71	0.03	1.47	0.51	Shanghai	0.50	0.03	2.47	0.40
Changchun	0.60	0.03	1.88	0.34	Changdu	0.90	0.05	1.08	0.57
Urumqi	0.59	0.07	1.46	0.31	Chengdu	0.58	0.02	1.78	0.72
Erlianhaote	0.70	0.09	1.29	0.20	Wuhan	0.51	0.01	2.58	0.59
Hami	0.71	0.05	1.44	0.38	Hangzhou	0.60	0.01	2.17	0.63
Erjinaqi	0.76	0.10	1.11	0.29	Lasa	0.84	0.05	1.29	0.43
Shenyang	0.57	0.06	1.50	0.30	Chongqing	3.19	0.01	0.94	0.25
Tunhang	0.80	0.13	0.89	0.35	Nanchang	0.55	0.01	2.62	0.64
Peking	0.60	0.04	1.64	0.39	Changsha	0.56	0.02	2.07	0.66
Kashi	0.86	0.07	1.03	0.51	Guiyang	0.59	0.02	1.88	0.59
Leting	0.61	0.03	1.84	0.44	Fuzhou	0.58	0.02	2.00	0.63
Tianjin	0.53	0.03	1.87	0.41	Guilin	0.60	0.03	1.83	0.69
Yinchuan	0.70	0.04	1.51	0.46	Kunming	0.71	0.01	2.02	0.71
Taiyuan	0.56	0.03	1.76	0.44	Shantou	0.58	0.03	2.15	0.58
Hetian	0.76	0.06	1.24	0.50	Guangzhou	0.51	0.02	2.12	0.61
Jinan	0.54	0.03	1.98	0.41	Nanning	0.54	0.01	2.27	0.65
Xining	0.71	0.05	1.32	0.59	Jinghong	0.55	0.02	2.06	0.64
Geermu	0.73	0.02	1.79	0.33	Haikou	0.53	0.08	1.68	0.43
Lanzhou	0.71	0.04	1.33	0.47	Sanya	0.60	0.08	1.72	0.31

and 0.72 is the maximum value (results at Xian and Chongqing are excluded). The model runs better in the low latitude area than in the high latitude area (Fig. 2). The averaged values for a, b and c are 0.64, 0.045 and 1.70, respectively (results at Xian and Chongqing are excluded).

The values most frequently reported for these coefficients are 0.7 for a, the range 0.004–0.010 for b and 2.4 for c [1]. The coefficients at some stations in Table 3 are close to the prior report.

From the NSE values, the Bristow–Campbell model results are not as good as the Angström model and the Bahel model results in the present study. The Bristow–Campbell model results in the present study are also worse than prior reports, such as Refs. [1,15].

3.4. Allen model

Table 4 shows the Allen model results. The NSE value varied as 0.11–0.55, and with an averaged value of 0.39. That is to say, the Allen model results are worse than the Bristow–Campbell model results.

The coefficient a varies as 0.11–0.20, and the averaged value is 0.15. The coefficient a is less than the averaged value that Francisco reported, 0.29, which varies as 0.01–0.47 [1].

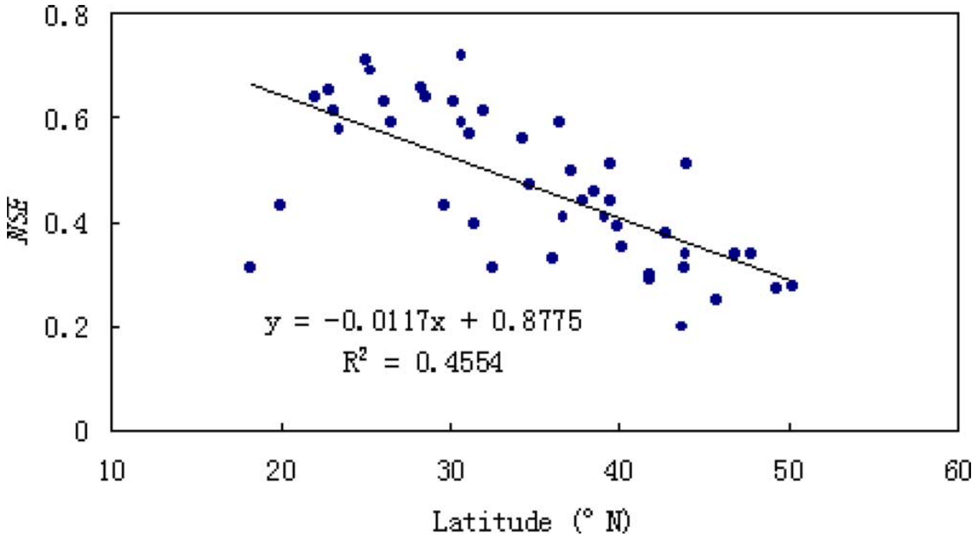

Fig. 2. Relationship between latitude and the Bristow–Campbell model NSE value.

3.5. Hargreaves model

The Hargreaves model results are also shown in Table 4. The NSE value varies as 013–0.73, and with an averaged value 0.44. These results are better than those of the Allen model, but still are worse than the Bristow–Campbell model results.

The coefficient a varies as 0.10–0.29, and the averaged value is 0.19. The coefficient b varies as −0.41 to 0.24 with an averaged value of −0.13.

3.6. New results

In the present study, the relationship between R_G/R_A and $T_M - T_m$ is not as good as the results reported in the literature using the models in Sections 2.3, 2.4 and 2.5. The new expression is found as

$$\frac{R_G}{R_A} = a\ln(T_M - T_m) + b \tag{7}$$

The model constants are shown in Table 5. The NSE value varies as 0.12–0.70 with an averaged value of 0.45. Although the model results are not good, it is better than the Allen model and Hargreaves model results. The coefficient a varies as 0.16–0.42, and the averaged value is 0.28. The coefficient b varies as −0.45 to 0.12 with an averaged value of −0.15.

Another new expression is

$$\frac{R_G}{R_A} = a\ln(T_M - T_m) + b\left(\frac{n}{N}\right)^c + d \tag{8}$$

The averaged NSE value is 0.85 (Table 5), which is larger than that of the Angström model and the Bahel model. The NSE value of the new model is larger than the value of the Bahel model at

Table 4
Allen model and Hargreaves model results

Stations	Allen model		Hargreaves model			Stations	Allen model		Hargreaves model		
	a	NSE	a	b	NSE		a	NSE	a	b	NSE
Heihe	0.15	0.23	0.13	0.08	0.24	Zhengzhou	0.13	0.49	0.18	−0.15	0.53
Hailaer	0.16	0.19	0.12	0.13	0.20	Xian	0.11	0.13	0.10	0.02	0.13
Alatai	0.16	0.30	0.21	−0.15	0.32	Geer	0.20	0.30	0.19	0.07	0.30
Tacheng	0.16	0.33	0.16	0.01	0.33	Nanjing	0.14	0.48	0.21	−0.22	0.55
Haerbin	0.15	0.22	0.13	0.09	0.23	Hefei	0.14	0.47	0.24	−0.28	0.56
Yining	0.15	0.46	0.20	−0.20	0.50	Shanghai	0.17	0.32	0.21	−0.10	0.33
Changchun	0.16	0.29	0.19	−0.09	0.30	Changdu	0.14	0.53	0.18	−0.17	0.57
Urumqi	0.15	0.27	0.17	−0.05	0.27	Chengdu	0.11	0.52	0.22	−0.30	0.71
Erlianhaote	0.17	0.11	0.11	0.24	0.17	Wuhan	0.14	0.43	0.25	−0.31	0.55
Hami	0.16	0.34	0.14	0.06	0.35	Hangzhou	0.15	0.48	0.26	−0.34	0.61
Erjinaqi	0.17	0.26	0.14	0.12	0.27	Lasa	0.18	0.41	0.19	−0.04	0.41
Shenyang	0.14	0.27	0.14	0.01	0.27	Chongqing	0.11	0.53	0.23	−0.30	0.73
Tunhang	0.15	0.34	0.13	0.09	0.35	Nanchang	0.15	0.46	0.27	−0.32	0.58
Peking	0.15	0.35	0.19	−0.11	0.36	Changsha	0.14	0.51	0.23	−0.26	0.62
Kashi	0.15	0.49	0.18	−0.11	0.50	Guiyang	0.12	0.44	0.23	−0.30	0.57
Leting	0.16	0.38	0.19	−0.09	0.39	Fuzhou	0.14	0.49	0.25	−0.30	0.61
Tianjin	0.14	0.36	0.17	−0.10	0.37	Guilin	0.14	0.54	0.24	−0.28	0.67
Yinchuan	0.16	0.42	0.19	−0.10	0.43	Kunming	0.16	0.55	0.29	−0.41	0.70
Taiyuan	0.13	0.39	0.15	−0.08	0.40	Shantou	0.17	0.46	0.28	−0.28	0.54
Hetian	0.16	0.48	0.19	−0.12	0.49	Guangzhou	0.13	0.46	0.24	−0.29	0.58
Jinan	0.15	0.34	0.21	−0.19	0.38	Nanning	0.13	0.48	0.26	−0.34	0.63
Xining	0.14	0.55	0.17	−0.13	0.57	Jinghong	0.14	0.53	0.15	−0.04	0.53
Geermu	0.17	0.27	0.16	0.06	0.27	Haikou	0.16	0.38	0.23	−0.16	0.41
Lanzhou	0.13	0.42	0.20	−0.22	0.47	Sanya	0.19	0.28	0.23	−0.10	0.29

19 stations while being less at 3 stations. The NSE value of this new model is larger than the value of the Angström model at 32 stations. The coefficient a varies as −0.03 to −0.1, and the averaged value is 0.04. The averaged values for b, c and d are 0.48, 0.83 and 0.11, respectively.

4. Conclusion

In China, the daily global radiation may be estimated relatively accurately using sunshine based models. The simple Angström model can provide good results. The Bahel model results are slightly better than the Angström model results. However, the new expression (Eq. (8)) runs best.

The models that are functions of R_A and $T_M - T_m$ are not suitable for daily global radiation estimation in China. In the low latitude area, the relationship between R_G/R_A and $T_M - T_m$ is

Table 5
New models results

Stations	New model 1			New model 2					Stations	New model 1			New Model 2				
	a	*b*	NSE	*a*	*b*	*c*	*d*	NSE		*a*	*b*	*NSE*	*a*	*b*	*c*	*d*	NSE
Heihe	0.21	0.01	0.26	0.02	0.49	0.80	0.15	0.87	Zheng-zhou	0.26	−0.18	0.55	0.03	0.47	0.73	0.10	0.90
Hailaer	0.21	0.03	0.23	0.02	0.49	0.96	0.19	0.80	Xian	0.16	−0.04	0.12	0.06	0.41	0.61	0.07	0.74
Alatai	0.33	−0.24	0.33	0.02	0.56	0.85	0.11	0.78	Geer	0.34	−0.11	0.31	0.08	0.60	1.04	0.08	0.59
Tacheng	0.25	−0.05	0.34	−0.03	0.54	1.03	0.29	0.83	Nanjing	0.28	−0.20	0.58	0.03	0.48	0.73	0.07	0.92
Haerbin	0.20	0.04	0.24	0.05	0.44	0.80	0.11	0.80	Hefei	0.30	−0.21	0.57	0.06	0.46	0.66	0.05	0.88
Yining	0.32	−0.28	0.50	0.04	0.56	0.90	0.03	0.86	Shanghai	0.25	−0.03	0.36	0.01	0.51	0.60	0.12	0.89
Chang-chun	0.29	−0.14	0.32	0.01	0.57	0.86	0.13	0.87	Changdu	0.33	−0.36	0.57	0.02	0.55	1.24	0.21	0.86
Urumqi	0.24	−0.07	0.29	0.02	0.50	0.85	0.16	0.80	Chengdu	0.26	−0.21	0.67	0.10	0.37	0.78	−0.01	0.87
Erlian-haote	0.20	0.12	0.18	0.01	0.52	0.94	0.22	0.83	Wuhan	0.30	−0.23	0.55	0.05	0.45	0.70	0.03	0.86
Hami	0.27	−0.10	0.37	0.02	0.55	1.20	0.19	0.85	Hangzhou	0.32	−0.25	0.61	0.05	0.54	0.76	0.04	0.90
Erjinaqi	0.25	−0.02	0.28	0.03	0.50	1.00	0.19	0.85	Lasa	0.35	−0.24	0.42	0.04	0.50	1.04	0.22	0.80
Shenyang	0.23	−0.07	0.29	0.03	0.48	0.89	0.12	0.83	Chongqing	0.25	−0.16	0.67	0.09	0.38	0.65	0.01	0.90
Tunhang	0.24	−0.05	0.35	0.03	0.49	1.21	0.18	0.86	Nanchang	0.31	−0.20	0.59	0.05	0.49	0.62	0.05	0.92
Peking	0.28	−0.15	0.38	0.01	0.53	0.99	0.15	0.88	Changsha	0.26	−0.14	0.61	0.07	0.44	0.65	0.04	0.89
Kashi	0.28	−0.18	0.49	0.09	0.38	1.01	0.08	0.76	Guiyang	0.28	−0.22	0.55	0.08	0.42	0.58	0.03	0.82
Leting	0.29	−0.15	0.42	0.02	0.51	0.84	0.13	0.87	Fuzhou	0.30	−0.21	0.60	0.09	0.40	0.57	0.03	0.81
Tianjin	0.26	−0.15	0.39	0.03	0.44	0.86	0.12	0.80	Guilin	0.28	−0.17	0.65	0.06	0.46	0.69	0.06	0.91
Yinchuan	0.31	−0.22	0.45	0.02	0.55	0.88	0.13	0.89	Kunming	0.42	−0.45	0.70	0.06	0.54	0.72	0.05	0.92
Taiyuan	0.25	−0.17	0.42	0.02	0.46	0.92	0.14	0.80	Shantou	0.34	−0.18	0.56	0.06	0.46	0.70	0.09	0.92
Hetian	0.31	−0.21	0.50	0.06	0.43	1.05	0.13	0.89	Guang-zhou	0.28	−0.20	0.58	0.08	0.38	0.63	0.02	0.86
Jinan	0.28	−0.17	0.39	0.04	0.48	0.81	0.08	0.86	Nanning	0.31	−0.23	0.62	0.07	0.45	0.60	0.02	0.90
Xining	0.30	−0.25	0.58	0.03	0.50	0.88	0.14	0.88	Jinghong	0.24	−0.11	0.58	0.05	0.39	0.69	0.10	0.78
Geermu	0.29	−0.12	0.30	0.03	0.55	0.94	0.17	0.87	Haikou	0.26	−0.05	0.42	0.01	0.51	0.65	0.11	0.90
Lanzhou	0.31	−0.31	0.47	0.00	0.52	0.87	0.14	0.87	Sanya	0.29	−0.04	0.30	0.06	0.45	0.71	0.12	0.83

better than in the high latitude area in China. A logarithmic relationship is found between R_G/R_A and $T_M - T_m$.

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