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A Hybrid Method for Generation of Typical Meteorological Years for Different Climates of China

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Abstract: Since a representative dataset of the climatological features of a location is important for calculations relating to many fields, such as solar energy system, agriculture, meteorology and architecture, there is a need to investigate the methodology for generating a typical meteorological year (TMY). In this paper, a hybrid method with mixed treatment of selected results from the Danish method, the Festa-Ratto method, and the modified typical meteorological year method is proposed to determine typical meteorological years for 35 locations in six different climatic zones of China (Tropical Zone, Subtropical Zone, Warm Temperate Zone, Mid Temperate Zone, Cold Temperate Zone and Tibetan Plateau Zone). Measured weather data (air dry-bulb temperature, air relative humidity, wind speed, pressure, sunshine duration and global solar radiation), which cover the period of 1994–2015, are obtained and applied in the process of forming TMY. The TMY data and typical solar radiation data are investigated and analyzed in this study. It is found that the results of the hybrid method have better performance in terms of the long-term average measured data during the year than the other investigated methods. Moreover, the Gaussian process regression (GPR) model is recommended to forecast the monthly mean solar radiation using the last 22 years (1994–2015) of measured data.

Keywords: solar energy; solar radiation; typical meteorological year (TMY); climatic zones

1. Introduction

It is known that China is the most populous country in the world, with a population of more than 1.3 billion and covering an area of over 9.6 million km^2. The fact that China ranks as the second largest consumer of energy raises concern about energy conservation and environmental protection [1–3]. Solar energy, as a kind of renewable energy, is more energy-efficient and eco-friendly than oil and coal [4–6]. Solar energy has received much attention in China as it is considered to meet a portion of China's energy demand. Quite a few weather files have been developed over the years for acquiring representative meteorological data, which is used to predict the annual performance of solar energy systems and evaluate building energy simulation [7–9]. These weather files, known as test reference year (TRY) [10,11], design reference year (DRY) [12], and typical meteorological year (TMY) [13–15], are a representative database for one year and consist of a concatenation of 12 individual months selected from different years over the measured data duration.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has built up a simple selection procedure to gather the climatic information in a TRY [16]. In the process of a TRY selection, only one meteorological variable—dry-bulb temperature—is considered. More crucially, the available years, which contain months with extremely high or extremely low dry-bulb temperature, are ruled out until only one year remains, which is chosen to be the representative month of the TRY.

This selection procedure may lead to an unrepresentative database, so it is not recommended for use in research of long-term performance of solar energy systems performed by the ASHRAE [17]. DRY is a modified version of the TRY in which it adjusts main meteorological variables (e.g., dry-bulb temperature, air relative humidity, and solar radiation) by substituting some days from other years for certain days in the same month.

Sharing a common feature with TRY, in that it uses real and effective weather data, TMY is widely accepted by most researchers. During the process of generating a TMY, 12 typical meteorological months are determined by applying the weather data from a long time period. In addition, various methods have been reported by numerous researchers in the literature for forming TMYs. Such methods include the Sandia method [18–20], the Crow method [21], the Danish method [22], the Festa-Ratto method [23], the Miquel-Bilbao method [24], and the Gazela-Mathioulakis method [25]. Among them, the Sandia method, proposed by Hall et al. [20], is the most commonly-used one. Efforts have also been put into generating TMYs for some cities with a different number of meteorological indices and assigned weightings by Pissimanis et al. [26,27], Skeiker [12], Chan et al. [28,29], Argiriou et al. [30], Kalogirou [13], and Yang et al. [11,31].

Recently, several studies have focused on obtaining the TMYs for different locations in China. In accordance with Zhang [32], the typical meteorological database for 57 Chinese locations was developed, but because no data exists on solar radiation in the observations, a method to estimate solar radiation with dry bulb temperature difference, relative humidity, total cloud cover and wind speed was developed. Chow et al. [33] and Chan et al. [29], respectively, provide TMYs for Hong Kong. Chow et al. [33] also applied the method to Macau and conducted analysis of typical weather year files. Jiang [34], Xu, and Zang [35] generated TMYs only for eight representative locations in China.

In this study, TMYs are composed of a mixture of the results of the Danish method, the Festa-Ratto method, and the modified typical meteorological year method for 35 representative locations in six climatic zones in China. The three methods are employed firstly with a set of weather data covering at least 10 years. Then a comparison between the results of the three methods and the long-term measured data are implemented by the value of ERMSD. Finally, those months that have meteorological data closest to long-term weather observations (the value of ERMSD is smallest for each individual month) are selected to generate a TMY for a certain city.

2. Climatic Zones and Data Collection

China is a vast country with a varied climate [2,36]. Among the different ways to classify the climatic types in China, the temperature-strip method is recommended in this paper. According to this method [37,38], it can be divided into six climatic types based on annual accumulated temperature, which is obtained from the summation of the daily mean temperatures over 10 °C within a year, namely Tropical Zone (TZ) (>8000 °C), Subtropical Zone (SZ) (4500 °C–8000 °C), Warm Temperate Zone (WTZ) (3400 °C–4500 °C), Mid Temperate Zone (MTZ) (1600 °C–3400 °C), Cold Temperate Zone (CTZ) (<1600 °C) and the special zone-Tibetan Plateau Zone (TPZ). Figure 1 shows a general layout of the six major climate areas.

To cover the six major climate types, a total of 35 meteorological stations are taken into account in this study. The weather data (including daily air dry-bulb temperature, relative humidity, wind speed, pressure, sunshine duration and global solar radiation) in these cities are available from China meteorological stations. For each station, measured weather data cover at least 10 years during a period from 1 January 1994 to 31 December 2015. The 35 stations cover longitudes from 75°59′ E (Kashgar) to 130°17′ E (Jiamusi), latitudes ranging from 18°14′ N (Sanya) to 53°28′ N (Mohe), and have considerably variable altitude from 2.5 m (Tianjin) to 4507 m (Nagqu).

Information on the selected 35 typical stations is given in Table 1.

Figure 1. A general layout of the six major climates across China. TZ = Tropical Zone; SZ = Subtropical Zone; WTZ = Warm Temperate Zone; MTZ = Mid Temperate Zone; CTZ = Cold Temperate Zone; PZ = Tibetan Plateau Zone [1].

Table 1. The main information of the 35 cities selected for the present study.

Number	Location	Latitude (N)	Longitude (E)	Elevation (m)	Climates	Period	Total Years
1	Haikou	20°02′	110°21′	14	TZ	1994–2015	22
2	Sanya	18°14′	109°31′	6	TZ	1994–2015	22
3	Changsha	28°13′	112°55′	68	SZ	1994–2015	22
4	Chengdu	30°40′	104°01′	506	SZ	1994–2003	10
5	Fuzhou	26°05′	119°17′	84	SZ	1994–2015	22
6	Guangzhou	23°10′	113°20′	41	SZ	1994–2015	22
7	Guiyang	26°35′	106°44′	1224	SZ	1994–2013	20
8	Hangzhou	30°14′	120°10′	42	SZ	1994–2015	22
9	Hefei	31°52′	117°14′	28	SZ	1994–2015	22
10	Kunming	25°01′	102°41′	1892	SZ	1994–2015	22
11	Nanchang	28°36′	115°55′	47	SZ	1994–2015	22
12	Nanjing	32°00′	118°48′	7	SZ	1994–2015	22
13	Nanning	22°38′	108°13′	122	SZ	1994–2015	22
14	Shanghai	31°24′	121°29′	6	SZ	1994–2015	22
15	Wuhan	30°37′	114°08′	23	SZ	1994–2015	22
16	Beijing	39°48′	116°28′	31	WTZ	1994–2015	22
17	Jinan	36°36′	117°03′	170	WTZ	1994–2015	22
18	Kashgar	39°28′	75°59′	1289	WTZ	1994–2015	22
19	Lanzhou	36°03′	103°53′	1517	WTZ	1994–2003	10
20	Taiyuan	37°47′	112°33′	778	WTZ	1994–2015	22
21	Tianjin	39°05′	117°04′	3	WTZ	1994–2015	22
22	Xian	34°18′	108°56′	398	WTZ	1994–2004	11
23	Zhengzhou	34°43′	113°39′	110	WTZ	1994–2015	22
24	Changchun	43°54′	125°13′	237	MTZ	1994–2015	22
25	Dongsheng	39°50′	109°59′	1460	MTZ	1994–2015	22
26	Hami	42°49′	93°31′	737	MTZ	1994–2015	22
27	Harbin	45°45′	126°46′	142	MTZ	1994–2015	22
28	Jiamusi	46°49′	130°17′	81	MTZ	1994–2015	22
29	Shenyang	41°44′	123°27′	45	MTZ	1994–2015	22
30	Urumqi	43°47′	87°39′	935	MTZ	1994–2015	22
31	Yinchuan	38°29′	106°13′	1111	MTZ	1994–2015	22
32	Mohe	53°28′	122°31′	433	CTZ	1997–2007	11
33	Lhasa	29°40′	91°08′	3649	TPZ	1994–2015	22
34	Nagqu	31°29′	92°04′	4507	TPZ	1994–2015	22
35	Xining	36°43′	101°45′	2295	TPZ	1994–2015	22

For the data shown in Table 1, missing and invalid measurements account for 0.32% of the database. Using interpolation, the missing and invalid measurements are usually replaced with the values for previous or subsequent days. Moreover, if more than 5 days' measured data are not available in a month, the month will be eliminated from the database [30].

3. Description of Methodologies for TMY Generation

It is well known that the typical meteorological year can be obtained through a number of methods, like the Danish method, the Festa-Ratto method, the typical meteorological year method, etc. In this part, the three methods are introduced in their original form with some variations in selection procedures. In view of the actual situation in China and the characteristics of solar energy systems, different meteorological indices are applied in this paper. In addition, a hybrid method is proposed aiming for generating TMY for 35 stations in China. The TMY which is available from the hybrid method has minimal differences from long-term average measured data in every month and is selected from a mixture of the results from the three methods.

3.1. The Danish Method

The Danish method was initially proposed by Lund and Eidorff [39], and several researchers, such as Janjai and Deeyai [18], and Skeiker [19], have contributed to its improvement and promotion. According to this method, seven daily meteorological parameter indices are cited for selection of typical meteorological months (TMMs) for each of the selected 35 meteorological stations: maximum air dry-bulb temperature, mean air dry-bulb temperature, mean air relative humidity, mean wind speed, mean pressure, sunshine duration and global solar radiation. This is an approach that uses a 3-step procedure to select individual months from different years during the measuring period.

In the first step, by considering the characteristics of solar energy systems, only three daily meteorological parameter indices are taken into account, namely, maximum air dry-bulb temperature, mean air dry-bulb temperature, and global solar radiation.

To eliminate seasonal variation, daily meteorological parameter indices are converted into daily residuals with regard to the smoothed daily long-term values obtained by Fourier analysis:

$$Y(y,m,d) = x(y,m,d) - \mu_x(m,d) \tag{1}$$

where $Y(y, m, d)$ is the residual of meteorological parameter index x for year y, month m, and day d, with respect to the smoothed daily long-term mean $\mu_x(m, d)$ as calculated over the available years.

For each individual month, absolute values for the standardized mean $f_\mu(y, m)$ and the standardized standard deviation $f_\sigma(y, m)$ of the residuals obtained using Equation (1) are calculated as follows:

$$f_\mu(y,m) = \left| \frac{\mu_Y(y,m) - \mu_{\mu Y}(y)}{\sigma_{\mu Y}(y)} \right| \tag{2}$$

$$f_\sigma(y,m) = \left| \frac{\sigma_Y(y,m) - \mu_{\sigma Y}(y)}{\sigma_{\sigma Y}(y)} \right| \tag{3}$$

where $\mu_Y(y, m)$ is the monthly mean and $\sigma_Y(y,m)$ is the standard deviation of the $Y(y,m,d)$ for the year y, month m; $\mu_{\mu Y}(y)$ and $\sigma_{\mu Y}(y)$ are the mean and standard deviation of $\mu_Y(y,m)$ for year y; $\mu_{\sigma Y}(y)$, $\sigma_{\sigma Y}(y)$ are the mean and standard deviation of $\sigma_Y(y,m)$ for year y. Thus, each individual month is characterized by six values, while three meteorological parameter indices are used in all.

Then, the six values of $f_\mu(y,m)$ and $f_\sigma(y,m)$ for each individual month are compared to select the maximal value ($f_{\max}(y,m)$):

$$f_{\max}(y,m) = \max\{f_\mu(y,m,j), f_\sigma(y,m,j) | 1 \le j \le 3|\} \tag{4}$$

where (y,m,j) represents the standardized mean or standardized standard deviation for meteorological parameter index j for year y, month m. For month m, the first three months will be selected as priority candidate months when the months during available years are ranked in ascending order according to the value for $f_{\max}(y,m)$.

In the second step, the long-term and short-term mean values of the seven daily meteorological parameter indices are calculated. If the short-term mean value of parameter index x for year y, month m differs by more than one standard deviation from the long-term mean value of the respective month, the month scores 0. Otherwise, a score of 1 is given to the month. The final score of each individual month is the sum of the scores, with a maximum value of 7. In the last step, among the three priority candidate months, the month with the highest score is included in the TMY.

3.2. The Festa-Ratto Method

The Festa-Ratto method is a modification of the Danish method and involves a rather complicated statistical treatment of the data. For the purposes of this study, seven daily meteorological parameter indices which are similar with that in the Danish method are utilized for this method.

In step 1, the daily meteorological parameter indices are converted into standardized residuals with respect to the smoothed long-term values, obtained as follows:

$$X(y,m,d) = \frac{x(y,m,d) - \mu_x(m,d)}{\sigma_x(m,d)} \tag{5}$$

where $X(y,m,d)$ is the standardized residual of meteorological parameter index x, for year y, month m, and day d, with respect to the smoothed long-term mean $\mu_x(m,d)$ and standard deviation $\sigma_x(m,d)$ as calculated for the available years.

In step 2, the first-order product of the standardized residuals is calculated:

$$z(y,m,d) = X(y,m,d) \cdot X(y,m,d+1) \tag{6}$$

The first-order products $z(y,m,d)$ are converted into standardized residuals with respect to the smoothed long-term values using:

$$Z(y,m,d) = \frac{z(y,m,d) - \mu_z(m,d)}{\sigma_z(m,d)} \tag{7}$$

where $Z(y,m,d)$ is the standardized residual of new parameter index z for year y, month m, and day d, with respect to the smoothed long-term mean $\mu_z(m,d)$ and standard deviation $\sigma_z(m,d)$ as calculated for the available years. Since the number of daily meteorological parameters involved is 7, there are 7 new parameter indices Z created in total.

In step 3, the short-term mean value $\mu_X(y,m)$ and standard deviation $\sigma_X(y,m)$ for standardized residual $X(y, m, d)$ for year y, month m are calculated. At the same time, the long-term mean value $\mu_{\mu X}(m)$ and standard deviation $\sigma_{\mu X}(m)$ for month m during the available years are obtained based on $\mu_X(y,m)$. A similar procedure is carried out to obtain $\mu_Z(y,m)$, $\sigma_Z(y,m)$, $\mu_{\mu Z}(m)$, and $\sigma_{\mu Z}(m)$. The short-term and long-term cumulative distribution function (*CDF*) for $X(y,m,d)$ and $Z(y,m,d)$ are also determined.

Based on the above results, the statistical distance between the short-term and the long-term mean values d_{av} and standard deviations d_{sd}, as well as the Kolmogorov-Smirnov parameter, d_{ks}, are calculated for each X and Z parameter and each individual month as follows:

$$d_{av,X}(y,m) = \left|\mu_X(y,m) - \mu_{\mu X}(m)\right| \tag{8}$$

$$d_{av,Z}(y,m) = \left|\mu_Z(y,m) - \mu_{\mu Z}(m)\right| \tag{9}$$

$$d_{sd,X}(y,m) = \left|\sigma_X(y,m) - \sigma_{\mu X}(m)\right| \tag{10}$$

$$d_{sd,Z}(y,m) = |\sigma_Z(y,m) - \sigma_{\mu Z}(m)| \quad (11)$$

$$d_{ks,X}(y,m) = \max|CDF_{y,m}(X) - CDF_m(X)| \quad (12)$$

$$d_{ks,Z}(y,m) = \max|CDF_{y,m}(Z) - CDF_m(Z)| \quad (13)$$

Next, the composite distances $d_X(y,m)$ and $d_Z(y,m)$ for each daily meteorological parameter index are calculated using the following equations:

$$d_X(y,m) = (1-a-b) \cdot d_{ks.X}(y,m) + a \cdot d_{av.X}(y,m) + b \cdot d_{sd.X}(y,m) \quad (14)$$

$$d_Z(y,m) = (1-a-b) \cdot d_{ks.Z}(y,m) + a \cdot d_{av.Z}(y,m) + b \cdot d_{sd.Z}(y,m) \quad (15)$$

where $a = b \approx 0.1$.

In step 4, for each month, 14 sets of distances are obtained from Equations (14) and (15), and the maximum value is sorted to form a new set of distances for that month. Then the month with the minimum distance in the new set is selected to be a member of the TMY. This min-max approach is shown as follows:

$$d_{\min.\max}(m,1) = \min\{\max[d_X(y,m,j), d_Z(y,m,j)]|1 \leq j \leq 7|\} \quad (16)$$

3.3. The Modified Typical Meteorological Year (TMY) Method

The TMY method, primarily proposed by Sandia National Laboratories, is one of the most popular methods for determining typical years. In this method, a set of 12 typical meteorological months (TMMs) is selected from a multi-year database using the Finkelstein-Schafer (*FS*) statistical method [40]. Unlike the two methods described above, this method primarily pays attention to eight daily meteorological parameter indices to select typical months: maximum air dry-bulb temperature, mean air dry-bulb temperature, minimum air dry-bulb temperature, mean air relative humidity, minimum air relative humidity, maximum wind speed, mean wind speed, and global solar radiation. The selection procedure for the TMY consists of two steps.

In the first step, for each month of the different years, five candidate months having a *CDF* closest to the respective long-term distributions are selected. This selection is based on the variation between annual *CDF* and long-term *CDF* for the month in question. Moreover, to measure the variation, an empirical *CDF* for each meteorological parameter is determined using the following function:

$$S_n(x) = \begin{cases} 0 & for \quad x < x_1 \\ (i-0.5)/n & for \quad x_i \leq x < x_{i+1} \\ 1 & for \quad x \geq x_n \end{cases} \quad (17)$$

where $S_n(x)$ is the value of the *CDF* for parameter index x; i is the rank order number. n is the total number of meteorological parameters. From its definition, $S_n(x)$ is a monotonic increasing function with steps of sizes $1/n$ occurring at x_i and is bounded by 0 and 1. Then the value of *FS* statistics of each parameter is obtained using:

$$FS_x(y,m) = \frac{1}{N}\sum_{i=1}^{N}|CDF_m(x_i) - CDF_{y,m}(x_i)| \quad (18)$$

where $FS_x(y,m)$ is the *FS* statistic for year y, month m; CDF_m is the long-term and $CDF_{y,m}$ is the short-term *CDF* of parameter index x for month m; and N is the number of daily readings of the month.

The weighted sum (*WS*) of the *FS* statistics is derived by applying weighting factors WF_x to the *FS* statistics values corresponding to each specific month in the selected period:

$$WS(y,m) = \frac{1}{M}\sum_{x=1}^{M} WF_x \cdot FS_x(y,m) \quad (19)$$

$$\sum_{x=1}^{M} WF_x = 1 \quad (20)$$

where $WS(y,m)$ is the weighted sum of the FS statistics for eight meteorological parameter indices for year y, month m; WF_x is the weighting factor for parameter index x; M is the number of meteorological parameter indices. Furthermore, the five months with lowest WS values are selected to be candidate months.

It is worth mentioning that the weighting factors are essential for choosing TMY from the measured data. In consideration of the fact that this criterion is mainly applied to solar energy systems, global solar radiation gets the highest value among weighting factors. The assigned weighting factors are shown in Table 2.

Table 2. Weighting factors for TMY type.

Parameter Indices	Ref. [12,26]	[17,33]	[41]	[13]	[34]	Present Article
Max Dry-Bulb Temperature	1/24	5/100	1/20	1/32	1/20	1/24
Min Dry-Bulb Temperature	1/24	5/100	1/20	1/32	1/20	1/24
Mean Dry-Bulb Temperature	2/24	30/100	2/20	2/32	3/20	3/24
Range Dry-Bulb Temperature	–	–	–	1/32	–	–
Max Relative Humidity	1/24	2.5/100	1/20	1/32	–	–
Min Relative Humidity	1/24	2.5/100	1/20	1/32	1/20	1/24
Mean Relative Humidity	2/24	5/100	2/20	2/32	2/20	2/24
Range Relative Humidity	–	–	–	1/32	–	–
Max Wind Speed	2/24	5/100	1/20	1/32	1/20	2/24
Min Wind Speed	–	–	–	1/32	–	–
Mean Wind Speed	2/24	5/100	1/20	2/32	1/20	2/24
Range Wind Speed	–	–	–	1/32	–	–
Mean Wind direction	–	–	–	1/32	–	–
Global Solar Radiation	12/24	40/100	5/20	8/32	5/20	12/24
Direct Solar Radiation	–	–	5/20	8/32	5/20	–

In the second stage, among various methods [10,25] for selecting TMMs from the five candidate months, a simpler selection process [26,42], starting with calculation of the root mean square difference ($RMSD$), is adopted. The $RMSD$ is defined as follows:

$$RMSD = \left[\frac{\sum_{k=1}^{N}(H_{y,m,k} - H_{ma})^2}{N}\right]^{1/2} \quad (21)$$

where $RMSD$ is the root mean square difference of global solar radiation; $H_{y,m,k}$ is the value of daily global solar radiation for year y, month m and day k; H_{ma} is the long-term mean value of global solar radiation for the month m; and N is the number of daily readings of the month. The month with the minimum $RMSD$ is finally selected as the TMM.

3.4. TMY Selection Procedure

The final TMY selection is based on the hybrid method, by which the results of the Danish method, the Festa-Ratto method, and the modified typical meteorological year method are combined. After obtaining TMYs using the aforementioned methods, those results having the minimum differences from long-term average measured data for each month will be used to form a typical meteorological year. The selection procedure is described as below:

First, for the three TMYs determined using the above methods, the values of indices 1, 2, 3, 4, which correspondingly represent the daily average values of global solar radiation, air dry-bulb temperature, mean air relative humidity, and wind speed, are compared with daily mean long-term average measured data for the same parameter indices by applying *RMSD*. The definition of *RMSD* for global solar radiation is shown in Equation (21), and that for other indices likes it.

Next, the sum of yearly values of *RMSD* (*SYRMSD*) are respectively calculated for the four mentioned parameter indices for each method:

$$SYRMSD_p = \sum_{i=1}^{12} RMSD_p^i \tag{22}$$

where p is the number of the index; i represents the month number.

Finally, the highest ranked one among the results of three months for every month, in ascending order of the *ERMSD*, is used in the TMY. The *ERMSD* parameter is defined using this equation:

$$ERMSD^i = \frac{RMSD_1^i}{SYRMSD_1} + \frac{RMSD_2^i}{SYRMSD_2} + \frac{RMSD_3^i}{SYRMSD_3} + \frac{RMSD_4^i}{SYRMSD_4} \tag{23}$$

where i is the number of the month; ${RMSD_1}^i$ is the root mean square difference of index 1 for month i; $SYRMSD_1$ is mean yearly values of *RMSE* of index 1; ${RMSD_2}^i$ and $SYRMSD_2$ are for index 2; ${RMSD_3}^i$ and $SYRMSD_3$ are for index 3; and ${RMSD_4}^i$ and $SYRMSD_4$ are for index 4.

4. Performance Comparison

Application of the selection procedures described above and the data at the 35 stations provided in Table 1 generates the TMYs for 35 stations. Table 3 provides the TMYs data obtained using the Danish method (TMY_D), the Festa-Ratto method (TMY_F), and the modified typical meteorological year method (TMY_M) for six stations.

Table 3. TMYs obtained using the Danish method, Festa-Ratto method, and modified typical meteorological year method for 6 different cities in China.

Station	Method	Month											
		Jan.	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
Haikou (TZ)	TMY_D	1994	2006	1997	1998	2004	2010	1998	2003	2001	1999	2003	2009
	TMY_F	1996	1998	1999	1999	1994	2003	2000	1999	2000	2000	1996	2015
	TMY_M	1994	1994	2001	1998	2004	2000	1998	1996	2000	1996	1996	1998
Shanghai (SZ)	TMY_D	1994	2003	2000	2000	2004	1995	1996	2005	2013	1997	1996	2009
	TMY_F	1996	1997	2012	1997	2004	2007	2010	2005	1994	2013	2014	2006
	TMY_M	2010	2011	1995	2000	2000	2003	2012	2005	2013	1997	1999	2011
Zhengzhou (WTZ)	TMY_D	1998	1997	2015	2009	2015	2013	2002	2012	2000	2011	1999	1997
	TMY_F	1997	1994	1995	2007	2010	2001	1999	2009	2000	2011	1999	2006
	TMY_M	1997	1998	2013	2007	2015	1998	2009	2002	2000	2008	1998	1998
Yinchuan (MTZ)	TMY_D	2010	2013	2012	2003	2008	2002	2015	2008	2000	2013	2005	2004
	TMY_F	2010	2006	2005	2012	1999	1995	2007	2000	2000	2010	1999	2006
	TMY_M	2007	2003	2005	2007	2012	2003	2007	2008	1999	2003	2007	2003
Mohe (CTZ)	TMY_D	2000	2004	2004	2001	2003	2005	2002	2007	1998	2000	2005	2001
	TMY_F	2003	2007	2000	1998	2005	2002	2007	1999	2003	2003	1999	2002
	TMY_M	2003	2000	2006	2003	2004	1999	2006	2006	2007	2005	2005	2004
Lhasa (TPZ)	TMY_D	1998	2010	2005	2005	2010	1997	1999	2001	2006	1999	1998	2003
	TMY_F	1994	2007	2008	2008	2011	2006	1999	2010	2001	2010	1999	2000
	TMY_M	2001	1999	2009	2008	1994	1994	2014	2014	2001	2000	2012	2001

The selected cities (Haikou, Shanghai, Zhengzhou, Yinchuan, Mohe, and Lhasa) respectively represent the six different climate types (TZ, SZ, WTZ, MTZ, CTZ, and TPZ) and provide a good sample of the range of latitude, longitude, and elevation. In Table 3, it can be seen that for each city the TMY comprises 12 individual months selected from different years of the measuring period for each particular method. Taking Lhasa (TPZ) as an example, it is apparent that a year considered typical for a certain month might not be inevitably typical for another month. For instance, January 1994 is selected as a TMM with TMY_F, while February is the one in 2007 in the same TMY. What is more, the composition of TMYs generated using the three methods is not identical for selected cities.

To gain a good understanding of selection patterns, we consider Lhasa again as an example for pictorial display. The values for *RMSD* of the three methods are computed and separately shown for the four meteorological parameter indices of Lhasa in Figures 2–5. In Figure 2, most of the result for global solar radiation obtained from TMY_M is the smallest for each individual month of the year. At the same time, the air relative humidity result of TMY_M, which is plotted in Figure 4, has greater agreement with those obtained from the measuring period data than do the air relative humidity results from TMY_D and TMY_F for most months of the year. It can be also confirmed from Figures 3 and 5 that the minimum *RMSD* for dry-bulb temperature and wind speed are respectively produced by TMY_D and TMY_F for the majority of months.

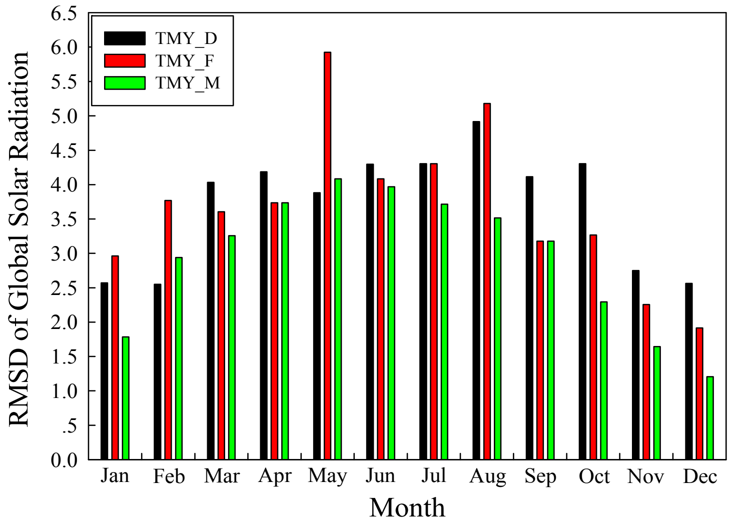

Figure 2. *RMSD* results of global solar radiation by the three methods in Lhasa.

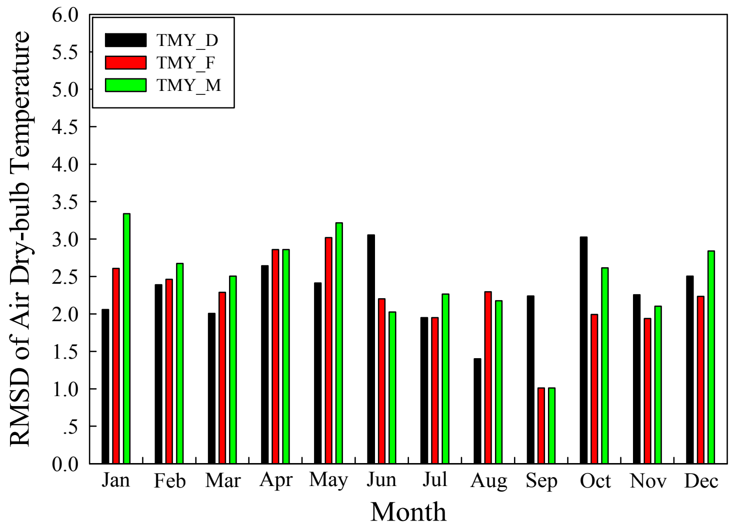

Figure 3. *RMSD* results of air dry-bulb temperature by the three methods in Lhasa.

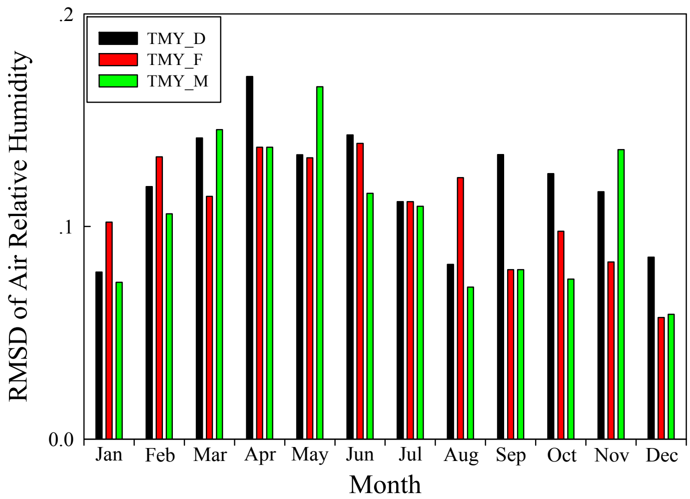

Figure 4. *RMSD* results of air relative humidity by the three methods in Lhasa.

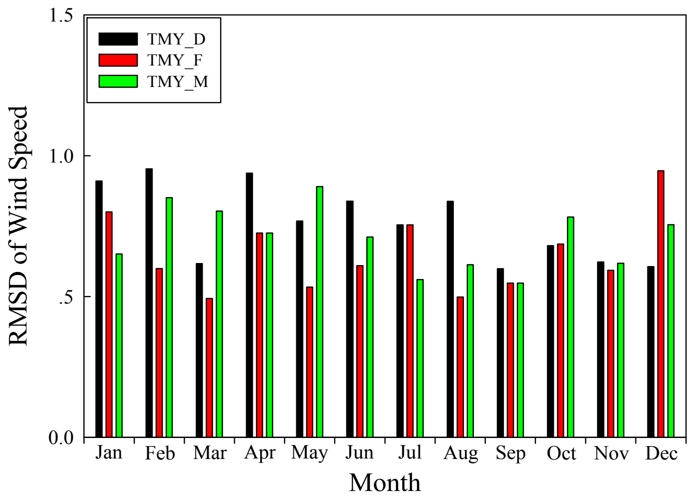

Figure 5. *RMSD* results of wind speed by the three methods in Lhasa.

Next follows the calculation of the sum of yearly values for *RMSD* of the four main indices. Table 4 provides the values for *ERMSD*, which are assigned to the respective months using Equation (22). The *ERMSDs* often differ from month to month in a typical meteorological year, as well as vary in approach to each month as shown in Table 4. Moreover, the months with the smallest *ERMSD* values are shown with bold characters. In the end, the selected method for each month is determined by the minimum value of *ERMSD*. The smaller the *ERMSD* is, the better agreement will be with the mean measured data over time. The information about *ERMSD* for each candidate month in Lhasa is tabulated in Table 4. As demonstrated, the numbers printed in bold cells identify the TMMs. The same procedure is applied to other 34 stations and the results are listed in Table 5. Moreover, the monthly mean solar radiation data and monthly mean wind speed acquired from TMYs data for 35 stations are given in Tables A1 and A2, respectively.

Also, Table 6 shows the selected times of each year for 12 TMMs in total. It is clear that 2008 is the most frequent year while the least frequent year is 2012, which is selected eight times altogether.

Table 4. ERMSD of the three candidate years for each month in Lhasa (the bold number shows the lowest ERMSD value in the month).

Month	Method	TMY_D	TMY_F	TMY_M
Jan.	Year ERMSD	**1998** **0.286**	1994 0.313	2001 0.293
Feb.	Year ERMSD	**2010** **0.330**	2007 0.331	1999 0.350
Mar.	Year ERMSD	2005 0.328	**2008** **0.297**	2009 0.380
Apr.	Year ERMSD	2005 0.410	**2008** **0.360**	2008 0.390
May	Year ERMSD	**2010** **0.351**	2011 0.394	1994 0.453
Jun.	Year ERMSD	1997 0.397	**2006** **0.334**	1994 0.350
Jul.	Year ERMSD	1999 0.327	**1999** **0.322**	2014 0.329
Aug.	Year ERMSD	2001 0.310	2010 0.340	**2014** **0.297**
Sep.	Year ERMSD	2006 0.331	**2001** **0.219**	2001 0.247
Oct.	Year ERMSD	1999 0.366	**2010** **0.283**	2000 0.299
Nov.	Year ERMSD	1998 0.291	**1999** **0.239**	2012 0.293
Dec.	Year ERMSD	2003 0.273	**2000** **0.253**	2001 0.259

Table 5. The TMYs for the hybrid method of 35 cities in six different climatic zones of China.

Climates	Station	Month											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
TZ	Haikou	1996	2006	1997	1998	2004	2003	2000	1999	2001	1996	1996	2015
TZ	Sanya	2002	2002	2002	2002	1996	2003	2004	1994	2000	1999	2003	2004
SZ	Changsha	2004	1997	2015	2014	2012	2003	2008	1995	2004	2012	1999	2006
SZ	Chengdu	1994	1998	1995	2003	2002	1998	2000	1995	2003	1999	2001	1994
SZ	Fuzhou	2007	2015	1995	2008	2002	1994	1998	2008	2007	2001	2004	2006
SZ	Guangzhou	2007	2002	2003	1997	2010	2002	2008	2001	2004	1999	1999	1996
SZ	Guiyang	2006	2002	2005	2005	2012	2007	2009	2007	2006	2010	2004	2010
SZ	Hangzhou	1995	2003	2015	1997	2015	2014	2011	2011	2008	2008	2010	2006
SZ	Hefei	1995	2003	2015	1997	2015	2014	2011	2011	2008	2008	2010	2006
SZ	Kunming	1998	2015	2001	2002	2013	2004	2014	2008	2008	2006	2000	2000
SZ	Nanchang	2004	1995	2014	2014	1998	2007	2008	2008	2009	2015	1999	2006
SZ	Nanjing	2013	1997	1994	2000	2000	2007	2002	1996	2007	2005	1996	2013
SZ	Nanning	2007	2011	2005	2008	2002	2014	2008	2012	2012	2014	2013	2010
SZ	Shanghai	1994	2011	1995	2000	2004	2003	2010	2005	2013	2013	2014	2011
SZ	Wuhan	2006	1997	2006	2001	2005	2014	2004	1995	2007	2008	1997	2006
WTZ	Beijing	2005	2015	2004	1997	2000	2006	2008	2011	2000	2013	2004	2000
WTZ	Jinan	2005	2015	2008	2009	2015	2010	2010	2001	1996	2005	2007	2006
WTZ	Kashgar	2005	2013	2005	2010	2011	2006	2008	2003	2006	2008	1999	2006
WTZ	Lanzhou	2000	1994	2000	2000	1999	2001	2002	2000	1996	1998	1997	2003
WTZ	Taiyuan	2007	1995	2008	2009	2005	2006	2002	2011	2000	2008	2001	2006
WTZ	Tianjin	2005	2011	2009	2004	2003	2007	2005	2002	2005	2012	2004	1996
WTZ	Xian	1995	2001	1995	1995	1997	2002	2000	1999	1999	2001	2004	1997
WTZ	Zhengzhou	1997	1997	2015	2007	2010	2001	2009	2002	2000	2008	1998	2006
MTZ	Changchun	2004	1997	2006	2011	2013	2011	2002	2005	2006	2006	2006	1995
MTZ	Dongsheng	1997	2011	2000	2000	1996	2006	2004	2013	2011	2008	2002	1999
MTZ	Hami	2008	2015	2009	1997	2009	2006	2014	2006	2008	2006	2011	2006
MTZ	Harbin	2003	1994	2009	2004	2001	1995	2008	2005	2004	2008	2001	1996
MTZ	Jiamusi	2005	2013	2000	2001	2003	2015	2010	1995	2002	2008	2008	1994
MTZ	Shenyang	2009	2003	2009	2000	2007	2013	2005	2008	2006	2006	2004	2003
MTZ	Urumqi	2012	2009	2006	2009	2005	2014	1994	2004	2013	2008	2005	2011
MTZ	Yinchuan	2007	2003	2012	2003	2008	2003	2007	2008	2000	2010	1999	2003
CTZ	Mohe	2003	2004	2006	2003	2005	2002	2002	2007	2003	2003	2005	2001
TPZ	Lhasa	1998	2010	2008	2008	2010	2006	1999	2014	2001	2010	1999	2000
TPZ	Nagqu	2010	2007	2003	2003	2015	2009	1998	2009	2008	2000	2001	2013
TPZ	Xining	2013	2001	2000	2000	2013	2010	2007	2008	2003	2008	1995	2006

Table 6. The year selection frequency of each month to be a TMM in the period of 1994–2015.

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total Times
1994	2	2	1	0	0	1	1	1	0	0	0	2	10
1995	3	2	4	1	0	1	0	4	0	0	1	1	17
1996	1	0	0	0	2	0	0	1	2	1	2	3	12
1997	2	5	1	5	1	0	0	0	0	0	2	1	17
1998	2	1	0	1	1	1	2	0	0	1	1	0	10
1999	0	0	0	0	1	0	1	2	1	3	6	1	15
2000	1	0	4	6	2	0	3	1	5	1	1	3	27
2001	0	2	1	2	1	2	0	2	2	2	4	1	19
2002	1	3	1	2	3	3	5	2	1	0	1	0	22
2003	2	4	2	4	2	5	0	1	3	1	1	3	28
2004	3	1	1	2	2	1	3	1	3	0	6	1	24
2005	5	0	3	1	4	0	2	3	1	2	2	0	23
2006	2	1	4	0	0	6	0	1	4	4	1	12	35
2007	5	1	0	1	1	4	2	2	3	0	1	0	20
2008	1	0	3	3	1	0	7	6	5	11	1	0	38
2009	1	1	4	3	1	1	2	1	1	0	0	0	15
2010	1	1	0	1	3	2	3	0	0	3	2	2	18
2011	0	4	0	1	1	1	2	4	1	0	1	2	17
2012	1	0	1	0	2	0	0	1	1	2	0	0	8
2013	2	2	0	0	3	1	0	1	2	2	1	2	16
2014	0	0	1	2	0	5	2	1	0	1	1	0	13
2015	0	5	4	0	4	1	0	0	0	1	0	1	16

According to the summary, it can be concluded that 2008 follows long-term weather patterns more closely than the others over the period of 1994–2015. Moreover, for different months the times may vary for the same year, and 12 and 0 are the largest and lowest numbers, respectively. That is to say, a particular month is selected for no more than 12 cities among the selected stations.

Monthly solar radiation data gained from TMY_D, TMY_F, TMY_M, and the proposed hybrid method are compared with the long-term monthly mean measured data for Haikou (TZ), Shanghai (SZ), Zhengzhou (WTZ), Yinchuan (MTZ), Mohe (CTZ) and Lhasa (TPZ), shown separately in Figure 6.

It can be clearly seen that the solar radiation data obtained from the four methods all agree well with the measured data during the period 1994–2015. Moreover, the hybrid method performs better than other three methods especially for the four stations, Zhengzhou (WTZ), Yinchuan (MTZ), Mohe (CTZ) and Lhasa (TPZ). Additionally, the prediction of monthly mean solar radiation is researched in the paper. The excellence and distinctive features of Gaussian Process Regression (GPR) forecasting model include its output probability distribution characteristic and capabilities to adaptively obtain the hyper-parameters in the model [43,44]. In this part, the GPR model is recommended to forecast the monthly mean solar radiation by year 2016 using the last 22 years historical data. The selection of input variables includes solar radiation, dry-bulb temperature, relative humidity and wind speed in the last four years.

In order to test the forecasting performance of the GPR model, a simulation is carried out to forecast the monthly solar radiation in 2015. The index analysis of interval forecasting results under the 90% confidence level is shown in Table 7. It can be concluded that most of actual monthly mean solar radiation is within the confidence interval, and the forecasting results can well track the change of solar radiation from the view of MAPE values. The smaller the MAPE, the better the forecasting accuracy, which illustrates that the predictive value is closer to actual result. The best forecasting results are obtained in Lhasa and the interval width is narrower with the increasing forecasting accuracy. Besides, the FICP reduces due to the narrower interval width of smaller FIAW. The monthly mean solar radiation forecasting results by 2016 in different climates of China are shown in Table A3. It can be seen from the table that the predicted results have high similarities with historical data which indicates stable solar radiation change rules in these areas. In conclusion, the GPR forecasting model can directly generate the monthly mean solar radiation interval forecasting result rather than deterministic point value which reflects the uncertain change of future solar radiation. Further, the interval forecasting results can give more guiding significance for actual application related to energy areas.

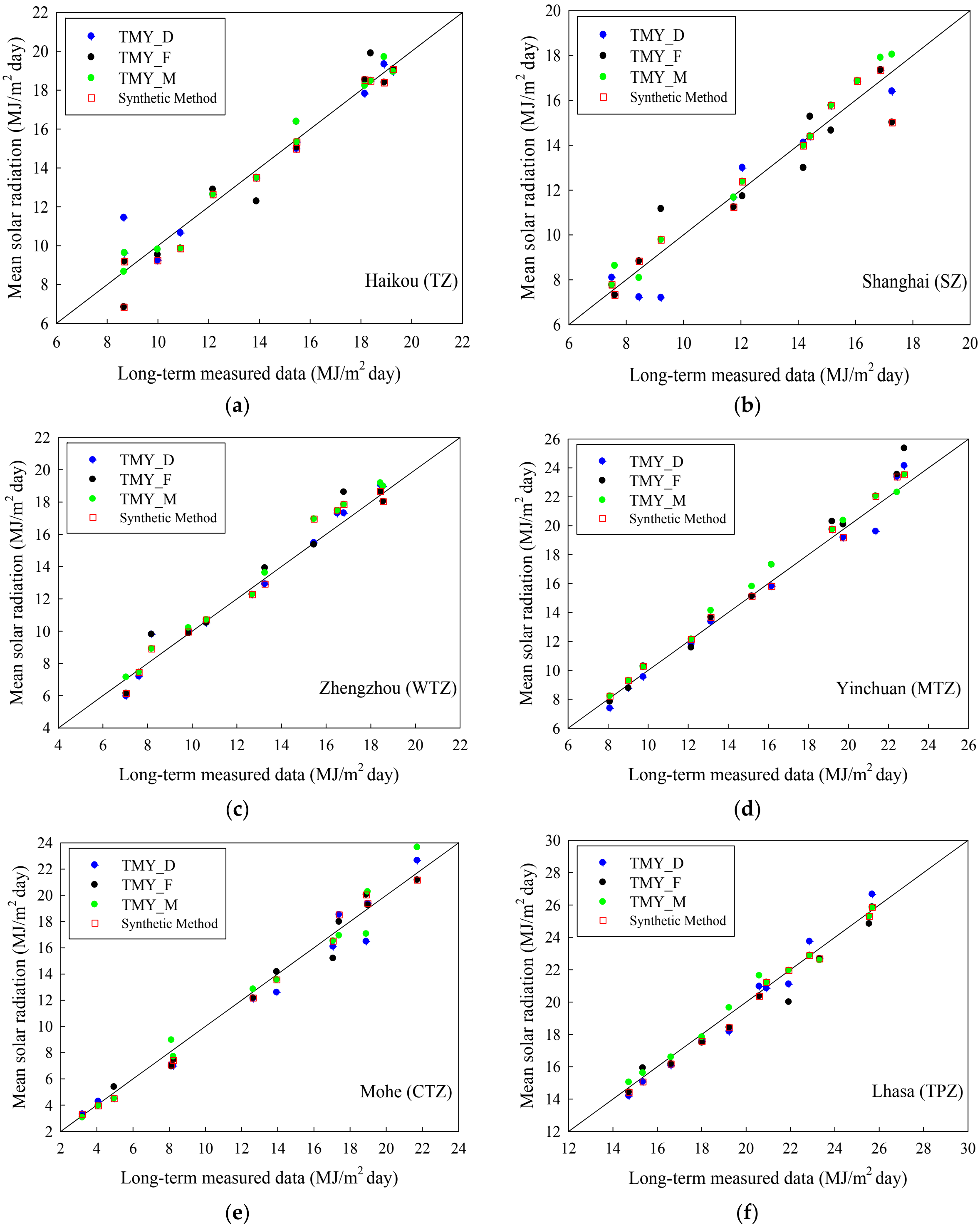

Figure 6. Comparing the long-term measured monthly mean solar radiation and the monthly mean solar radiation from TMYs using TMY_D, TMY_F, TMY_M and hybrid method for six typical climatic zones of China, at (**a**) Haikou; (**b**) Shanghai; (**c**) Zhengzhou; (**d**) Yinchuan; (**f**) Lhasa stations (1994–2015 measured data); and (**e**) Mohe station (1997–2007 measured data).

Table 7. The index results of monthly mean solar radiation forecasting for 2015 in different climates of China.

Stations	MAPE (%) [45]	RMSE (MJ/m^2) [45]	FICP (%) [46]	FIAW [46]
Haikou (TZ)	11.03	1.9919	91.67	0.5153
Shanghai (SZ)	10.75	1.3626	100	0.6256
Zhengzhou (WTZ)	13.47	1.6059	91.67	0.5199
Yinchuan (MTZ)	9.77	1.5892	91.67	0.3812
Lhasa (TPZ)	7.27	1.5325	83.33	0.2124

5. Conclusions

The generation of the TMY data is essential and important for solar energy utilization. In this paper, the performance of four TMY generation methods: the Danish method, the Festa-Ratto method, the Modified Typical Meteorological Year Method and the hybrid method are compared. These methods are used to generate and investigate TMYs for 35 stations in six different climatic zones of China using at least 10 years measured weather data, including air dry-bulb temperature, relative humidity, wind speed, pressure, sunshine duration and global solar radiation. Taking Lhasa as an example, the process of the hybrid method are presented and analyzed in this study. The monthly mean solar radiation data and monthly mean wind speed acquired from TMYs data, using the hybrid method, are appeared in the tabulation. There is a good agreement between the typical solar radiation data and the long-term measured data for the hybrid method on a monthly basis. Moreover, the proposed GPR model has good performance for forecasting monthly mean solar radiation. It is believed that the TMY data will have good impact on the related scientific research. Future work will focus on the in-depth long-term prediction of the climatology for different areas in China. We hope to report these findings in the near future.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Summary of monthly mean solar radiation data of 35 cities in six different climatic zones of China from the TMYs using the synthetic method.

Climates	Station	Month											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
TZ	Haikou	9.177	9.231	12.628	15.330	18.470	18.386	19.059	18.518	14.981	13.484	9.852	6.826
TZ	Sanya	14.055	15.278	16.459	21.555	20.720	18.314	17.675	19.706	18.060	14.590	14.721	12.576
SZ	Changsha	4.139	5.724	7.265	10.369	11.314	14.570	18.974	19.259	12.416	9.254	8.574	5.993
SZ	Chengdu	5.146	4.491	8.851	11.301	12.995	12.602	12.495	13.814	7.931	5.589	5.369	3.435
SZ	Fuzhou	7.466	9.497	9.504	12.403	14.187	16.131	18.320	18.166	12.802	13.044	9.449	7.504
SZ	Guangzhou	9.995	10.471	8.118	9.360	10.872	14.429	15.315	15.015	15.371	13.545	11.965	10.598
SZ	Guiyang	5.208	5.983	8.138	13.836	11.995	12.296	14.874	16.986	14.133	10.050	6.989	6.917
SZ	Hangzhou	9.608	8.566	11.257	13.431	15.240	14.203	18.066	14.778	12.344	9.885	8.348	7.843
SZ	Hefei	8.120	8.464	12.997	17.106	17.435	16.782	17.734	16.202	12.148	10.404	9.107	6.954
SZ	Kunming	15.034	18.440	18.423	20.271	19.387	14.843	16.457	13.782	14.314	12.719	14.342	12.086
SZ	Nanchang	5.765	8.584	9.360	12.010	15.703	14.821	20.261	16.786	15.273	12.404	9.694	7.960
SZ	Nanjing	8.368	9.531	12.477	16.325	17.168	14.333	19.253	16.040	12.273	12.104	6.453	7.811
SZ	Nanning	8.246	7.898	7.656	12.272	14.841	15.148	17.001	17.474	16.166	14.993	11.274	8.674
SZ	Shanghai	7.321	9.778	12.373	15.763	17.342	13.972	15.006	16.856	14.387	11.231	8.821	7.773
SZ	Wuhan	5.922	8.048	12.245	14.108	14.604	14.251	17.768	15.667	14.179	10.413	7.578	7.176
WTZ	Beijing	8.536	10.489	14.559	18.707	21.316	17.732	17.279	17.128	14.939	11.255	8.643	6.707
WTZ	Jinan	8.208	10.385	14.578	18.077	18.943	18.317	16.494	15.346	14.300	11.401	8.797	6.783
WTZ	Kashgar	7.329	10.388	12.489	18.224	23.711	26.325	24.731	21.653	15.905	13.923	8.155	6.098
WTZ	Lanzhou	7.921	10.664	14.536	17.873	19.168	19.910	20.832	18.297	15.987	10.614	8.160	7.023
WTZ	Taiyuan	7.358	11.339	13.841	18.930	20.140	18.322	19.063	16.732	14.539	11.709	8.813	6.090
WTZ	Tianjin	7.451	10.103	14.896	17.916	18.830	16.502	17.447	17.625	13.020	11.334	8.104	6.406
WTZ	Xian	7.727	8.117	13.105	15.641	18.433	17.651	17.908	18.632	12.142	6.944	7.149	5.087
WTZ	Zhengzhou	7.436	9.947	12.907	17.456	18.023	18.648	17.835	16.941	12.256	10.692	8.897	6.129
MTZ	Changchun	6.817	10.962	14.136	17.933	21.114	20.140	19.448	14.707	15.687	11.256	7.667	5.784
MTZ	Dongsheng	9.657	11.450	16.749	19.914	24.373	23.592	22.361	20.068	15.216	13.717	10.045	8.349
MTZ	Hami	7.738	11.036	16.181	22.887	25.072	26.175	24.427	21.980	17.514	12.980	7.664	6.700
MTZ	Harbin	5.589	9.381	13.535	16.980	19.872	21.614	17.579	15.910	14.545	9.690	6.717	4.651
MTZ	Jiamusi	5.465	9.658	12.025	16.210	18.045	20.722	18.044	17.465	13.473	9.458	5.958	4.711
MTZ	Shenyang	6.982	9.788	14.603	16.557	20.265	20.131	17.108	17.280	15.450	11.165	6.243	6.307
MTZ	Urumqi	5.909	7.156	13.301	18.448	22.087	23.989	23.226	20.243	17.687	11.529	5.974	3.926
MTZ	Yinchuan	9.285	12.145	15.802	19.165	23.365	23.526	22.035	19.730	15.120	13.658	10.284	8.207
CTZ	Mohe	3.941	7.055	13.544	16.511	20.027	21.158	19.364	18.506	12.161	7.410	4.492	3.307
TPZ	Lhasa	15.057	17.569	20.352	22.874	25.299	25.862	22.668	21.951	21.205	18.407	16.164	14.415
TPZ	Nagqu	14.408	14.884	19.939	22.281	21.559	24.003	21.835	21.291	18.503	18.451	17.801	14.235
TPZ	Xining	10.700	12.703	16.434	20.058	20.161	21.389	20.452	20.352	16.429	13.258	10.886	8.845

Table A2. Summary of monthly mean wind speed of 35 cities in six different climatic zones of China from the TMYs using the synthetic method.

Climates	Station	Month											
		Jan.	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
TZ	Haikou	2.1742	1.7857	1.8129	2.2500	1.8065	2.0100	1.8000	1.7194	1.5367	2.2161	2.3200	3.1839
TZ	Sanya	1.7387	1.8786	1.4032	1.4633	1.7839	1.8767	1.5097	1.2323	1.7767	2.0677	1.9233	1.8032
SZ	Changsha	2.1065	2.1179	2.4903	1.8500	1.8839	1.9400	2.2677	2.6258	2.0733	2.0774	2.1733	2.0097
SZ	Chengdu	0.8871	1.0643	1.3742	1.9067	1.7774	1.8667	1.3161	1.1871	1.5833	0.9032	1.0133	0.8774
SZ	Fuzhou	2.2968	1.9607	2.3871	2.2700	2.5677	2.9467	2.9484	2.5710	2.7867	2.6548	2.5067	2.4032
SZ	Guangzhou	1.5935	1.4250	1.8935	1.7500	1.5258	1.8833	1.5774	1.3742	1.2733	1.6484	1.6067	1.5903
SZ	Guiyang	2.6161	3.1107	2.6613	2.7433	2.6258	2.2467	2.4903	2.2000	2.3533	2.3871	2.3733	2.2161
SZ	Hangzhou	1.9194	2.0500	1.9968	2.2600	2.2484	1.9367	2.0065	2.0871	2.2433	1.5645	1.6733	1.7806
SZ	Hefei	2.8097	2.6750	3.0871	2.6433	2.4226	2.1233	2.7484	2.6161	2.3200	2.0984	2.4767	1.9323
SZ	Kunming	2.1194	2.9464	2.1258	2.4067	2.8000	1.8433	2.0258	2.1065	2.0467	2.1323	1.3700	1.3968
SZ	Nanchang	1.8194	2.2357	1.7839	1.6467	1.8226	1.6133	2.1032	1.7903	2.2433	1.6839	1.7500	1.7968
SZ	Nanjing	2.4161	1.9000	2.5387	2.2767	1.9581	2.0533	1.9387	2.2742	1.9167	1.8581	2.3733	2.0548
SZ	Nanning	1.5968	1.4214	1.4839	1.6733	1.3548	1.3967	1.7161	1.6516	1.4800	1.1355	1.3767	1.4645
SZ	Shanghai	2.5968	2.5286	2.9806	3.1467	3.2774	2.5467	2.9774	3.9871	2.7167	2.9097	2.3567	2.7355
SZ	Wuhan	1.3516	0.9536	1.2677	1.2900	1.3194	1.2933	1.1129	1.6258	1.4833	1.0548	0.8900	1.1871
WTZ	Beijing	2.4516	2.3357	2.8710	2.8500	2.9387	2.4033	2.0419	1.9387	1.7767	1.7516	2.1767	2.2968
WTZ	Jinan	3.0548	2.0821	3.2710	3.2000	2.7065	2.5433	2.0806	2.7774	2.5667	2.9710	2.8600	2.6710
WTZ	Kashgar	1.3645	1.4857	1.5452	1.9967	2.0581	2.5667	2.1516	2.1968	1.5667	1.3645	1.2833	1.1774
WTZ	Lanzhou	0.4323	0.5536	0.7839	1.0100	1.2065	1.3367	1.4516	0.8548	1.0900	0.4516	0.4967	0.2065
WTZ	Taiyuan	1.7323	2.1607	2.2194	2.0533	2.7419	2.0400	1.0161	1.2806	1.1667	1.4290	1.7967	1.6645
WTZ	Tianjin	2.3742	2.4500	2.9548	3.3067	2.4355	2.2933	2.1484	1.7613	1.8133	2.4387	2.3567	2.1903
WTZ	Xian	1.5226	0.9429	1.9903	1.9767	2.0677	1.0733	1.5484	1.9968	1.4967	0.7484	1.1533	1.2710
WTZ	Zhengzhou	2.1871	2.0786	2.0839	2.3433	2.4161	2.3567	2.0774	2.1387	1.7800	1.5871	1.8833	1.8774
MTZ	Changchun	2.8387	3.3500	3.9935	3.8067	3.5806	3.0867	2.7516	2.3387	2.5867	2.9645	3.4633	2.8710
MTZ	Dongsheng	2.3290	2.5143	2.7065	3.8667	3.5129	2.8767	2.5097	2.6677	2.3867	2.5194	2.8033	3.1355
MTZ	Hami	1.3871	1.3000	1.7387	1.3400	1.5871	1.2800	1.2516	1.2774	1.0367	1.0484	1.1833	1.2903
MTZ	Harbin	2.5194	2.1321	2.4645	2.9467	3.3677	3.1600	1.9097	1.8226	2.4533	2.1387	3.0100	2.5839
MTZ	Jiamusi	1.9323	2.5750	3.5903	3.1267	3.2903	2.3900	2.1194	2.7161	2.3133	2.8452	2.9833	2.8000
MTZ	Shenyang	2.0032	2.6143	2.8161	3.4500	2.7903	2.3867	2.3000	1.8032	2.2067	2.7226	2.4600	2.4484
MTZ	Urumqi	1.5355	1.6714	2.0839	2.9467	2.6290	2.4300	2.4968	2.4742	2.3433	2.1161	1.8033	1.6000
MTZ	Yinchuan	1.7935	2.1071	2.1484	3.4600	2.1968	2.8400	1.8548	1.7097	1.9967	1.4452	2.0300	2.0613
CTZ	Mohe	0.6161	0.6966	2.1129	2.5967	2.5806	2.0267	1.6194	1.7000	1.8933	2.2839	1.4733	1.1194
TPZ	Lhasa	2.1516	1.4821	1.8452	1.7967	2.1871	1.9800	1.7226	1.8484	1.5800	1.4032	1.0700	1.3452
TPZ	Nagqu	1.6258	2.3429	3.1226	3.0767	2.6194	2.2567	2.0613	1.9032	1.7100	2.2968	1.5333	2.1677
TPZ	Xining	0.8516	0.8857	1.0258	1.3833	1.1742	1.0767	0.8613	0.9290	0.7867	0.7839	0.6900	0.7484

Table A3. The monthly mean solar radiation interval forecasting by 2016 in different climates of China.

Month	Station	90% Confidence Level	Forecasting Mean Results	Station	90% Confidence Level	Forecasting Mean Results
Jan.	Haikou (TZ)	[5.28, 12.46]	8.87	Shanghai (SZ)	[4.47, 11.19]	7.83
Feb.		[6.92, 14.07]	10.49		[3.74, 10.50]	7.12
Mar.		[8.95, 15.71]	12.33		[8.78, 15.47]	12.13
Apr.		[12.66, 19.39]	16.03		[12.50, 19.32]	15.91
May		[16.88, 23.73]	20.30		[12.81, 19.49]	16.15
Jun.		[16.29, 23.28]	19.79		[9.71, 16.41]	13.06
Jul.		[16.29, 23.22]	19.76		[13.43, 20.65]	17.04
Aug.		[16.33, 23.05]	19.69		[12.83, 19.92]	16.38
Sep.		[15.42, 22.41]	18.91		[10.67, 17.32]	13.99
Oct.		[12.10, 18.94]	15.52		[9.10, 15.76]	12.43
Nov.		[9.42, 16.31]	12.87		[5.76, 12.52]	9.14
Dec.		[4.94, 11.97]	8.45		[4.56, 11.40]	7.68
Jan.	Zhengzhou (WTZ)	[3.75, 9.35]	6.55	Yinchuan (MTZ)	[6.58, 11.55]	9.07
Feb.		[5.85, 11.39]	8.62		[9.63, 14.61]	12.12
Mar.		[10.05, 15.54]	12.80		[14.07, 18.95]	16.51
Apr.		[13.51, 19.01]	16.26		[17.02, 21.88]	19.45
May		[15.05, 20.57]	17.80		[18.22, 23.13]	20.67
Jun.		[15.51, 21.07]	18.29		[18.30, 22.18]	20.74
Jul.		[14.90, 20.38]	17.64		[17.69, 22.58]	20.14
Aug.		[13.75, 19.40]	16.57		[16.55, 21.37]	18.96
Sep.		[10.69, 16.25]	13.47		[13.04, 17.88]	15.46
Oct.		[9.25, 14.74]	11.99		[10.92, 15.82]	13.37
Nov.		[5.96, 11.65]	8.81		[7.02, 12.09]	9.56
Dec.		[4.40, 9.99]	7.19		[6.29, 11.26]	8.77
Jan.	Lhasa (TPZ)	[12.99, 17.08]	15.04			
Feb.		[15.93, 20.05]	17.9			
Mar.		[18.92, 23.03]	20.98			
Apr.		[20.16, 24.27]	22.22			
May		[22.62, 26.79]	24.71			
Jun.		[23.51, 27.67]	25.59			
Jul.		[21.71, 25.88]	23.79			
Aug.		[19.77, 23.91]	21.84			
Sep.		[18.59, 22.71]	20.65			
Oct.		[16.33, 20.46]	18.39			
Nov.		[13.92, 18.04]	15.98			
Dec.		[12.02, 16.19]	14.11			

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