Journal of Global Change Data & Discovery. 2022, 6(4): 533-544
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Global Change Research Data Publishing & Repository

30-year Average Monthly/1-km Climate Variable Dataset of China (1951–1980, 1981–2010)

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Abstract: Spatial climate data are widely used in meteorology, geography, and ecology. These data are necessary for studying terrestrial ecosystems and climate change. In this study, we collected and sorted 30-year averaged meteorological records of China's national weather stations in two time periods (1951–1980, 1981–2010). We used the thin plate smoothing spline technique and ANUSPLIN 4.4 software to interpolate three climatic variables (temperature, precipitation, and percentage of sunshine). The error statistics of the observed and interpolated data were calculated using generalized cross validation, mean absolute errors, root mean squared errors, and linear regression to confirm the accuracy of the interpolated data. Climate data with 1 km resolution were obtained in three different raster formats (ASCII character set encoding text file, two-dimensional uniform grid, and label image file). The spatial distribution patterns and trends of temperature, precipitation, and percentage of sunshine were further analyzed.

Keywords: China; temperature; precipitation; percentage of sunshine; monthly; 30 years

DOI: https://doi.org/10.3974/geodp.2022.04.04

CSTR: https://cstr.escience.org.cn/CSTR: 20146.14.2022.04.04

Dataset Availability Statement:

The dataset supporting this paper was published and is accessible through the *Digital Journal of Global Change Data Repository* at: https://doi.org/10.3974/geodb.2022.06.03.V1 or https://cstr.escience.org.cn/CSTR:20146.11. 2022.06.03.V1.

1 Introduction

Meteorological records and climate data are the basis of many ecological studies, including those on the geographic distribution patterns of ecosystems, communities, populations and species and their relationships with climate[1–4], climate interpretation of biodiversity patterns[5], and climate-driven mechanisms of spatiotemporal changes in vegetation biomass and productivity[6–8]. In the face of climate change, species distribution and its response to climate change can be further simulated using climate data[9,10], and so can the impacts of

Received: 01-07-2022; **Accepted:** 17-11-2022; **Published:** 24-12-2022

Foundation: Ministry of Science and Technology of P. R. China (2019QZKK0402)

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Data Citation: [1] Cheng, Q., Wu, X. Q., Wei, L. F., *et al*. 30-year average monthly/1-km climate variables dataset of China (1951−1980, 1981−2010) [J]. *Journal of Global Change Data & Discovery*, 2022, 6(4): 533–544. https://doi.org/10.3974/geodp. 2022.04.04. https://cstr.escience.org.cn/CSTR:20146.14.2022.04.04.

[2] Cheng, Q., Wu, X. Q., Wei, L. F., *et al*. 30-year average monthly/1-km climate variables dataset of China (1951−1980, 1981−2010) [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2022. https://doi.org/10.3974/geodb.2022.06.03.V1. https://cstr.escience.org.cn/CSTR:20146.11. 2022.06.03.V1.

climate change on ecosystem patterns and functions[9–13]. Therefore, meteorological records and climate data are not only the basis of atmospheric science, but also important driving data for many disciplines and research fields, such as ecology and earth sciences; they are closely related to human life.

Meteorological observation data are usually from the continuous instrumental records of meteorological stations. However, due to the limited number of stations and uneven spatial distribution, these data are difficult to be directly applied in large-scale ecological studies. Therefore, spatial climate variables need to be interpolated. Kriging and thin plate smoothing spline (TPSS) methods are usually employed to interpolate spatial climate variables. Many studies have shown that the TPSS method can obtain highly accurate results[14–16]. Therefore, this method and the derivative software ANUSPLIN[17,18] have been widely used internationally.

Most of the spatial interpolation datasets of climate variables at global and regional scales are currently available[3]. Two datasets are commonly used at the global scale. The first one is WorldClim v2.1[1]. This dataset contains seven climate variables (mean annual temperature, minimum temperature, maximum temperature, annual precipitation, solar radiation, wind speed, and water vapor pressure) with four spatial resolutions (10′, 5′, 2.5′, and 30″) on the average over the period of 1970–2000 and 19 bioclimatic variables[19]. The second dataset is the UK Climate Research Unit (CRU) monthly dataset (CRU TS v4.05) with nine climate variables having 0.5° resolution grid cells for the period 1901–2020[20]. Since 1950, China has gradually established relevant standardized and widely distributed instrumental meteorological stations. The numbers of stations and meteorological variables increased after 1980[21]. However, due to the vast territory of China, the meteorological stations are still limited and unevenly distributed, especially in the western areas with high mountains and plateaus and the northwestern desert areas. Therefore, the spatial interpolation of climate variables is particularly important. In the past 20 years, Chinese scientists have been establishing several spatial datasets of climate variables for different research purposes. Examples include the recently published national monthly temperature and precipitation datasets at 1-km spatial resolution in different time periods (2000–2012[22], 1901–2017[23], and 1980–2017[24]), the dataset of evaporation and evapotranspiration ratio every eight days at 0.05° resolution for 1981–2015[25], and the national weather-driven dataset at high spatial and temporal resolutions for 1979–2018[26]. However, these datasets have different time scales and used for different purposes by different groups of scientists. Many time series datasets are available, but long-term, multi-year-averaged climatic datasets, which are crucial for ecological studies, are scarce. Given the temporal variability, multi-year averages of climate variables are commonly used in ecological studies to characterize the regional patterns of climate. These variables are particularly important for the simulation of vegetation and species distribution[4].

Therefore, a multi-year-average climate dataset covering long-time series and having a high spatial resolution needs to be established. In this study, the observational records of mean monthly temperature, precipitation, and sunshine percentage from national meteorological stations in two periods of 1951–1980 and 1981–2010 are interpolated into 1-km spatial resolution data by using the TPSS method and ANUSPLIN software to provide a multi-year-average climate dataset for ecological and geological studies in China.

2 Metadata of the Dataset

The metadata of the 30-year average monthly/1-km climate variables dataset of China (1951–1980 and 1981–2010)[27] are shown in Table 1.

[1] http://worldclim.org.

Table 1 Metadata summary of the 30-year average monthly/1-km climate variables dataset of China (1951–1980 and 1981–2010)

Items	Description		
Dataset full name	30-year average monthly/1-km climate variables dataset of China (1951–1980 and 1981–2010)		
Dataset short name	ChinaClimate_1951-2010		
Authors	Cheng, Q., Zhejiang Normal University, 875544767@qq.com Wu, X. Q., Zhejiang Normal University, 1632314650@qq.com Wei, L. F., Zhejiang Normal University, 552535060@qq.com Hu, X. F., Zhejiang Normal University, 976860215@qq.com Ni, J. I-7067-2012, Zhejiang Normal University, nijian@zjnu.edu.cn		
Geographical region	China	Time coverage	1951–1980，1981–2010
Temporal resolution	Monthly for 30-year average	Spatial resolution	1 km
Data format	.asc, .tif, .grd	Data size	3.35 GB (after compression)
Data files	Eight files divided into two time periods: 1951–1980 and 1981–2010. Each period consists of three different file formats		
Foundation	Ministry of Science and Technology of P. R. China (2019QZKK0402)		
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn		
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101, China		
Data sharing policy	***Data*** from the Global Change Research Data Publishing & Repository includes metadata, datasets (in the *Digital Journal of Global Change Data Repository*), and publications (in the *Journal of Global Change Data & Discovery*). ***Data*** sharing policy includes: (1) ***Data*** are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use ***Data*** subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute ***Data*** subject to written permission from the GCdataPR Editorial Office and the issuance of a ***Data*** redistribution license; and (4) If ***Data*** are used to compile new datasets, the 'ten per cent principal' should be followed such that ***Data*** records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[28]		
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS/ISC, GEOSS		

3 Methods

3.1 Data collection

The meteorological data included the standardized monthly records of surface climates during 1951–1980 and 1981–2010. The former originated from the Chinese Surface Climate Dataset (1951–1980)[29] and a personal collection of a small amount of data. The latter was from the China Meteorological Data Service Center[2], and the data on Taiwan Province were from the Central Weather Bureau of Taiwan[3]. The metadata of the dataset consisted originally of standardized monthly values of temperature, precipitation, sunshine duration, percentage of sunshine, air humidity, evaporation, snow accumulation, and wind and soil temperatures recorded by the national basic and benchmark surface meteorological stations. In this study, only three variables (temperature, precipitation, and percentage of sunshine) were selected for interpolation. For 1951–1980, the publicly available data of 673 national benchmark and basic stations were included together with the personal collection of 200 national or provincial general stations. The records with short time spans were excluded, and 858 meteorological station records were finally used for interpolation. For 1981–2010, 2152 meteorological records of national benchmark, basic, and general stations were included (Figure 1). Given the differences in the number of stations between the two time periods, especially in the western region, and the ambiguous classification of some early stations, all meteorological stations were referred to as national surface meteorological stations.

The two monthly datasets of standard surface climates used in this study were processed

[2] http://data.cma.cn.

[3] https://www.cwb.gov.tw.

by the National Meteorological Information Center in accordance with the standard national statistical compilation method for climate data. The station files with problems and disagreements were revised separately, and stations with obvious non-uniformity (e.g., station removal) were processed separately in accordance with different time periods before and after the station removal, thus ensuring the uniformity and accuracy of the data. The two original datasets were interpolated separately, and the results were relatively independent so that problems, such as station removal, in one set of data would not affect the other.

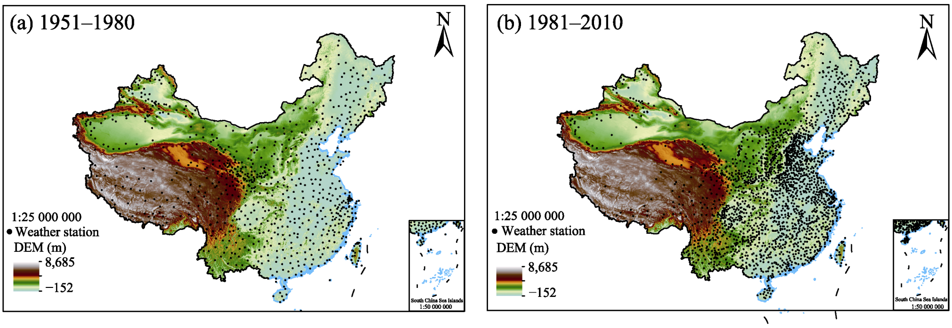


Figure 1 Spatial distribution of weather stations in China

3.2 Algorithms

The 12 monthly values of each climate variable were interpolated into raster data with a spatial resolution of 0.01° (≈1 km) by using the georeferenced TPSS method[17,18] and ANUSPLIN 4.4 software[30]. This interpolation was combined with the U.S. Shuttle Radar Topographic Mapping Mission digital elevation model[31], whose original record had 90 m spatial resolution and resampled to 0.01°.

The TPSS method is a widely validated approach for fitting and interpolating climate surfaces. It can fit discrete data as spline function curves with one to multiple independent variables, so it is widely used in global and regional climate interpolations. The method and its software ANUSPLIN are commonly used in China, and their solid reliability and superiority over other interpolation methods have been proven[14,32,33]. In the interpolation of ANUSPLIN software based on this method, the latitude and longitude are used as the independent variables of the spline function, and elevation is adopted as the covariate to establish the change in temperature along the altitudinal gradient (temperature lapse rate). A local TPSS is constructed to fit the 12-month temperature ratio change in time and space and achieve temperature interpolation. For precipitation interpolation, the original TPSS function is used to fit the surface, and elevation is adopted as the independent variable instead of the covariate. For the interpolation of the percentage of sunshine, the altitude is not used for fitting, but precipitation data can be used for verification. This study employed the above-mentioned common parameter settings and the default settings in the software[30] for the other parameters to fit and interpolate the monthly temperature, precipitation, and sunshine percentage.

4 Data Results and Validation

4.1 Data Composition

The 0.01° spatial resolution raster datasets of temperature, precipitation, and percentage of sunshine for 1951–1980 and 1981–2010 were available in eight compressed folders. The file naming rules were as follows. ChinaClimate_S_Z.rar. S indicated the years, including 1951–1980 and 1981–2010. Z indicated the format of the data, namely, a two-dimensional uniform grid format (.grd), ASCII character set encoded text file format (.asc), and labeled image file format (.tif), which could be used for different research purposes.

4.2 Data Products

By ANUSPLIN interpolation, the data with geo-location longitude, latitude, and climate values were obtained as two-dimensional uniform grid files, which were then converted into ASCII character set encoded text files and label image files by the Python program of ArcGIS 10.5 version. The spatial distribution characteristics of three climate variables were statistically analyzed, and the spatial distribution of each climate variable was mapped using ArcGIS based on the vegetation regionalization map of China[34]. For the two 30-year periods, the spatial distribution characteristics of the January, July, and annual values of each climate variable were briefly described, and the temporal trends between the two time periods were compared. The comparisons included the differences between two climate variables (mean annual temperature and percentage of sunshine) and the rate of annual precipitation change (precipitation in 1981–2010 − precipitation in 1951–1980) / precipitation in 1981–2010).

4.2.1 Temperature

The overall trend of temperature in China showed a decreasing trend from the southeast to the northwest. The mean temperature in January (Figure 2a, 2b) decreased greatly from south to north, with relatively high temperatures in southern and central China and relatively low temperatures in northeast, north, and northwest areas and the Qinghai–Tibet Plateau. The maximum values appeared in the tropical monsoon and rain forest region, followed by the subtropical evergreen broadleaf forest region, both of which had temperatures higher than 0 ℃. The third highest value was in the warm-temperate deciduous broadleaf forest region with a temperature of −5 ℃, followed by the temperate desert region and the temperate steppe region with temperatures lower than −10 ℃ and −15 ℃, respectively. The January temperature in the Qinghai-Tibet Plateau alpine vegetation region was between the values for the desert and steppe regions. The temperate mixed coniferous and broadleaf deciduous forest region had a temperature near −20 ℃, and the cold-temperate coniferous forest region had a temperature near −30 ℃. The mean temperature in January increased in 1981–2010 compared with the average during 1951–1980, with a relatively large increase in the cold-temperate coniferous forest region, the tropical monsoon and rain forest region, and the temperate mixed coniferous and broadleaf deciduous forest region. The smallest increase was in the Qinghai–Tibet Plateau alpine vegetation region.

The differences between the north and south in terms of the mean temperature in July (Figure 2c, 2d) were relatively small, but relatively low in the Qinghai–Tibet Plateau and central and western alpine regions. The regional differences in the mean temperature in July were smaller than those of the mean temperature in January. The Qinghai–Tibet Plateau alpine vegetation region had the minimum July temperature of about 6–7 ℃, followed by the cold-temperate coniferous forest region with a minimum July temperature between 17 ℃ and 18 ℃ and other regions with temperatures above 20 ℃. The maximum July temperature of about 24 ℃ appeared in the warm-temperate deciduous broadleaf forest region. The mean temperature in July in the last 30 years also increased, especially in the Qinghai–Tibet Plateau alpine vegetation region (more than 1 ℃).

The mean annual temperature (Figure 2e, 2f) also showed a decreasing trend from south to north and from southeast to northwest, with relatively high temperatures in southern, central, and northwestern China and relatively low temperatures in the northeast of China and the Qinghai–Tibet Plateau. The difference in the mean annual temperature in each vegetation region was small. The minimum mean temperature of about −4 ℃ appeared in the Qinghai–Tibet Plateau alpine vegetation region, which was colder than the cold-temperate coniferous forest region (less than 0 ℃). The mean annual temperature was higher than 1℃ and 5 ℃ in the temperate mixed coniferous and broadleaf deciduous forest region and temperate desert region, respectively, and the temperature of the temperate steppe region was in between. The other regions had a temperature above 10 ℃. The maximum value of 16℃ –17 ℃ appeared in the tropical monsoon and tropical forest region. The mean annual temperature in the majority of China increased generally over the past 60 years, especially in the Hengduan Mountain region on the southern edge of the Qinghai–Tibet Plateau (Figure 2g). However, the minority of the regions in central and southwestern China, particularly Tianshan Mountains, showed a downward trend.

4.2.2 Precipitation

Generally, the precipitation in China showed a decreasing trend from southeast to northwest. The precipitation in January (Figure 3a, 3b) decreased widely from southeast to northwest, with a relatively high value in the southern areas. The maximum value of about 30–35 mm appeared in the subtropical evergreen broadleaf forest region. The next value of about 18–19 mm was in the tropical monsoon and tropical rain forest region, and the other regions had precipitation below 10 mm. The minimum value of about 2.5 mm appeared in the temperate desert region. Compared with the period of 1951–1980, the last 30 years showed an overall increase. The increase in the subtropical evergreen broadleaf forest region was relatively high and reached 6 mm per year. Meanwhile, the other regions showed a small decrease, with a maximum decrease of 1 mm in the tropical monsoon and tropical rain forest regions.

The differences between north and south in terms of the precipitation of July (Figure 3c, 3d) were relatively large, which meant that the precipitation in summer was generally high across China but relatively low in the northwest. The July precipitation in the different regions varied significantly. The minimum of about 30 mm appeared in the temperate desert region, which is drier than the temperate steppe region with precipitation of about 100 mm and the other regions with precipitation above 130 mm. The maximum value of above 200 mm appeared in the tropical monsoon and tropical rain forest region. Compared with the period of 1951–1980, the last 30 years showed an overall increase, except for the slight decrements in the cold-temperate coniferous forest region, warm-temperate deciduous broadleaf forest region, and temperate steppe region. The largest increase was observed in the tropical monsoon and tropical rain forest regions, the values of which exceeded 30 mm.

The annual precipitation (Figure 3e, 3f) also showed a decreasing trend from south to north and from southeast to northwest. The precipitation in south China was relatively high, whereas that in northwest, north, and Qinghai–Tibet Plateau was relatively low. The maximum annual precipitation (near 1,350 mm) appeared in the tropical monsoon and tropical rain forest region (above 1,200 mm), followed by the temperate coniferous and deciduous broadleaf mixed forest and the warm-temperate deciduous broadleaf forest region (600–700 mm) then the cold-temperate coniferous forest region and the Qinghai–Tibet Plateau alpine vegetation region (500 and 350 mm, respectively). The annual precipitation of the temperate steppe region was in between. The minimum of about 140 mm appeared in the temperate desert region. Compared with the annual precipitation in 1951–1980, the annual precipitation in 1981–2010 decreased, especially in the warm-temperate broadleaf deciduous forest region, by more than 48 mm. The change rate of annual precipitation in the two time periods (Figure 3g) was complex. The increasing trend was obvious in the southeast, south, and part of southwest China. The annual precipitation in the northwest, Qinghai–Tibet Plateau, and northeast of China greatly increased, whereas the precipitation in the central regions decreased obviously.

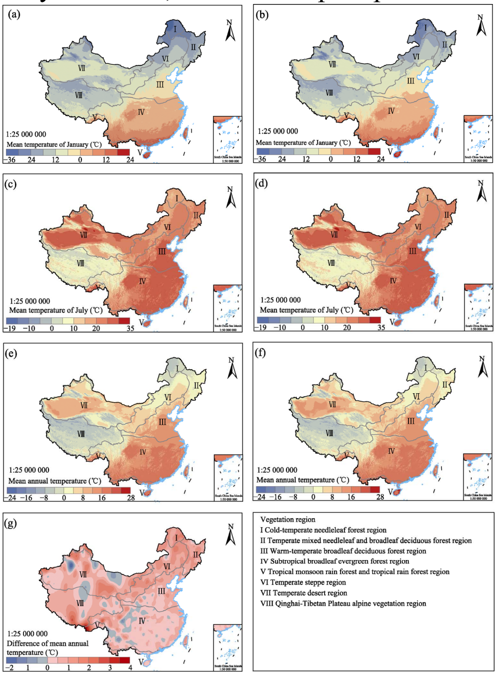


Figure 2 Maps of spatial distribution of temperature in China (1951–1980, 1981–2021)

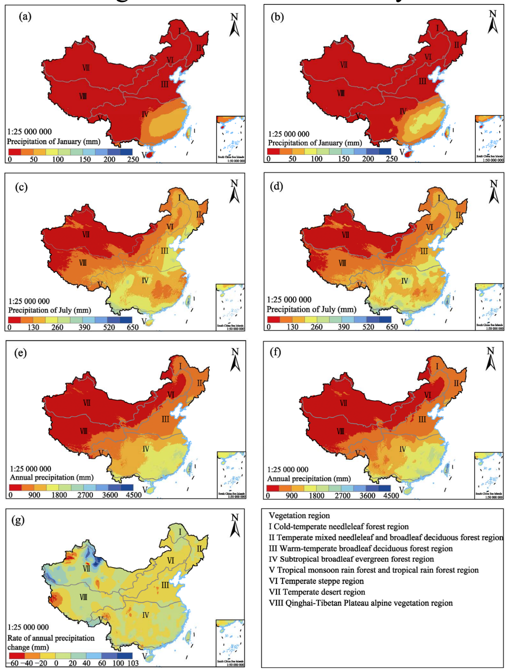


Figure 3 Maps of spatial distribution of precipitation in China (1951–1980, 1981–2021)

4.2.3 Percentage of Sunshine

The differences between north and south in terms of the percentage of sunshine in January across China (Figure 4a, 4b) were large. The sunshine percentage was low in the south and northwest of China and in the southeastern part of the Qinghai–Tibet Plateau but relatively high in the other regions. The sunshine percentages in January in the temperate steppe region, temperate desert region, and Qinghai–Tibet Plateau alpine vegetation region were higher than 65%, followed by those of the cold-temperate coniferous forest region and tropical monsoon and tropical forest region (less than 65% and 50%, respectively). The sunshine percentages of the temperate mixed coniferous and broadleaf deciduous forest region and the warm-temperate deciduous broadleaf forest region were in between. The minimum value of about 35%–40% appeared in the subtropical evergreen broadleaf forest region. The January sunshine percentage decreased from 1951–1980 to 1981–2010, especially in the temperate mixed coniferous and broadleaf deciduous forest region and the warm-temperate deciduous broadleaf forest region (reduction > 5%), whereas that in the Qinghai–Tibet Plateau alpine vegetation region increased by nearly 2%.

The percentage of sunshine in July (Figure 4c, 4d) varied considerably between the east and the west, which meant that percentage of sunshine in summer was generally high across China but relatively low in the southwest and northeast regions. The maximum July sunshine percentage appeared in the temperate desert region, followed by the steppe region and Qinghai–Tibet Plateau alpine vegetation region (all higher than 55%). The next value of about 50% was observed in the warm-temperate deciduous broadleaf forest region and the cold-temperate coniferous forest region. The values for the other regions were below 50%. The amount of July sunshine generally decreased from 1951–1980 to 1981–2010, especially in the warm-temperate deciduous broadleaf forest region and the subtropical evergreen broadleaf forest region (>5%), whereas that in the Qinghai–Tibet Plateau alpine vegetation region increased by nearly 1%. The mean annual percentage of sunshine (Figure 4e, 4f) also showed an increasing trend from south to north and from southeast to northwest. It was high in the north and northwest of China and in the Qinghai–Tibet Plateau, but relatively high in the southern regions. It was higher than 60% in the temperate steppe region, the temperate desert region, and the Qinghai–Tibet Plateau alpine vegetation region. The next values were between 50% and 60% in the cold-temperate coniferous forest region, the temperate mixed coniferous and broadleaf deciduous forest region, and the warm-temperate deciduous broadleaf forest region, followed by the subtropical broadleaf evergreen forest region and the tropical monsoon and tropical rain forest region (all < 50%).

Compared with the sunshine percentage of 1951–1980, that of 1981–2010 generally decreased by within 5%, except for an increase of nearly 1% in most part of the Qinghai–Tibet Plateau alpine vegetation region. The values for the other regions decreased by within 5%. Meanwhile, the central and western parts of northern China and the western and northeastern parts of the Qinghai–Tibet Plateau showed an increasing trend (Figure 4g).

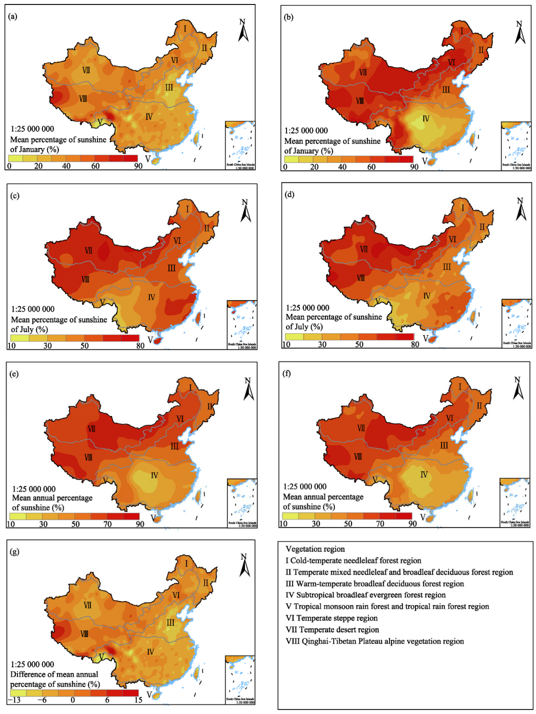


Figure 4 Maps of spatial distribution of percentage of sunshine in China (1951–1980,1981–2021)

4.3 Data Validation

4.3.1 Quality Control

The generalized cross validation (GCV) method is used in ANUSPLIN to compare the interpolated and observed climates and test the reliability of the interpolated data. In this study, the generalized cross-validation root mean square (RTGCV), mean absolute error (MAE), and root mean square error (RMSE) were used as the indicators of evaluation[24,30]. The calculation formulas were as follows:

$$RTGCV = \frac{1}{N}\frac{\sum_{i=1}^{N}\left(O_i - f\left(x_i\right)\right)^2}{\left(1-\frac{d_f}{N}\right)^2}, \tag{1}$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|\left(P_i - O_i\right)|, \tag{2}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(P_i - O_i\right)^2}, \tag{.3}$$

where O_i is the true observed value, $f(x_i)$ is the smooth function value of component variable x around point i, $\sum_{i=1}^{N}(O_i - f(x_i))^2$ is the residual sum of squares, d_f is the degree of freedom of the model, P_i the interpolation result, and N is the number of samples.

In accordance with the geographical coordinates of the meteorological stations in the two datasets and their original climate data, the corresponding values of each element of the interpolation dataset were extracted using the "Extract values from point" tool in ArcGIS software, and the correlation between the original and interpolation data was verified through linear fitting to further test the accuracy and credibility of the interpolated data. In addition, the density and distribution patterns of meteorological stations can affect the accuracy of interpolated data. In this study, the number of stations in the two time periods was different. We further compared the difference between the MAE and RMSE of the interpolated data with different station densities.

4.3.2 Quality Evaluation

Through the GCV test on all input data, the overall data could be judged based on its RTGCV. The RTGCV of the monthly climate variables in 1951–1980 and 1981–2010 (Figure 5) showed that the RTGCV changes in temperature and precipitation were relatively stable. In the first 30 years, the RTGCV of temperature fluctuated in the range of 0.7–1.5 °C, with the largest change in winter and the smallest in summer. The RTGCV of precipitation fluctuated roughly in the range of 0.7–1.6 mm, with the maximum in autumn and the minimum in spring. For the next 30 years, the RTGCV of temperature fluctuated in the range of 0.4–0.7 °C, with the largest in winter and the smallest in summer. The RTGCV of precipitation fluctuated roughly in the range of 0.3–0.8 mm, with the maximum in summer and the minimum in spring.

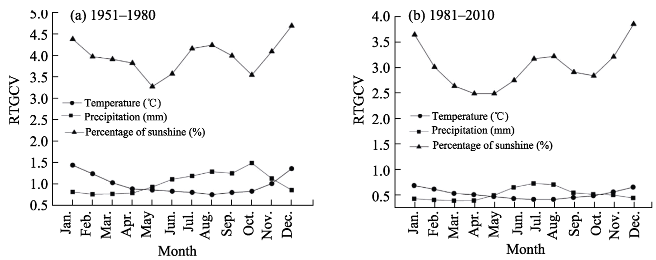


Figure 5 The generalized cross-validation root mean square (RTGCV) of temperature, precipitation, and percentage of sunshine

The sunshine percentage was affected by many factors, and its RTGCV fluctuated in the range of 2.5%–4.8%. The seasonal variation of the meteorological data inevitably increased the interpolation error of the climate variables, but the data quality was controllable and reasonable as a whole. The MAE and RMSE (Table 2) of the interpolation can also be used to test the accuracy of the interpolated data. MAE reflects the size of the estimated error, and the closer the value is to zero, the better the result is[32]. In this study, the MAE of temperature in winter and spring was large, whereas that in summer and autumn was small, but both were relatively small. The value was between 0.75 and 1.41 in 1951–1980, and between 0.42 and 0.69 in 1981–2010, indicating that the temperature interpolation was accurate and reliable. On the contrary, the MAE of precipitation in winter and spring was smaller than that in summer and autumn, which was related to the amount of precipitation in different seasons. However, it was also relatively small, and the coefficient of variation was low, with an average of 28% in the first 30 years and 13% in the next 30 years. The seasonal characteristics of the MAE of sunshine percentage were unobvious and mostly between 2.5 and 4.6, so the data accuracy was good. RMSE measures the average dispersion of a set of data. The smaller the standard deviation is, the more stable the data are. In this study, the mean RMSE of temperature in the first 30 years was within 0.06 (Table 2), and that in the next 30 years was within 0.04, indicating that the temperature interpolations were highly stable. The average RMSE of sunshine percentage was within 0.2, indicating that the data were also stable.

Table 2 Statistics of mean absolute errors (MAE) and root mean squared errors (RMSE) of temperature, precipitation, and percentage of sunshine in China (1951–1980, 1981–2010)

Month	Temperature (℃)				Precipitation (mm)				Sunshine percentage (%)			
	1951–1980		1981–2010		1951–1980		1981–2010		1951–1980		1981–2010	
	MAE	RMSE	MAE	RMSE	MAE	RMSE	MAE	RMSE	MAE	RMSE	MAE	RMSE
1	1.41	0.083	0.69	0.049	4.05	0.264	2.13	0.121	4.30	0.216	3.72	0.223
2	1.21	0.071	0.62	0.044	4.25	0.265	2.23	0.117	3.88	0.195	3.07	0.185
3	1.02	0.060	0.54	0.038	5.45	0.315	2.82	0.135	3.79	0.190	2.69	0.162
4	0.87	0.051	0.52	0.037	7.60	0.400	3.63	0.173	3.77	0.190	2.56	0.154
5	0.85	0.050	0.48	0.034	12.00	0.645	6.19	0.321	3.18	0.159	2.57	0.154
6	0.82	0.048	0.44	0.030	17.80	0.998	10.30	0.589	3.52	0.177	2.82	0.169
7	0.80	0.047	0.42	0.030	22.00	1.260	13.20	0.806	4.14	0.209	3.27	0.196
8	0.75	0.044	0.43	0.030	23.20	1.350	12.00	0.752	4.25	0.214	3.34	0.200
9	0.81	0.047	0.47	0.033	17.60	1.010	6.96	0.418	3.96	0.200	3.00	0.180
10	0.83	0.049	0.51	0.035	14.90	0.893	4.51	0.237	3.47	0.175	2.91	0.175
11	1.01	0.059	0.58	0.041	7.55	0.470	3.00	0.160	4.02	0.202	3.27	0.197
12	1.33	0.078	0.67	0.047	4.21	0.275	2.07	0.122	4.62	0.232	3.92	0.236
Mean	0.98	0.057	0.53	0.037	11.72	0.679	5.75	0.329	3.91	0.197	3.10	0.186

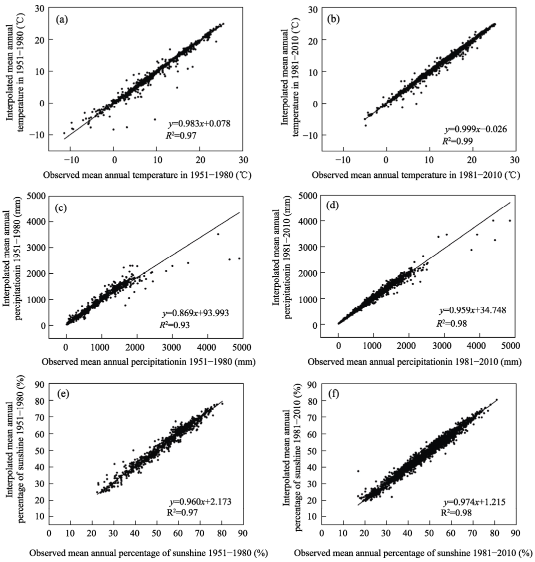
For historical reasons, the number of meteorological stations from 1951 to 1980 accounted for only about 40% of that from 1981 to 2010. The number and density of stations increased significantly in the last 30 years, but the spatial distribution pattern of the meteorological stations in the two periods was basically the same. The greater the density of the stations was, the smaller the interpolation error was and the better the interpolation was, especially for the two variables of temperature and precipitation.

The comparison between the observation of meteorological stations in the two time periods and the corresponding grid point interpolation showed a significant linear positive correlation (Figure 6), effectively reflecting the real climate situation. Regardless of the time period, the R^2 of temperature (Figure 6a, 6b) and sunshine percentage (Figure 3e, 3f) were between 0.97 and 0.99, indicating that the accuracy of the interpolation was extremely high. The R^2 of precipitation fitting was 0.93 and 0.98 (Figure 6c, 6d), and the accuracy of the interpolation was relatively low probably because ANUSPLIN underestimated the precipitation.

5 Discussion and Conclusion

In this study. The temperature, precipitation, and sunshine percentage were interpolated into grid data with a spatial resolution of 0.01° (≈1 km) on the basis of the monthly records of China's surface meteorological stations and by using the TPSS method and ANUSPLIN 4.4 software. The interpolation method applied in this study, TPSS, is a well-verified general geographic reference interpolation method and has been proven to be effective and reliable. For the dataset, three methods were employed for quality control and evaluation: generalized cross validation was used to test the validity of the original station data, mean absolute and root mean square errors were employed to evaluate the accuracy of the interpolated data, and linear fitting of the station and interpolated data was applied to verify the accuracy again.

The interpolation method adopted in this study has some advantages, and the spatial resolution of 0.01° is high, both of which mean that the climate interpolations are reliable and can be used as an effective substitute for the extraction of Chinese climate data from global datasets. In addition to the three climate variables considered in this study, other variables, such as underground temperature, relative humidity, evaporation, and wind speed, can also be interpolated. This dataset can be further utilized or referenced as: (1) basic data for studying the relationship between species or ecosystems and climate at national or regional scales to analyze their geographical distribution, dynamic changes, and climate driving mechanisms; (2) input data for driving species distribution models to simulate the potential geographical distribution of plant and animal species in China. At the early stage of plant species modeling, Chinese scientists mostly used the WorldClim climate dataset[4]. The dataset proposed in this study, especially the data from 1981 to 2010, may produce improved simulations if it can be combined with other ecologically meaningful bioclimatic variables[3,35] because this regional interpolation approach uses numerous meteorological stations, and its accuracy has been well verified. This dataset can also be further utilized as (3) input data for driving large-scale terrestrial biosphere models or other vegetation models to simulate the potential geographical distribution of vegetation in China and its productivity and carbon cycles. CRU or WorldClim data have been commonly used in the past, but the current dataset could be a reliable substitute. If it is combined with the interpolation of time series climate data[36], the dynamic change in vegetation can be further simulated. Moreover, this dataset can be further utilized as (4) basic data that can be applied in the study of climate and vegetation regionalization and in other studies in ecology, atmosphere science, and geography.



Figur 6 Comparative validation of observed and interpolated climate data

Author Contributions

Cheng, Q. collected, processed, and analyzed the data and wrote the manuscript. Wu, X. Q., Wei, L. F., and Hu, X. F. contributed to the data processing and analyses. Ni, J. designed the research and interpolation method and finalized the paper.

Acknowledgements

The authors are grateful to the China Meteorological Data Service Center and the Central Weather Bureau of Taiwan province for providing the observational records of the meteorological stations. The authors also thank Chen, X. Y. for assisting in the climate data processing.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Fang, J. Y. Ecoclimatological analysis of the forest zones in China [J]. *Acta Ecologica Sinica*, 1991, 11(4): 377–387.

[2] Zhang, X. S. A vegetation-climate classification system for global change studies in China [J]. *Quaternary Sciences*, 1993, 13(2): 157–169, 193.

[3] Ni, J. An introduction to bioclimatic factors in global change research [J]. *Quaternary Sciences*, 2017, 37(3): 431–441.

[4] Liu, X. T., Yuan, Q., Ni, J. Research advances in modelling plant species distribution in China [J]. *Chinese Journal of Plant Ecology*, 2019, 43(4): 273–283.

[5] Feng, J. M. Spatial patterns of species diversity of seed plants in China and their climatic explanation [J]. *Biodiversity Science*, 2008, 16(5): 470–476.

[6] Piao, S. L., Fang, J. Y., He, J. S., *et al*. Spatial distribution of grassland biomass in China [J]. *Chinese Journal of Plant Ecology*, 2004, 28(4): 491–498.

[7] Piao, S. L., Fang, J. Y., Zhou, L. M., *et al*. Changes in vegetation net primary productivity from 1982 to 1999 in China [J]. *Global Biogeochemical Cycles*, 2005, 19(2): GB2027.

[8] Liu, L., Yang, H., Xu, Y., *et al*. Forest biomass and net primary productivity in southwestern China: a meta-analysis focusing on environmental driving factors [J]. *Forests*, 2016, 7(12): 173.

[9] Cui, S. P., Luo, X., Li, C. W., *et al*. Predicting the potential distribution of white-lipped deer using the MaxEnt model [J]. *Biodiversity Science*, 2018, 26(2): 171–176.

[10] Zhang, X. J., Gao, X. M., Ji, C. J., *et al*. Response of abundance distribution of five species of Quercus to climate change in Northern China [J]. *Chinese Journal of Plant Ecology*, 2019, 43(9): 774–782.

[11] Ni, J., Sykes, M. T., Prentice, I. C., *et al*. Modelling the vegetation of China using the process-based equilibrium terrestrial biosphere model BIOME3 [J]. *Global Ecology and Biogeography*, 2000, 9(6): 463–479.

[12] Ni, J. Carbon storage in terrestrial ecosystems of China: estimates at different spatial resolutions and their responses to climate change [J]. *Climatic Change*, 2001, 49(3): 339–358.

[13] Piao, S., Ciais, P., Huang, Y., *et al*. The impacts of climate change on water resources and agriculture in China [J]. *Nature*, 467(7311): 43–51.

[14] Yan, H. Modeling spatial distribution of climate in China using thin plate smoothing spline interpolation [J]. *Scientia Geographica Sinica*, 2004, 24(2): 163–169.

[15] Hijmans. R. J., Cameron, S. E., Parra, J. L., *et al*. Very high resolution interpolated climate surfaces for global land areas [J]. *International Journal of Climatology*, 2005, 25(15): 1965–1978.

[16] Tan, J. B., Li, A. N., Lei, G. B. Contrast on Anusplin and Cokriging meteorological spatial interpolation in southeastern margin of Qinghai-Xizang Plateau [J]. *Plateau Meteorology*, 2016, 35(4): 875–886.

[17] Hancock, P. A., Hutchinson, M. F. Spatial interpolation of large climate data sets using bivariate thin plate smoothing splines [J]. *Environmental Modelling & Software*, 2006, 21(12): 1684–1694.

[18] Xu, T. B., Hutchinson, M. F. New developments and applications in the ANUCLIM spatial climatic and bioclimatic modelling package [J]. *Environmental Modelling & Software*, 2013, 40: 267–279.

[19] Fick, S. E., Hijmans, R. J. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas [J]. *International Journal of Climatology*, 2017, 37(12): 4302–4315.

[20] Harris, I., Osborn, T. J., Jones, P., *et a*l. Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset [J]. *Scientific Data*, 2020, 7: 109.

[21] Chen, L. X., Zhou, X. J., Li, W. L., *et al*. Characteristics of the climate change and its formation mechanism in China in last 80 years [J]. *Acta Meteorologica Sinica*, 2004, 62(5): 634–646.

[22] Wang, J. B., Wang, J. W., Ye, H., *et al*. An interpolated temperature and precipitation dataset at 1 km grid resolution in China (2000—2012) [J/OL]. *China Scientific Data*, 2017, 2(1): 73–80.

[23] Peng, S. Z., Ding, Y. X., Liu, W. Z., *et al*. 1 km monthly temperature and precipitation dataset for China from 1901 to 2017 [J]. *Earth System Science Data*, 2019, 11(4): 1931–1946.

[24] Chen, W., Sun, L. Q., Li, Q. L., *et al*. An interpolation dataset for temperature and precipitation at 1km grid resolution in Chinese mainland for recent 38 Years [J]. *Meteorological Science and Technology*, 2021, 49(3): 355–361.

[25] Niu, Z. G., He, H. L., Zhu, G. F., *et al*. A spatial-temporal continuous dataset of the transpiration to evapotranspiration ratio in China from 1981–2015 [J]. *Scientific Data*, 2020, 7: 369.

[26] He, J., Yang, K., Tang, W., *et al*. The first high-resolution meteorological forcing dataset for land process studies over China [J]. *Scientific Data*, 2020, 7: 25.

[27] Cheng Q., Wu, X. Q., Wei, L. F., *et al*. 30-year average monthly/1-km climate variables dataset of China (1951–1980, 1981–2010) [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2022, https://doi.org/10.3974/geodb.2022.06.03.V1. https://cstr.escience.org.cn/CSTR:20146.11.2022.06.03.V1.

[28] GCdataPR Editorial Office. GCdataPR data sharing policy [OL]. https://doi.org/10.3974/dp.policy.2014.05 (Updated 2017).

[29] The Central Meteorological Administration Information Office. The Dataset of China's Climate Surface [M]. Beijing: Meteorological Press, 1984.

[30] Hutchinson, M. F., Xu, T. B. ANUSPLIN Version 4.4 User Guide [M]. Canberra: Fenner School of Environment and Society, the Australian National University, 2013.

[31] Farr, T. G., Rosen, P. A., Caro, E., *et al*. The shuttle radar topography mission [J]. *Reviews of Geophysics*, 2007, 45(2): RG2004.

[32] Liu, Z. H., Li, L. T., McVicar, T. R., *et al.* Introduction of the professional interpolation software for meteorology data: ANUSPLINN [J]. *Meteorological Monthly*, 2008, 34(2): 92–100.

[33] Jiang, X. J., Liu, X. J., Huang, F., *et al*. Comparison of spatial interpolation methods for daily meteorological elements [J]. *Chinese Journal of Applied Ecology*, 2010, 21(3): 624–630.

[34] The Editorial Committee of Vegetation Map of China, Chinese Academy of Science. Vegetation Atlas of China (1:1000 000) [M]. Beijing: Science Press, 2001.

[35] Wei, L. F., Hu, X. F., Cheng, Q., *et al*. A dataset of spatial distribution of bioclimatic variables in China at 1km resolution [J/OL]. *China Scientific Data*, 2022. DOI: 10.11922/11-6035.csd.2022.0003.zh.

[36] Wu, X. Q., Cheng, Q., Wei, L. F., *et al*. A time series dataset of climate variables from 1951 to 2014 in karst region of southwestern China [J/OL]. *China Scientific Data*, 2022. DOI: 10.11922/11-6035.csd.2022.0004.zh.