


## Article

# Spatial Homogenization Adjustment and Application of Weather Station Networks in Xinjiang, China

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**Abstract:** In this study, we define the  $S_0$  value (buffer zone area centred on a meteorological station) and two inhomogeneity measurement parameters, the station domain area and station network density, for 89 weather stations in the Xinjiang region, and we construct the weight coefficient of the station network according to the station domain area. Applying the weight coefficient, we calculate the mean temperature, maximum temperature, and minimum temperature in January, April, July, October, and annually in the Xinjiang region from 1961 to 2021. The results show that the  $S_0$  value of 200,000 km<sup>2</sup> is suitable for determining the weight coefficient of the station network in the Xinjiang region. The two measurement parameters can quantitatively reflect the inhomogeneity of the distribution of 89 weather stations in the Xinjiang region. The spatial distribution density of the station network is positively proportional to the station network density and inversely proportional to the station domain area and weight coefficient of the stations. The equal-weighted average is lower than the spatially homogenized revised average, which underestimates the mean temperature in the Xinjiang region, and the spatially homogenized revised average better reflects the real temperature in the Xinjiang region. The annual and monthly mean temperatures, maximum and minimum temperatures calculated by the spatially homogenized revised average, and the equal-weighted average have the same upwards trend, and the mean temperature warming trend calculated by the two methods have differences, but the differences are not significant. The annual, January, April, July, and October minimum temperature warming trends according to the spatial homogenization revised average are greater than the maximum temperature warming trend and the mean temperature warming trend, and the annual minimum temperature warming trend is 3.3 times the annual maximum warming trend and two times the annual mean temperature.

**Keywords:** Xinjiang region; weather station network; spatial homogenization adjustment; equal-weighted average



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## 1. Introduction

Currently, the global surface mean temperature has increased by 1.1 °C relative to 1850–1900, and the warming caused by human activities in the past 2000 years is unprecedented. Global surface temperatures have increased faster since 1970 than in any 50-year period in the last 2000 years. Human-influenced climate change has caused many kinds of weather and climate extremes in every region of the globe, including extreme events such as heatwaves, very heavy rainfall, droughts, and tropical storms [1]. The annual average

surface temperature in China shows a significant upwards trend, with a warming trend of  $0.26\text{ }^{\circ}\text{C}$  per decade, which is higher than the global average warming level ( $0.15\text{ }^{\circ}\text{C}$  per decade) during the same period [2]. The trend of the annual mean temperature in Xinjiang is higher than that in the global land and China, with an average increase of  $0.30\text{ }^{\circ}\text{C}$  per decade [3]. At present, climate change is a popular topic in atmospheric science research and is also a major issue of concern to the international community [4,5].

The observational data of weather stations are the basis for studying climate change. Long-term and high-quality climate data are essential for monitoring and studying climate variability and change [6]. Measurements are often affected by non-climatic influences such as station relocations, uneven station spatial distribution, observer changes, changes in the station environment, changes in instruments, and station maintenance. Although inhomogeneities in site observations have limited influence on the estimate of the observed temperature trend performed on a global scale [7], these can substantially affect the outcomes for local and regional scale patterns of climate change. Many exploratory studies have been performed in the field of homogenization. Many scholars have homogenized revised daily, monthly and annual scale temperature data from Canada, Australia, and other countries by methods such as the percentile-matching (PM) adjustment method [8], a similar adjustment method [9], quantile-matching (QM) adjustment method [10], and statistical methods [11]. In China, the current national meteorological information centre has created a national set of homogenized information [12] by applying the RHTests V3.0 software developed by Wang and Feng [13] that has applications in the detection and attribution of observational change for Asia and China [14,15] and even for northwest China [16]. However, most studies only revised the inhomogeneity of temperature in the time series and did not take into account spatial homogeneity. The spatial distribution of climate stations is often extremely heterogeneous, and the spatial heterogeneity of climate information also has an impact on climate change research, especially in low-density station regions.

Some researchers have proposed that the area-weighted average should be used in the calculation of spatial average [17,18]. Zhu Changhan [19] pointed out that the factor of the area represented by the site must be taken into account in the national average method of calculating factors with the data of the site. An area weight coefficient should be constructed for each site that represents the area proportional to the total area of the weight size; to calculate the ratio of the area of each province and region to the total area of China, the calculation stations of each province and region is divided to find the area weight coefficient; Wang Panxing et al. [20] defined the station domain area and station network density of 160 stations in China, which reflected the inhomogeneity of the stations' network distribution, and constructed the weight coefficient of 160 stations in a network using station domain area. These 160 stations were used to obtain the national climatic average and average square deviation of temperature in January, April, July, and October in China, and the revised results were shown to be reasonable. Although this method is troublesome in the process of determining the coefficients, once the weighting coefficients of the meteorological stations are determined it is easy to apply them in meteorological operations, and the application also shows that the homogenized revised scheme is concise, the analysis results obtained with the revised information are theoretically reasonable, and the actual analysis results are improved compared with the original. The disadvantage of this method is that once the area is changed, the weighting coefficients of the original meteorological stations must be recalculated. The above scholars' research can solve the problem of the uneven spatial distribution of meteorological stations, but they only homogenized and revised the whole network of China and did not consider smaller regional networks.

Xinjiang is in northwestern China and occupies one-sixth of the national area. Its regional climate is very sensitive to global climate change, meanwhile, extreme precipitation and temperature events have been high and recurring in recent years [21,22]. Some scholars have used meteorological station data to study climate change in Xinjiang [23–26] and its

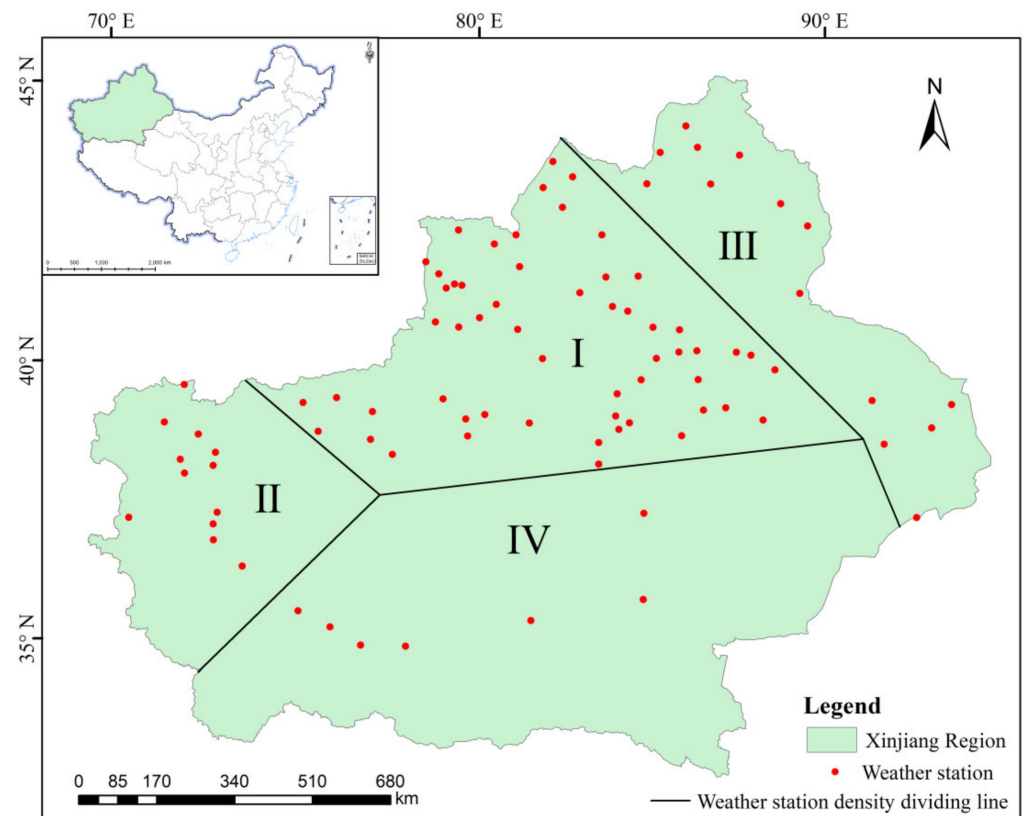
impact on water resources, the forestry and fruit industry, diseases and insect pests, flood disasters, and the agricultural economy in the region [27–33] and have obtained valuable results. However, the above scholars adopted the equal-weight average method to calculate the regional average of the long time series of the temperature, without considering the heterogeneity of the meteorological stations' spatial distribution, i.e., only considering the uniformity in the time domain and not considering the uniformity in the space domain. The spatially homogenized and revised meteorological elements obtained from weather stations not only reflect the objective facts of climate change in the study area, but also this work can help better identify and capture precipitation and temperature extremes. There are 89 weather stations in Xinjiang, and although it is obvious that the distribution of meteorological stations is extremely uneven, there are no indicators to quantify the unevenness of the distribution. In addition, how to homogenize the adjustment of the weather stations in Xinjiang to obtain more objective regional average temperature data is an urgent problem that needs to be addressed. This study determines two parameter values (station domain area and station network density) of inhomogeneity stations in Xinjiang and then constructs the weight coefficient of the station network of the Xinjiang region by station domain area. We structured it as follows: the data description is in Section 2, the methods are in Section 3, and the results are presented in Section 4, with the last part about discussions and conclusions in Section 4.

## 2. Materials and Methods

### 2.1. Materials

#### 2.1.1. Study Area

Xinjiang is in arid and semiarid areas in northwest China (Figure 1). It is the largest provincial administrative region in China in terms of land area, with a total area of one-sixth of China's land area (1.66 million square km).



**Figure 1.** The 89 weather stations distributed in Xinjiang region.

There are 89 weather stations in Xinjiang (Starting in 1961). The distribution of weather station networks is extremely uneven in Xinjiang. Figure 1 shows that the region I station network is the most densely distributed, the region II station network is more densely distributed, and region III and IV station networks are sparse. There are only 7 stations in region IV. If calculating the regional mean temperature only uses the equal-weight average method, the average value may be biased to the value in the dense region I of the network, which leads to the distortion of the calculated result and is unfavourable to the study of climate change in Xinjiang. Therefore, it is important to revise the spatial homogenization of this regional weather station in Xinjiang.

### 2.1.2. Dataset

From the Xinjiang Climate Centre, the longitude and latitude data of the 89 climate stations and the mean, maximum, and minimum temperature data for annual, January, April, July, and October of the 89 stations in the Xinjiang region from 1961 to 2021 were obtained. There are 105 national meteorological stations in Xinjiang, and only 89 national meteorological stations are currently available with complete data due to relocation, missing intermediate observations, short construction time, and withdrawal of stations. For example, the Kekodara meteorological station had a difference of approximately 100 km following relocation, resulting in a large difference between the data gathered before and after its relocation. Hence, the station data cannot be connected to the long time series data; the Tazhong meteorological station was built in the 1990s, which was too late to form long time series data. Therefore, these stations were excluded from this study. Xinjiang meteorological stations are divided into three categories: national basic meteorological stations, national benchmark meteorological stations, and national meteorological observation stations. In this study, 37 national basic meteorological stations, 22 national benchmark meteorological stations, and 30 national meteorological observation stations were selected. The data from the above meteorological stations passed strict quality control.

In this study, the data are used to calculate the mean temperature in Xinjiang by two methods: one is to calculate the average temperature by the spatial homogenization revised average of the network comprising 89 weather stations in the Xinjiang region, and the other is to calculate the average temperature of these stations by the equal-weighted average method.

## 2.2. Methods

### 2.2.1. Calculation of Daily, Monthly, and Annual Time-Scale Temperatures for a Single Station at Meteorological Stations

A daily mean temperature is calculated by averaging four 6-hourly observations in a day. The monthly mean temperature is averaged over the daily mean temperature for the month. The annual mean temperature is averaged from the mean temperature of the 12 months in the year. Minimum (maximum) temperature is the minimum (maximum) temperature at a certain moment in the daily, monthly and annual time scales; that is, the daily minimum (maximum) temperature is the minimum (maximum) temperature recorded at a certain moment in the day, the monthly minimum (maximum) temperature is the minimum (maximum) temperature at a certain moment in the month, and the annual minimum (maximum) temperature is the minimum (maximum) temperature at a certain moment in the year.

### 2.2.2. Spatial Homogenization Adjustment of the Xinjiang Weather Data Station Network

In this study, the station network spatial homogenization adjustment of climate data by Wang Panxing et al. [20,34] was adopted to determine the station domain area and station network density of the Xinjiang regional weather stations and to construct the weight coefficients of the 89 station network in the Xinjiang region based on the station domain area, which were applied to the calculation of the annual mean temperature and

the mean temperature in January, April, July, and October in the Xinjiang region from 1961 to 2021. The specific parameters are calculated as follows:

(1)  $S_0$  value selection

$S_0$  is the buffer zone area centred on the meteorological station point, and  $S_0$  is a prerequisite for determining the station domain area. Wang et al. [20] corrected the homogenization of China’s climatic data stations in the process, and the value of  $S_0$  is  $50 \times 10^4 \text{ km}^2$ . Due to the homogenized revised network of national climatological data stations, the scope is large, and it may be larger if this value is applied in the Xinjiang region. Given this situation, based on previous studies,  $S_0$  was assigned  $50 \times 10^4 \text{ km}^2$ ,  $30 \times 10^4 \text{ km}^2$ ,  $20 \times 10^4 \text{ km}^2$ ,  $15 \times 10^4 \text{ km}^2$ , and  $10 \times 10^4 \text{ km}^2$ . Through the application results of 5 groups of data, the value suitable for the Xinjiang region was determined.

(2)  $S_0$  is taken as different areas, corresponding to the coverage in Xinjiang

In the ArcGIS10.0 software platform, we overlaid the Xinjiang vector boundary map and 89 weather sites. Taking 89 meteorological stations in Xinjiang as the centre, we made buffer areas of  $50 \times 10^4 \text{ km}^2$ ,  $30 \times 10^4 \text{ km}^2$ ,  $20 \times 10^4 \text{ km}^2$ ,  $15 \times 10^4 \text{ km}^2$ , and  $10 \times 10^4 \text{ km}^2$ , and the spatial coverage with different values centred on 89 meteorological stations in Xinjiang was obtained. Using the ArcGIS10.0 software analysis tool, the spatial distribution profile of the area covered by different values in the Xinjiang region was obtained. On this basis, the area of different values in the Xinjiang region can be counted in the attribute table of the obtained data. Finally, the total area covered by values was divided by the total area of Xinjiang to obtain the coverage rates of different  $S_0$  values in the Xinjiang region.

(3) Station domain area

Taking the 89 weather station network of the Xinjiang region as an example,  $i$  station as the centre, the area of the  $S_0$  is  $\Omega_i$ , the area of Xinjiang on  $\Omega_i$  is  $D_i$ , and the number of stations belonging to this network on  $D_i$  is  $m_i$ . The area of Xinjiang represented by station  $i$  is defined as:

$$d_i = D_i / m_i \tag{1}$$

$d_i$  is the station domain area of station  $i$ .

The extraction of  $D_i$ : The 89 weather stations of the Xinjiang region are loaded into the ArcGIS10.0 interface, and a buffer zone with the area  $S_0$  is established at the centre of the  $i$  station, extracting the area of each buffer zone within the Xinjiang region by the analysis tool, denoted as  $D_i$ .

The extraction of  $m_i$ : The 89 weather stations of the Xinjiang region and  $D_i$  of each station are loaded into ArcGIS10.0, correlating their attributes, and extracting the number of weather stations in range  $D_i$ , denoted as  $m_i$ .

(4) Station network density

Among Xinjiang’s 89 weather stations, when  $S_0 = D_i$ , for inland stations; when  $S_0 > D_i$ , for boundary stations. The distribution of the inland and border station numbers depends on the value of  $S_0$ . The larger the value of  $S_0$  is, the more border stations there are, and the fewer inland stations there are. There is no comparability between sites near the boundary and inland sites, so the correction coefficient is  $\mu = S_0 / D_i$ , and  $m_i$  was revised in the Xinjiang region.

$$m_j = \mu_i m_i = S_0 / d_i \tag{2}$$

where  $m_j$  is the station network density; when  $S_0$  is the unit area,  $m_j$  and  $d_i$  are reciprocal.

(5) Construction of weighting coefficients for meteorological stations and calculation of spatially homogenized temperature averages

To calculate the average value  $[F_j]$  of the temperature field of  $F_j$  in the region covered by the network of 89 Xinjiang regional weather stations in a year, the area weight coeffi-

cient of the station domain area  $d_i$  of the 89 Xinjiang regional weather station network is constructed as follows:

$$w_i = d_i / \sum_{i=1}^n d_i \quad (3)$$

Based on the  $w_i$  weighting coefficients, the spatially homogenized temperature average is calculated as follows:

$$[F_j] = w_i F_j = \sum_{i=1}^n w_i F_{ij} \quad (4)$$

where  $n$  is the number of meteorological stations,  $w_i$  is the weight coefficient of station  $i$ ,  $F_{ij}$  is the temperature value of station  $i$  in year  $j$ , and  $[F_j]$  is the spatially homogenized revised average temperature in year  $j$ .

Formula (3) is used to calculate the weight coefficient of the 89 Xinjiang regional weather station network. Formula (4) calculates the monthly and annual scale minimum, maximum, and mean temperatures in the Xinjiang region. The method calculated by Formula (4) is called the spatially homogenized revised average. In this study,  $n$  is 89, i.e., 89 meteorological stations in the Xinjiang region.

### 2.2.3. The Equal-weighted Average of the Xinjiang Region Temperature Data

When calculating the spatial average temperature in the Xinjiang region, the 89 weather stations are considered to represent the same weight in space, and the temperature data from these meteorological stations on a certain time scale are arithmetically averaged, i.e., equal-weight average, calculated as follows:

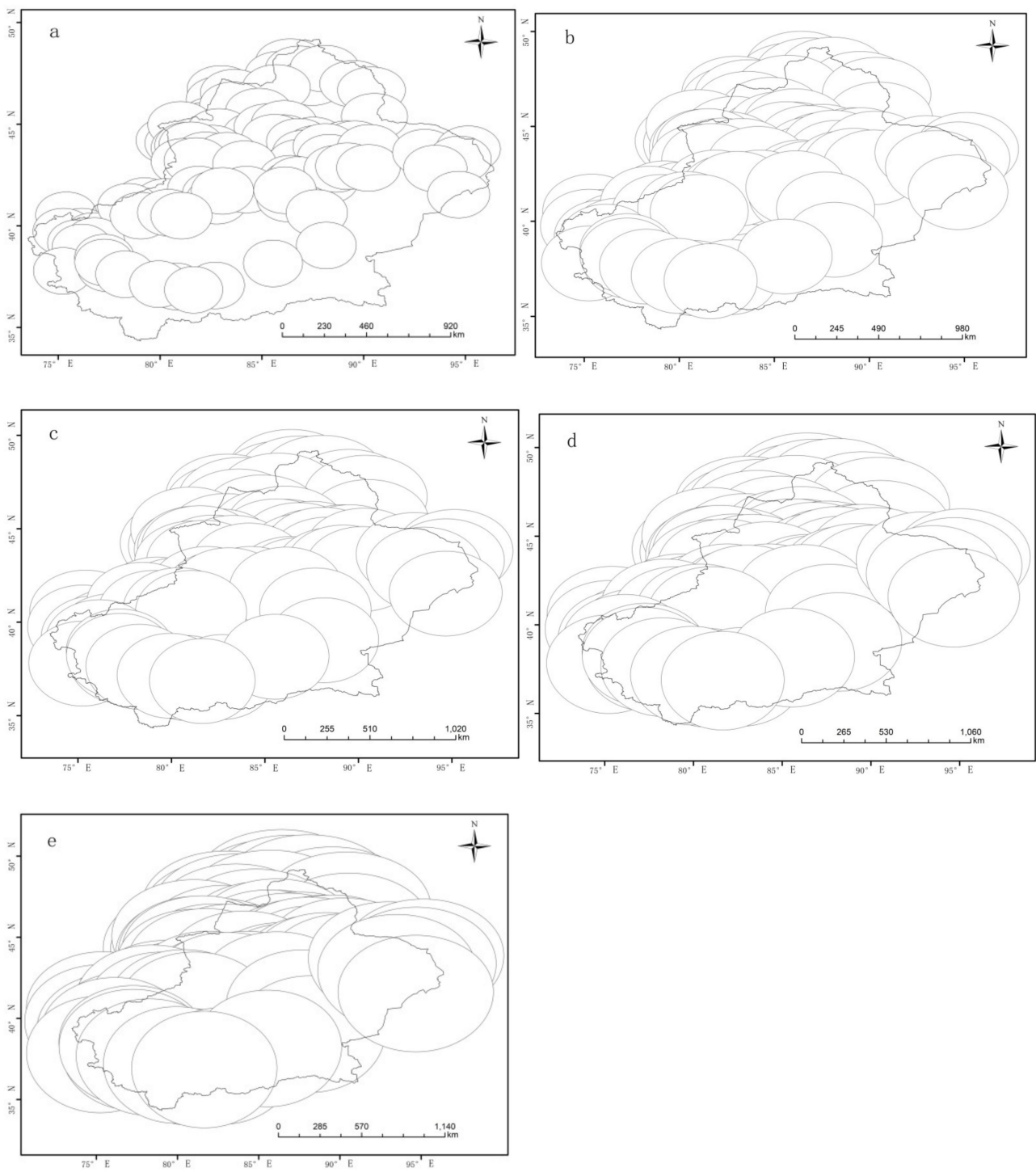
$$T_j = \left( \sum_{i=1}^n F_{ij} \right) / n \quad (5)$$

where  $T_j$  is the equal-weighted average temperature in year  $j$ . Formula (5) (the equal-weighted average) calculates the monthly and annual scale minimum, maximum, and mean temperatures in the Xinjiang region. This result is analysed in comparison with the spatially homogenized revised average result.

## 3. Results

### 3.1. Determination Area $S_0$

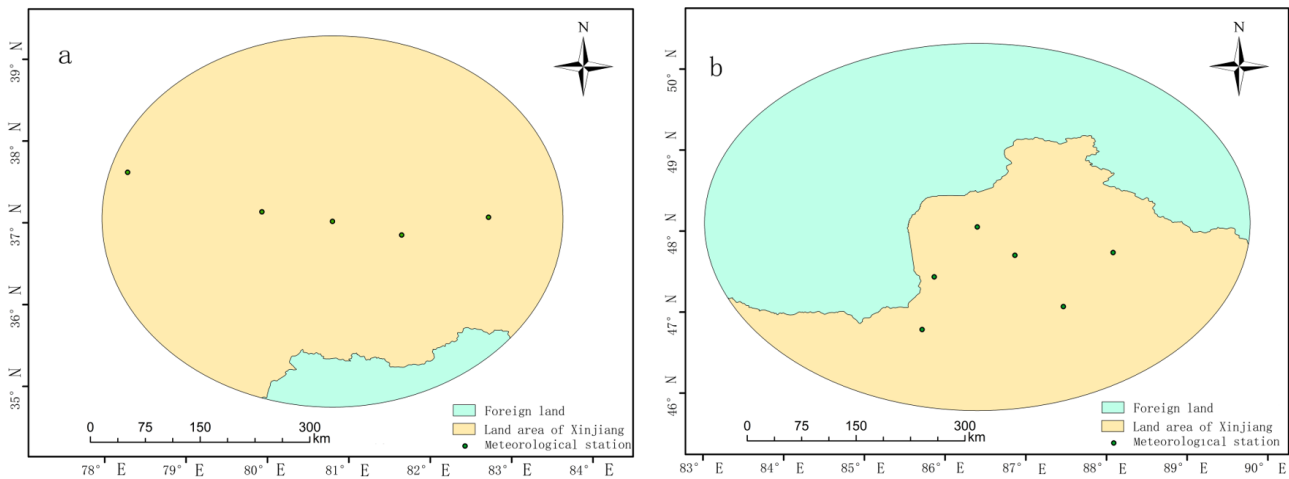
Figure 2 is the spatial coverage distribution diagram when  $S_0$  takes different values. When an area is 500,000 square kilometres and 300,000 square kilometres, all areas are covered except for a few areas in the southeast (Figure 2d,e), and the coverage rate reached 99.9% and 99.0% (Table 1, respectively). Although the coverage rate is high, due to the large value of  $S_0$ , the range of  $\Omega_i$  becomes larger, the number of sites in  $\Omega_i$  increases, and it appears to have a low correlation compared with site  $i$ , decreasing the overall representation of the whole site. When  $S_0$  is 100,000 square kilometres and 150,000 square kilometres, although the correlation between each station on  $\Omega_i$  and station  $i$  is relatively high, we can see from Figure 2a,b that  $\Omega_i$  does not cover the whole Xinjiang region, and the coverage rate is not high. In particular, when  $\Omega_i$  is 100,000 square kilometres, the coverage of the whole Xinjiang area is only 73.0%. In the belly of the Taklimakan Desert and the eastern part of Bazhou, a large area appears to be uncovered, and the results of the Xinjiang regional factors cannot reflect the real situation of the region. When  $S_0$  is 200,000 square kilometres, only parts of the area along the southeast border are not covered, and the rest of the area is covered (Figures 2c and 3), and coverage reaches 96.0%. It is above 100,000 square km and 150,000 square km. The correlation between each station in  $\Omega_i$  and station  $i$  is higher than when  $\Omega_i$  is 500,000 square km and 300,000 square km. Based on the above analysis,  $S_0$  is more representative, with 200,000 square kilometres in the Xinjiang region.



**Figure 2.** Weather station (89 stations) network coverage area schematic diagram in Xinjiang regionaa (a):  $S_0 = 10 \times 10^4 \text{ km}^2$ ; (b):  $S_0 = 15 \times 10^4 \text{ km}^2$ ; (c):  $S_0 = 20 \times 10^4 \text{ km}^2$ ; (d):  $S_0 = 30 \times 10^4 \text{ km}^2$ ; (e):  $S_0 = 50 \times 10^4 \text{ km}^2$ .

**Table 1.** Area coverage under different assignments of  $S_0$ .

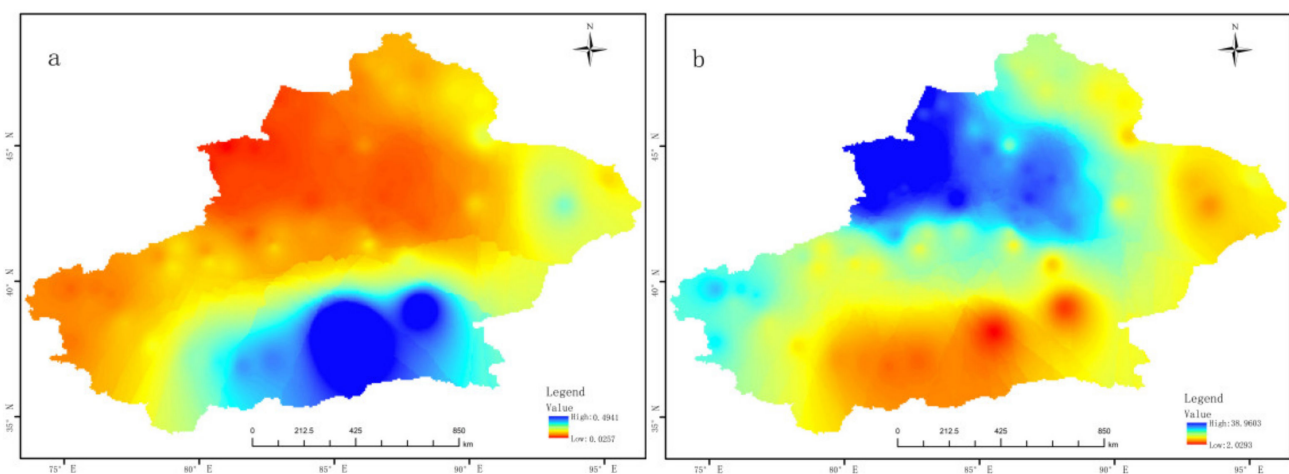
$S_0/\text{km}^2$	$10 \times 10^4$	$15 \times 10^4$	$20 \times 10^4$	$30 \times 10^4$	$50 \times 10^4$
Coverage/%	73.0	92.9	96.0	99.0	99.9



**Figure 3.**  $S_0$  value of 200,000 km<sup>2</sup> measuring station schematic diagram of parameter value estimation (elliptic line  $\Omega_i$  boundary, (a): Cele station; (b): Habahe station).

### 3.2. Station Network Density and Station Domain Area Analysis

As shown in Figure 4, the station network density ( $m_j$ ) of the 89 Xinjiang weather stations is large on the northern and southern slopes of the Tianshan Mountains and their vicinity and decreases in the north, east, and southeast directions. The minimum value is in the southern part of Bazhou; the station network density ( $m_j$ ) is opposite to the spatial distribution of the station domain area ( $d_i$ ). The maximum value of  $m_j$  occurred in Wenquan (39 stations/ $20 \times 10^4$  km<sup>2</sup>), followed by Khorgos (34 stations/ $20 \times 10^4$  km<sup>2</sup>), correspondingly  $d_i$  is 0.026 ( $20 \times 10^4$  km<sup>2</sup>/ station) and 0.029 ( $20 \times 10^4$  km<sup>2</sup>/ station), respectively; the minimum value of  $m_j$  appeared in Qiemo (2 stations/ $20 \times 10^4$  km<sup>2</sup>), followed by Ruoqiang (3 stations/ $20 \times 10^4$  km<sup>2</sup>), correspondingly  $d_i$  is 0.495 ( $20 \times 10^4$  km<sup>2</sup>/ station) and 0.326 ( $20 \times 10^4$  km<sup>2</sup>/ station), respectively. The comparison with Figure 1 shows that the more densely distributed the stations are, the greater the station network density ( $m_j$ ) and the smaller the station domain area ( $d_i$ ). It can be concluded that the two measurement parameters of station network density and station domain area can quantitatively reflect the uneven distribution of the 89-weather station network in the Xinjiang region. For the station domain area ( $d_i$ ) and the station network density ( $m_j$ ) of the 89 Xinjiang regional weather stations, please refer to the Appendix A.

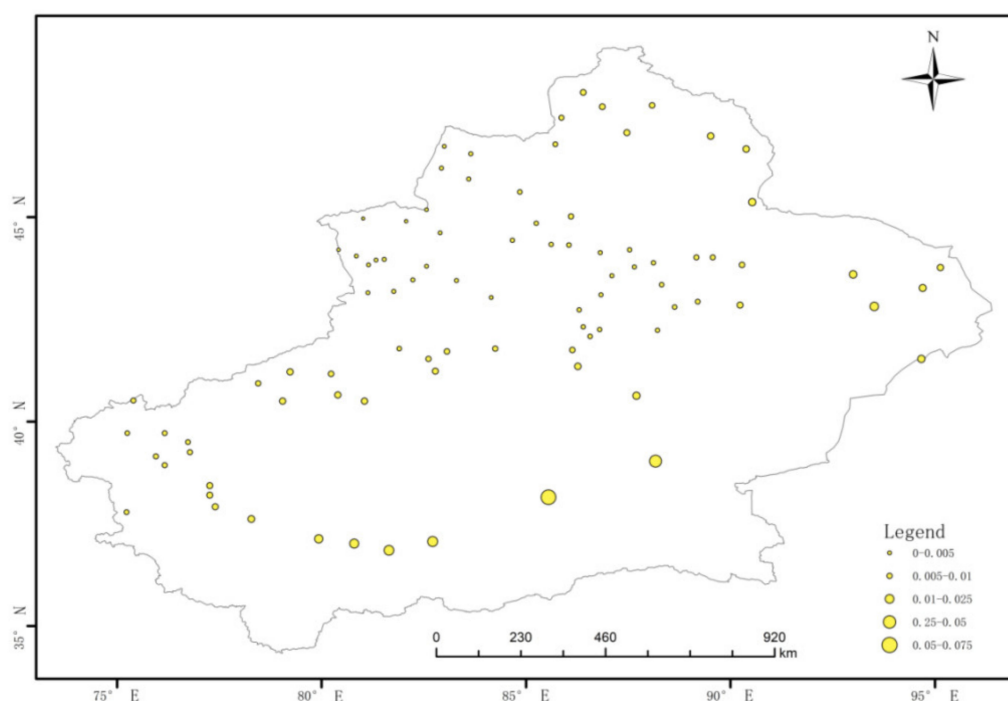


**Figure 4.** The station network of the Xinjiang regional 89 weather stations inhomogeneity measurement parameters distribution (a): Station domain area (unit:  $20 \times 10^4$  km<sup>2</sup>/station); (b): Station network density (unit: station/ $20 \times 10^4$  km<sup>2</sup>).



### 3.3. Distribution of Weighting Coefficients of 89 Meteorological Stations in the Xinjiang Region

Figure 5 shows that the weight coefficients of each station on the northern and southern slopes of Tianshan Mountain and its vicinity are all small, and the weight coefficient of Wenquan station is the lowest, at only 0.0037. The weight coefficient of meteorological stations is relatively large in northern Xinjiang, eastern Xinjiang, Hotan, and southern Bazhou; in particular, the weight coefficient of Qiemo station in southern Bazhou is the largest, at 0.07. Compared with Figure 4, it can be seen that the spatial distribution change in the weight coefficient of the 89 weather stations in the Xinjiang region is consistent with the change in the station domain area but contrary to the change in the station network density. Compared with Figure 1, it can be seen that the size of the weight coefficient is related to the density of the site distribution; the more densely distributed the sites are, the smaller the weight coefficient. See the Appendix A for the weight coefficient  $w_i$  of the 89 Xinjiang regional weather stations.



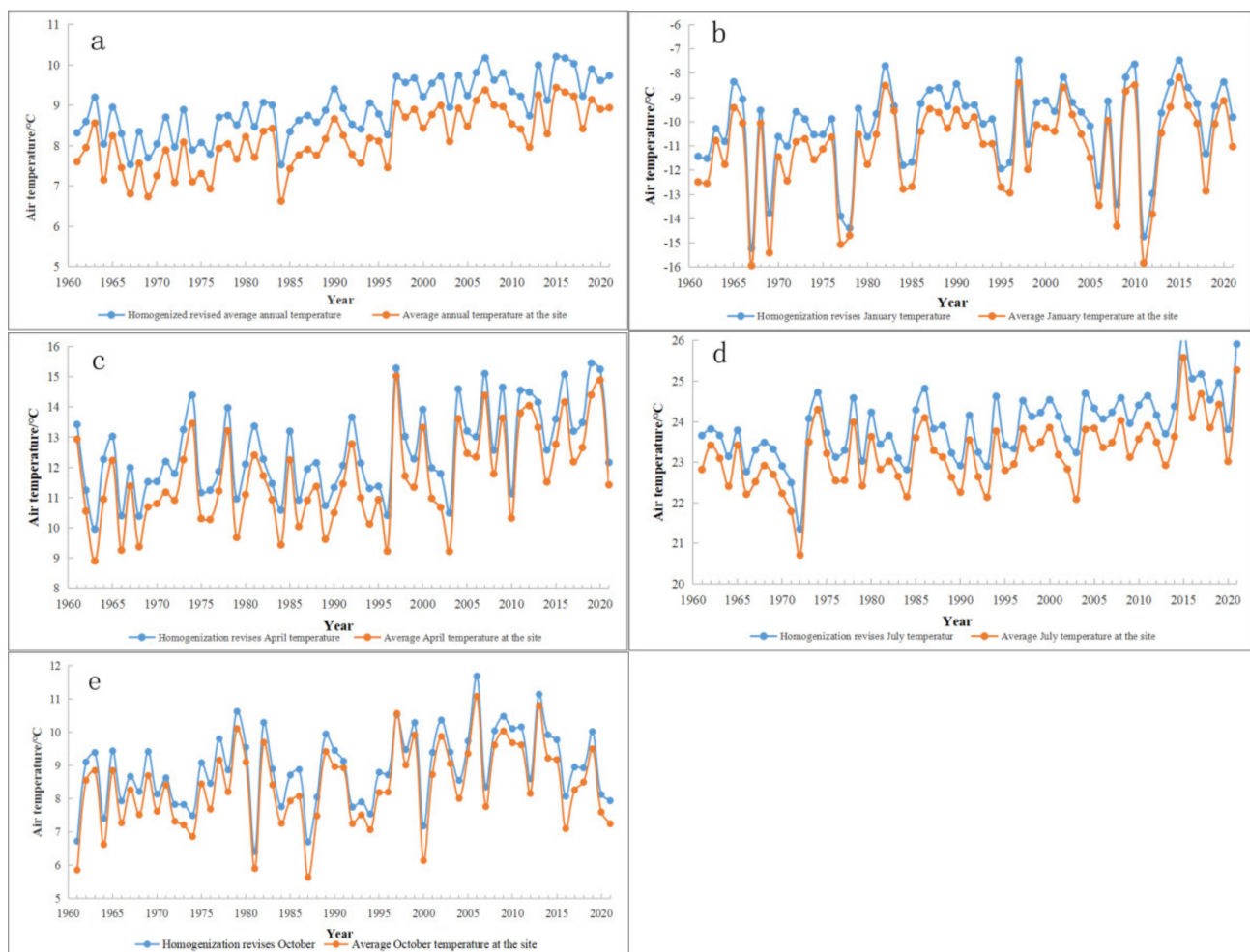
**Figure 5.** Weight coefficients distribution of the 89 stations in Xinjiang region.

### 3.4. Analysis of the Temperature Change Characteristics in Xinjiang

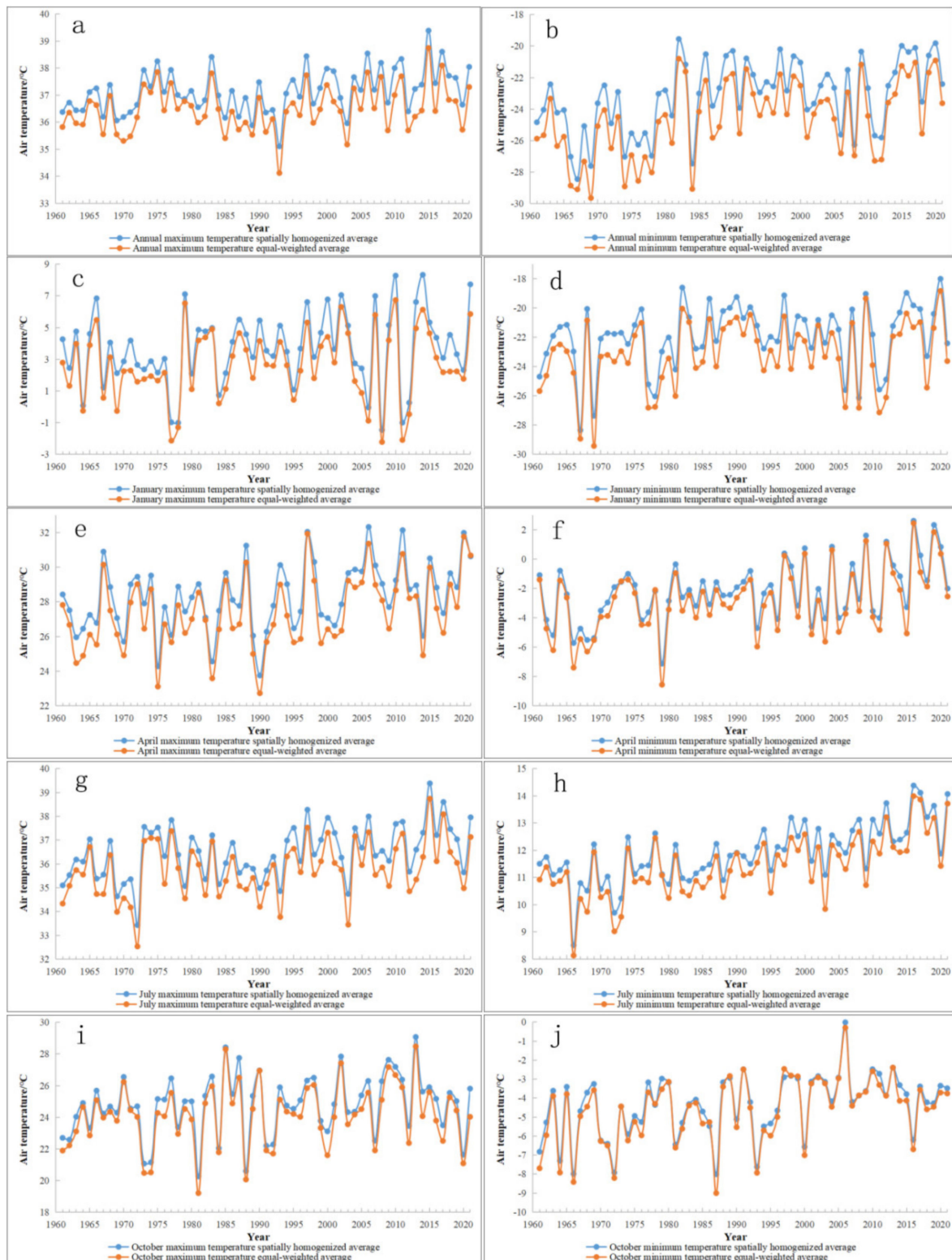
#### 3.4.1. Analysis of the Mean Temperature in Xinjiang

The average annual, January, April, July, and October temperatures of the 89 weather stations are calculated by Formula (4) (spatially homogenized revised average) and Formula (5) (equal-weight average) in the Xinjiang region from 1961 to 2021 (Figure 6). It can be seen from the curves in the figure that the spatially homogenized revised average temperature curve and equal-weight average temperature curve have roughly the same change trend, but the numerical results of the spatially homogenized revised average temperature curve are significantly higher than the equal-weight average. During the study period, the annual, January, April, July, and October mean temperature by the spatially homogenized revised average were 8.85 °C, −10.19 °C, 12.54 °C, 23.89 °C, and 8.92 °C, respectively, and the annual, January, April, July, and October mean temperature by the equal-weight average were 8.07 °C, −11.09 °C, 11.66 °C, 23.22 °C, and 8.36 °C, respectively. The annual, January, April, July, and October mean temperature, the spatially homogenized revised average were 0.78 °C, 0.90 °C, 0.88 °C, 0.67 °C and 0.56 °C higher than the equal-weight average, respectively. Again, the maximum and minimum temperatures were calculated for annual, January, April, July, and October from 1961 to 2021 at 89 weather stations in

the Xinjiang region, respectively, by Formulas (4) and (5) (Figure 7). It can be seen that the annual, January, April, July, and October maximum and minimum temperatures for the spatially homogenized revised average are higher than the equal-weighted average, a finding that is consistent with the mean temperature. During the study period, the annual, January, April, July, and October mean maximum temperature by the spatially homogenized revised average were 37.15 °C, 3.67 °C, 28.32 °C, 36.49 °C, and 24.78 °C, respectively, and the annual, January, April, July, and October mean temperature by the equal-weighted average were 36.5 °C, 2.64 °C, 27.38 °C, 35.78 °C, and 24.12 °C, respectively. The annual, January, April, July, and October mean maximum temperature by the spatially homogenized revised average were 0.65 °C (annual), 1.03 °C (January), 0.94 °C (April), 0.71 °C (July), and 0.66 °C (October) higher than the equal-weighted average, a finding that is consistent with the mean temperature; During the study period, the annual, January, April, July, and October mean minimum temperature by the spatially homogenized revised average were −23.20 °C, −21.90 °C, −2.19 °C, 11.91 °C, and −4.37 °C, respectively, and the annual, January, April, July, and October mean temperature by the equal-weighted average were −24.65 °C, −23.13 °C, −2.84 °C, 11.41 °C, and −4.64 °C, respectively. The annual, January, April, July, and October mean minimum temperature by the spatially homogenized revised average were 1.45 °C (annual), 1.23 °C (January), 0.65 °C (April), 0.50 °C (July), and 0.27 °C (October) higher than the equal-weighted average, a finding that is consistent with the mean temperature.



**Figure 6.** The annual temperatures of the spatially homogenized revised average and equal-weighted average in Xinjiang, 1961–2021(a): Annual; (b): January; (c): April; (d): July; (e): October.



**Figure 7.** The maximum and minimum temperatures of the spatial homogenization revised average and equal-weighted average in Xinjiang, 1961–2021 (a): Annual maximum temperature; (b): Annual minimum temperature; (c): January maximum temperature; (d): January minimum temperature; (e): April maximum temperature; (f): April minimum temperature; (g): July maximum temperature; (h): July minimum temperature; (i): October maximum temperature; (j): October minimum temperature.

### 3.4.2. Analysis of the Temperature Change Characteristics in the Xinjiang Region

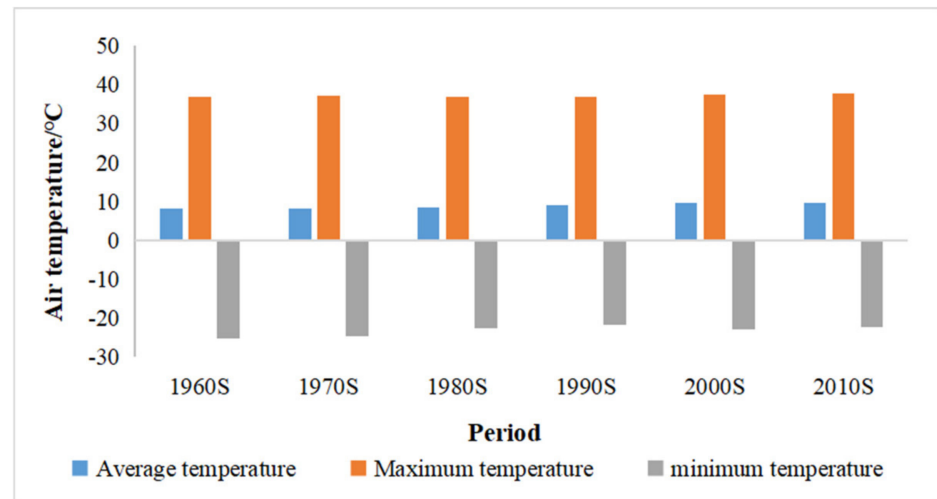
We can see from Figure 6 that the overall trend of the mean annual, January, April, July, and October temperatures are warming regardless of the spatially homogenized revised average or the equal-weighted average calculation. Although the mean temperature warming trend calculated by the two methods differed, the differences were not significant, mostly within 0.03 °C per decade. From the spatially homogenized revised average data, it can be concluded that the annual mean temperature increases by 0.30 °C per decade, the most obvious warming is in April, with an average increase of 0.41 °C per decade, and the warming is relatively slow in October, with an average increase of 0.21 °C per decade. The warming in January and July is 0.24 °C and 0.27 °C per decade, respectively. The baseline period values (the mean temperature during 1961–1990) in annual, January, April, July, and October are 8.4 °C, −10.5 °C, 11.9 °C, 23.5 °C, and 8.6 °C, respectively. The warmest years of annual mean temperature occurred in 2007, 2015, and 2016, which were 10.1 °C, and 1.7 °C higher than the baseline period values. The coldest years occurred in 1967 and 1984, which were 7.4 °C, 1.0 °C below the baseline period values. The warmest January mean temperature was −7.5 °C in 1997 and 2015; the warmest April, July and October mean temperatures were 15.5 °C, 26.2 °C and 11.7 °C in 2019, 2015, and 2006, which were 3.0 °C, 3.6 °C, 2.7 °C and 3.1 °C higher than the baseline period values, respectively; the coldest years in January, April, July and October were −15.2 °C, 10.0 °C, 21.4 °C and 6.4 °C in 1967, 1963, 1972 and 1981, which were 4.7 °C, 1.9 °C, 2.1 °C, and 2.2 °C lower than the baseline period values, respectively.

The spatially homogenized revised average and the equal-weighted average calculated annual, January, April, July, and October maximum temperature trends are consistent with an increasing trend (Figure 7), which is consistent with the mean temperature trend. The difference between the maximum temperature warming trend calculated by the two methods is not significant, with a difference of 0.04–0.07 °C per decade. From the average data of the spatial homogenization revised average, it can be concluded that the annual maximum temperature increased by 0.18 °C per decade, with the most significant warming in April, averaging an increase of 0.41 °C per decade, and relatively slow warming in January, averaging an increase of 0.26 °C per decade. The baseline period values of the maximum annual, January, April, July, and October temperatures were 36.9 °C, 3.3 °C, 27.6 °C, 36.0 °C and 24.4 °C, respectively. The maximum value of annual maximum temperature occurred in 2015, at 39.4 °C, 2.5 °C higher than the baseline period values, and the minimum value of annual maximum temperature occurred in 1993, at 35.1 °C, 1.8 °C lower than the baseline period values.

The spatially homogenized revised average and the equal-weighted average calculated annual, January, April, July, and October minimum temperature trends are consistent with an increasing trend (Figure 7), which is consistent with the annual mean and maximum temperature trends. The difference in the warming trend of the minimum temperature calculated by the two methods is not significant, with a difference of 0.02–0.06 °C per decade. From the spatially homogenized revised average data, it can be concluded that the annual minimum temperature increased by 0.60 °C per decade, with the most pronounced warming in April, averaging an increase of 0.54 °C per decade, and relatively slow warming in January, averaging an increase of 0.31 °C per decade. The baseline period values of the minimum annual, January, April, July, and October temperatures were −24.1 °C, −22.3 °C, −3.0 °C, 11.2 °C and −5.0 °C, respectively. The maximum value of annual minimum temperature occurred in 1982, at −19.5 °C, 4.6 °C higher than the baseline period values, and the minimum value of annual minimum temperature occurred in 1967, at −28.5 °C, 4.4 °C lower than the baseline period values.

As seen from the interdecadal map of Xinjiang (Figure 8), the annual mean temperature, annual maximum temperature and annual minimum temperature in Xinjiang from 1961 to 2020 show an increasing trend from one decade to another. The annual mean temperature and annual minimum temperature were lower than the baseline period values before the 1980s but higher than the baseline period values after the 1980s and increased by 1.3 °C and

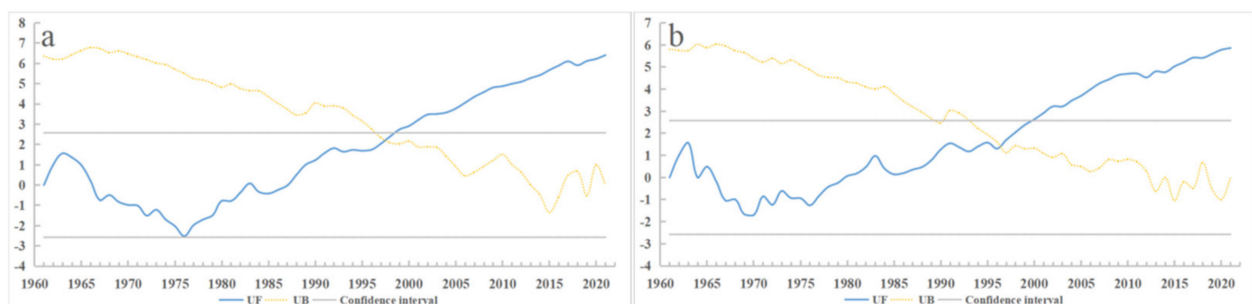
3.0 °C, respectively, in the 2010s compared with the 1960s, with increases of 15% and 11.9%, respectively. The annual maximum temperature was lower than the baseline period values in the 1990s and 1980s, while all other periods were higher than the base period mean values and increased by 1.1 °C in the 2010s compared with the 1960s, with an increase of 3.0%.



**Figure 8.** Interdecadal variation of the mean temperature in Xinjiang during 1961–2020.

### 3.4.3. Analysis of Mutation Temperature in the Xinjiang Region

The M-K mutation test was used to analyse the mutation of the spatially homogenized revised and equally weighted average revised mean temperatures in the Xinjiang region, and the results showed that during the study period, the mutation point of the annual mean temperature in the Xinjiang region calculated by the spatially homogenized revision occurred during 1997–1998 (Figure 9a), while the mutation point by the equally weighted average occurred during 1996–1997 (Figure 9b), and the spatially homogenized revision lagged behind the equally weighted average mutation by one year.



**Figure 9.** The mutation temperature change curve in Xinjiang, 1961–2021 ((a) the spatially homogenized revised average; (b) the equal-weighted average).

## 4. Conclusions and Discussion

This study obtained results for the mean temperature of Xinjiang that are reasonable according to the spatially homogenized revised average, and this method is suitable for the calculation of the spatially mean temperature of the Xinjiang region. The conclusions are as follows:

$S_0$  assigns  $S_0 = 10 \times 10^4 \text{ km}^2$ ,  $S_0 = 15 \times 10^4 \text{ km}^2$ ,  $S_0 = 20 \times 10^4 \text{ km}^2$ ,  $S_0 = 30 \times 10^4 \text{ km}^2$  and  $S_0 = 50 \times 10^4 \text{ km}^2$ . Through comparative analysis, a  $S_0$  value of 200,000  $\text{km}^2$  is suitable for determining the weight coefficient of the 89 weather station network in the Xinjiang region.  $S_0$  is  $50 \times 10^4 \text{ km}^2$  for a homogenized and revised network of national climatological

data stations [20], the value of  $S_0$  for Xinjiang is smaller than the national average, which is mainly due to the inconsistency of the spatial scale and the number of meteorological stations between the two studies, and verifies that the previously mentioned  $S_0$  assigns  $50 \times 10^4 \text{ km}^2$  is too large in Xinjiang and is not suitable for Xinjiang. Although the  $S_0$  value of  $200,000 \text{ km}^2$  is more suitable for Xinjiang than the other four groups of data, it does not necessarily meet the requirement that all the stations in  $\Omega_i$  have a high correlation with station  $i$ . In addition, the local microclimate also leads to poor correlation between some stations in  $\Omega$ , and all these factors will lead to errors between the calculated results of the average value of regional temperature and the objective facts. When the  $S_0$  value is  $200,000 \text{ km}^2$ , some regions along the southeastern boundary are not covered, and the calculation results of the average value of regional temperature will also produce errors. In the future, we can try to include the stations in neighboring provinces to compensate for the lack of coverage in the southeastern boundary region of Xinjiang and reduce the error of the calculation results of the average value of regional temperature in Xinjiang.

The denser the spatial distribution of the station network is, the larger the density of the station network, the smaller the area of the station domain, and the smaller the weight coefficient of the station. Xinjiang regional meteorological stations are densely distributed in Zone I, the values of station network density are large, the values of station domain area are small, and the calculated station weight coefficients are small, while the results in the sparsely distributed meteorological stations of the region IV are the opposite. From a qualitative perspective, we can see that the distribution of stations around the Wenquan meteorological station is the densest, and from a quantitative perspective, the value of the station network density of the Wenquan meteorological station is the largest among the 89 meteorological stations in Xinjiang, with a value of 39 (stations/ $20 \times 10^4 \text{ km}^2$ ) and a minimum station domain area value of 0.026 ( $20 \times 10^4 \text{ km}^2$ /station); similarly, from a qualitative perspective, we can see that the distribution of stations around the Qiemo meteorological station is the sparsest, and from a quantitative perspective, the value of the station network density of the Qiemo meteorological station is the smallest among the 89 meteorological stations in Xinjiang, with a value of 2 (stations/ $20 \times 10^4 \text{ km}^2$ ) and a maximum station domain area value of 0.495 ( $20 \times 10^4 \text{ km}^2$ /station). Therefore, the distribution of station domain area and station network density can quantitatively reflect the uneven distribution of the Xinjiang 89 weather station network.

The spatially homogenized revised mean temperature is higher than the equal-weighted mean temperature in the Xinjiang region. However, the homogenization of 160 stations was revised in China as follows: the spatially homogenized revised average result is significantly lower than the equal-weighted average [4], contrary to the conclusion of this study. This is because the stations are densely distributed in southeast China, so in this region, the weight of stations in the national average is reduced in the homogenization revision, and the mean temperature is higher than other stations in China, hence, the homogenization revision result of 160 stations is significantly lower than the equal-weight average in China. For the Xinjiang region, the spatial distribution of the meteorological stations in Xinjiang is extremely uneven, with a relatively dense distribution in Zone I and a sparse distribution in Zone IV. The temperature at all time scales in Zone I with a dense station distribution is lower than that in Zone IV with sparse stations, and the results calculated by the equal-weighted average will be biased towards the dense station area and lower than the true temperature. Therefore, the equal-weighted average calculation result will underestimate the regional mean temperature in Xinjiang. With the spatially homogenized revision of the Xinjiang regional meteorological stations, the sparsely stationed Zone IV stations obtained relatively large weighting coefficients, the densely stationed Zone I stations obtained relatively small weighting coefficients, and the spatially homogenized revised average Xinjiang regional mean temperature was higher than the equal-weighted mean temperature and closer to the real temperature. Therefore, the homogenized adjustment of the meteorological stations in Xinjiang is necessary, and the obtained results are reasonable.

The annual, January, April, July, and October average, maximum, and minimum temperatures calculated by the spatially homogenized revised average and the equal-weighted average have the same trend of increasing, and the mean temperature warming trend calculated by the two methods are different, but the differences are not significant. The two methods yielded approximately the same year of mutation in the temperature sequence. The two methods can respond well to the trend of temperature change in Xinjiang. The annual, January, April, July, and October minimum temperature warming trends by the spatial homogenization revised average are greater than the maximum temperature warming trend and the mean temperature warming trend, and the annual minimum temperature warming trend is 3.3 times the annual maximum warming trend and two times the annual mean temperature. The temperature trend in Xinjiang, obtained by the spatially homogenized revised average, remains one of the most sensitive regions for global climate change.

Xinjiang regional weather station network homogenization revisions can be applied to Xinjiang regional mean temperature, although the results obtained are more objective and reasonable compared with the equal-weighted average. At present, only the factor of station representative area is considered. For Xinjiang, with its rugged terrain and staggering altitude, different altitudes also greatly impact regional meteorological elements. In response to this situation, future work will attempt to take altitude, topography, and other imaging factors into account and further revise the unevenness of the Xinjiang regional weather station network to improve its monitoring capability.

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

## Appendix A

Order Number	Weather Site	Station Domain Area $d_i/(20 \times 10^4 \text{km}^2/\text{station})$	Station Network Density $m_j/(\text{station}/20 \times 10^4 \text{km}^2)$	Weight Coefficient $w_i$
1	Haba River	0.07977	12.54	0.01137
2	Jeminay	0.06241	16.02	0.008892
3	Bulzin	0.08398	11.91	0.01197
4	Fuhai	0.08592	11.64	0.01224
5	Altay	0.07347	13.61	0.01047
6	Fuyun	0.1012	9.880	0.01442
7	Tacheng	0.03665	27.29	0.005221

Order Number	Weather Site	Station Domain Area $d_i/(20 \times 10^4 \text{ km}^2/\text{station})$	Station Network Density $m_j/(\text{station}/20 \times 10^4 \text{ km}^2)$	Weight Coefficient $w_i$
8	Yumin	0.04270	23.42	0.006084
9	Emin	0.04384	22.81	0.006247
10	Hobukesar	0.05825	17.17	0.008299
11	Qinghe	0.1056	9.468	0.01505
12	Alataw Pass	0.03403	29.38	0.004849
13	Bole	0.03018	33.14	0.004290
14	Toli	0.04038	24.77	0.005753
15	Karamay	0.05290	18.90	0.007537
16	Baytik Mountain	0.1228	8.142	0.01750
17	Khorgos	0.02935	34.07	0.004182
18	Huocheng	0.03618	27.64	0.005155
19	Wenquan	0.02563	39.02	0.003651
20	Jinghe	0.03520	28.41	0.005015
21	Wusu	0.04469	22.38	0.006367
22	Battery	0.04484	22.30	0.006388
23	Moso bay	0.06601	15.15	0.009406
24	Shihezi	0.04987	20.05	0.007106
25	Shawan	0.04750	21.05	0.006767
26	Caijiahu	0.04534	22.06	0.006460
27	Hutubi	0.04337	23.06	0.006179
28	Jimsar	0.06077	16.45	0.008659
29	Qitai	0.06375	15.69	0.009082
30	Qapqal	0.03916	25.54	0.005579
31	Yining	0.03792	26.37	0.005403
32	Nilka	0.03832	26.10	0.005460
33	Yining County	0.04007	24.96	0.005709
34	Gongliu	0.04107	24.35	0.005852
35	Xinyuan	0.04025	24.85	0.005735
36	Zhaosu	0.03794	26.36	0.005406
37	Takes	0.04103	24.38	0.005845
38	Urumqi	0.04337	23.06	0.006179
39	Small canal	0.04337	23.06	0.006179
40	Balguntay	0.04534	22.06	0.006460
41	Daxigou	0.04156	24.06	0.005921
42	Tianchi	0.04750	21.05	0.006767
43	Dabancheng	0.04987	20.05	0.007106
44	Mori	0.07215	13.86	0.01028
45	ümüx	0.04750	21.05	0.006767
46	Bayanbulak	0.03836	26.07	0.005466
47	Hejing	0.04750	21.05	0.006767
48	Yanqi	0.04987	20.05	0.007106
49	Hoxud	0.04750	21.05	0.006767
50	Toksun	0.05250	19.05	0.007480
51	Turpan	0.05541	18.05	0.007895
52	Shanshan	0.09067	11.03	0.01292
53	Wushi	0.09514	10.51	0.01356
54	Aksu	0.07182	13.92	0.01023
55	Baicheng	0.05007	19.97	0.007134
56	Xinhe	0.06988	14.31	0.009957
57	Sanga	0.09044	11.06	0.01289
58	Luntai	0.07124	14.04	0.01015
59	Kuqa	0.07652	13.07	0.01090
60	Yuli	0.09974	10.03	0.01421



Order Number	Weather Site	Station Domain Area $d_i/(20 \times 10^4 \text{km}^2/\text{station})$	Station Network Density $m_j/(\text{station}/20 \times 10^4 \text{km}^2)$	Weight Coefficient $w_i$
61	Korla	0.07672	13.03	0.01093
62	torugart	0.06122	16.33	0.008723
63	Atux	0.05662	17.66	0.008067
64	Wuqia	0.05191	19.26	0.007396
65	Jiashi	0.05753	17.38	0.008196
66	Aktao	0.06560	15.24	0.009347
67	Aheqi	0.07020	14.25	0.01000
68	Yopurga	0.06084	16.44	0.008668
69	Keping	0.09802	10.20	0.01397
70	Awat	0.09841	10.16	0.01402
71	Alar	0.09539	10.48	0.01359
72	Tikanlik	0.1247	8.021	0.01776
73	Ruoqiang	0.3264	3.064	0.04650
74	Yingjisha	0.06563	15.24	0.009351
75	Tashkurgan	0.05708	17.52	0.008133
76	Shache	0.08703	11.49	0.01240
77	Yecheng	0.08581	11.65	0.01223
78	Zepu	0.08619	11.60	0.01228
79	Pishan	0.1101	9.085	0.01568
80	Cele	0.1857	5.386	0.02645
81	Hotan	0.1622	6.165	0.02311
82	Minfeng	0.2274	4.397	0.03240
83	Qiemo	0.4945	2.022	0.07045
84	Yutian	0.2197	4.552	0.03130
85	Barkol	0.1340	7.461	0.01910
86	Nom	0.09446	10.59	0.01346
87	Yiwu	0.1162	8.605	0.01656
88	Hami	0.1657	6.035	0.02361
89	Red willow river	0.1237	8.081	0.01763

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