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Variations in Maximum and Minimum Temperature in Mount Qomolangma during 1971–2020

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Abstract: Based on the daily maximum and minimum temperature observational data during 1971–2020, the variabilities of the maximum and minimum temperature of Mount Qomolangma are analyzed. The daily maximum temperature is 25.8 °C and the daily minimum temperature is −31.4 °C during the study period in Mount Qomolangma. Overall, there has been an upward trend with decadal laps for both maximum and minimum temperature. On monthly, seasonal, and annual scales, neither maximum temperature nor minimum temperature time series exhibit an increasing trend from 1971 to 2020. The increasing trends in monthly minimum temperature are even more pronounced than those in maximum temperature. Abrupt changes are noted in both monthly, seasonal, and annual maximum and minimum temperature time series. Specifically, an abrupt change in annual maximum temperature occurred in the 1980s, while an abrupt change in annual minimum temperature occurred in the 1990s. Differences between the north and south slope of Mount Qomolangma are evident, with temperature fluctuations of the north slope being more extreme than those of south slope. The seasonal and annual maximum temperature of the north slope is higher than that of the south slope, except for winter, and the seasonal and annual minimum temperatures of the north slope are all lower than those of the south slope. The tendences of maximum and minimum temperatures in the north slope are more dominant than those in the south slope. The findings are beneficial for understanding the characteristics of local climate change on the Tibetan plateau and to underscore the significant role of Mount Qomolangma in the context of global warming.

Keywords: climate change; mount Qomolangma; maximum temperature; minimum temperature; trend test

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1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) reported that the global mean surface temperature increased by 0.85 °C between 1880 and 2012 [1]. Based on the IPCC Sixth Assessment Report (AR6), the global mean surface temperature increased by 1 °C between 1850 and 1900 at present [2]. The year 2021 was the sixth global warmest year since 1880 [3]. The China Meteorology Administration (CMA) issued that the annual average temperature was 1.0 °C above the climatology of 1981–2010 in 2021 around China, and its warming broke the historical record since 1951 [4]. In 2022, the annual mean temperature was 10.51 °C over China, which was 0.62 °C above the climatology of 1991–2020 and was the second highest annual mean temperature in history. Despite the low temperatures in winter, the temperatures in spring, summer, and autumn broke the historical record in China [5]. Thus, global warming is a certain fact for concern, which reveals a potential hazard for human socio-economic systems and lifestyle [6].

Global warming and its impacts have become a significant subject within the field of climate change. The variation in extreme temperature, including maximum and minimum temperature, constitutes one of the important contents for climate study. Karl et al. [7] found the dependency of global warming on the difference between maximum and minimum temperature. Easterling et al. [8] and Vose et al. [9] revealed the space distribution of maximum and minimum temperature trends for the globe. Navarro-Serrano et al. [10] assessed the maximum and minimum temperature lapse rates in the Andean region of Ecuador and Peru for the first time. Bubathi et al. [11] found the worsening situation of accelerated climate change on the maximum temperature differences in western Sydney compared with coastal Sydney. Curado et al. [12] studied the annual behavior of the maximum, mean, and minimum temperatures for all regions of Brazil. Yaya et al. [13] found that the understanding of trend changes for the annual mean, maximum, and minimum temperature was very important for predicting and mitigating the impacts of climate change in Africa. In China, studies on the maximum and minimum temperature are also highlight issues and attract widespread attention. For example, Zhai and Ren [14] revealed the spatiotemporal changes of China's maximum and minimum temperatures. Ma [15] analyzed the asymmetric characteristics of maximum and minimum temperatures in northwest China. Du [16] analyzed the asymmetric change in maximum and minimum temperatures in the Tibetan Plateau (TP). Wang et al. [17] studied the variation and its impact of maximum and minimum temperatures in northern China. Zhou et al. [18] studied the changes of minimum temperature in different climatic zones of east China in winter. Dong and Huang [19] studied the relations between elevation and variation in maximum and minimum temperatures in China.

The TP, known as the third pole, is one of the most sensitive regions to global climate change [20,21]. The increasing of temperature over TP is the most obvious of global warming, and the study on the temperature change in TP has become one of the more attentive hotspots under the background of global warming [22,23]. Mount Qomolangma (MQ), as the most important part of TP and the highest peak on Earth, exhibits unique climatic variations distinct from other regions worldwide. For example, the increasing temperature rate in MQ is higher than that of the global mean temperature change, and the time of onset of warming in MQ is earlier than that of the other places around the word [24]. The response to temperature change in MQ from global warming has become a significant scientific interest [24,25]. Yang et al. [24] analyzed the spatial and temporal patterns of the mean, maximum, and minimum temperatures in MQ region from 1971 to 2004. According to the extreme temperature indices recommended by the World Meteorological Organization, Du et al. [26] and Wang [27] studied the spatiotemporal changes of extreme temperature events in MQ during 1971–2012 and 1971–2020, respectively.

However, there is little research on the variation in maximum and minimum temperature of MQ up to now. The results of the existing literatures included some studies focused on the mean, maximum, and minimum temperature [24], while others used the extreme temperature indices method to study the extreme temperature events [26,27]. In this study, according to the new daily maximum and minimum temperature observational data during 1971–2020 in MQ, using the Mann–Kendall (MK) test, linear trend test and the departure accumulation method, the variabilities of maximum and minimum temperature are analyzed, including the general characteristics, trend test, and abrupt diagnosis for the first time, which is beneficial for the comprehending of the temperature change features in MQ under the background of global warming.

2. Data and Methodology

In this study, the two national meteorological stations, Nielamu station (hereinafter referred to as Nielamu) and Dingri station (hereinafter referred to as Dingri), are the nearest meteorological stations with long-term observations and available data around MQ. So, the observed daily maximum and minimum temperature data from the two stations from 1971 to 2020 are selected to study the variations in the maximum and minimum temperature in MQ. Nielamu, located at 28°11′ N and 85°58′ E, being in south slope of MQ, is at an elevation of 3810.0 m. It lies in the main water vapor transport path of the southwest monsoon. Dingri, located at 28°38′ N and 87°05′ E, being in north slope of MQ, is at an elevation of 4301.7 m. It sits between the Himalayas and the Gangdis Mountains [27–30]. Figure 1 shows the location of Nielamu, Dingri, and MQ.

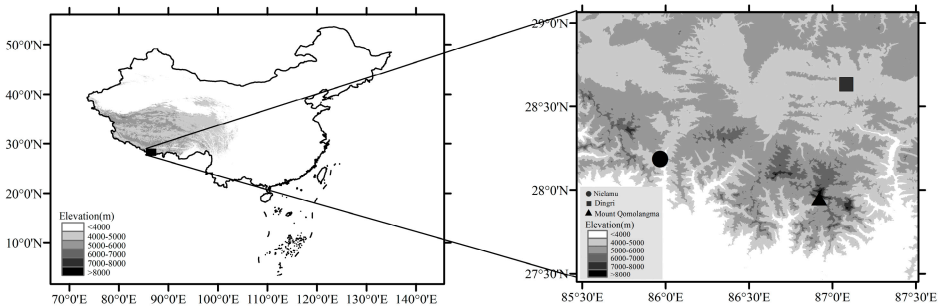

Figure 1. Location of Nielamu station, Dingri station, and Mount Qomolangma.

The observed daily maximum and minimum temperature of Nielamu and Dingri is obtained by CMA, which has been checked by the primary quality control. In this research, the daily maximum and minimum temperature (hereinafter referred to as T_{max} and T_{min} for short) in the course of a continuous time interval of 24 h, are the highest and lowest temperatures of a day. That is to say, monthly, seasonal, and annual T_{max} or T_{min} indicate the monthly, seasonal, and annual daily highest or lowest temperature in the period from 1971 to 2020.

This research uses the meteorological season and year, namely, spring (March to May), summer (June to August), autumn (September to November), and winter (December through February of the following year).

The MK test is adopted to detect the time series trend, and a positive or negative value of the trend estimator (Z) indicates an increasing or decreasing trend for the test time series [31–37]. When the absolute value of Z is greater than 1.96 or 2.576, the test time series can be regarded as a statistically significant trend at 95% or 99% confidence level [33,38,39]. The Sen's slope (β) is used to denote the rate of trend change [31,40]. The time series abrupt change is identified by using departure accumulation [27] and the MK–Sneyers test [41].

3. Results

3.1. General Characteristics

During 1971–2020, at Nielamu, the T_{max} of 22.4 °C was recorded on 31 July 1983, while the T_{min} of −21.7 °C occurred on 29 January 2019. At Dingri, the T_{max} of 25.8 °C occurred on 25 July 2009, and the T_{min} of −31.4 °C occurred on 21 December 2018.

Table 1 shows that the monthly occurrences of T_{max} and T_{min} were in July and January at Nielamu, while occurring in July and December at Dingri. Notably, the range (the difference between T_{max} and T_{min}) of Dingri was greater than that of Nielamu every month. The biggest or smallest range was 38.2 °C or 18.5 °C in January or July at Nielamu, which was 46.0 °C or 24.0 °C in December or August at Dingri. This indicates that the monthly temperature fluctuations in Dingri were more prominent than those in Nielamu.

According to Table 1, the seasonal and annual T_{max} of Dingri were higher than those of Nielamu except for in winter, while the seasonal and annual T_{min} of Dingri were obviously lower than those of Nielamu. The seasonal and annual temperature fluctuations in Dingri were also more prominent than those of Nielamu based on the range values, and the biggest seasonal fluctuating amplitude took place during winter. At Dingri, the monthly T_{max} appeared in summer, principally in June and July. At Nielamu, the monthly T_{max} mainly occurred in summer, but it occurred once in April in 1985 and November in 2011, respectively, as well as five times in September and seven times in May. At Dingri, the monthly T_{min} appeared in winter, principally in January. At Nielamu, the monthly T_{min} also mainly occurred in winter, while it occurred twice in spring, namely during May in 1971 and 1990.

Table 1. Statistics of monthly, seasonal and annual temperature (°C).

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Spring	Summer	Autumn	Winter	Annual
T_{max}	Nielamu	16.5	17.7	17.6	19.2	20.6	21.6	22.4	21.7	19.2	18.4	18.6	18.1	20.6	22.4	19.2	18.1	22.4
	Dingri	14.7	15.3	18.7	20.8	23.8	25.1	25.8	23.4	22.9	20.2	17.3	14.6	23.8	25.8	22.9	15.3	25.8
T_{min}	Nielamu	−21.7	−17.8	−16.8	−12.0	−5.5	−1.3	3.9	2.8	−2.3	−8.9	−14.8	−19.0	−16.8	−1.3	−2.3	−21.7	−21.7
	Dingri	−27.7	−25.3	−19.0	−14.3	−8.4	−4.0	0.7	−0.6	−4.4	−12.3	−19.0	−31.4	−19.0	−4.0	−19.0	−31.4	−31.4
Range	Nielamu	38.2	35.5	34.4	31.2	26.1	22.9	18.5	18.9	21.5	27.3	33.4	37.1	37.4	23.7	21.5	39.8	44.1
	Dingri	42.4	40.6	37.7	35.1	32.2	29.1	25.1	24.0	27.3	32.5	36.3	46.0	42.8	29.8	41.9	46.7	57.2

Tables 2 and 3 show the decadal variation for the monthly, seasonal, and annual temperature. On the whole, there was an upward trend in monthly T_{max} and T_{min} into the 21st century, but there are exceptions to this. For instance, the monthly T_{max} occurred in June, July, August, and October in the 1980s at Nielamu, and the monthly T_{min} occurred in December in the 2010s at Dingri.

Table 2. Decadal variation for monthly, seasonal, and annual T_{max} (°C).

	1971–1980		1981–1990		1991–2000		2001–2010		2011–2020	
	Nielamu	**Dingri**	**Nielamu**	**Dingri**	**Nielamu**	**Dingri**	**Nielamu**	**Dingri**	**Nielamu**	**Dingri**
January	11.7	11.3	16.3	13.5	12.2	14.0	15.7	14.7	16.5	14.7
February	11.3	13.9	16.4	14.6	17.7	15.0	15.7	14.0	14.4	15.3
March	13.4	14.7	15.2	16.7	14.3	17.4	17.6	18.7	15.9	16.9
April	16.4	18.7	17.8	17.9	18.0	20.8	17.1	18.6	19.2	18.5
May	18.8	22.0	19.9	22.1	20.6	23.5	19.4	23.8	20.0	23.0
June	19.9	24.0	21.6	24.6	17.5	24.9	20.3	25.1	20.8	24.8
July	19.9	24.5	22.4	24.8	22.1	24.1	19.2	25.8	18.3	25.2
August	18.1	21.5	21.7	23.4	19.2	22.5	20.3	22.7	20.4	23.3
September	15.9	20.6	18.9	21.6	18.1	20.5	19.2	22.8	17.8	22.9
October	16.2	19.1	18.4	18.4	15.8	18.0	15.9	19.3	18.1	20.2
November	15.3	15.8	15.0	17.2	14.4	14.3	16.1	15.2	18.6	17.3
December	16.5	12.4	15.1	11.9	13.7	13.4	15.9	13.0	18.1	14.6
Spring	18.8	22.0	19.9	22.1	20.6	23.5	19.4	23.8	20.0	23.0
Summer	19.9	24.5	22.4	24.8	22.1	24.9	20.3	25.8	20.8	25.2
Autumn	16.2	20.6	18.9	21.6	18.1	20.5	19.2	22.8	18.6	22.9
Winter	16.5	13.9	16.4	14.6	17.7	15.0	15.9	14.7	18.1	15.3
Annual	19.9	24.5	22.4	24.8	22.1	24.9	20.3	25.8	20.8	25.2

Table 3. Decadal variation for monthly, seasonal, and annual T_{min} (°C).

	1971–1980		1981–1990		1991–2000		2001–2010		2011–2020	
	Nielamu	**Dingri**	**Nielamu**	**Dingri**	**Nielamu**	**Dingri**	**Nielamu**	**Dingri**	**Nielamu**	**Dingri**
January	−20.6	−24.4	−19.1	−27.7	−19.1	−24.1	−17.1	−24.5	−21.7	−23.1
February	−17.3	−24.8	−17.0	−25.3	−17.8	−23.5	−17.1	−20.8	−14.4	−22.9
March	−16.8	−18.8	−14.3	−18.2	−11.9	−19.0	−10.9	−16.7	−13.4	−18.5
April	−9.7	−14.3	−9.5	−13.3	−12.0	−14.0	−9.2	−12.2	−7.8	−11.6
May	−4.7	−8.4	−5.3	−8.3	−5.3	−8.0	−4.0	−8.0	−5.5	−8.2
June	−0.8	−3.0	−0.5	−2.8	−1.3	−4.0	0.5	−0.4	1.5	−0.4
July	4.5	0.7	4.4	1.4	3.9	2.8	5.3	3.2	5.1	3.4
August	2.8	−0.6	3.0	0.4	4.3	0.2	5.2	0.3	4.4	3.0
September	−2.3	−4.4	−2.2	−4.1	−0.4	−2.5	0.5	−2.9	0.1	−2.7
October	−8.9	−11.9	−8.3	−11.9	−8.6	−12.3	−6.8	−11.6	−8.3	−11.5
November	−14.8	−17.4	−11.6	−19.0	−10.5	−17.1	−9.3	−16.4	−9.5	−15.7
December	−19.0	−22.5	−18.2	−27.5	−14.1	−26.5	−11.6	−20.5	−13.7	−31.4
Spring	−16.8	−18.8	−14.3	−18.2	−12.0	−19.0	−10.9	−16.7	−13.4	−18.5
Summer	−0.8	−3.0	−0.5	−2.8	−1.3	−4.0	0.5	−0.4	1.5	−0.4
Autumn	−2.3	−17.4	−2.2	−19.0	−0.4	−17.1	0.5	−16.4	0.1	−15.7
Winter	−20.6	−24.8	−19.1	−27.7	−19.1	−26.5	−17.1	−24.5	−21.7	−31.4
Annual	−20.6	−24.8	−19.1	−27.7	−19.1	−26.5	−17.1	−24.5	−21.7	−31.4

According to Tables 2 and 3, there was increase for the seasonal T_{max} into 21st century in all locations, but the summer T_{max} showed a fluctuant decrease at Nielamu from the 1980s to 2010s. On the other hand, the changes in seasonal T_{min} are more complex. They exhibit an increasing trend with the decadal lapse at Nielamu in spring and autumn. However, the winter T_{min} occurred during 2011–2020 at both Nielamu and Dingri, with the rest showing an increase with the decadal lapse.

3.2. Trends Analysis

The trend results of the MK test for the monthly, seasonal, and annual temperatures are shown in Table 4. Neither T_{max} nor T_{min} has a positive trend. Although some series show nonsignificant increases, the positive Sen's slope also exhibits an increasing change. It is consistent with that of extreme temperature events in MQ [26,27]. The increasing trends for monthly T_{min} are even more marked than those of T_{max} overall. Yang et al. [29] also indicated the increasing rates of temperature were larger in winter and spring than those in other seasons.

At Nielamu, the monthly T_{max} in March and December has a statistically significant increasing trend at a confidence level of 95%, and the monthly T_{max} in August and September have a statistically significant increasing trend at a 99% confidence level. The monthly

T_{min} in February, June, and September have a statistically significant increasing trend at a 95% confidence level, and the monthly T_{min} in April, July, August, and November have a statistically significant increasing trend at a 99% confidence level. The top three of the Sen's slopes for T_{max} are in March (0.057 °C per year), February (0.056 °C per year), and December (0.056 °C per year), and the top three of the Sen's slopes for T_{min} are in November (0.058 °C per year), April (0.056 °C per year), and February (0.047 °C per year).

Table 4. MK trend test results for monthly, seasonal, and annual temperature.

	T_{max}				T_{min}			
	Z		**β (°C/Year)**		**Z**		**β (°C/Year)**	
	Nielamu	**Dingri**	**Nielamu**	**Dingri**	**Nielamu**	**Dingri**	**Nielamu**	**Dingri**
January	1.63	1.91	0.050	0.044	0.45	1.72	0.009	0.024
February	1.92	1.03	0.056	0.020	2.01 *	2.63 **	0.047	0.055
March	2.51 *	2.09 *	0.057	0.042	1.47	3.40 **	0.033	0.056
April	0.12	0.81	0.000	0.012	2.58 **	3.06 **	0.056	0.045
May	0.68	0.67	0.016	0.014	0.05	0.65	0.000	0.011
June	0.45	1.73	0.005	0.016	2.20 *	2.79 **	0.031	0.040
July	0.46	2.38 *	0.005	0.030	4.74 **	4.02 **	0.038	0.044
August	2.70 **	2.64 **	0.029	0.029	3.43 **	2.63 **	0.041	0.045
September	3.10 **	3.12 **	0.030	0.038	2.51 *	2.00 *	0.043	0.025
October	0.23	3.15 **	0.003	0.039	1.56	1.06	0.021	0.013
November	1.55	1.61	0.033	0.034	3.01 **	3.11 **	0.058	0.047
December	2.33 *	2.90 **	0.056	0.063	1.09	2.10 *	0.021	0.035
Spring	1.77	0.67	0.032	0.014	1.7	3.40 **	0.034	0.056
Summer	1.17	2.36 *	0.017	0.023	2.24 *	3.18 **	0.032	0.039
Autumn	2.50 *	3.12 **	0.023	0.038	2.51 *	3.11 **	0.043	0.047
Winter	2.30 *	3.06 **	0.063	0.067	1.79	1.75	0.048	0.024
Annual	1.44	2.36 *	0.022	0.025	2.54 *	1.75	0.065	0.024

Notes: * 95% confidence level, ** 99% confidence level.

At Dingri, the monthly T_{max} in March and July have a statistically significant increasing trend at a 95% confidence level, and the monthly T_{max} in August, September, October, and December have a statistically significant increasing trend at a 99% confidence level. The monthly T_{min} in September and December have a statistically significant increasing trend at a 95% confidence level, and the monthly T_{min} in February, March, Aprile, June, July, August, and November have a statistically significant increasing trend at a confidence level of 99%. The top three of the Sen's slopes for T_{max} are in December (0.063 °C per year), January (0.044 °C per year), and March (0.042 °C per year), and the top three of the Sen's slopes for T_{min} are in March (0.056 °C per year), February (0.055 °C per year), and November (0.047 °C per year).

On the seasonal scale, T_{max} and T_{min} are increasing during the period of 1971–2020, but different patterns of change are found at Nielamu and Dingri (Table 4). At Nielamu, the T_{max} in autumn and winter show a statistically significant increasing trend at a 95% confidence level, and the trends increase at the rates of 0.063 and 0.023 °C per year, respectively. There is a slight increase with the rates of 0.032 and 0.017 °C per year in spring and summer (not statistically significant at the level of 95%). T_{min} has a statistically significant increasing trend at a 95% confidence level in summer and autumn with the rates of 0.032 and 0.043 °C per year, while an insignificant increasing trend is detected in spring and winter by 0.034 and 0.048 °C per year, respectively. On the other side, the seasonal T_{max} series at Dingri exhibit a statistically significant increasing trend at a 95% confidence level, except for spring, showing a slight and insignificant increasing trend, and increasing trends with a significance at a 99% confidence level are detected in autumn and winter. At Dingri, the seasonal T_{max} have increased by 0.014, 0.023, 0.038, and 0.067 °C per year, for spring, summer, autumn and winter, respectively. The seasonal T_{min} series at Dingri have experienced a statistically significant increasing trend at the level of 99% in spring, summer, and autumn by 0.056, 0.039, and 0.047 °C per year. There is only a winter T_{min} at Dingri showing a slight and insignificant increasing trend with the estimated rates of 0.056 °C per year. The greatest magnitude of the increase for seasonal T_{max} occurred in winter at Nielamu and Dingri, while that for T_{min} occurred in winter at Nielamu and in spring at Dingri. The seasonal increasing trends of Dingri seem more dominant than those of Nielamu, so it is for the increasing magnitudes, which are consistent with the existing research [24].

Figures 2–4 show the monthly, seasonal, and annual variations with time for T_{max} and T_{min}. The annual T_{max} and T_{min} time series are the same as those of summer and winter at Dingri; however, the annual T_{max} and T_{min} time series show slightly different variations from the summer and winter at Nielamu. A visual analysis can also evidence the increasing trends for the T_{max} and T_{min} series based on the linear trend (see the dash line in Figures 2–4).

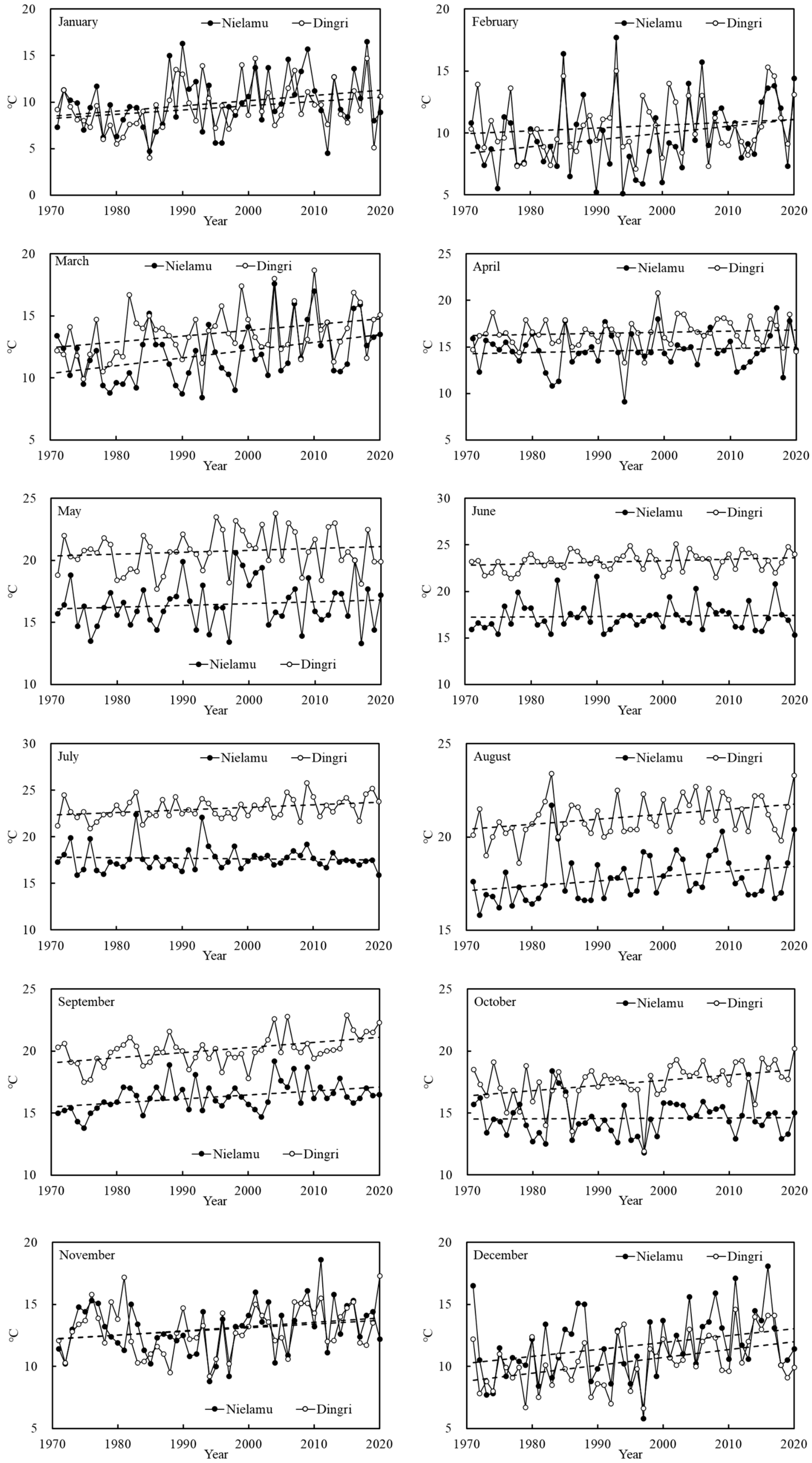

Figure 2. Time series of monthly T_{max} and dash line indicates linear trend.

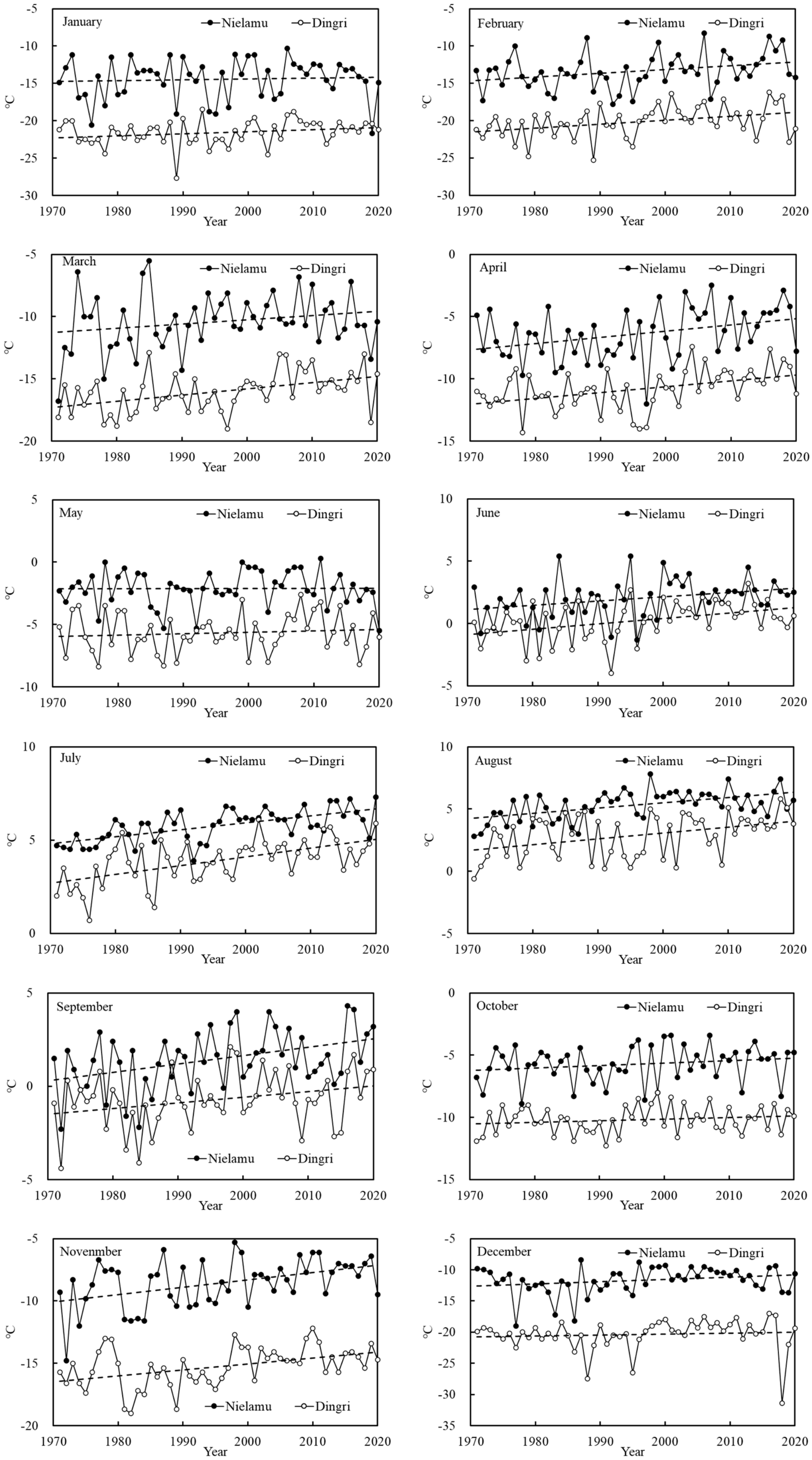

Figure 3. Time series of monthly T_{min} and dash line indicates linear trend.

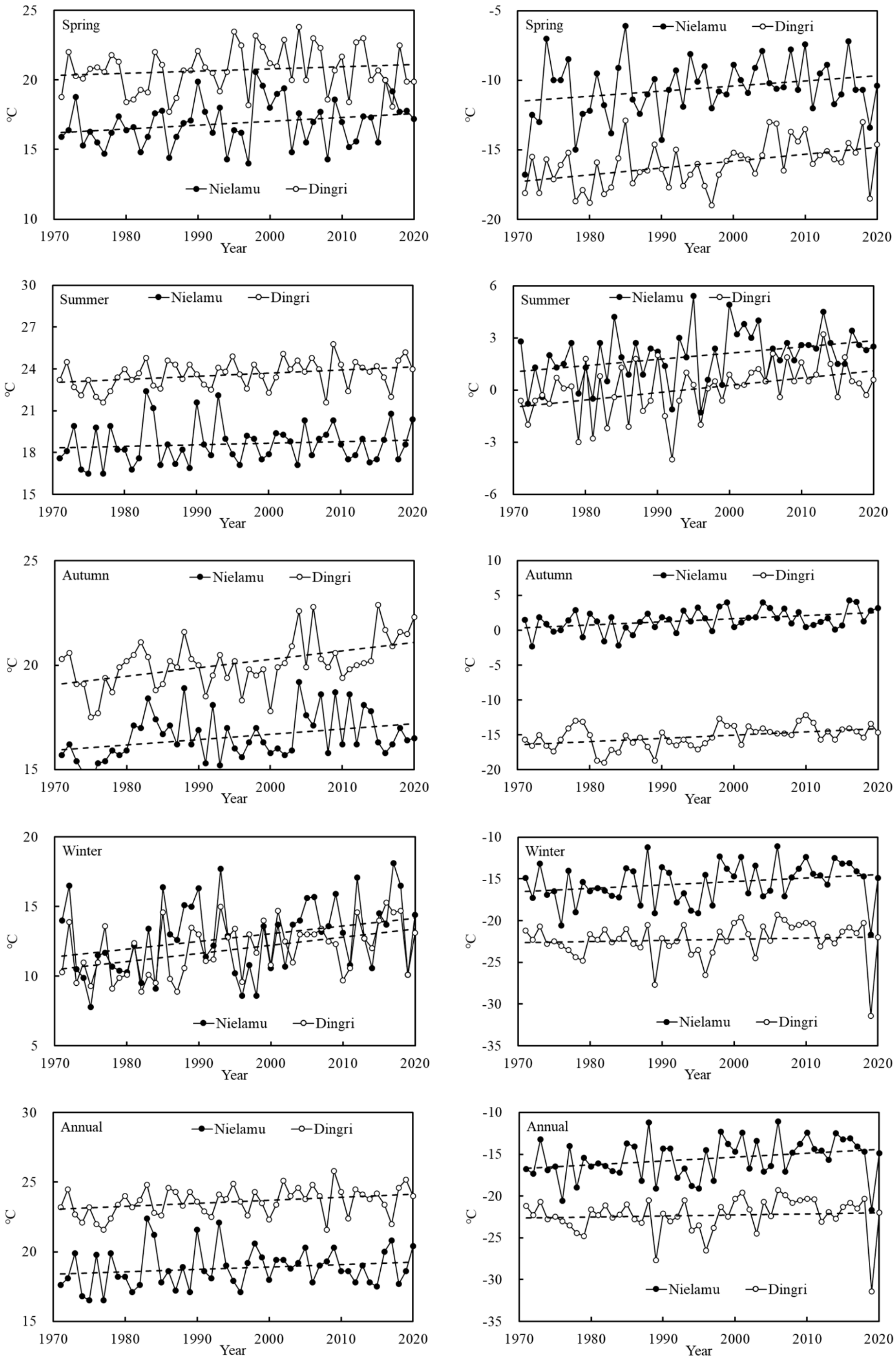

Figure 4. Time series of seasonal and annual T_{max} (**left**) and T_{min} (**right**) and Dash line indicates linear trend.

3.3. Abrupt Diagnosis

The abrupt diagnosis results using an MK test for T_{max} and T_{min} are shown in Table 5. The abrupt changes of monthly T_{max} and T_{min} mainly take place during 1980s–2020s, and the abrupt points occur 2 times in 1970s, 16 times in 1980s, 16 times in 1990s, 13 times in 2000s and 3 times in 2010s, respectively. On the seasonal scale, abrupt changes of T_{max} and T_{min} mainly take place in 1980s and 1990s, with only one change each in 1970s, 2000s, and 2010s for the T_{max}. The annual T_{max} abrupt changes take place in 1980s, while the annual abrupt change for the T_{min} take place in 1990s. Du et al. [26] also found that the maximum value of the daily maximum temperature had an abrupt change in 1980.

Table 5. MK abrupt year of temperature.

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Spring	Summer	Autumn	Winter	Annual
T_{max}	Nielamu	1998	2013	2004	2016	1982	1981	1982	1982	1978	1998	2004	1999	1986	1980	1979	2002	1980
	Dingri	1988	1997	1982	1988	1987	1989	2000	1982	2013	2001	2000	1998	1987	1982	2013	1992	1982
T_{min}	Nielamu	1980	2001	1980	2003	1987	1988	1986	1977	1990	1994	1996	1995	1981	1986	1990	1997	1997
	Dingri	2000	1988	1999	2003	2000	1993	1994	2002	1997	1993	1997	1998	1999	1997	1997	1998	1998

The cumulative departure curves of the T_{max} and T_{min} time series are shown in Figures 5–7, which also evidences the abrupt points for the temperature time series.

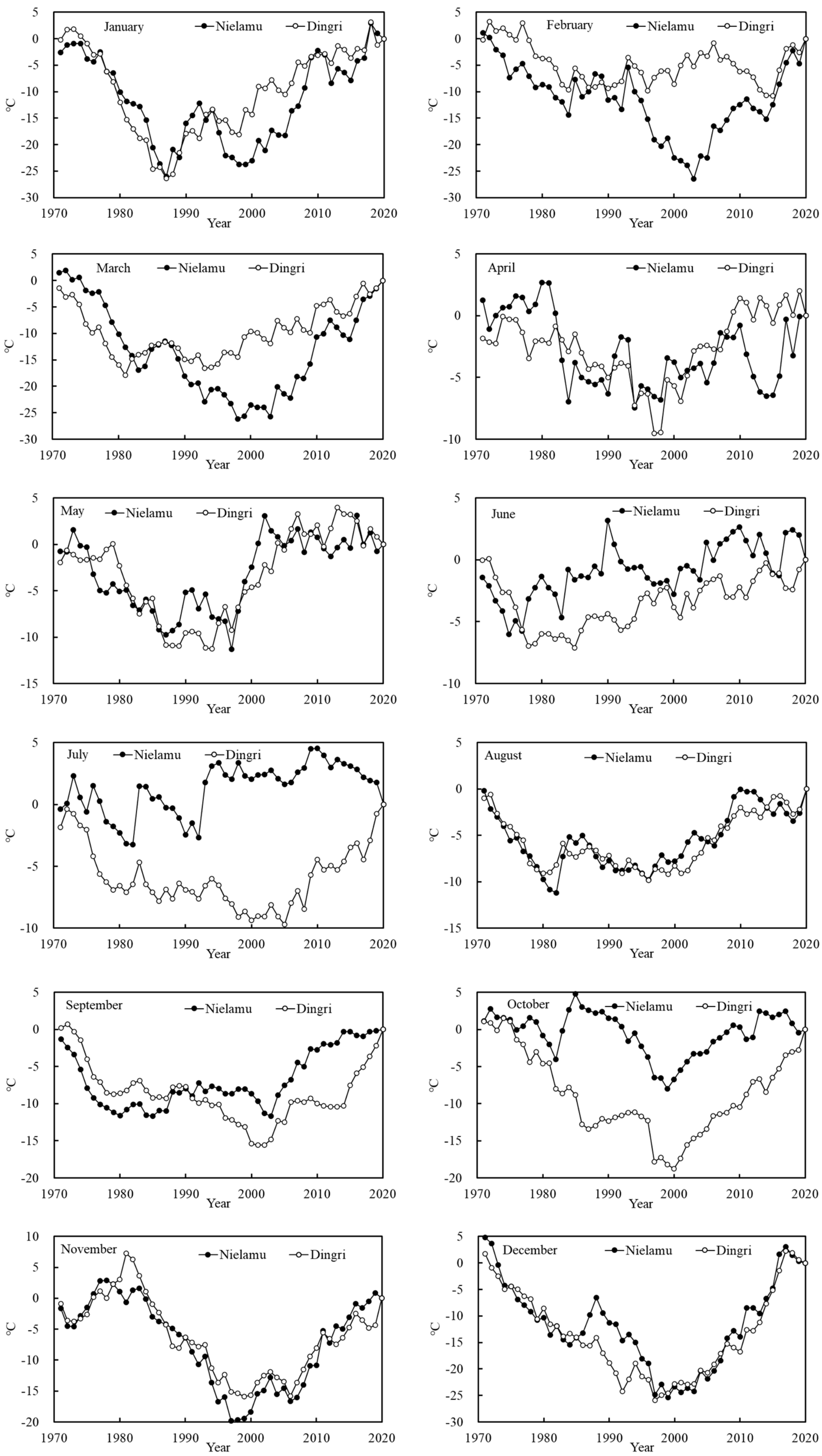

Figure 5. Cumulative departure curve for monthly T_{max}.

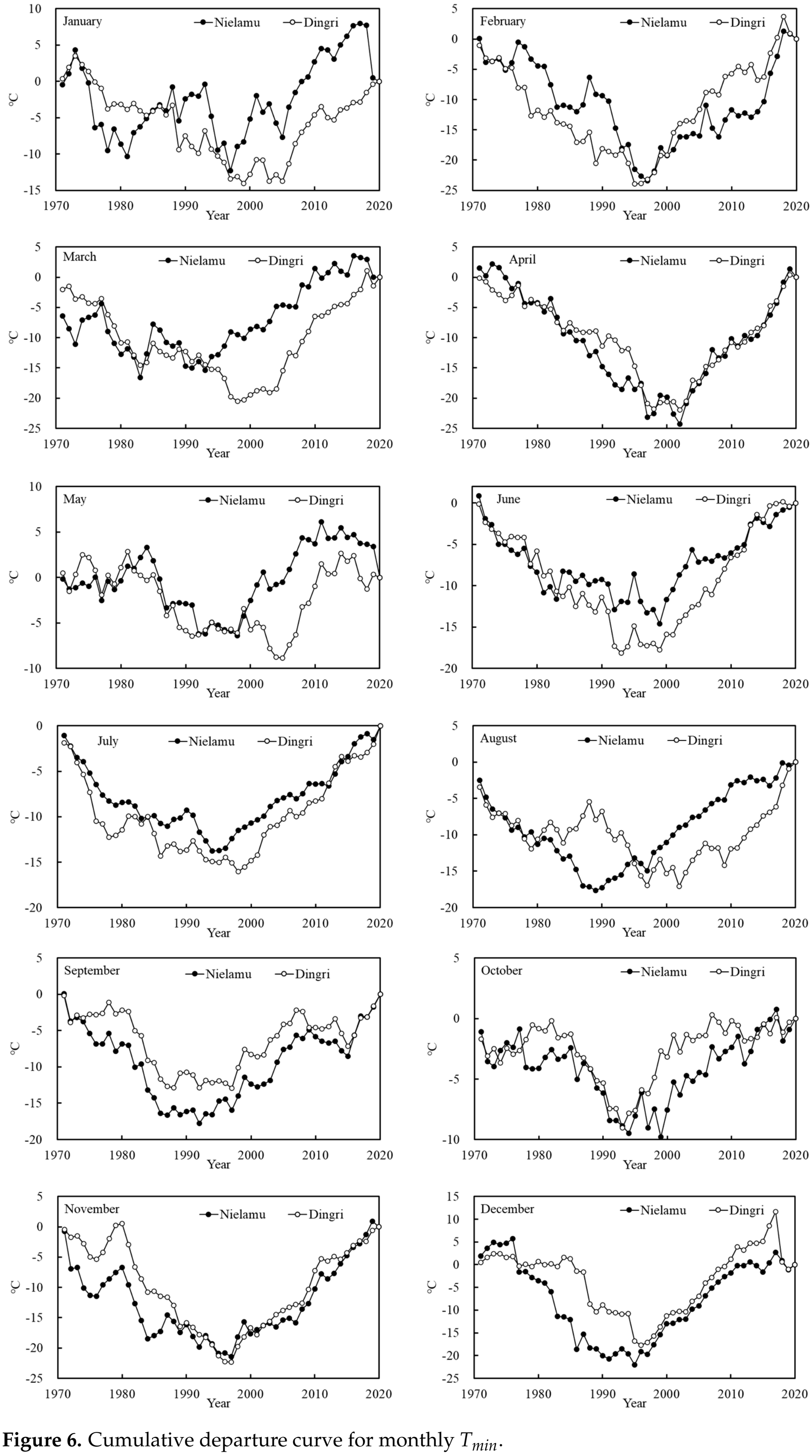

Figure 6. Cumulative departure curve for monthly T_{min}.

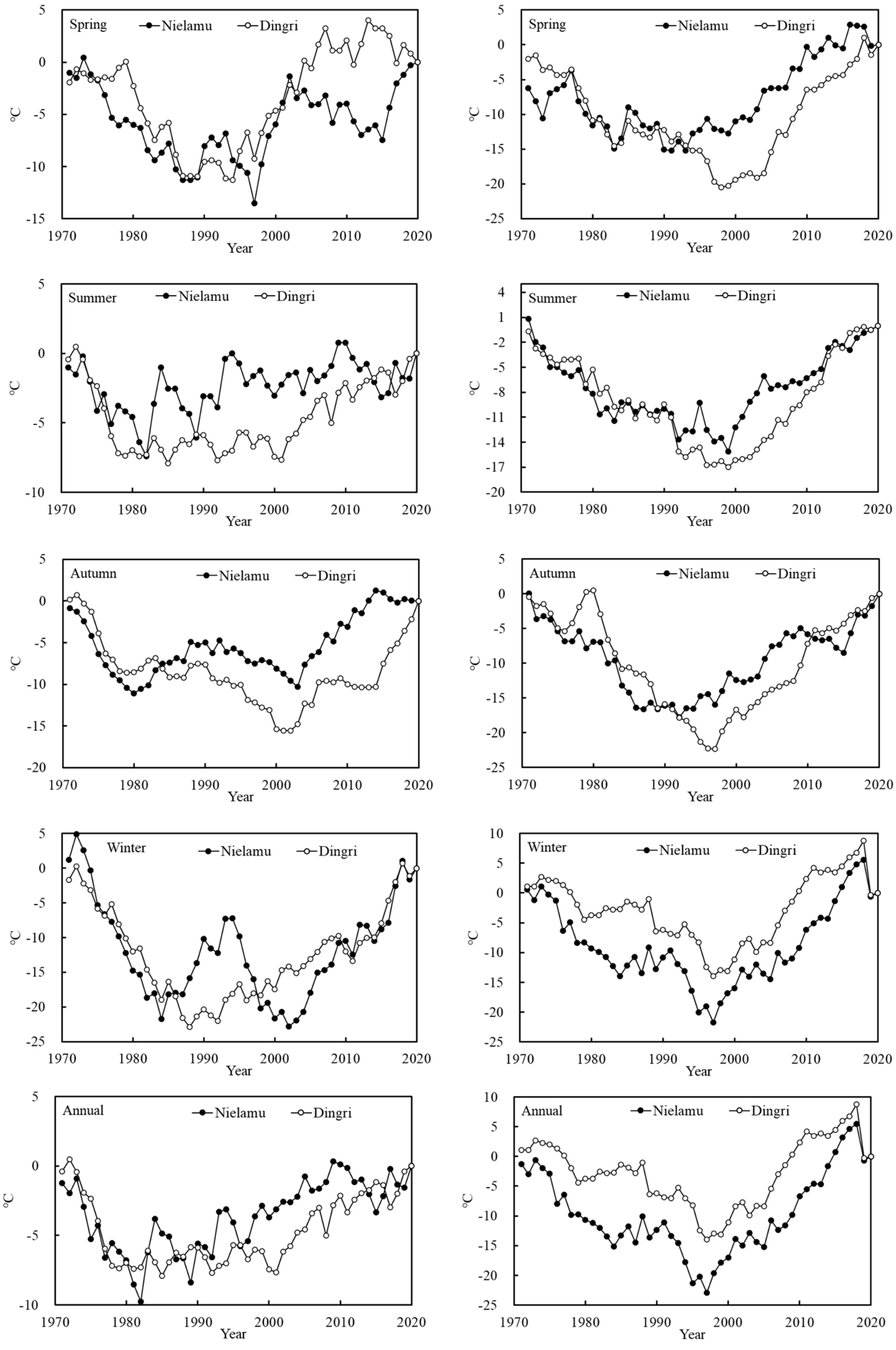

Figure 7. Cumulative departure curve for seasonal and annual T_{max} (**left**) and T_{min} (**right**).

4. Discussions and Conclusions

Based on the observational daily temperature data from Nielamu and Dingri, this study conducts a general characteristic analysis, trend test, and abrupt diagnosis for the T_{max} and T_{min} in MQ during the last five decades. The results would be beneficial to understand the variations in extreme temperature in MQ.

The maximum T_{max} was 25.8 °C and the minimum T_{min} was −31.4 °C in MQ, which all occurred in Dingri. The maximum T_{max} appeared in summer, and the minimum T_{min} appeared in winter. The maximum T_{max} or minimum T_{min} occurred in August or January at Nielamu, while occurring in July or December at Dingri. The decadal variations for T_{max} and T_{min} had upward trend on the whole, but the winter minimum T_{min} occurred during 2011–2020 at both Nielamu and Dingri.

On monthly, seasonal, and annual scales, neither T_{max} nor T_{min} time series exhibits a discernible increasing trend. Although some series show a slight and insignificant increasing trend at a 95% confidence level, the positive Sen's slopes also exhibit an increasing change during the study period. The increasing trends for monthly T_{min} are even more marked than those of T_{max} overall. On the seasonal scale, the greatest increasing magnitude for T_{max} occurred in winter at Nielamu and Dingri, while that for T_{min} occurred in winter at Nielamu and in spring at Dingri. The seasonal increasing trends at Dingri seem more dominant than those at Nielamu, so it is for the increasing magnitudes.

The monthly T_{max} and T_{min} abrupt change mainly took place during 1980s–2020s. The seasonal T_{max} or T_{min} abrupt change mainly took place in 1980s or 1990s, and only the T_{max} in winter at Nielamu and in autumn at Dingri had an abrupt change that took place in 2000s and 2010s, respectively. The annual T_{max} abrupt change took place in 1980s, while the annual T_{min} abrupt change took place in 1990s.

This study found the differences between the north slope (Dingri) and the south slope (Nielamu) of MQ. For example, the fluctuations in the T_{max} and T_{min} in the north slope are more extreme than those of the south slope. On the seasonal and annual scale, the T_{max} in the north slope were higher than those in the south slope, except for in winter. The seasonal and annual T_{min} in the north slope were all lower than those in the south slope. The tendence of T_{max} and T_{min} in the north slope was more dominant than those in the south slope.

The differences in T_{max} and T_{min} between the south and north slope of MQ are found in this research, which is consistent with those of existing results. Yang et al. [24] found the increasing trend for temperature at Dingri is most significant in MQ. Yang et al. [29] indicates the temperature increasing rate at Dingri is larger than that at Nielamu. Qi et al. [42] points out the increasing annual mean temperature is mainly due to the increasing maximum temperature in MQ, while the annual mean temperature increase in the north slope of MQ is mainly owing to the minimum temperature rise [42]. On the other hand, studies show the Himalayas barrier is the major contributor to the climate difference between the north and south slope of MQ [43,44]. Because of the Himalayas barrier, the Mongolia–Siberia cold air cannot access the south slope, and the warm moisture influence from the Indian Ocean is waned in north slope. So, the south slope temperature is higher than that of north slope [27]. It further demonstrates that climate change shows obvious regional or local difference, which is not neglectable in practice research.

This research shows the spatiotemporal variations in the T_{max} and T_{min} trend and abrupt change in MQ on the basis of observation data. However, only two stations with long-term observations are used. Further analysis is needed to determine whether we can comprehensively reveal the characteristics of T_{max} and T_{min} over MQ. It is also necessary that the conclusion in this study be verified by using other methods and data. At the same time, the results in this study need further research to reveal the influencing mechanism.

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