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No Significant Shift of Warming Trend over the Last Two Decades on the Mid-South of Tibetan Plateau

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Received: 12 May 2019; Accepted: 17 July 2019; Published: 19 July 2019

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Abstract: Climate warming on the Tibetan Plateau has been regarded as an important driving force of regional environmental change. Although several studies have analyzed the shift of warming trends on this plateau within the context of a recent global warming "hiatus" since 1998, their disparate findings have hindered a comprehensive and regional understanding. Based on the daily mean temperature (T_{mean}), maximum temperature (T_{max}), and minimum temperature (T_{min}) collected from meteorological stations on the period of 1961–2017, we re-examined the timing and magnitude of temperature phase change using piecewise linear regression on the mid-south of Tibetan Plateau. The results show that among the trends in regional annual T_{mean}, T_{max} and T_{min}, the statistically significant change-point was observed only in annual T_{max} ($p < 0.01$). The warming trend of annual T_{max} has accelerated significantly since 1992 and has exceeded that of annual T_{min} after 2000, causing a remarkable reversal from decline to increase in diurnal temperature range (DTR) ($p < 0.01$). Spatially, the occurrence time of change-points in T_{mean}, T_{max}, and T_{min} varied among stations, but most of them occurred before the mid-1990s. Besides, the trend shifts in T_{max}/DTR during the cold season played a primary role in the significant trend shifts in annual T_{max}/DTR. This study underscores that there is no significant shift of warming trends over the last two decades on the mid-south of Tibetan Plateau.

Keywords: climate warming; diurnal temperature range; change-point analysis; Tibetan Plateau

1. Introduction

The global surface climate is warming inexorably but unevenly [1]. The rates in climate warming appeared spatial heterogeneous, and the shifts in regional temperature trends are also asynchronous with that of global-averaged temperature [2,3]. Mounting studies have provided evidence that high mountains experienced stronger warming than their lower-elevation counterparts over the past several decades [4,5], resulting in serious effects on alpine ecosystems and downstream [6]. Thus, the spatial and temporal variability of warming in high elevation areas has been attracting increasing attention [5,7].

Climate change in the Tibetan Plateau, the highest and largest plateau in the world, is widely regarded to be the driving force for both regional environmental change and the amplification of environmental changes throughout the world [8,9]. Previous studies based on temperature records from surface stations have showed that mid-eastern Tibetan Plateau has been experiencing significant warming since the 1950s [10,11], which exceeded those of the Northern Hemisphere and the globe [12,13]. The projected rate of future warming on the plateau is also higher than the global average [14]. The overall warming might hide some characteristics of temperature phase change [2]. Several studies noted that annual mean temperature (T_{mean}) began to increase rapidly in the 1980s across the mid-eastern Tibetan Plateau [2,15–17]. Nevertheless, within the context of recent heated debates on whether a significant global warming "hiatus" has occurred since 1998 [3,18,19], similar debate has also appeared regarding the Tibetan Plateau. Several studies have pointed out that mid-eastern Tibetan Plateau displayed an accelerated warming trend by applying the period of global warming "hiatus" for a priori justification [12,20]. In contrast, other studies argue that there has been a warming "hiatus" or slowdown since 1998 in this region [21,22]. Meanwhile, An et al. [22] also reported that a delayed warming hiatus occurred in the mid-2000s in the regions of the Tibetan Plateau with elevations higher than 4000 m; however, You et al. [23] showed that the T_{mean} values from five stations with elevations above 4500 m continued to increase rapidly.

Apart from the T_{mean}, changes in maximum temperature (T_{max}), minimum temperature (T_{min}), and diurnal temperature range (DTR) provide reference information on the identification of climate warming, and some climate processes are dependent on T_{max} and T_{min} [24,25]. Numerous studies have shown that annual T_{min} has risen faster than annual T_{max} on the Tibetan Plateau since the 1960s, resulting in a narrowing of the DTR [26–30]. However, You et al. [24] indicated that the DTR in this region narrowed rapidly before the 1980s and appeared mute change afterwards. A recent study calculated the trend in DTR according to the change-point of T_{mean} and showed that the trend in DTR has also shifted since 1998, especially during the plant-growing season [21]. Regarding the heated discussion of a post-1990 warming hiatus, relatively less attention has been paid to the trend shifts in T_{max}, T_{min} and DTR on this plateau.

Given these disparate findings in the aforementioned studies, using a statistical method to re-examine the timing and magnitude of climate phase change on this plateau is particularly necessary [3]. Change-point analysis is a testable method for objectively detecting the significant shift of temperature trends, such as piecewise linear regression [2,3,31,32].

Both observations and model studies showed that Tibetan Plateau exhibits an uneven warming trend with greater warming at higher elevations [11,33–35]. The mid-south of Tibetan Plateau with the average altitude above 4,000 m is the main body of the Tibetan Plateau [36], which has been known as "the roof of the world". In this study, we therefore revisited the observed temperature records during the period of 1961–2017 using piecewise linear regression to accurately examine whether a significant shift in warming trend on the mid-south of Tibetan Plateau occurred around 1998, and to explore how the changes in T_{max} and T_{min} contribute to the variation in DTR. The results will deepen our understanding of the surface–atmosphere energy balance along with the regional and global climate effects of the Tibetan Plateau.

2. Data and Methods

2.1. Data Source

The daily T_{mean}, T_{max}, and T_{min} records from 27 meteorological stations were downloaded from the China Meteorological Data Service Center (CMDC; http://data.cma.cn/). These data have been homogenized by the CMDC to reduce non-climatic errors and have been shown to be superior to raw data for analyses [37,38]. Because most meteorological stations on the mid-south of Tibetan Plateau were not operational until the end of 1950s, we selected stations that collected data since 1961. We then removed meteorological stations with more than sixty missing values in any given year, leaving a total of 17 meteorological stations with near-complete daily data for the period between 1961 and 2017 (Figure 1 and Table A1). These meteorological stations are mainly in the eastern part of Tibet Autonomous Region. Furthermore, to ensure the completeness of the data, a few missing values in the daily T_{mean}, T_{max}, and T_{min} data were interpolated by stepwise linear regression from adjacent stations with time series data. Data from an additional ten stations with shorter time periods were also employed to calculate trends for the periods of 1970–2017 and 1980–2017 at the regional scale (Figure 1 and Table A1), in order to compare with the warming trends during 1961–2017. In this study, DTR is defined as the difference between T_{max} and T_{min}. Monthly and annual T_{mean}, T_{max}, T_{min}, and DTR were then calculated from these station records. A monthly gridded dataset at 0.5° resolution was also provided by the CMDC, which was interpolated using the using ANUSPLIN version 4.2 software based on over 2400 stations of China. The warm season was considered to be from May to October, and the cold season was from the previous November to April [39].

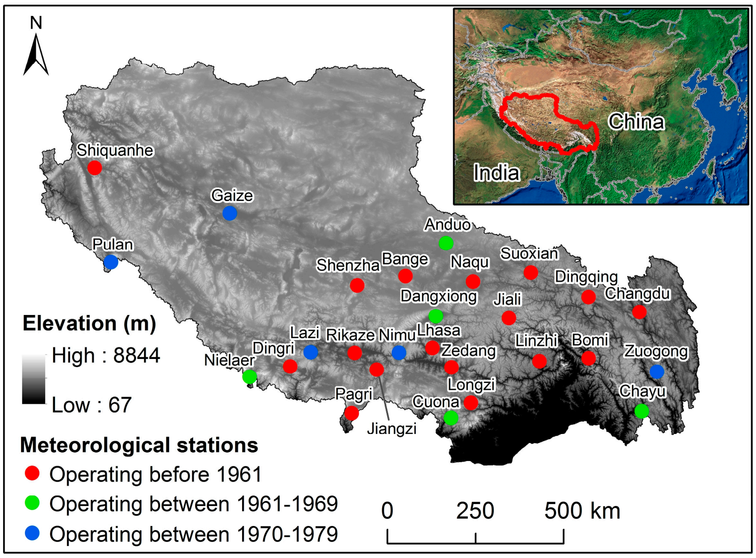

Figure 1. Spatial distribution of the meteorological stations over the mid-south of Tibetan Plateau considered in this study. The stations that are valid during 1961–2017, 1970–2017 and 1980–2017 are denoted by red, green and blue circles, respectively.

2.2. *Statistical and Spatial Analyses*

Two regression models were used to estimate the temporal trend of temperature change on the mid-south of Tibetan Plateau over the study period. We initially applied the Mann–Kendall test and Sen's slope estimator to examine the gradual change of annual temperature and its significance (Section 3.1). Given that the gradual change over a long time series of temperature might accelerate or reverse [2,3], we then employed the piecewise linear regression model to investigate if there was a change-point during the study period (Sections 3.2–3.4).

2.2.1. Mann–Kendall Test and Sen's Slope Estimator

The Mann-Kendall test is one of the most popular nonparametric approaches that has been widely applied to examine the significance of trends in a meteorological time series [30,40,41]. The advantage of this test is that the time series does not require a certain sample distribution, thus there is no need to specify whether the trend of the time series is linear or nonlinear. It is given as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{var(S)}}, S > 0 \\ 0,\ S = 0 \\ \frac{S+1}{\sqrt{var(S)}}, S < 0 \end{cases} \quad (1)$$

in which

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} sgn(x_k - x_i) \tag{2}$$

$$sgn(x_k - x_i) = \begin{cases} 1, x_k - x_i > 0 \\ 0, x_k - x_i = 0 \\ -1, x_k - x_i < 0 \end{cases} \tag{3}$$

$$var(S) = \frac{n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)}{18} \tag{4}$$

where n indicates the length of data time series, while x_k and x_i denote to sequential data values. t represents the extent of any given period. For a given significance level α, there exists a significant trend if $|Z| \geq Z_{1-\alpha/2}$. The critical value of $|Z|$ at the α = 5% significance level of the trend test is equal to 1.96.

The Sen's slope estimator is a popular nonparametric approach for estimating the monotonic trend of a time series, which is more robust to outliers than a simple linear regression. Thus, the monotonic trend of annual temperature over the study period was predicted by the Sen's slope estimator [42], as follows:

$$\beta = Median\left(\frac{x_k - x_i}{k - i}\right), \forall k < i \tag{5}$$

where $1 < k < i < n$, and β refers to a robust estimate of temperature trend magnitude.

2.2.2. Piecewise Linear Regression Model

The piecewise linear regression model is a useful tool for solving the problem of heterogeneous trends in time-series climatic data with long time periods [2,3]. Two forms of this model are applied to different problems: The first one is fitting trends to separate periods in a staircase-like fashion, and the second one is continuous at each change-point [31]. This means that the first form breaks down the consecutive change during the whole period into two independent segments while the second form does not. Meanwhile, Rahmstorf et al. [32] noted that the first form has some pitfalls that might enhance the impression of a reduction in global warming rate in many past studies. The purpose of this study was to examine the possible change-point indicating a significant shift in warming trends. Thus, we used the second form with one change-point to test the significance of possible change-points in temperature trends during 1961–2017 at the station-level and regional level [43,44]. This approach can estimate the changes in a time series by fitting linear regressions to two temporal segments across the change-point, as follows:

$$y_t = \begin{cases} a_0 + b_1 x_t + \varepsilon & x_t \leq j \\ a_0 + b_1 x_t + b_2(x_t - j) + \varepsilon & x_t > j \end{cases} \tag{6}$$

where y_t represents the temperature time series; x_t is the time; j is the year of change-point in the temperature time series. a_0, b_1 and b_2 are the regression coefficients; a_0 is the fitted intercept; and ε is the residual of the fit. The temperature trend before the change point is b_1, and that after the change point is $b_1 + b_2$. This model was used to investigate the year of change-point and the temperature trends before and after it. In order to ensure sufficient length (no less than 5 years) for each segment [3,45], the timing of the change-point was restricted to the period between 1965 and 2013. Both the pseudo-score statistics test and the Davies test can be used to test for a non-constant regression parameter in the linear predictor or the existence of one breakpoint. However, previous simulation studies indicated that the pseudo-score statistics test is more powerful than the Davies test when the alternative hypothesis is "one change-point" [46]. Thus, when the change-point was captured, the significance of the overall non-linearity in this regression was tested using the pseudo-score statistics test. In this study, the piecewise linear regression model was fitted in R using the "segmented" package [43].

3. Results

3.1. Trends of Regional Annual Temperature on the Mid-South of Tibetan Plateau

Regional annual temperature increased significantly during 1961–2017. The rates of warming in annual T_{mean}, T_{max}, and T_{min} calculated based on data from the 17 stations were 0.34, 0.31, and 0.43 °C/decade, respectively (Table 1). This result indicates that the rate of increase on the mid-south of Tibetan Plateau was highest for T_{min}, followed by T_{mean}, and the rate of increase was lowest for T_{max}. This asymmetric warming pattern of T_{max} and T_{min} resulted in a narrowing of annual DTR with a rate of −0.12 °C/decade over the whole study period. We also analyzed the rates of temperature change on the period of 1970–2017 and 1980–2017. The rates of change in annual T_{mean}, T_{max}, T_{min}, and DTR calculated based on records from the 17 stations were all highly consistent with those determined based on 22 stations and 27 stations during the overlapping periods (Table 1). The differences between the rates of change in these four temperature indices during the two given overlapping time periods were less than 0.02 °C/decade. Meanwhile, the change of annual temperature at 17 long-observed stations showed high synchrony with that of gridded data from the CMDC over the past five decades (Figures A1 and A2). These results indicates that the warming rate calculated based on 17 long-observed stations accurately mirrors the overall regional temperature change for the period of 1961–2017.

Table 1. Trends of regional temperature on the mid-south of Tibetan Plateau for different time periods (°C/decade).

	Number of Stations					
	17	**22**	**27**	**17**	**22**	**27**
Time Period	Trend in T_{mean}			Trend in T_{max}		
1961–2017	0.34***			0.31***		
1970–2017	0.34***	0.33***		0.33***	0.32***	
1980–2017	0.42***	0.42***	0.42***	0.42***	0.43***	0.44***
Time Period	Trend in T_{min}			Trend in DTR		
1961–2017	0.43***			–0.12***		
1970–2017	0.43***	0.42***		–0.10**	–0.10*	
1980–2017	0.48***	0.47***	0.49***	–0.05	–0.03	–0.05

Trend and its significance were estimated by the Sen's slope estimator and Mann–Kendall test. Significance: *** $p < 0.001$, ** $p < 0.01$, *$p < 0.05$.

3.2. Regional Annual Temperature Trend Shifts on the Mid-South of Tibetan Plateau

We examined the significance of possible change-points in the regional annual temperature during 1961–2017 using change-point analysis (Figure 2). The trend shifts in annual T_{mean} and T_{max} appeared around 1992, but the former was insignificant ($p > 0.05$). The rate of increase in T_{mean} after this change point was 0.47 °C/decade, approximately twice the rate before the change-point. The rate of increase in T_{max} after this change-point was 0.55 °C/decade, higher than the rate of increase in T_{mean} for the same period. In contrast, before the change point, the rate of increase in T_{max} was only half of that of T_{mean}. It is worth noting that the trend shift in T_{max} was significant ($p < 0.01$). T_{min} declined before 1967 but drastically increased at a rate of 0.45 °C/decade afterwards, but this shift in trend was also insignificant ($p > 0.05$). Considering the asymmetric warming patterns of T_{max} and T_{min}, a significant shift in DTR trend ($p < 0.01$) occurred around 2000. Specifically, T_{min} increased faster than T_{max} prior to 2000, leading to a reduction in DTR (−0.21 °C/decade), whereas the increase in T_{max} accelerated significantly after 1992 and exceeded that of T_{min} since 2000, resulting in an increase in DTR (0.20 °C/decade) during 2000–2017.

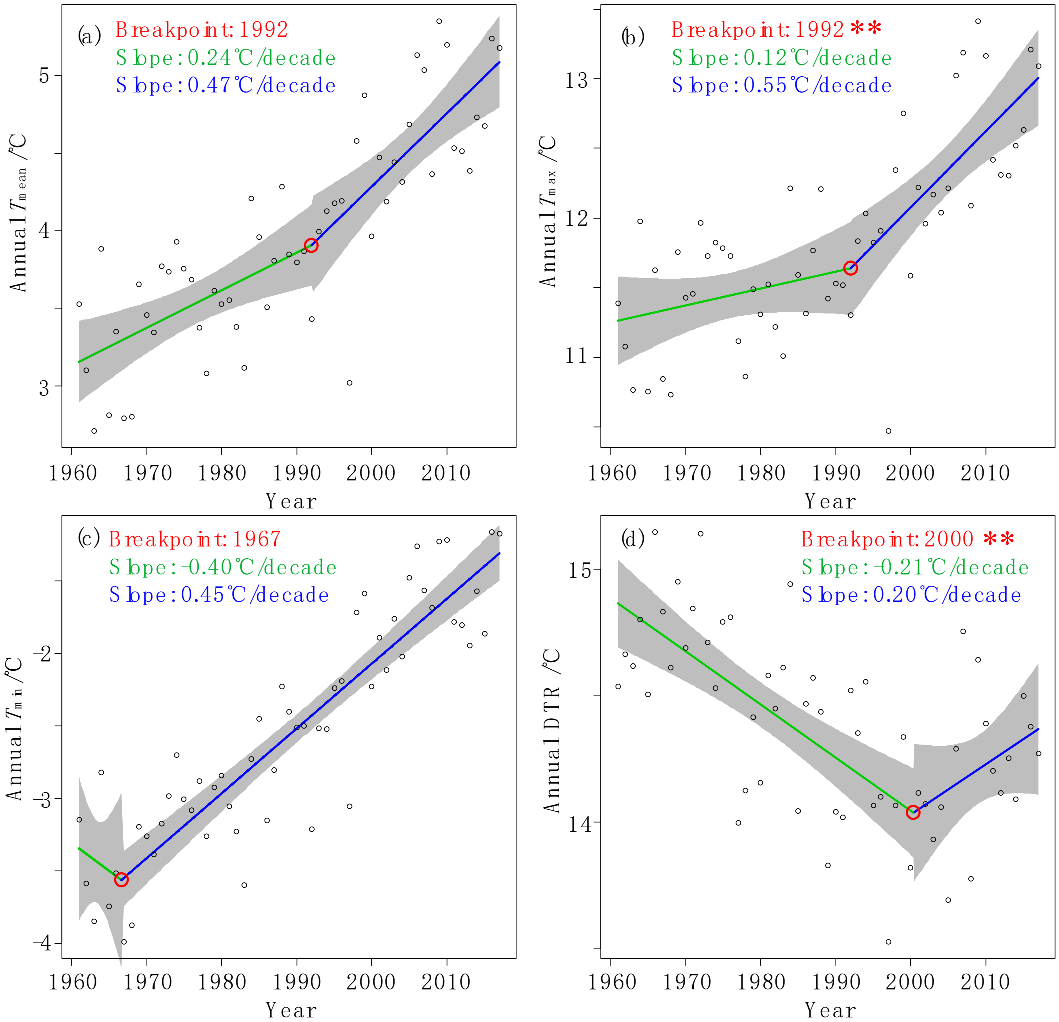

Figure 2. Change-point analysis of regional annual temperature indices on the mid-south of Tibetan Plateau during 1961–2017. (**a**–**d**) indicate the annual T_{mean}, T_{max}, T_{min}, and DTR, respectively. The red circle in each panel indicates the occurrence year of change-point, and the green and blue lines represent the trends in temperature change prior to and after the change-point, respectively. Significance: *** $p < 0.001$, ** $p < 0.01$, *$p < 0.05$.

3.3. Regional Temperature Trend Shifts in the Cold and Warm Seasons

The occurrence time of the change-point differed between the cold and warm seasons (Table 2). The significant change-points in T_{max} and DTR in the cold season occurred in the early and middle 1990s, close to the year of change-points for the corresponding annual temperature indices, but the shift trends in T_{mean} and T_{min} were insignificant. On the contrary, the significant change-points in T_{max} and other two temperature indices (T_{mean} and T_{min}) during the warm season occurred after 2000 and before 1970, respectively, which far differed from those of corresponding annual temperature indices apart from T_{min} (Table 2 and Figure 2). The rate of increase in T_{max} after the change-point was greater in the cold season (0.76 °C/decade) as compared to the annual and warm-season values. Additional, compared to the annual trend, DTR showed stronger rates of decline (−0.34 °C/decade) and increase (0.30 °C/decade) before and after the change-point in the cold season, respectively.

Table 2. Change-point analysis of four temperature indices during the cold and warm seasons on the mid-south of Tibetan Plateau on the period of 1961–2017.

Indices	Cold Season (°C/Decade)			Warm Season (°C/Decade)		
	Year of Change-Point	Trend Before Change-Point	Trend After Change-Point	Year of Change-Point	Trend Before Change-Point	Trend After Change-Point
T_{mean}	1992	0.31	0.55	1965*	−1.72	0.31
T_{max}	1994*	0.16	0.76	2001*	0.14	0.53
T_{min}	1973	0.73	0.46	1967***	−1.67	0.41
DTR	1995***	−0.34	0.30	1967	0.79	−0.15

Significance: *** $p < 0.001$, ** $p < 0.01$, *$p < 0.05$.

3.4. Spatial Patterns of Temperature Trend Shifts on the mid-south of Tibetan Plateau

Accelerated warming trends in annual T_{mean}, T_{max}, and T_{min} appeared after the change-points at most stations on the mid-south of Tibetan Plateau compared to before the change-points (Figure 3a–f). The change-points of T_{mean} and T_{max} primarily occurred in the 1990s, while those of T_{min} occurred before 1990. Specifically, at about half of stations, the change-points in T_{mean} occurred in the early 1990s, while the change-points in T_{max} occurred in the middle 1990s. Moreover, the trends in DTR at more than half of the stations shifted from decline to increase around 2000; the remaining stations displayed lower rates of change after the change-points than that before the change-points, which mainly occurred before 1970 (Figure 3g,h).

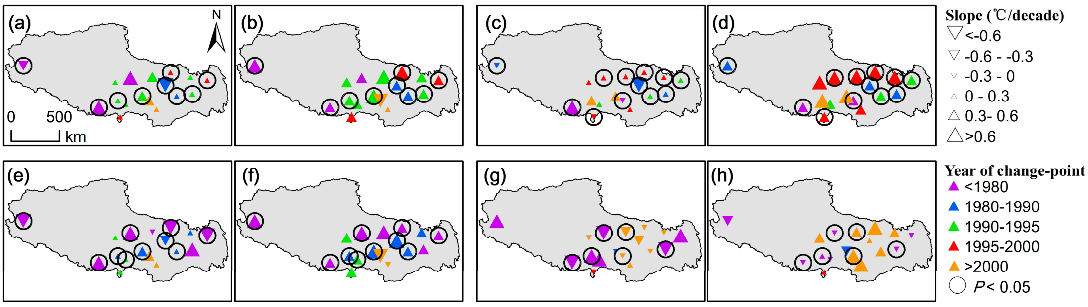

Figure 3. Trends in annual temperature change before (**a**,**c**,**e**,**g**) and after (**b**,**d**,**f**,**h**) change-points: (**a**,**b**) Annual T_{mean}, (**c**,**d**) annual T_{max}, (**e**,**f**) annual $T_{min,}$ and (**g**,**h**) annual DTR. The sizes of points represent the magnitude of the change rate, while the colors indicate the occurrence time of change-points. A black circle indicates that the change-point is significant.

In the cold season, the change-points of T_{mean} and T_{min} primarily occurred before 1980, but these trend shifts in most stations were insignificant (Figure 4a,b,e,f). The change-points in T_{max} mainly occurred in the 1990s, especially in the early 1990s, and the increasing trend in T_{max} at most stations was much higher after the change-points than before the change-points (Figure 4c,d). Moreover, the DTR at most stations displayed a narrowing trend before the change-points and an expanding trend afterwards (Figure 4g,h). In the warm season, the change-points in T_{mean}, T_{max}, and T_{min} at most stations occurred before 1980 (Figure 5a–f). At more than half of the stations, T_{mean} and T_{min} showed decreasing trends before the change-points but showed rapid warming afterwards. The trends in DTR shifted from increasing to decreasing before 1985 at more than half of stations (Figure 5g,h).

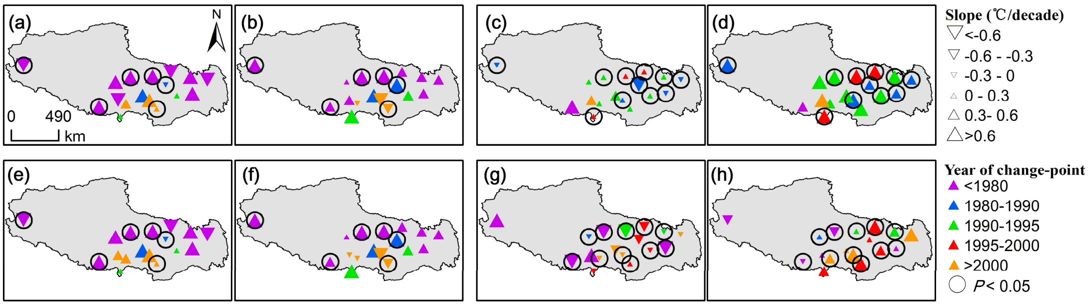

Figure 4. Same as Figure 3, but for the cold season.

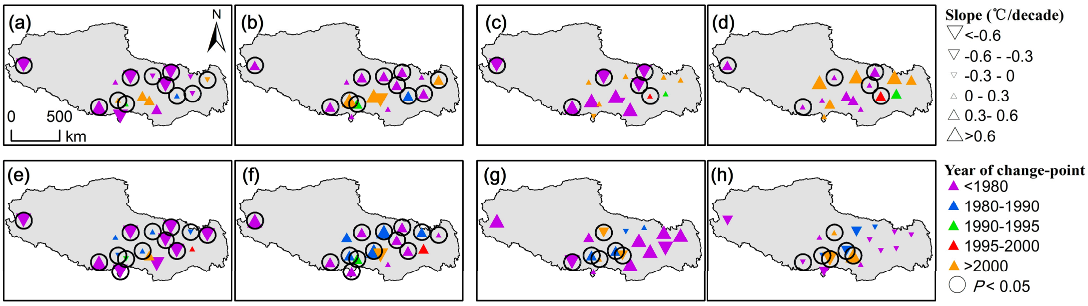

Figure 5. Same as Figure 3, but for the warm season.

Comparing the trend shifts in annual temperature with that during the cold and warm seasons on the mid-south of Tibetan Plateau, both at the regional level (Figure 2 and Table 2) and station level (Figures 3–5), it can be concluded that the trend shifts in T_{max}/DTR in the cold season determined the significant trend shifts in annual T_{max}/DTR over the past 57 years. In contrast, the significant trend shifts in T_{min} in the warm season induced insignificant trend shifts in annual T_{min} to some extent. Moreover, the trend shifts in DTR were primarily attributed to the accelerated warming trend in T_{max} after the 1990s, especially for the cold season.

4. Discussion

Regional annual T_{mean} increased significantly in the on the mid-south of Tibetan Plateau during 1961–2017 at a rate of 0.34 °C/decade, which is slightly higher than the rate across the Tibetan Plateau on the period of 1961–2013/2015 [33,47]. This study also showed an asymmetric warming pattern of T_{max} and T_{min} on the mid-south of Tibetan Plateau, which is consistent with previous studies [27,30]. However, the rates of increase in T_{max} and T_{min} over the mid-south of Tibetan Plateau on the period of 1961–2017 were higher than and similar to those across the Tibetan Plateau from 1961 to 2013, respectively, resulting in a lower narrowing rate of DTR (−0.12 °C/decade) than that of the Tibetan Plateau (−0.19 °C/decade) [24].

Among regional annual T_{mean}, T_{max}, and T_{min}, a significant change-point was only observed in annual T_{max} (around 1992), and no significant change-point occurred around 1998 or the mid-2000s, suggesting that the mid-south of Tibetan Plateau underwent continuous warming in the last two decades. This result neither corresponds to the accelerated warming trend on the mid-eastern of the Tibetan Plateau since 1998 [12,20] nor the robust warming slowdown since 1998 or the mid-2000s [21,22]. This disagreement may have several causes. First, some of these studies applied the period of global warming "hiatus" (i.e., 1998) for a priori justification to calculate the trend of temperature change on this plateau, rather than using a testable statistical method for detecting the significance of temperature trend shifts. These studies also combined with the model with discontinuous trends (i.e., discontinuous); however, this model with discontinuous trends might have enhanced the impression of accelerated warming since 1998 [32,48]. Second, short-term fluctuations in surface air temperature are unavoidable at both global and regional scales [31,32], and temperature trends over short time periods are extremely sensitive to records in start and end years [1,14]. A short-term reduction trend appeared in our study from the mid-2000s to 2013 on the mid-south of Tibetan Plateau, similar to the results of An et al. [22]; however, the temperature recovered after 2013 and this short-term fluctuation could not overwhelm the persistent warming (Figures 2 and A3). Intriguingly, a recent study selected 2001 as the start year rather than 1998 to explore whether a warming "hiatus" appeared on this plateau and found no clear shift from rapid warming to near stagnation after 2001 [49]. Additionally, the mid-south of Tibetan Plateau is the main body of the Tibetan Plateau, and as mentioned above, the rate of temperature increase in this region is generally higher and more predominant than those at lower elevations of the Tibetan Plateau [11,33–35]. This phenomenon might, to some extent, contribute to the disagreement between this study and previous studies on the Tibetan Plateau.

Meanwhile, the regional annual T_{max} exceeded the warming trend in annual T_{min} after 2000, which caused the trend in DTR to shift from decreasing to increasing. The narrowing trend in DTR before 2000 was −0.21 °C/decade, which is in line with a previous study on the Tibetan Plateau [27]. However, the occurrence time of this significant change-point was latter than that from You et al. [24] and Liu et al. [24], likely because this study employed a statistical method to examine the timing of DTR phase change.

The significant warming on the plateau might be related to cloud–radiation feedback [20,50,51], snow–albedo feedback and the change of atmospheric circulation [52], as well as the increase in greenhouse gas emissions [8]. In particular, the continuous warming on the mid-eastern Tibetan Plateau over the last two decades rather than warming "hiatus" is likely due to decreased daytime clouds [20] or enhanced radiatively-forced temperature warming [53]. Meanwhile, the increased amounts of nocturnal low-level clouds and decrease amounts of daytime low clouds contributed to the diminished DTR on the Tibetan Plateau during 1961–2003 [50]. However, the correlation between DTR and cloud cover over the plateau exerts spatial-temporal heterogeneity, and the impact of warming on the DTR is still inconclusive [50]. Besides, even though the surface air temperature increased significantly overall on the mid-south of Tibetan Plateau, spatial differences appeared in the timing of temperature phase change, which is also likely due to the differences in the topography (e.g., valley and summit) [41] and atmospheric circulations [54]. Therefore, further investigations on the underlying mechanism of trend shifts in climate warming and DTR change over Tibetan Plateau are required, especially for T_{max}.

Additionally, we acknowledge that the limited number of stations in the western Tibetan Plateau, particularly long-term stations, limits our understanding of the detailed spatial-temporal characteristics of temperature change, especially of the western Tibetan Plateau. Some studies pointed out Karakoram summer air temperatures displayed recent anomalous cooling, which was dominated by variability of the "Western Tibetan Vortex" [55–57]. Thus, the spatial heterogeneity of trend shifts in temperature change on the north-west of the Tibetan Plateau remains an issue to be further explored.

5. Conclusions

Our study re-examined the existence of significant shifts in temperature trend on the mid-south of Tibetan Plateau during 1961–2017. The results show that the regional trend in annual T_{mean}, T_{max}, and T_{min}, and diurnal temperature range (DTR) during 1961–2017 were 0.34, 0.31, 0.43, and −0.12 °C/decade, respectively. Among regional annual T_{mean}, T_{max}, and T_{min}, only annual T_{max} showed a statistically significant change-point ($p < 0.01$), which occurred around 1992, and there was no significant change-point occurring around 1998 or the mid-2000s. Meanwhile, the occurrence time of change-points in T_{mean}, T_{max}, and T_{min} varied among stations, but most of them occurred before the mid-1990s. These results indicate that the mid-south of Tibetan Plateau has undergone continuous warming in the last two decades, rather than a significant shift of warming trend. Regional annual T_{max} displayed an accelerated warming trend after 1992 that exceeded that of T_{min} since 2000, resulting in the trend in DTR to shift from decline to increase ($p < 0.01$). Besides, the trend shifts in T_{max}/DTR during the cold season determined the significant trend shifts in annual T_{max}/DTR.

Author Contributions: Y.Z. conceived and designed this study, L.L. analyzed the data and wrote the paper; Y.Z., W.Q., Z.W., Y.L. and M.D. revised the paper and contributed to result explanation and discussion. All authors have read and approved the final vision of the manuscript.

Funding: This work is funded by the Second Tibetan Plateau Scientific Expedition and Research (2019QZKK0600), Strategic Priority Research Program of the Chinese Academy of Sciences (XDA20040201) and International Partnership Program of Chinese Academy of Sciences (131C11KYSB20160061).

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

Appendix A

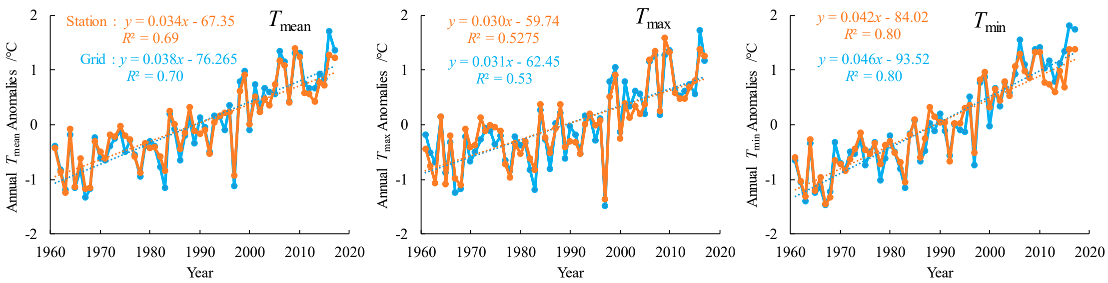

Figure A1. Comparison of the anomalies of annual temperature at surface stations with that of gridded data from the China Meteorological Data Service Center (CMDC) during 1961–2017. Trends were estimated by the ordinary least squares (OLS).

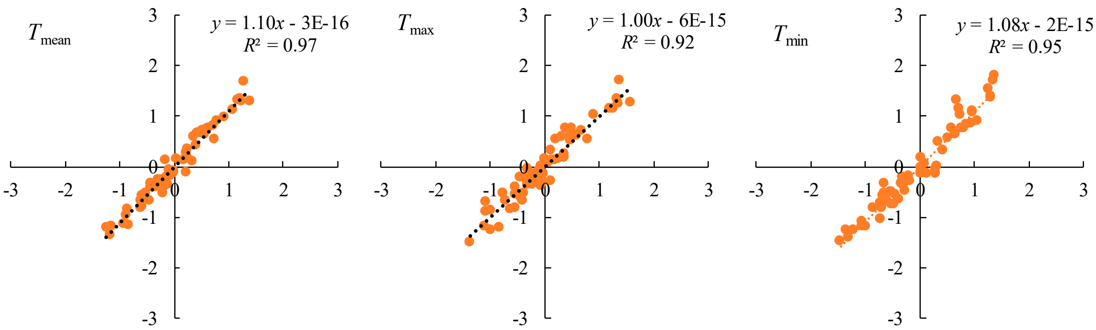

Figure A2. Correlation between the anomalies of annual temperature at surface stations with that of gridded data from CMDC during 1961–2017.

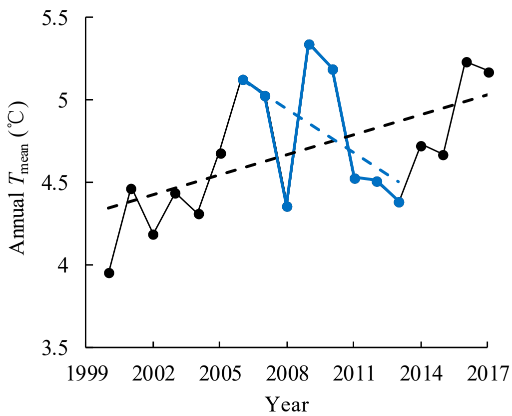

Figure A3. Short-term reduction trend over the mid-south of Tibetan Plateau from the mid-2000s to 2013.

Table A1. Detailed information of the selected meteorological stations.

Number	Station ID	Station Name	Latitude (N)	Longitude (E)	Elevation (m)	Start Year
1	55228	Shiquanhe	32°30′	80°05′	4278	1961
2	55279	Bange	31°23′	90°01′	4700	1956
3	55299	Naqu	31°29′	92°04′	4507	1954
4	55472	Shenzha	30°57′	88°38′	4672	1960
5	55578	Rikaze	29°15′	88°53′	3836	1955
6	55591	Lhasa	29°40′	91°08′	3649	1955
7	55598	Zedang	29°15′	91°46′	3560	1956
8	55664	Dingri	28°38′	87°05′	4300	1959
9	55680	Jiangzi	28°55′	89°36′	4040	1956
10	55696	Longzi	28°25′	92°28′	3860	1959
11	55773	Pali	27°44′	89°05′	4300	1956
12	56106	Suoxian	31°53′	93°47′	4022	1956
13	56116	Dingqing	31°25′	95°36′	3873	1954
14	56137	Changdu	31°09′	97°10′	3315	1954
15	56202	Jiali	30°40′	93°17′	4488	1954
16	56227	Bomi	29°52′	95°46′	2736	1955
17	56312	Linzhi	29°40′	94°20′	2991	1954
18	55294	Anduo *	32°21′	91°06′	4800	1965
19	55493	Dangxiong *	30°29′	91°06′	4200	1962
20	55655	Nielaer *	28°11′	85°58′	3810	1966
21	55690	Cuona *	27°59′	91°57′	4280	1967
22	56434	Chayu *	28°39′	97°28′	2327	1969
23	55248	Gaize **	32°09′	84°25′	4414	1973
24	55437	Pulan **	30°17′	81°15′	3900	1973
25	55569	Lazi **	29°05′	87°36′	4000	1977
26	55585	Nimu **	29°26′	90°10′	3809	1973
27	56331	Zuogong **	29°40′	97°50′	3780	1978

*, ** denotes the stations that are start operated during the period of 1961–1970 and 1970–1980, respectively.

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