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Analysis of diurnal air temperature range change in the continental United States

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ABSTRACT

Diurnal temperature range (DTR) is an important indicator for climate change. In this paper, diurnal air temperature range variations of the continental United States over the past one hundred years were investigated to discover the temporal trend and spatial patterns. While the annual mean DTR of the United States has steadily decreased during the past decades, it is found that the decreased amplitude has spatial and seasonal patterns. Seasonal and spatial variations of DTR were analyzed for the four regions, northeastern, northwestern, southeastern, and southwestern. Fall and summer witnessed a significant decrease in DTR in all regions. Spring and winter, on the other hand, have experienced much smaller decreases. Temporal trend and spatial patterns of daily maximum and minimum temperatures were also investigated to gain insight of DTR change.

1. Introduction

Daily mean temperature is generally used as a universal measurement for climate change study. However, mean temperature alone is not enough to reflect the complicated variations of climate. In fact, trends in mean surface temperature are often due to changes in daily maximum and minimum temperatures (Sun et al., 2006). So, diurnal temperature range is also an important indicator for climate change (Karl et al., 2004). DTR has steadily decreased throughout the United States (Karl et al., 1991), which can be attributed to the increase in mean daily temperature and a steady daily maximum temperature (Karl et al., 1991; Karl et al., 1984). Karl et al. studied cloudy and clear sky conditions and their impacts on diurnal temperature range (Karl et al., 1987). They found a significant decrease in diurnal temperature range over time during cloudy days. Many other additional factors that affect in diurnal temperature range including land use/land cover changes (Gallo et al., 1996), irrigation (Karl et al., 1988), station moves, desertification, and other climatic effects (Karl et al., 1993). Urbanization, also, has been extensively investigated in many papers (Karl et al., 1988; Landsberg, 1981; Wang et al., 2012). It was found that as the population of an urban center increases, the diurnal temperature range would shift in an asymmetrical manner (Karl et al., 1991). Despite these confounding variables, many studies have been conducted on diurnal temperature range study. A variety of data and methods have been used. Most studies utilized station observations and analyzed the trends of diurnal temperature range on global level (Karl et al., 2004; Easterling et al., 1997; Leathers et al., 1998). Karl et al. studied the decreasing diurnal temperature range in the United States and Canada (Karl et al., 1991). Sun et al. used satellites measurements to evaluate the diurnal temperature range (Sun et al., 2006). Park and Joh used climate models to predict diurnal temperature range changes (Park and Joh, 2005). These studies have analyzed the diurnal temperature range in the United States, but many of these studies used limited number of station observations, or covered limited historical period.

The primary objective of this study is to analyze the diurnal temperature range changes over the continental United States since 1911 through spatial and temporal analysis of observations from thousands of stations over the continental United States. The United States was separated into 4 regions where the trends of each region were analyzed as well as the United States as a whole. The four regions were analyzed through their four seasons as well as their yearly averages. DTR, as well as daily maximum temperature (TMAX) and minimum temperature (TMIN) are not only analyzed for region to region differences, but also, season to season differences.

2. Data and methodology

2.1. Data and study area

For this study, daily maximum and minimum air temperature was obtained from the National Climate Data Center's Global

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Historical Climatology Network Daily (Menne et al., 2012). The Global Historical Climatology Network Daily contains records from over 75,000 stations around the world. Maximum and minimum air temperature, snowfall, snow depth, and daily precipitation are primary variables provided by these stations (Menne et al., 2012). The data is comprised of daily climate records from numerous sources that have been integrated to a plethora of quality assurance reviews (Menne et al., 2012). The Global Historical Climatology Network Daily contains the most complete collection of United States daily climate summaries available, even provides some of the earliest observations available for the United States.

In this study, we focused on DTR analysis over the continental United States from year 1911–2012. Time series of daily maximum temperature and minimum temperature were also analyzed for further understanding of DTR trend. We investigated DTR change of the continental United States first, then analyzed spatial variations of DTR trends by separating into four spatial regions with longitude and latitude. The northern and southern regions were separated at 40° latitude, and the eastern and western portions were separated at the −100° longitude. We can mark these four regions as North West Region (NWR), North East Region (NER), South West Region (SWR), and South East Region (SER).

2.2. Method

Daily DTR data was obtained by subtracting daily minimum temperature from daily maximum temperature at each station. Then, spatial and temporal averages were conducted for regional, annual and seasonal analysis to get DTR time series for the continental United States and the four study regions.

Regional mean DTR, regional mean maximum temperature and regional mean minimum temperature are the average of DTR, daily maximum temperature and daily minimum temperature, respectively, at stations within the specified spatial area, i.e.

$$DTR_{region} = \frac{1}{N}\sum_j DTR_j.$$

$$TMAX_{region} = \frac{1}{N}\sum_j TMAX_j$$

$$TMIN_{region} = \frac{1}{N}\sum_j TMIN_j$$

where N is the number of stations over the specified region, DTR_j, $TMAX_j$ and $TMIN_j$ are daily DTR, maximum temperature and minimum temperature for the No. j station of the study region, respectively. Monthly DTR was calculated by averaging DTR for each month. Annual mean DTR was obtained through yearly average of regional DTR. And similarly, seasonal mean DTR was obtained by averaging DTR over specified season. Monthly and seasonal average maximum and minimum temperatures were obtained similarly.

Since the duration of each season changes with geolocation, in this study, we used the approximate season period for northern hemisphere, i.e. Feb. Mar. and Apr. for spring, May, Jun. and Jul. for Summer, Aug., Sep., and Oct. for fall, and Nov., Dec. and Jan. for winter.

3. Results and analysis

3.1. DTR trend of the continental USA

Fig. 1 illustrates the yearly average diurnal air temperature range, maximum air temperature, and minimum air temperature of the continental USA from year 1911–2012. Despite the fluctuations from year to year because of various climate factors, a steadily decreasing trend of DTR can be identified statistically, with a slope of −0.004658 °C/yr. Especially, during recent decades, the decreasing trend is more significant. Since 1991, the yearly mean DTR are usually below 13.5 °C. As demonstrated in Fig. 1, the annual mean maximum air temperature has a slightly increasing

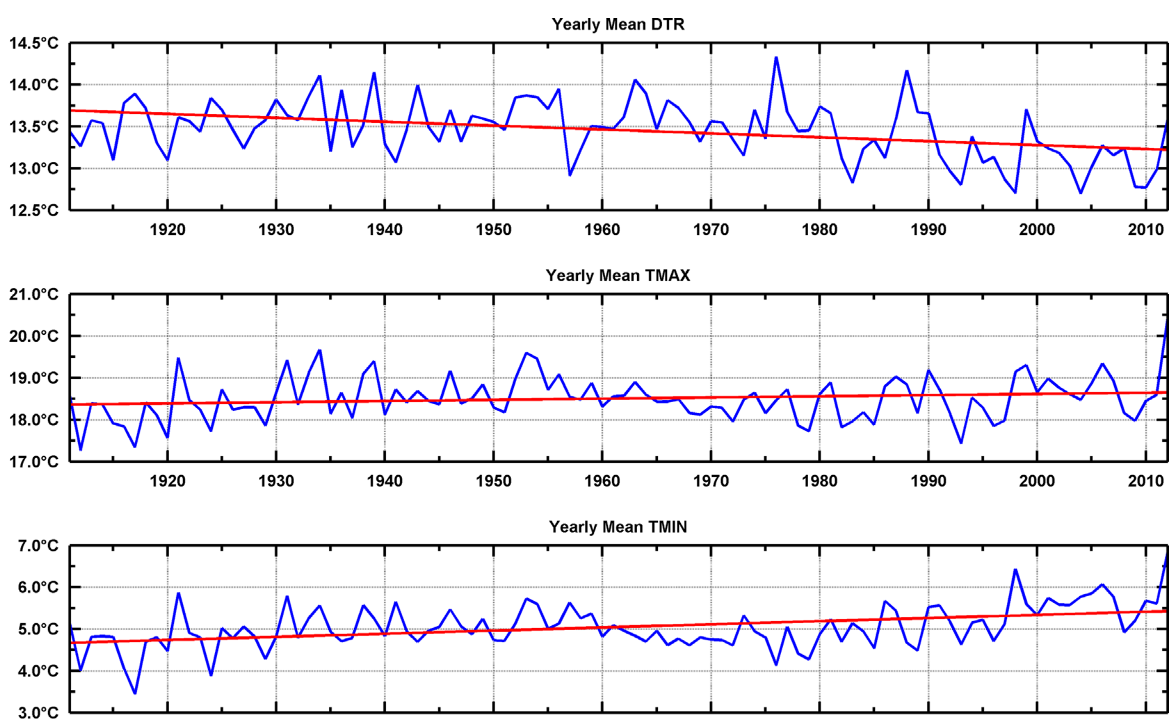

Fig. 1. Yearly average diurnal air temperature range (DTR), maximum air temperature, and minimum temperature of the continental USA.

trend at 0.002848 °C/yr, but the annual mean minimum air temperature is rising at a much faster rate, 0.007506 °C/yr. So, the significantly increasing trend of mean minimum temperature contributes to the decrease of mean DTR.

Since temperate change has seasonal patterns, time series of seasonal average DTR, TMAX, and TMIN of the continental USA were analyzed to investigate seasonal characteristics of DTR change, as illustrated in Figs. 2–5. Trends of seasonal DTR, TMAX and TMIN were summarized in Table 1. Obviously, from Figs. 2–5 and Table 1, TMAX and TMIN have different seasonal behaviors, and DTR change demonstrates seasonal patterns. DTR has decreasing trend in all the 4 seasons, with the highest decrease rate in summer, and the lowest decrease rate in winter. In summer, TMAX has a slightly decreasing trend, but TMIN shows the highest

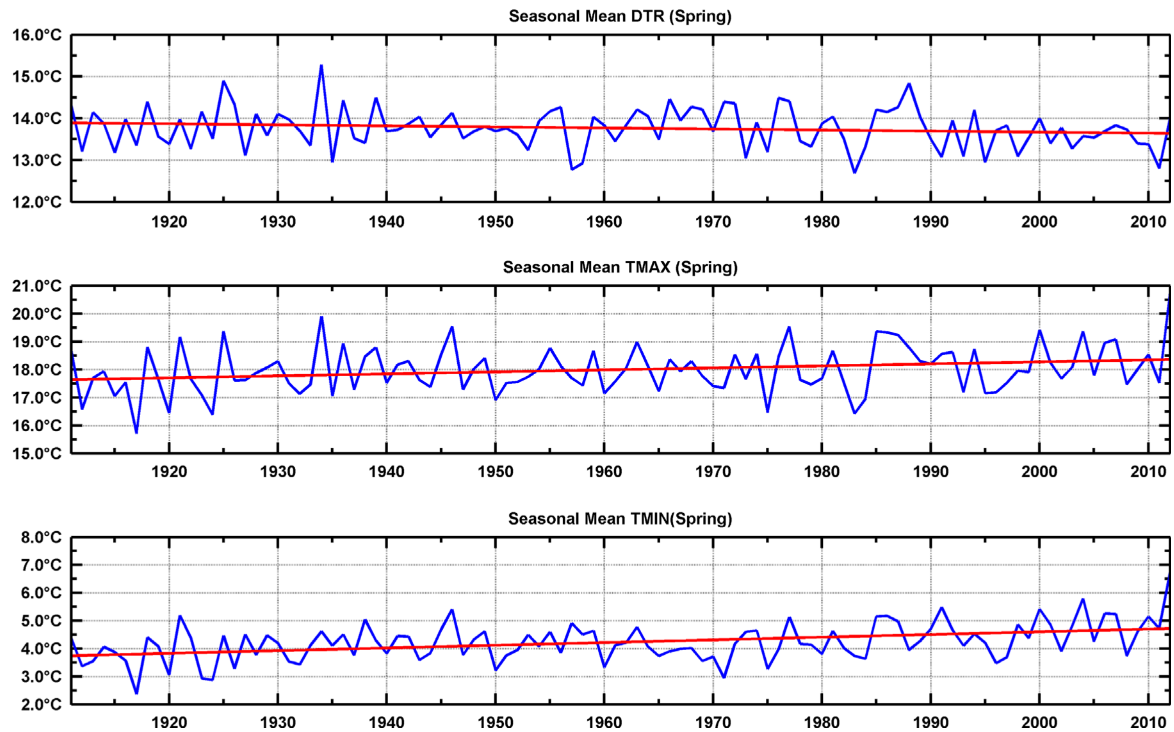

Fig. 2. Seasonal average diurnal air temperature range (DTR), maximum air temperature (TMAX), and minimum temperature (TMIN) of the continental USA in spring.

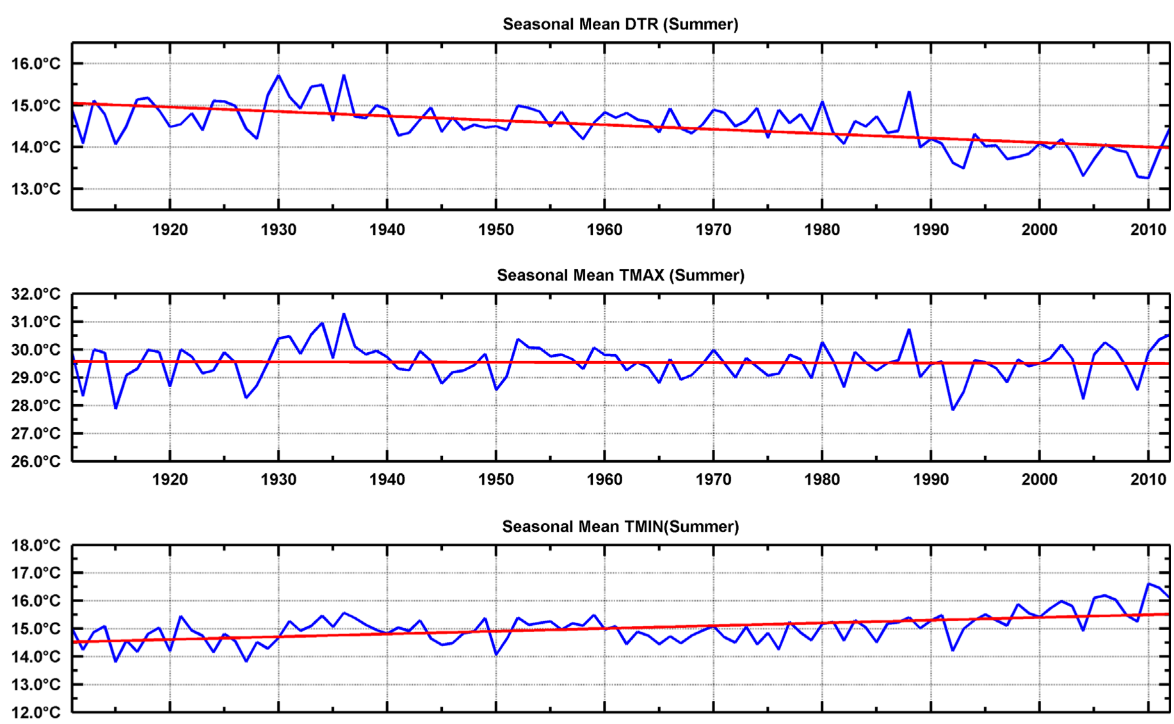

Fig. 3. Seasonal average diurnal air temperature range (DTR), maximum air temperature (TMAX), and minimum air temperature (TMIN) of the continental USA in summer.

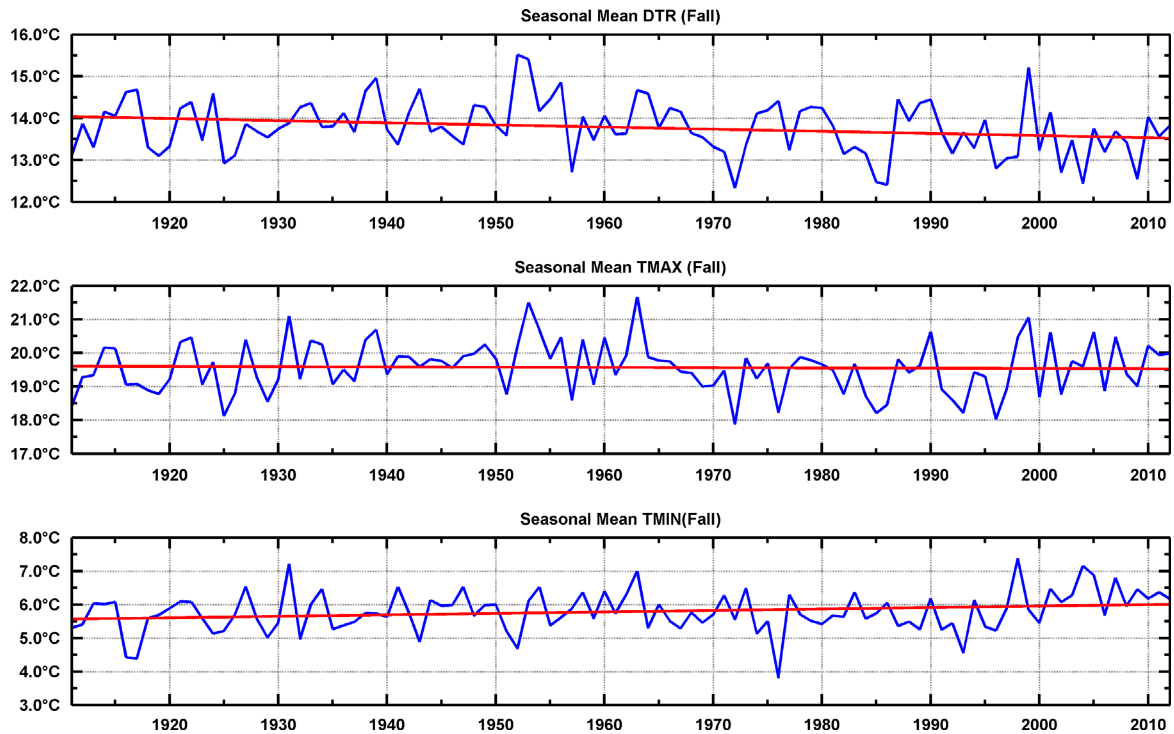

Fig. 4. Seasonal average diurnal air temperature range (DTR), maximum air temperature (TMAX), and minimum air temperature (TMIN) of the continental USA in fall.

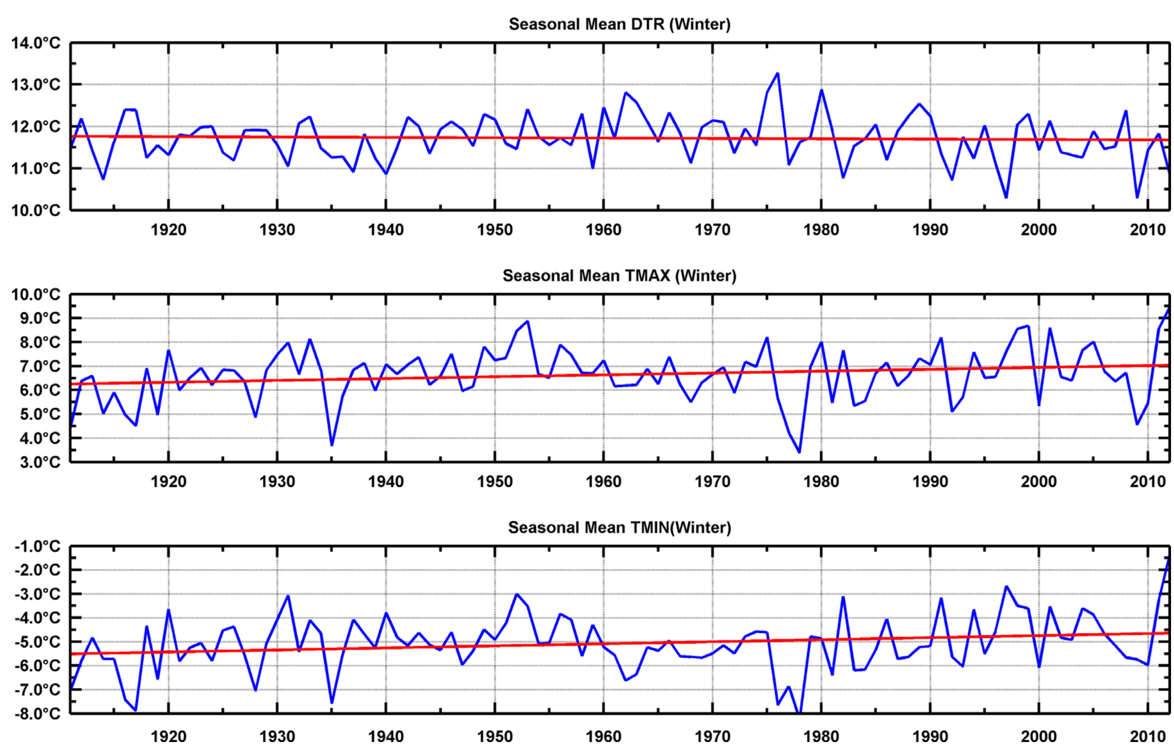

Fig. 5. Seasonal average diurnal air temperature range (DTR), maximum air temperature (TMAX), and minimum air temperature (TMIN) of the continental USA in winter.

increasing rate among the 4 seasons, so DTR demonstrates the most significantly decreasing trend, at the rate of -0.010594 °C/yr. In winter, both TMAX and TMIN demonstrate significantly increasing trend, however, the rates are close, so DTR shows relatively stable change comparing to other seasons.

3.2. Regional DTR trend

Climate elements, especially temperature and precipitation, usually vary both spatially and temporally. It is desirable to investigate regional patterns of DTR changes. Fig. 6 shows the

Table 1
Trends of seasonal average daily maximum temperature (TMAX), minimum temperature (TMIN), and diurnal air temperature range (DTR) (unit: °C/yr) of the continental USA.

Variable	Season			
	Spring	Summer	Fall	Winter
TMAX	0.007170	−0.000701	−0.000761	0.007740
TMIN	0.009669	0.009893	0.004355	0.008576
DTR	−0.002499	**−0.010594**	−0.005116	−0.000837

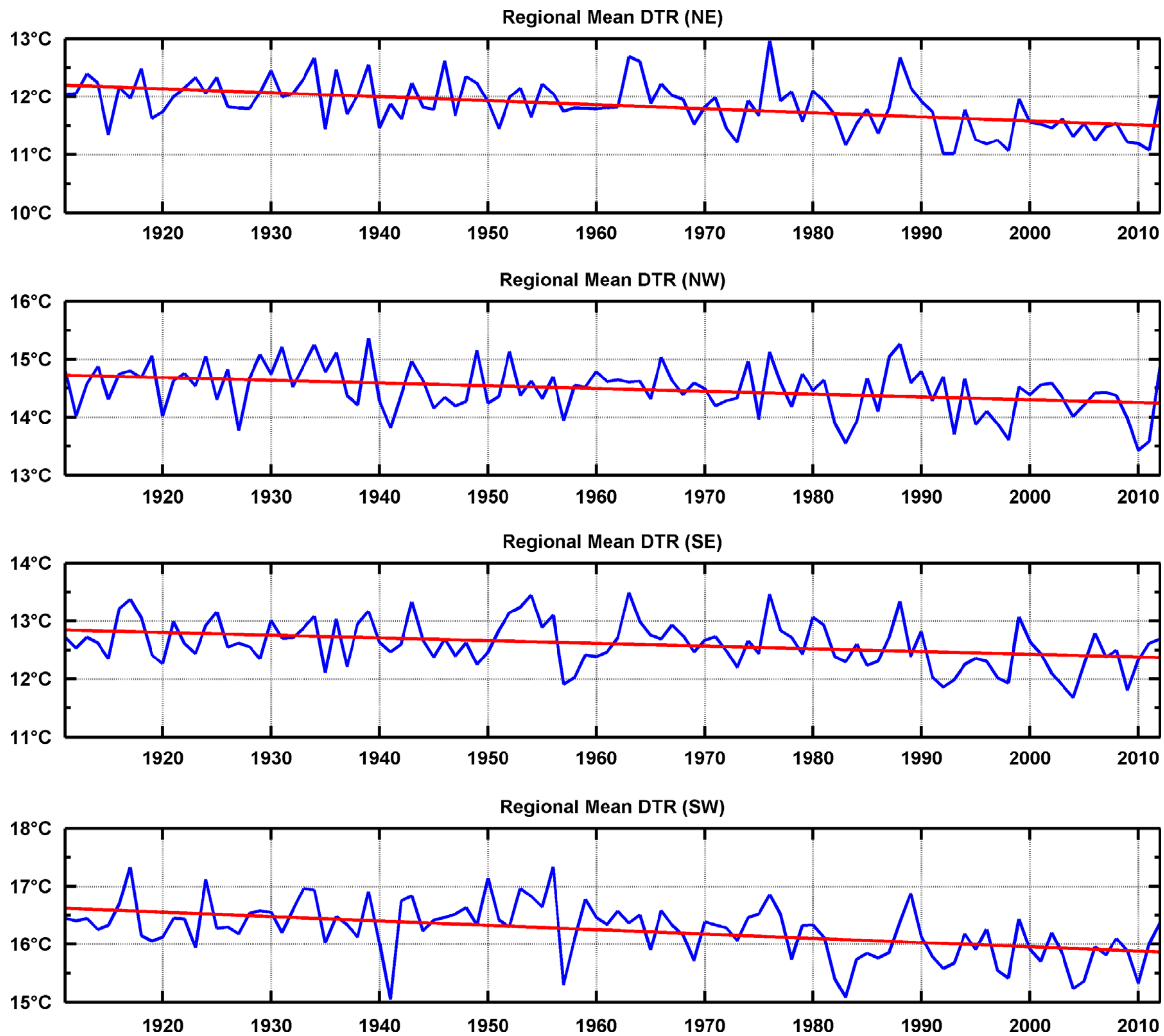

Fig. 6. Regional average diurnal air temperature range (DTR), maximum air temperature (TMAX), and minimum air temperature (TMIN) of the continental USA.

regional yearly mean DTR of the 4 regions mentioned above. Obviously, regional DTR differences are quite significant. The western regions usually have much higher DTR than the eastern regions. All the four regions show decreasing trend of DTR over the past 100 years.

DTR change also has significant regional differences, as indicated in Table 2 and Figs. 7 and 8. The Southwest region has most rapid DTR decreasing rate at −0.007462 °C/yr, while the Southeast region has the slowest DTR decreasing rate at −0.004661 °C/yr. All the four regions show increasing trend of yearly average minimum air temperature, especially the Northwest region, where the yearly average minimum temperature has a trend at 0.005847 °C/yr. But time series of yearly average maximum temperature shows remarkable differences in trend between eastern and western regions, the Southwest and Northwest regions demonstrate increasing trend, while the Southeast and Northeast show decreasing trend.

To further investigate the temporal and spatial changes of DTR, seasonal mean DTR, TMAX and TMIN of the 4 regions were analyzed. The DTR change rates are listed in Table 3, which demonstrates the spatial and seasonal variations of DTR trend. Trends of seasonal average maximum and minimum air temperature of the four regions were also investigated, as summarized in Tables 4 and 5. In spring, the Northeast region has the most rapid decreasing rate of DTR at −0.005277 °C/yr, but the Southwest regions has the most rapid increasing trend of both average

Table 2
Trends of yearly average daily maximum air temperature (TMAX), minimum air temperature (TMIN), and diurnal air temperature range (DTR) (unit: °C/yr) of the four regions.

Variable	Region			
	Northeast	Northwest	Southeast	Southwest
TMAX	−0.005425	0.001080	−0.001874	0.006946
TMIN	0.001503	0.005847	0.002787	0.014408
DTR	−**0.006928**	−0.004767	−0.004661	−**0.007462**

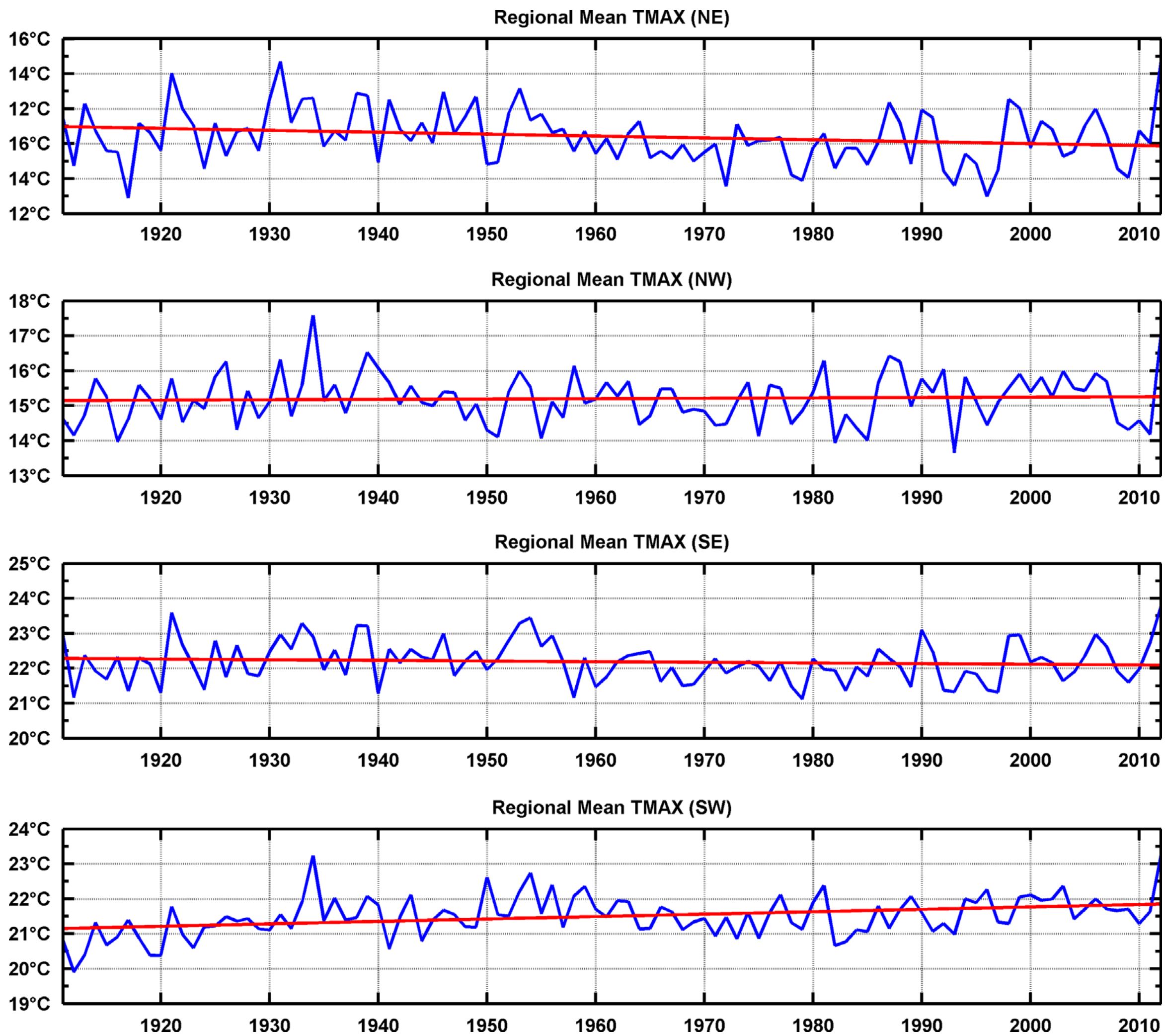

Fig. 7. Time series of regional yearly average maximum air temperature (TMAX).

maximum and minimum air temperature. In summer, all the four regions demonstrate highly decreasing rate of DTR and significantly increasing trend of average minimum air temperature, but the eastern regions and western regions show opposite trend in average maximum air temperature. In fall, the Southwest region has most significant decreasing trend of average DTR comparing with the other 3 regions. The DTR decreasing rate of Southwest region in fall is a little bit higher than that in summer, while all the DTR decreasing rates of other 3 regions are lower than the corresponding summer seasons. For average maximum air temperature in fall, the Southwest region shows increasing trend, while other regions show decreasing trend. For average minimum air temperature in fall, only the Northeast region shows decreasing trend, while other regions show increasing trend. In winter, the Northeast region has the most significant decreasing trend of average DTR, with a decreasing trend in average maximum air temperature.

And, for each region, the seasonal differences of DTR trend are obvious (Table 1 and Figs. 9–12). Figs. 9–12 illustrate the trend of seasonal average DTR over the past 100 years of the Northeast, the Northwest, the Southeast, and the Southwest region, respectively. In Northeast region (Fig. 9), the mean DTR in summer decreased much more significantly than the other seasons. The spring season has the less significant DTR decreasing rate. And the Northeast region shows decreasing trend of average minimum air temperature (Table 5), which is opposite to other seasons and regions.

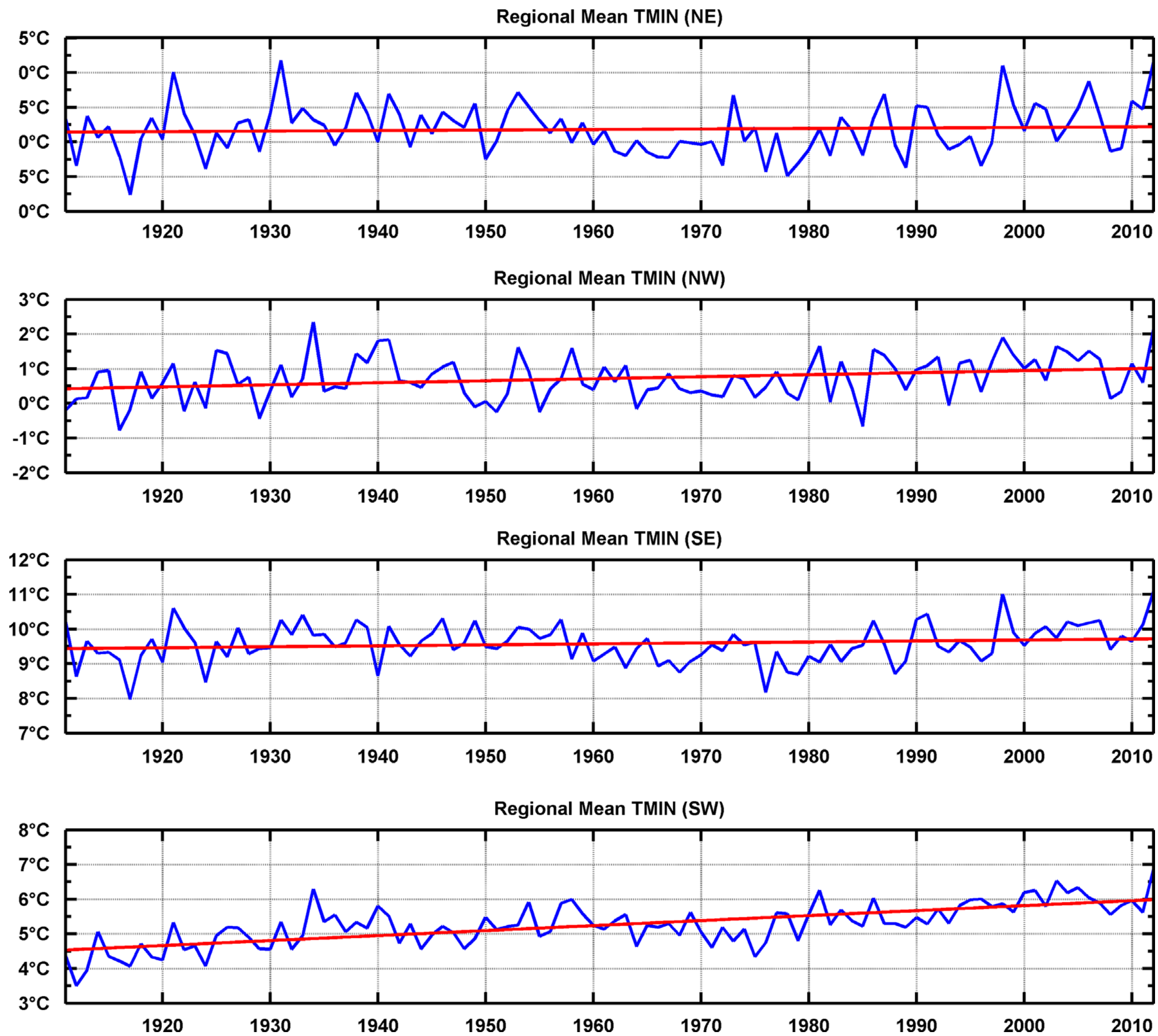

Fig. 8. Time series of regional yearly average minimum air temperature (TMIN).

Table 3
Trend of seasonal average diurnal air temperature range (DTR) (°C/yr) of the four regions.

Season	Region			
	Northeast	Northwest	Southeast	Southwest
Spring	−0.003918	−**0.005277**	−0.002702	−0.002759
Summer	−**0.013702**	−**0.008872**	−**0.010837**	−**0.011027**
Fall	−0.005797	−0.003041	−0.006048	−**0.012314**
Winter	−**0.004981**	−0.002062	0.000895	−0.004241

Table 4
Trend of seasonal average maximum air temperature (DTR) (°C/yr) of the four regions.

Season	Region			
	Northeast	Northwest	Southeast	Southwest
Spring	0.000494	0.000055	0.004035	**0.011730**
Summer	−**0.009398**	0.000204	−0.004526	**0.007694**
Fall	−**0.009143**	−0.000727	−0.004825	**0.002005**
Winter	−**0.000854**	0.006151	0.000368	**0.006597**

Table 5
Trend of seasonal average minimum air temperature (DTR) (°C/yr) of the four regions.

Season	Region			
	Northeast	Northwest	Southeast	Southwest
Spring	0.004412	0.005333	0.006737	**0.014489**
Summer	0.004304	0.009076	0.006311	**0.018716**
Fall	−0.003345	0.002314	0.001223	**0.014318**
Winter	0.004128	0.008213	−0.000527	**0.010838**

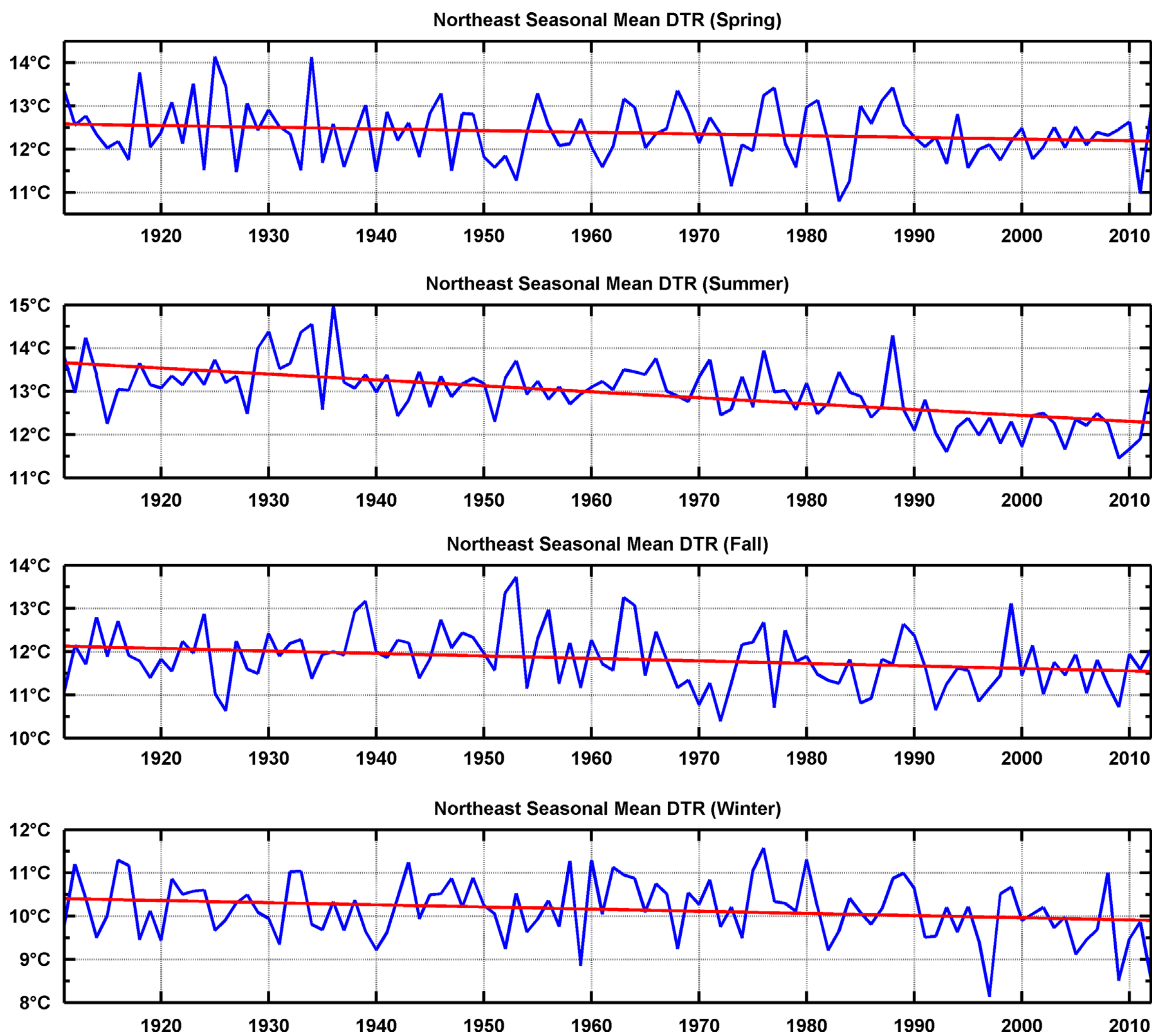

Fig. 9. Time series of seasonal average diurnal air temperature range (DTR) of the Northeast region.

In Northwest region (Fig. 10), the mean DTR in summer is higher than other three seasons, but relatively low than other regions during the summer season. The winter season has the lowest DTR decreasing rate. In Southeast region (Fig. 11), the most significant decrease of DTR occurred also in summer, while no significant decrease found during winter season. In Southwest region (Fig. 12), both summer and fall seasons demonstrate high decreasing rate of DTR, and the fall season has the most significant decreasing trend, which is different from other 3 regions. Especially, the Southwest region shows highest increasing rate in both average maximum and minimum air temperature (Tables 4 and 5).

4. Conclusions and discussions

Although there is a steady decreasing trend of DTR over the United States in the past 100 years, as demonstrated in this paper and previous studies, the DTR trend also has spatial and temporal variations. In this study, the temporal and spatial variations of DTR trend over the past 100 years were investigated. A steadily decreasing trend of average DTR over the continental USA was identified statistically. Especially, during recent decades, the DTR decreasing trend is more significant. While the annual mean maximum air temperature of the continental USA has a very

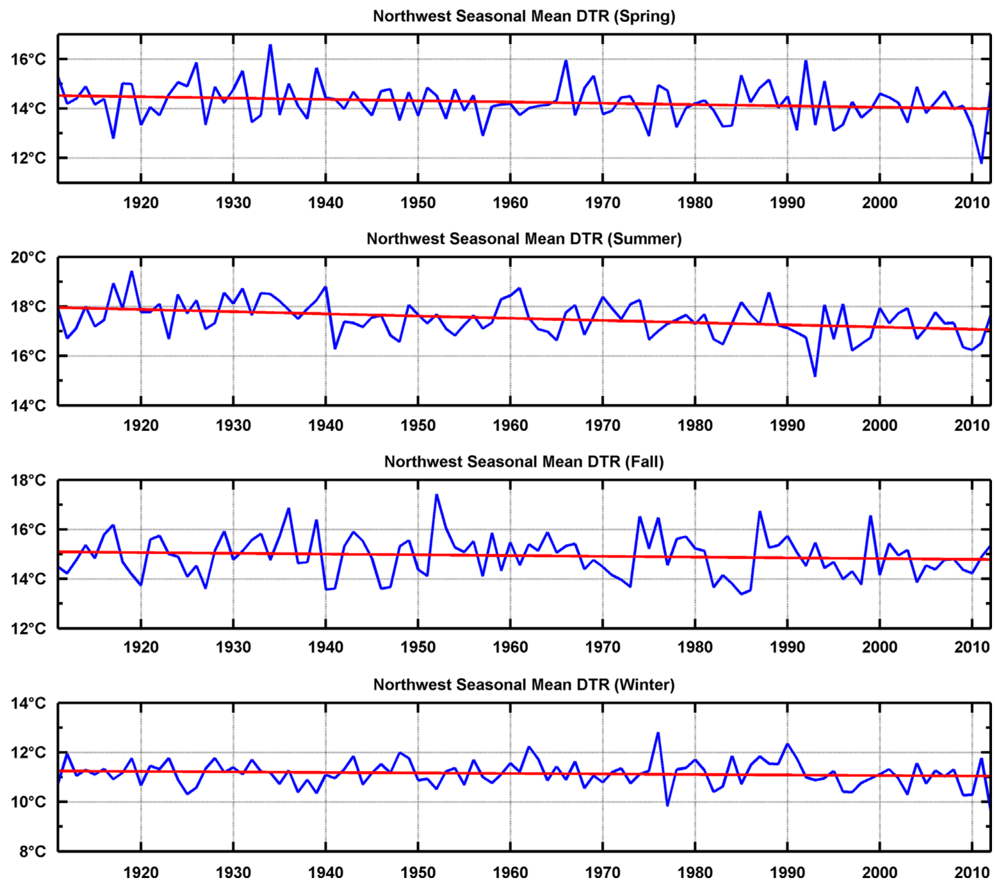

Fig. 10. Time series of seasonal average diurnal air temperature range (DTR) of the Northwest region.

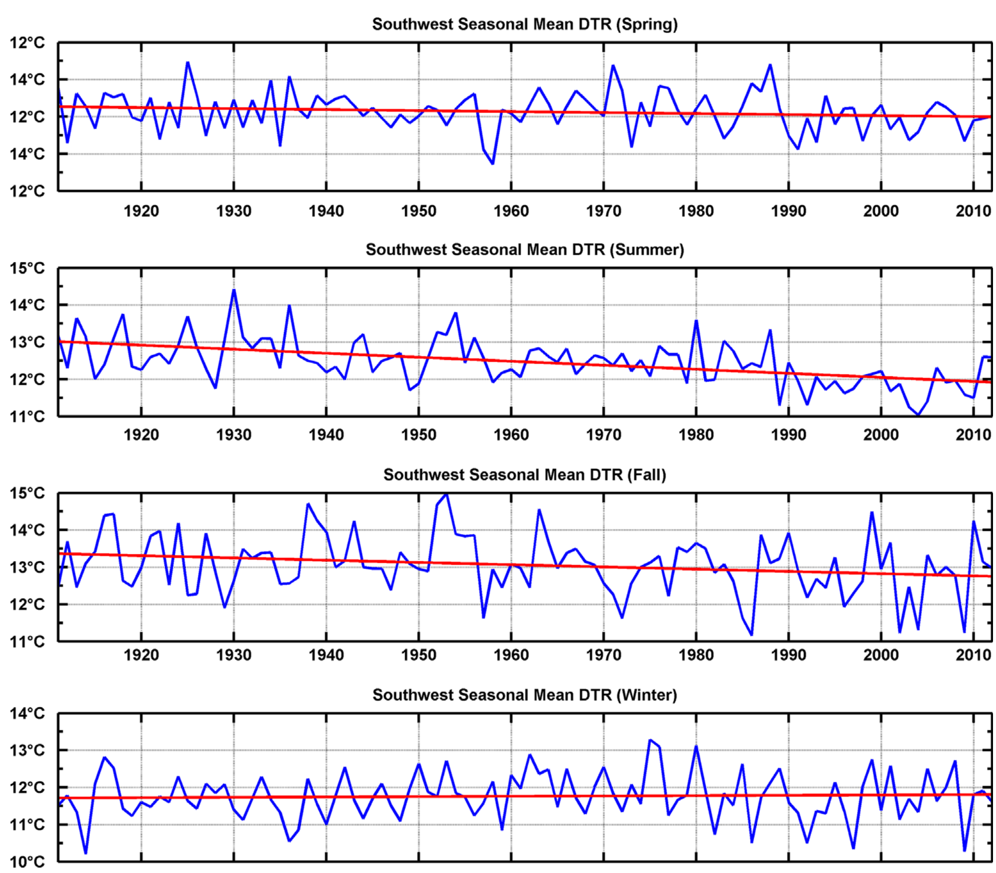

Fig. 11. Time series of seasonal average diurnal air temperature range (DTR) of the Southeast region.

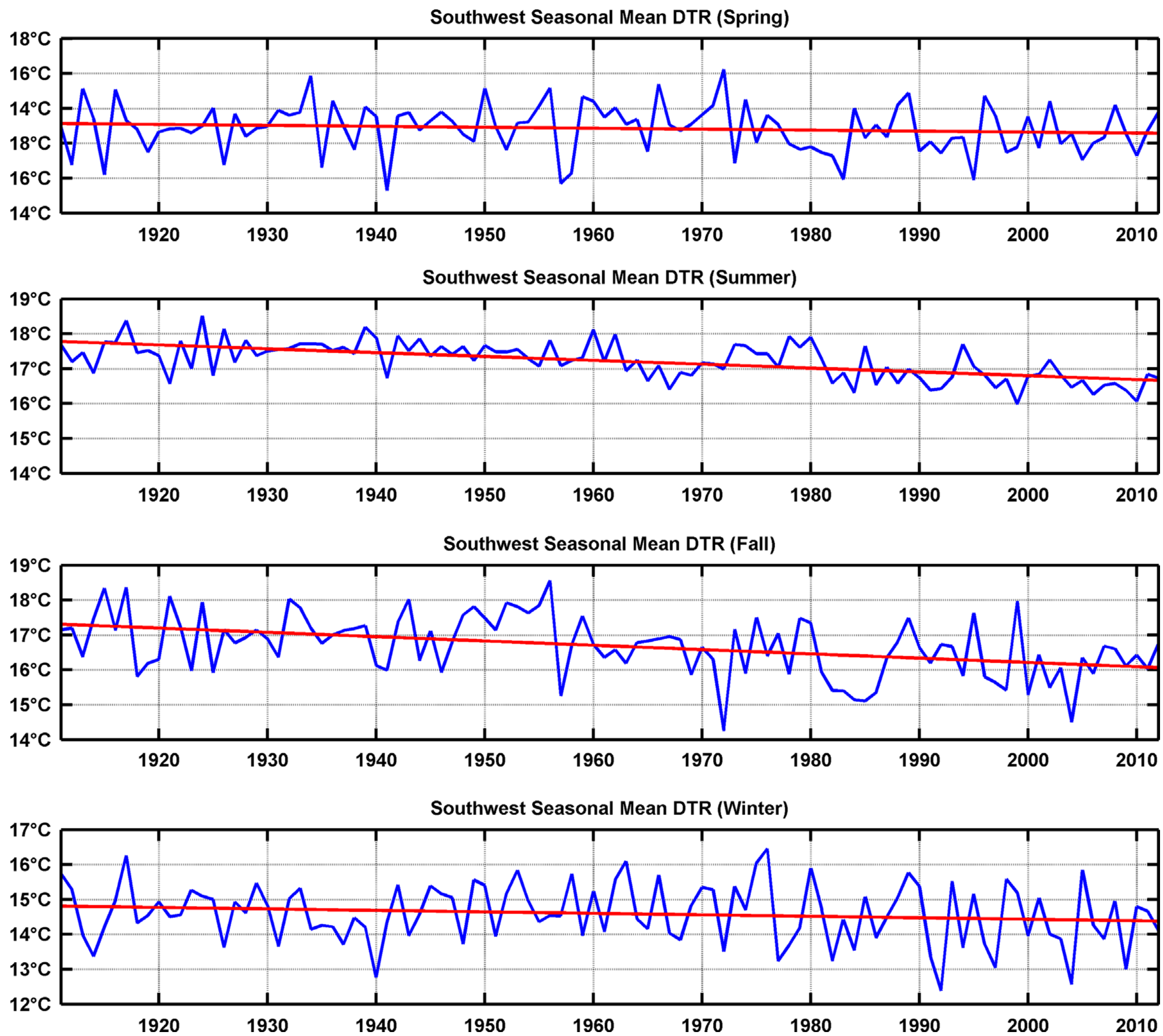

Fig. 12. Time series of seasonal average diurnal air temperature range (DTR) of the Southwest region.

slightly increasing trend, the annual mean minimum air temperature is rising at a much faster rate, which may explain the decrease of mean DTR. And, trends of average DTR, maximum air temperature and minimum air temperature have significant seasonal and regional differences. The summer and fall seasons usually demonstrate higher DTR decreasing rate than the spring and winter seasons. The DTRs over the 4 regions differ not just in value but also in the decreasing rates and seasonal variations. Although time series of average maximum air temperature and minimum air temperature can help understand DTR trend, further analysis is necessary in future study to investigate various factors related to the spatial and temporal changes of DTR trend.

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