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ORIGINAL PAPER

Inconsistencies of precipitation in the eastern and central Tibetan Plateau between surface adjusted data and reanalysis

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Abstract The Tibetan Plateau (TP) is the source of many Asian river systems and serves as "the Asian water tower". Precipitation variability is a strong component of both hydrological processes and energy cycles, and the study of precipitation in the TP is of great importance in the content of global warming. In this study, the annual and seasonal (spring: MAM; summer: JJA; autumn: SON; and winter: DJF) variations in precipitation are investigated in the eastern and central TP during 1961–2007, based on surface raw and adjusted observations as well as both NCEP/NCAR (1961–2007) and ERA-40 (1961–2001) reanalyses. The adjusted precipitation in the TP is higher than raw values on both the annual and seasonal basis due to adjustments of solid precipitation by a bias experiential model. At the annual spring and winter scales, the adjusted precipitation shows a significant increase calculated by the Mann–Kendall trend test. Compared with adjusted precipitation; both NCEP/NCAR and ERA-40 reanalyses capture the broad spatial distributions of mean annual and seasonal precipitation, but are less good at repeating the decadal variability. Both reanalyses show the drying phenomena in most regions and fail to represent the change patterns of precipitation observed by the adjusted observations. Both NCEP/NCAR and ERA-40 have larger inconsistencies which may be caused by the differences between actual and model topography. This suggests that it is crucial to use the adjusted precipitation in the climate research and reanalysis products should be paid more attention in the TP.

1 Introduction

The variability of precipitation is crucial for the operation of many Earth surface processes, and is an important component in water resources management, agriculture production, and drought and flood forecasting (IPCC 2007). Reliable estimates of precipitation are required because precipitation is a major component of the Earth's hydrological and energy cycles (Kang et al. 2010; Qiu 2008). Our knowledge of precipitation patterns is incomplete, particularly in areas of complex relief and at high elevations. The Tibetan Plateau (TP) has an average elevation of over 4,000 m a.s.l. and been called "the roof of the world", and it is the highest and biggest plateau in the world with an area of approximately 2.5×10^6 km^2. The TP influences global atmospheric circulation through both thermal and mechanical forcing (Duan and Wu 2005; Yeh and Gao 1979) and is also the source of

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many rivers in South and East Asia, as melting water from snow and glaciers at high elevation is released to the Indus, Ganges-Brahmaputra, Yangtze, and other river systems (Barnett et al. 2005; Immerzeel et al. 2010). Thus, the TP is called "the Asian water tower" (Xu et al. 2008a) supporting the livelihoods of Asian people. Furthermore, the TP contains the largest cryospheric area outside the polar zones, which includes mountain glaciers, latitudinal and altitudinal permafrost, seasonally frozen ground, ephemeral snow cover, and lake and river ice (Li et al. 2008). Therefore, the cryospheric system in the TP plays a significant role in hydrological cycle both at regional and global scales. Both climate and the cryosphere are undergoing rapid change (Kang et al. 2010; Qiu 2008), which will have profound effects on the Asian "water towers" (Immerzeel et al. 2010).

Causes and impacts of climate change have been represented and discussed in our previous papers (You et al. 2008a, b, 2010a, b, c), such as extreme climate, sunshine duration, and elevation effect. Mean annual temperature in the TP during 1961–2004 has significantly increased with a rate of 0.25°/decade (You et al. 2010b), in phase with the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) (IPCC 2007). The rising temperature has important consequences for the hydrological cycle, particularly at high elevations in the TP where water supply is currently dominated by melting snow and/or ice (Barnett et al. 2005). In a warmer world, summer precipitation may share a greater part in controlling water supply. Both precipitation in summer and winter in the TP already have important direct and indirect influences on the distributions of surface temperature, atmospheric water vapor, boundary layer moisture convergence, patterns of subsequent convection, and the development of the monsoon system (Duan and Wu 2005; IPCC 2007; Xu et al. 2008a; Yeh and Gao 1979; You et al. 2008a, 2010b). Most of the current precipitation (greater than 60–90% of the annual total) falls between June and September with less than 10% falling between November and February (Xu et al. 2008b). Summer precipitation gradually decreases from southeast to northwest, from 700 mm in the Yarlung Zangbo river basin to less than 50 mm in the Qaidam basin. Such changes are also reflected in a vegetation gradient, which varies from montane forest through grassland to desert (Liu and Yin 2001). This may be explained that the TP was influenced by different climate systems, and westerly flows influence the northern TP and southerly monsoon flows control the southeastern TP (Qian and Qin 2008).

Due to complex terrain and extreme elevations, precipitation data is scarce and its characteristics are not well studied (Kang et al. 2010), and knowledge of local patterns on precipitation is also limited. It is hard to obtain reliable observations where standard rain gauge is unavailable, snow is a major component of precipitation, and wind speed shows strong. On the other hand, reanalyses cover a large range of spatial and temporal scales and are potentially helpful in the data poor region. The objective of this study is to investigate the annual and seasonal (spring: MAM; summer: JJA; autumn: SON; and winter: DJF) precipitation variations in the eastern and central TP based on raw and adjusted observations, and furthermore to compare these variations with those in two reanalyses. The reanalyses consist of the National Centers for Environmental Prediction/National Center for Atmospheric Research Reanalysis (NCEP/NCAR hereafter) (Kalnay et al. 1996; Kistler et al. 2001) and European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis (ERA-40 hereafter) (Uppala et al. 2005).

2 Data and methods

2.1 Raw observational data

Monthly surface precipitation data for 71 stations in the Tibetan Plateau are provided by the National Meteorological Information Center, China Meteorological Administration (NMIC/CMA) (Fig. 1). Stations were selected according to described procedures (You et al. 2008a, b, 2010a, c). World Meteorological Organization number, name, longitude, latitude, elevation, and missing period of stations are described in You et al. (2008a). The TP covers most of the Tibet Autonomous Region and Qinghai Province, in addition to smaller portion of western Sichuan, southwestern Gansu, and northern Yunnan in China. Most meteorological stations were established until the middle of the 1950s, there are 156 stations in the raw dataset but 85 stations were excluded due to various reasons (low elevation, incomplete, or inconsistent data). The distribution of remaining 71 stations with elevations above 2,000 m a.s.l. is concentrated in the central and eastern part of plateau (Fig. 1) (You et al. 2008a, b, 2010a, c). The period of 1961–2007 was selected for analysis.

2.2 Adjusted observational data

Raw precipitation amounts (both rainfall and snowfall) are usually underestimated because of trace precipitation amounts, wind effects, wetting and evaporation losses, and equipment design. Bias adjustments to compensate for some of these factors are crucial in the TP because solid precipitation (a large proportion of the total) is especially sensitive to wind and gauge type (Ma et al. 2009; Yang et al. 2005; Ye et al. 2004). The general model for adjusting China Meteorological Administration

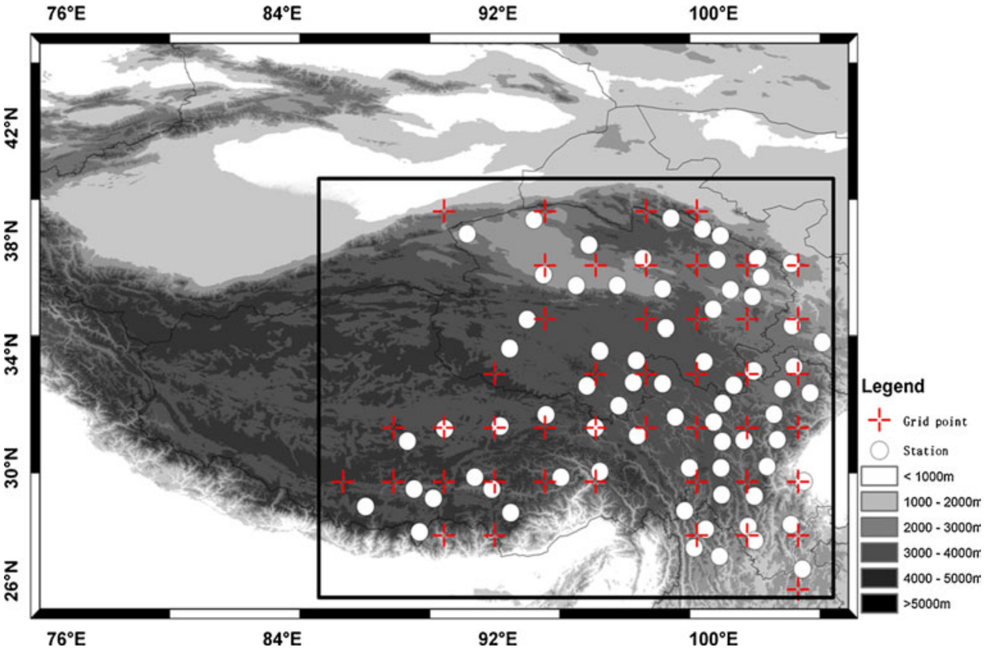


Fig. 1 Distributions of 71 surface stations (*dot*) and the nearest reanalysis (NCEP/NCAR and ERA-40) grid points to the stations (*cross in rectangle*) in the eastern and central Tibetan Plateau

(CMA) raw precipitation used by Yang et al. (2005) and Ye et al. (2004) is as follows:

$$P_c = K(P_g + \Delta P_w + \Delta P_e + \Delta P_t)$$

Where P_c is the adjusted precipitation, P_g is the gauge measured raw precipitation; ΔP_w and ΔP_w are adjustment for wetting loss and evaporation loss, respectively; ΔP_t is an adjustment for trace precipitation which is a small amount independent of wind effects; and K is the correction coefficient (usually $K>1$) to compensate for wind-induced errors.

Wetting loss experiments in China (Ye et al. 2004) show that the average wetting loss for measured precipitation are 0.23, 0.30, and 0.29 mm for rainfall, snow, and mixed precipitation, respectively. The adjustment for evaporation loss is set to zero because annual evaporation loss in China is very low, aided by the use of a funnel and container during the high-evaporation period (Ma et al. 2009). Trace precipitation (less than 0.10 mm) is recorded as zero but classified as a precipitation day. Thus, any trace observations are assigned a value of 0.10 mm (Ma et al. 2009). Wind-induced under-catch is often the largest error in precipitation measurements. Detailed methods to correct this bias are described in the literatures (Ma et al. 2009; Yang et al. 2005; Ye et al. 2004).

2.3 Reanalysis precipitation data

Mean monthly precipitation rates from NCEP/NCAR reanalysis are provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their website at http://www.cdc.noaa.gov/. The precipitation rate (unit: kg m^{-2} s^{-1}) is converted to precipitation amount (unit: mm). The dataset covers January 1948 to the present day with a spatial resolution of 2.5°×2.5° (Kalnay et al. 1996). Although NCEP/NCAR reanalysis produces fairly realistic precipitation in high latitudes over Asia and North America (Kistler et al. 2001), the quality of the product is influenced by the changing observation coverage with different quality for different regions (Ma et al. 2009). Mean monthly surface precipitation values in ERA-40 are obtained from the ECMWF website (http://www.ecmwf.int/). ERA-40 precipitation output includes both rainfall and snowfall, and convective precipitation and large-scale precipitation are added to produce the total precipitation amount. ERA-40 is available from September 1957 to August 2002, also with a spatial resolution of 2.5°×2.5° (Uppala et al. 2005). The advantage of reanalysis over operational analyses is that no system changes occur that might affect the analysis products, although there are often significant changes in the input observations (Betts et al. 2003). The period of 1961–2001 was selected for ERA-40. To compare the surface stations, the nearest reanalysis (NCEP/NCAR and ERA-40) grid points to the stations are derived, although the comparisons have limitations due to large spatial scale of reanalysis (Fig. 1). The method is still regarded as a simple and good choice to perform the difference between reanalysis and station.

2.4 Trend calculation

The Mann–Kendall test for a trend with Sen's slope estimates was used to detect and estimate trends in annual and seasonal precipitation (Sen 1968). It has been widely used to compute trends in hydrological and meteorological series. For example, the method was applied to study the spatial and temporal variability of precipitation in China in recent decades (Gemmer et al. 2004), and to investigate decadal trend of temperature and precipitation in the Tibetan Plateau (Xu et al. 2008b).

The Mann–Kendall statistic S is calculated as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \quad \operatorname{sgn}\,(x_j - x_k) = \left\{ \begin{array}{ccc} +1 & \text{if} & x_j - x_k > 0 \\ 0 & \text{if} & x_j - x_k = 0 \\ 1 & \text{if} & x_j - x_k < 0 \end{array} \right\}$$

The variance for the statistic S is defined by:

$$\mathrm{Var(S)} = \frac{n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)}{18}$$

The test statistic Z is estimated as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{VAR}(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sqrt{\mathrm{VAR}(S)}} & if \quad S < 0 \end{cases}$$

In which Z follows a standard normal distribution, if $|Z| > Z_{1-\alpha/2}$, where α denotes the significant level, then the trend is significant. Sen's method is used to estimate the Kendall slope, and it is defined as the median over all combinations of record pairs for the whole dataset. It is given as follows:

$$Q = \mathrm{median}(\frac{x_j - x_k}{j - k}); i = 1, \ldots\ldots N.$$

A trend is considered to be statistically significant at the 95% level ($P<0.05$).

3 Results

3.1 Comparison between adjusted and raw precipitation

Absolute differences between the adjusted and raw precipitation data illustrate that the adjusted precipitation in the Tibetan Plateau is higher than raw precipitation on the annual and seasonal basis (Fig. 2 and Table 1). The annual bias adjustment in individual years varies from 9.8 to 153.3 mm with an overall mean of 119.4 mm in the TP during the studied period, or about 2.0–30.6% with an average of 23.8% of the raw annual precipitation. These adjustments are similar to those used in the rest of China (8–740 mm with an overall mean of 130 mm (19%) at 710 stations during 1951–1998), corresponding to 6–62% (Ye et al. 2004). At a global scale, similar bias adjustments have been employed, enhancing monthly precipitation amounts by 5–20% (Yang et al. 2005). Our adjustments are greater in summer (58.8 mm) than in winter (6.6 mm) due to larger amount of precipitation in summer (Table 1). Bias adjustments also vary spatially with higher values in the southeastern TP, especially in the western Sichuan Basin. After adjustments have been applied, annual and seasonal precipitation amounts in the TP are much higher than previously reported, but consistent with other studies in China and on a global scale (Ma et al. 2009; Yang et al. 2005; Ye et al. 2004).

The precipitation has large spatial gradients in both raw and adjusted data across the TP (Fig. 2a, b). The adjusted mean annual precipitation decreases gradually from southeast to northwest (Fig. 2b) and this gradient is enhanced somewhat by the adjustments (Fig. 2c) which also has largest value in the southeastern part. The adjusted mean annual precipitation over the whole plateau is 620.4 mm, most of which falls in summer (355.4 mm or about 50–70% of the annual total (Fig. 3)). Summer precipitation contributes directly to surface runoff or deposits as snow on the highest mountains. The small amount of winter precipitation will be stored as snow-pack and only provide a slow release of water for summer river discharge (Xu et al. 2008a).

During the studied period (1961–2007), the annual adjusted precipitation in the TP has increased with a rate of 5.13 mm/decade, but this trend is not significant (Table 2). However, of the 71 stations, about 52 stations show increasing trends, mainly in the southern TP (Fig. 4). Spring and winter, on the other hand, show significant increasing trends for the plateau as a whole (4.74 and 1.05 mm/decade, respectively, $P<0.05$; Table 2). Overall, spatial patterns of precipitation trends are similar to previous studies which used raw precipitation data (Xu et al. 2008b). Stations in the southern TP show the largest trend magnitudes, while the area at the headwater of the Three-River-Area (the Yangtze River, the Lantsang River, and the Yellow River) shows a drying similar to that reported by Xu et al. (2008b). Our results are in agreement with that precipitation in the TP has increased in most regions over the past several decades, especially in the eastern and central TP.

3.2 Comparison between adjusted precipitation and reanalyses

3.2.1 Instantaneous climatology

Figure 5 shows the distributions of mean precipitation interpolated using NCEP/NCAR (1961–2007) and ERA-40 (1961–2001) on the annual and seasonal basis in the TP. The Kriging interpolation method is selected and calculated by Surfer software 7.0 Version. It is noticeable that the interpolation method has not considered the digital elevation

Fig. 2 Spatial distribution of mean annual raw precipitation (**a**), adjusted precipitation (**b**), and the differences between them (**c**) in the eastern and central Tibetan Plateau during 1961–2007. The unit is mm

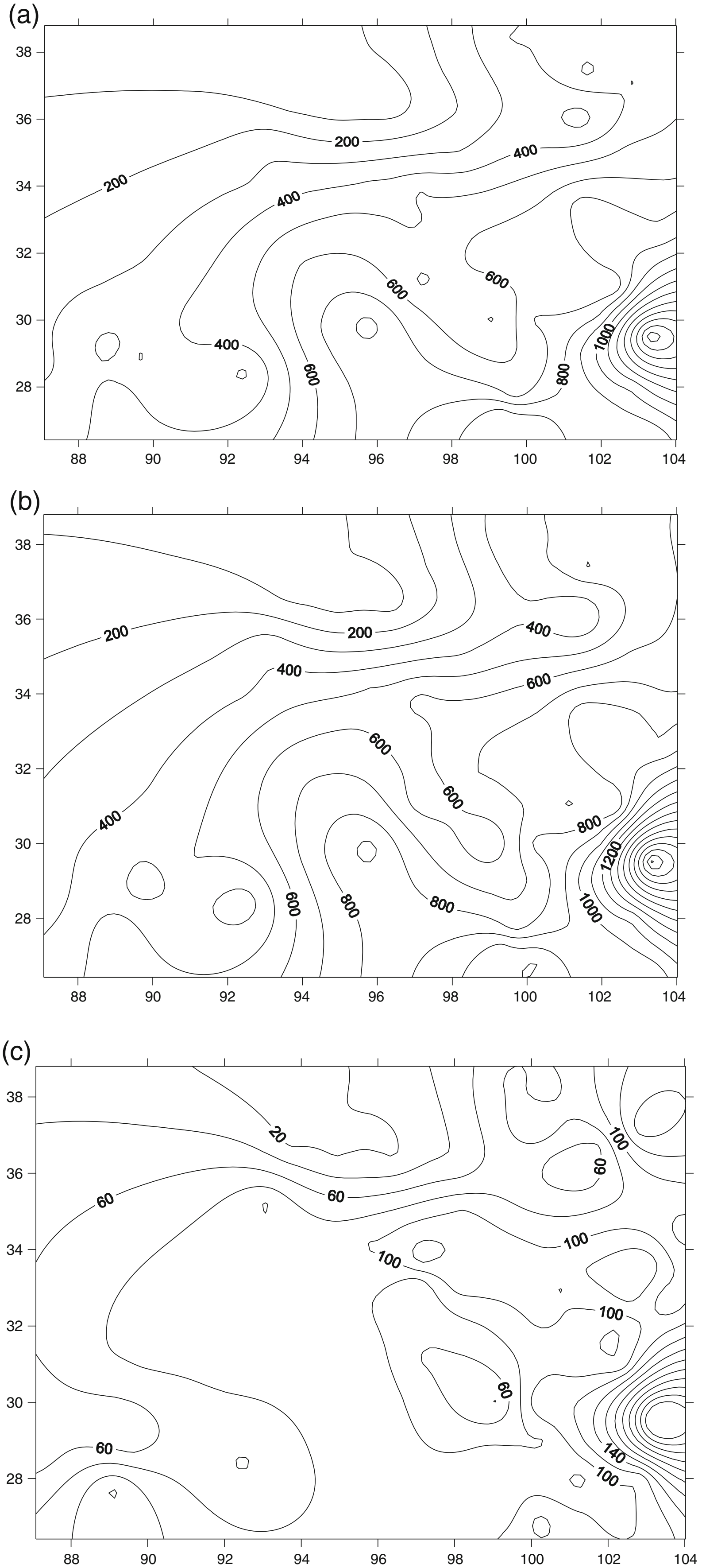


Table 1 Mean annual and seasonal precipitation for surface stations, NCEP/NCAR, and ERA-40 reanalysis grid points, along with the differences between the adjusted, raw precipitation, and reanalysis in the eastern and central Tibetan Plateau

		Annual	Spring	Summer	Autumn	Winter
Stations	Raw	501.0	84.3	296.6	109.8	11.0
	Adjusted	620.4	111.4	355.4	135.5	17.6
	Difference	119.4	27.1	58.8	25.7	6.6
NCEP/NCAR	Mean	1,032.0	227.6	544.8	225.0	34.5
	Difference	411.6	116.2	189.4	89.5	16.9
ERA-40	Mean	939.5	227.4	450.4	213.8	51.4
	Difference	319.1	116.0	95.0	78.3	33.8

Units are mm. The study periods for surface stations, NCEP/NCAR, and ERA-40 are 1961–2007, 1961–2007, and 1961–2001, respectively

model due to the assimilation of reanalysis. The mean differences between the surface stations and reanalysis grid point precipitations are also tabulated in Table 1. For NCEP/NCAR reanalysis, the mean annual precipitation has largest values in the southern TP (Fig. 5), and the mean annual precipitation over the whole region equals to 1,032 mm. The highest mean precipitation occurs in summer showing the effect of the summer monsoon (544.8 mm). For ERA-40 reanalysis, the distributions of both mean annual and seasonal precipitation are broadly similar to NCEP/NCAR,

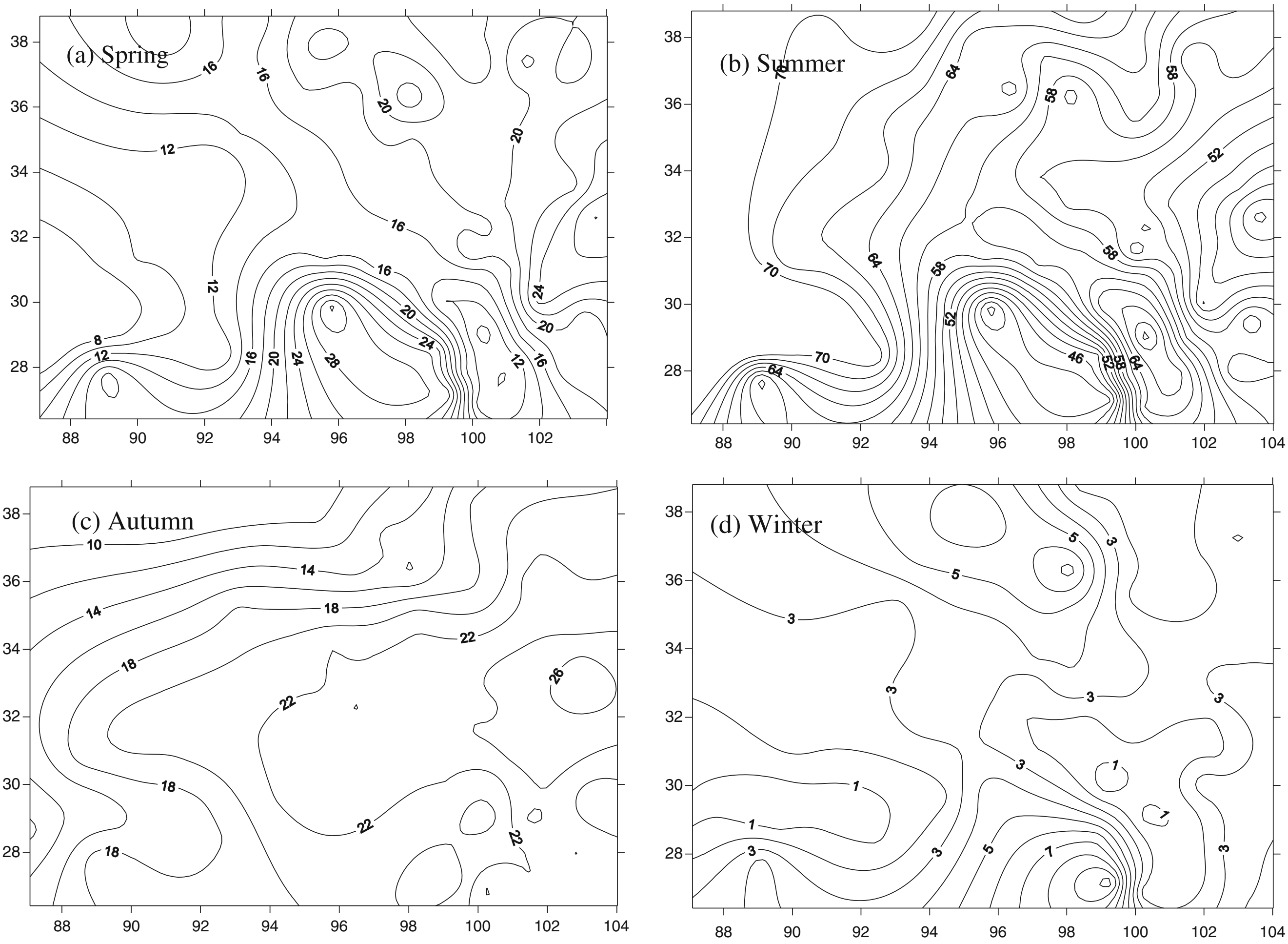


Fig. 3 Seasonal percentage of precipitation ratio (seasonal precipitation divides mean annual precipitation) in the eastern and central Tibetan Plateau during 1961–2007. The unit is %

Table 2 Mean annual and seasonal trends and *P* values of precipitation for surface stations, NCEP/NCAR, and ERA-40 reanalysis grid points in the eastern and central Tibetan Plateau

		Annual	Spring	Summer	Autumn	Winter
Stations	Trend	5.13	**4.74**	−0.81	−0.30	**1.05**
	P value	0.14	<0.001	0.80	0.91	0.03
NCEP/NCAR	Trend	**−46.62**	**−13.60**	**−24.84**	**−9.59**	−1.10
	P value	<0.001	<0.001	0.006	0.02	0.298
ERA-40	Trend	**−49.21**	3.27	**−28.50**	**−17.83**	−0.44
	P value	0.003	0.412	0.012	<0.001	0.807

The trends with a significance level greater than 95% are highlighted in bold. Units are mm/decade. The study periods for surface stations, NCEP/NCAR, and ERA-40 are 1961–2007, 1961–2007, and 1961–2001, respectively

with the mean annual precipitation of 939.5 mm. Summer (450.4 mm) contributes more than the other seasons to the annual mean. In summary, both reanalyses have broadly similar spatial distributions of mean precipitation, decreasing from southeastern to northwestern TP due to the weakening effect of the monsoon.

3.2.2 Spatial patterns

Despite similar climatology, trend patterns differ somewhat between the reanalyses (Fig. 6). For NCEP/NCAR on the annual basis, there is a wetting trend in the center of the northern TP, concentrated on 33° N and 90° E (Fig. 6, left panel). Drying takes place in most southern TP. The seasonal patterns correspond to the annual basis to some extent. Trends derived from ERA-40 have different patterns compared with NCEP/NCAR although the strongest changes occur in the southern TP (Fig. 6, right panel). The mean annual precipitation decreases in the eastern TP centered on the far west of the Sichuan basin, and increases in the southern TP. The seasonal patterns are also similar to the annual patterns. For both reanalyses, the southern region has higher mean annual precipitation and more spatial variance in trend magnitudes. This supports the idea that this area is the main water vapor transport region, and most water vapor originating from the Bay of Bengal and/or Indian Ocean is released over the southern TP after crossing the Brahmaputra, Nujiang, and Jinshajiang valleys.

3.2.3 Regional trends

The mean annual and seasonal precipitations anomalies estimated from NCEP/NCAR and ERA-40 reanalyses nearest grid points are compared with those derived from individual surface stations (Fig. 7). Although there is much correspondence between anomalies, trends look different and the correlation coefficients between them are smaller (not shown). For NCEP/NCAR, averaged over the region, there is a statistically drying trend of −46.62 mm/decade (Table 2). Precipitation in summer and spring also shows statistically significant drying (−24.84 mm/decade and −13.60 mm/decade, respectively; Table 2). For ERA-40, the annual trend is −49.21 mm/decade, and there is also a significant decreasing trend in summer and autumn (−28.5 mm/decade and −17.83 mm/decade; Table 2).

Compared with the adjusted precipitation observation, both NCEP/NCAR and ERA-40 do not correspond well on an individual station (Fig. 7). Indeed the largest overestimates by the reanalyses are in summer (Table 1). Both reanalyses overestimate precipitation in the south probably because of complex topography. Because of the preference for surface stations to be cited in sheltered valley, both annual and seasonal adjusted precipitation observations tend to be higher than both reanalyses (You et al. 2008b, 2010c).

4 Discussion and conclusions

In the Tibetan Plateau, the mean annual temperature has increased significantly since the 1960s, especially after 1980, which is primarily contributed by warming in winter and autumn (0.40°C/decade and 0.26°C/decade, respectively) (You et al. 2010b). In the context of rapid warming, the fragility of the cryospheric environments of the TP will increase, and understanding of the variability of precipitation is therefore critical, especially if water resources become more dependent on summer precipitation and less dependent on winter storage as snow and subsequent release (Kang et al. 2010). Warming also can cause more water vapor to escape into the atmosphere and lead to the slight increase in precipitation, which is consistent with the decreasing of evapotranspiration (Xie et al. 2010). Previous studies (Wu et al. 2007; Xie et al. 2010; Xu et al. 2008b) analyzed the spatial and temporal changes of precipitation based on raw (unadjusted) data in the TP. It has been recognized that uncertainties exist in the raw precipitation

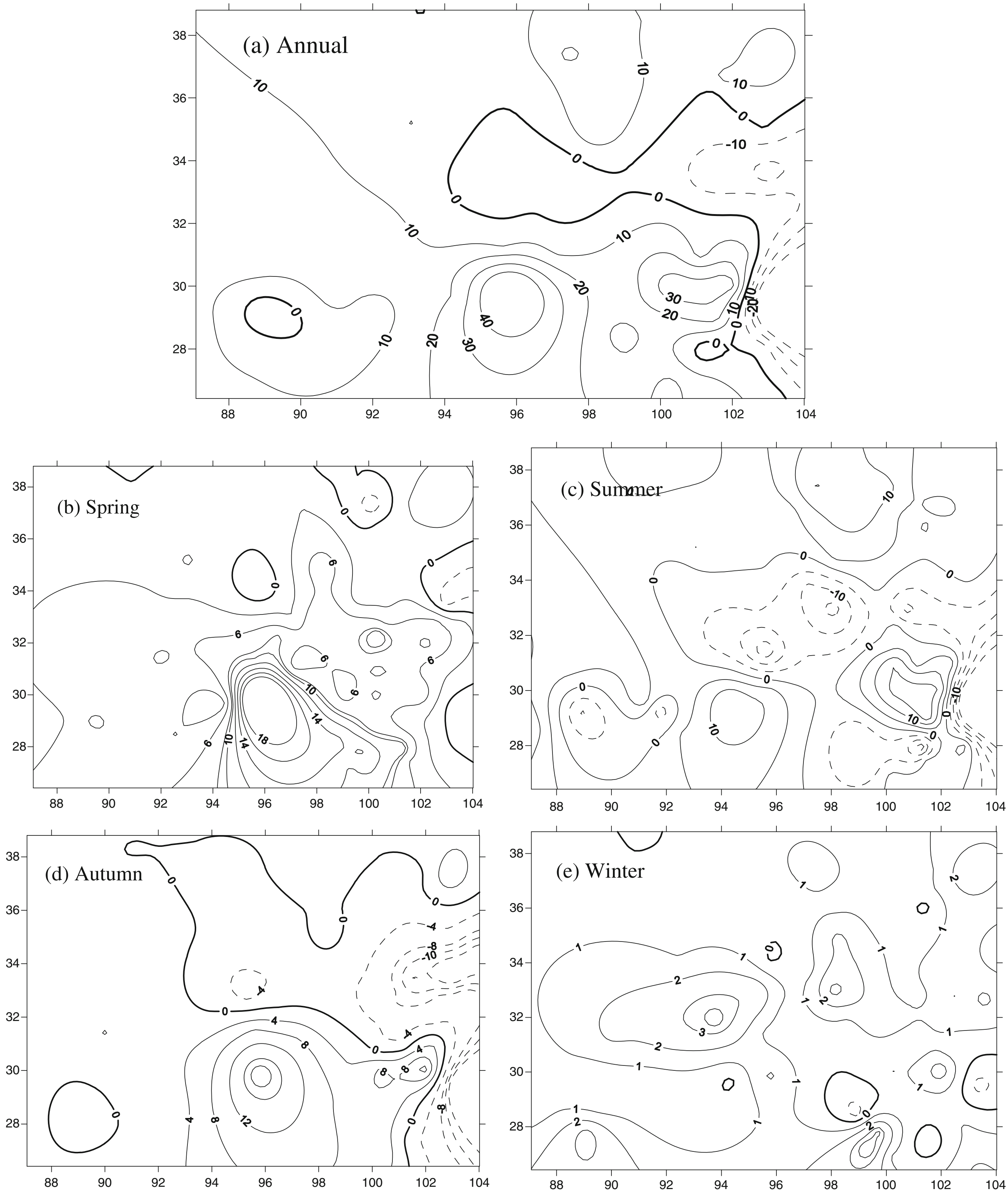
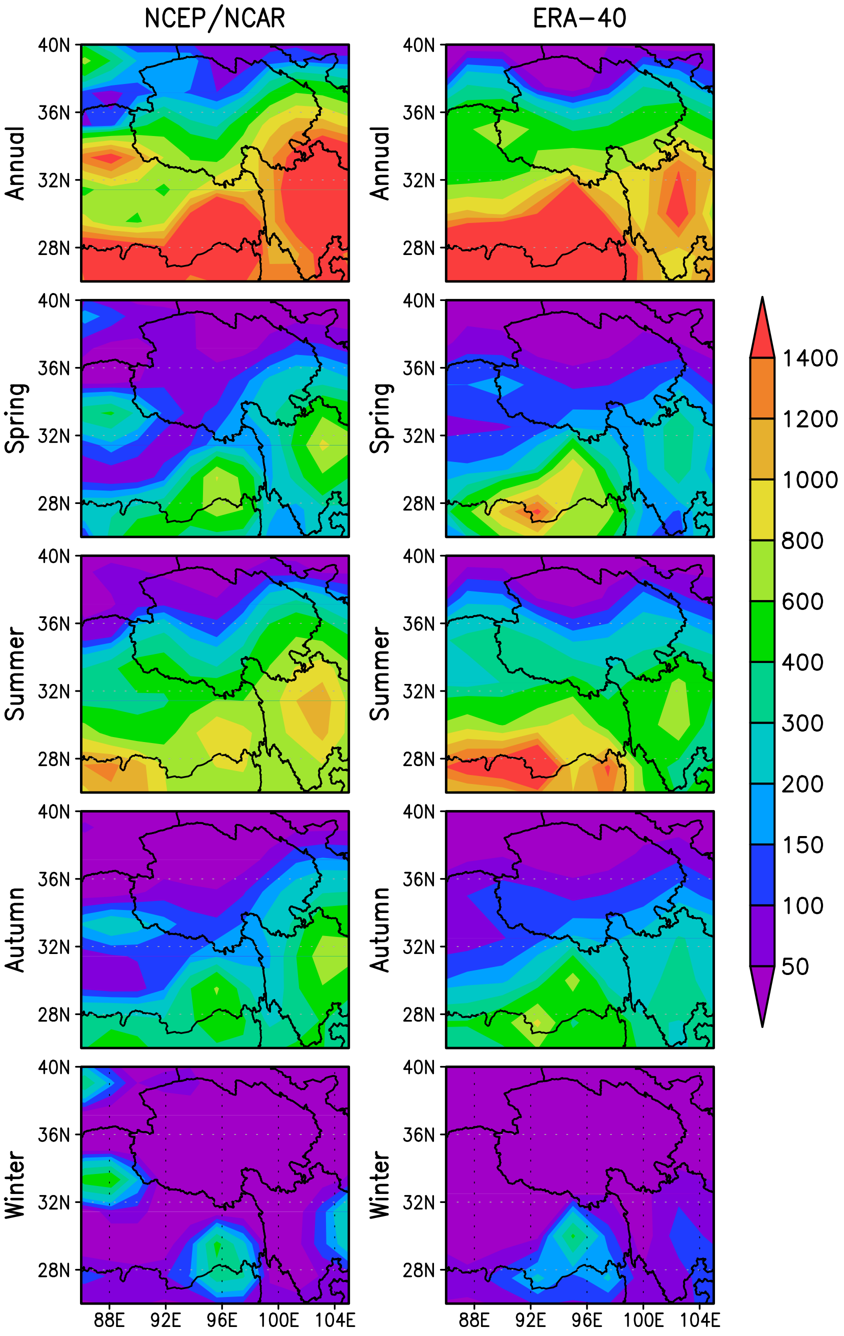


Fig. 4 Spatial trends of annual and seasonal of adjusted precipitation in the eastern and central Tibetan Plateau during 1961–2007. The unit is mm/decade

dataset is due to uneven distribution, discontinuities, and biases of measurement sites and gauges. At the same time, systematic errors in gauge measurements are critical because these biases affect all types of precipitation gauges, especially those used in cold environments (Ye et al. 2004). Compared with the raw precipitation, the adjusted

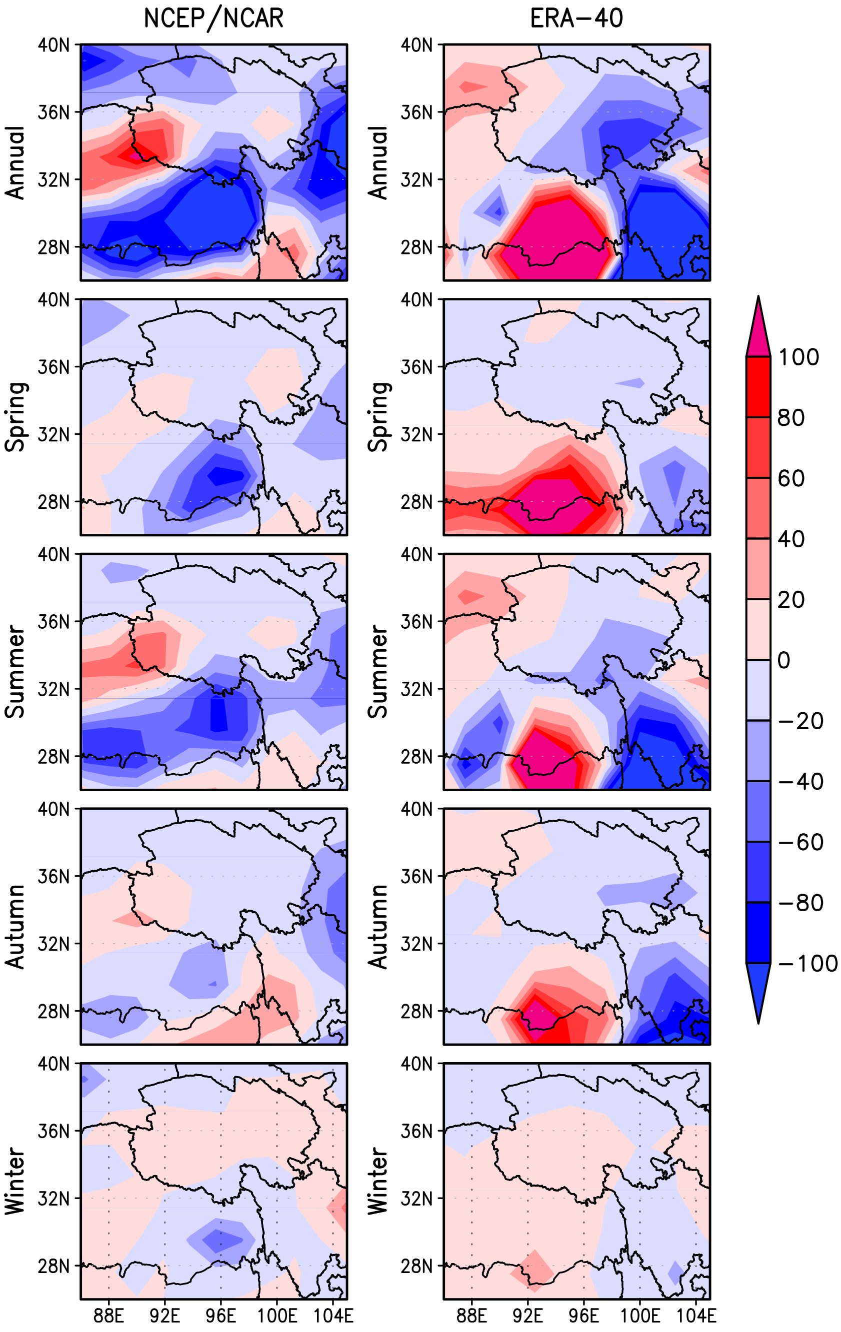
Fig. 5 Mean precipitation from NCEP/NCAR and ERA-40 on the annual and seasonal basis in the eastern and central Tibetan Plateau during 1961–2007. Study period for ERA-40 is 1961–2001. Unit is mm



precipitation is higher on both the annual and seasonal basis. However, the annual bias adjustment varies largely, consistent with other studies in China and on a global scale (Ma et al. 2009; Yang et al. 2005; Ye et al. 2004). During the studied period, the mean annual adjusted precipitation in the TP has an increasing trend (not significant). For individual stations, those in the southern TP show larger trend magnitudes. The results are quite similar to the previous studies (Qian and Qin 2008; Xie et al. 2010; Zhang et al. 2009). During 1971–2005, precipitation in spring, summer, and winter increased 54%, 11%, and 116%, respectively (Xie et al. 2010), and the majority of stations showed positive trend, and the increases were less pronounced in summer. The negative trends were observed mainly in the eastern and southeastern TP, such as the Qaidam Basin and the eastern part of Qinghai province. Yang et al. (2011) found that the variability of precipitation in the TP depends on the climate regimes. Precipitation in the arid and humid zone has decreasing trends, while it has increase slightly in the semi-arid zone (Yang et al. 2011).

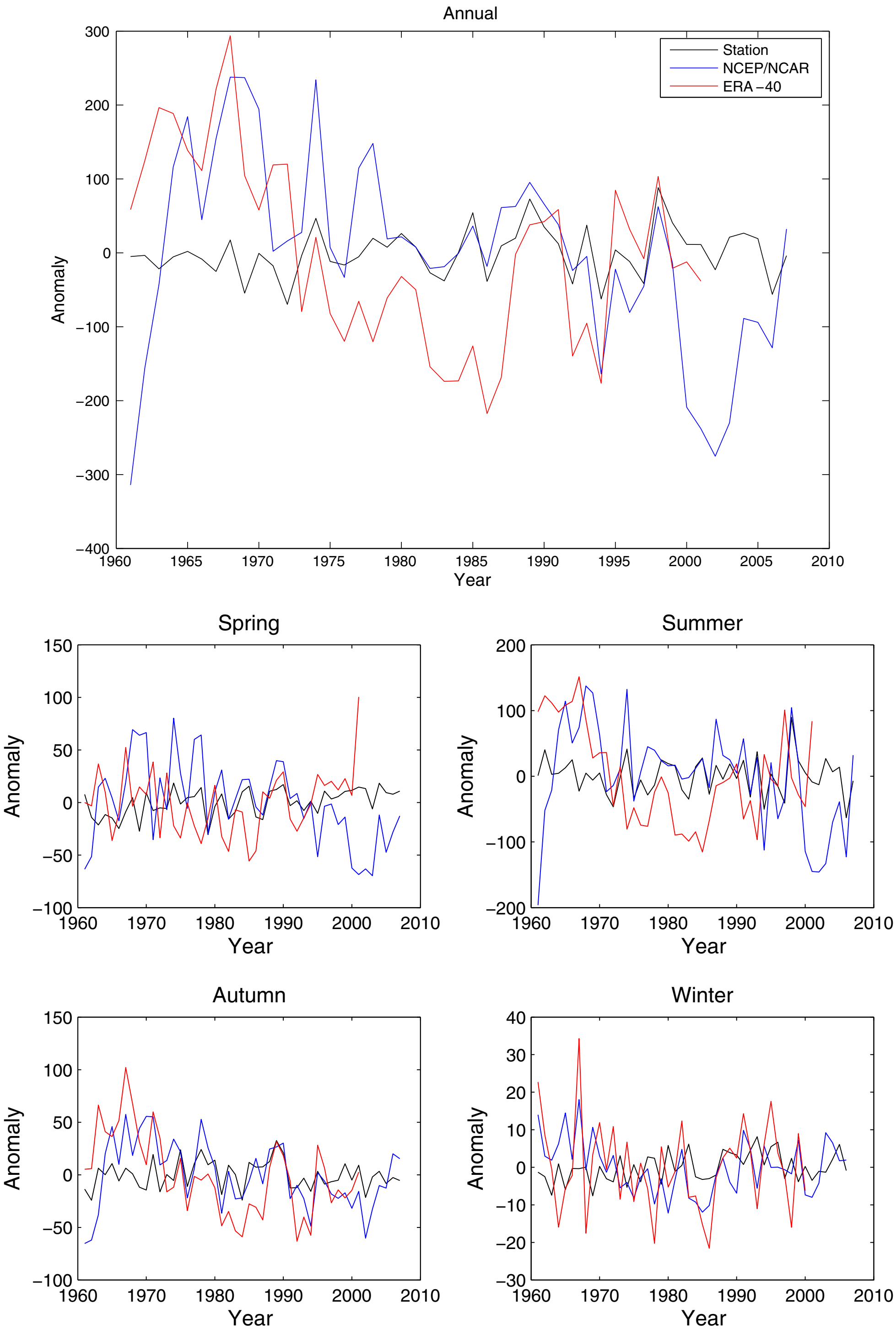
In this study, we also compared the variability of precipitation in the TP from adjusted surface observations with

Fig. 6 Spatial trends of precipitation from NCEP/NCAR and ERA-40 on the annual and seasonal basis in the eastern and central Tibetan Plateau during 1961–2007. Study period for ERA-40 is 1961–2001. Unit is mm/decade



both NCEP/NCAR and ERA-40 reanalyses. The variability of precipitation in both reanalysis products is on average stronger than in the adjusted observations. Both reanalyses can capture the broad spatial distributions of mean annual and seasonal precipitation, but are less good at recreating the annual variability. This may be caused by the discrepancies between the actual and model topography and scale issues between point measurements and grid cell average values. However, the scientist community concerns more about the daily time series in the field of meteorology and hydrology. Due to the poor performance of reanalysis data on simulating the precipitation at the daily scale, the direct applications of reanalysis data are also limited in this study. Meanwhile, both reanalyses are inconsistent with the observations when examining trends, and show a tendency towards drying (inconsistent with observations). Compared with ERA-40, NCEP/NCAR shows much stronger trends, particularly in winter. Thus, NCEP/NCAR has larger inconsistencies than ERA-40. Due to different data assimilation schemes and physical parameterizations, ERA-40 precipitation is generally proposed to be more realistic than NCEP/NCAR, particularly when it comes to the inter-annual

Fig. 7 Regional annual and seasonal anomalies of precipitation for surface adjusted stations, NCEP/NCAR, and ERA-40 reanalysis grid points in the eastern and central Tibetan Plateau during 1961–2007. Study period for ERA-40 is 1961–2001



variability of monthly totals in the subtropics (Betts et al. 2003). In China, ERA-40 precipitation is closer to the observed precipitation than NCEP/NCAR when looking at regional averages on a monthly basis (Ma et al. 2009), and our study confirms this. In previous studies, this was also the case for temperature (You et al. 2010c). Topographical differences between grid points and stations, and other reanalysis model differences such as surface land schemes, cause differences in trend identification and patterns in the TP (You et al. 2010c) and the whole China (Zhao et al. 2008). The course spatial resolution of 2.5°×2.5° for both NCEP/NCAR and ERA-40 reanalysis data leads to the limited number of grids covering the study area, which should be improved further by high-resolution dataset and monitoring data. After interpolating ERA-40 daily precipitation from a coarse grid (110 km) into a finer one of 1-km spatial resolution, the results have been improved in most mountainous areas in the Balkan Peninsula, Europe (Kostopoulou et al. 2010). The uncertainty of data in the TP particularly in the western part caused by the low density of stations, the complex topography, and the interpolation methods also can produce obvious bias between reanalysis and observation (Zhao and Fu 2006). Therefore, more attention should be given to all reanalysis systems when using them to represent past, present, and future surface precipitation.

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