Long-term trend of precipitation days for southeast Tibetan Plateau, China

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Abstract

In this paper, the spatiotemporal trend variability of precipitation days (PDs) in the southeast Tibetan Plateau (STP) from 1961 to 2012 is studied on annual and seasonal timescales for the first time. According to the results of the Mann-Kendall (M-K) test, the annual and seasonal area-averaged PDs shows a non-significant tendency except for spring PDs, and the spring PDs shows a significantly increased trend at 95\% confidence level during this period. The increase is 6.85 days per 100 years in annual PDs. The maximal increase occurs in spring, which is 7.13 days per 100 years. On the other hand, the PDs and their tendencies have notable spatial distribution variations over the STP. The PDs have some relationship with altitude, but their tendencies are unrelated to altitude in the STP. This study further finds that the Nuijiang River is a dividing line for the PDs, and latitude 30°N is such a line for the PDs tendency. The results revealed the local differences of the PDs over the Tibetan Plateau (TP), which is beneficial to understand the variations in precipitation patterns in the STP and gain insights into the change features of the TP under global changes.

Key words: Climate change; M-K test; Precipitation days; Southeast Tibetan Plateau; Trend

1. Introduction

The Tibetan Plateau (TP) is the world’s highest plateau, which is also well-known as the Earth’s third pole. Because of dynamic and thermodynamic features, the TP strongly influences the regional and even global climate, especially the Asian monsoon (Wu and Qian, 2003; Lin and Wu, 2011; Duan et al., 2013). The response relation between the climate change and the TP is one of the most important focuses of climatic change research at present (Immerzeel et al., 2010; Biermann et al., 2014). Some previous researches have revealed climatic changes of the TP based on precipitation, temperature, energy exchange and so on (Liu and Chen, 2000; Xu et al., 2008; Tang et al., 2011; Lu et al., 2012; Wang, 2018). However, the existing studies have also shown regional contrast in climate variations over the TP (Lu et al., 2008; Li, 2011; Salama et al., 2012; Wang, 2018). It is very important to study the local climate change characteristics in the TP, such as precipitation days (PDs) tendencies in the southeast TP (STP). A comprehensive analysis of PDs trend can promote understanding of variations in precipitation patterns. The recent researches have focused on PDs changes at deferent scales in deferent regions (Serquet et al., 2011; Liu, et al., 2011; Masoud et al., 2016), but so far there is no study on the PDs trend in the STP.

The STP (92° 30’–99° 30’ E, 26° 30’–32° 30’ N) is in southwestern China and in southeast of the TP (Li et al., 2008; Wang, 2018), which has distinct topography and landscape characteristics. There are four famous rivers that of the Jinshajiang River, Lancangjiang River, Nuijiang River and Yarlung Zangbo River in this area. At the same time, the STP is a key interaction area of the Asian monsoon system, which could interfere with the regional weather processes and water-heat balance of the TP (Zhou et al., 2015, 2016; Wang, 2018). The STP also is the main transport channel of water vapor from the Bay of Bengal to the TP. Therefore, it is very important to study the PDs trends across the STP, which maybe reveal the precipitation change rules in complex terrain of the TP. Research results of PDs trend for the STP are essential to the local management of water resources.

The STP is influential in climate patterns around and in the TP. Some reports have focused on precipitation, energy exchange and land- atmosphere parameters for the STP (Wang et al., 2014; Tang et al., 2015; Zhang et al., 2015; Zhou et al., 2015, 2016; Min, 2016; Wang, 2018). However, there is no study on spatiotemporal trend variation of the PDs in the STP. In this study, the tendency variations of the PDs from 1961 to 2012 in the STP are analyzed at different timescales for the first time. It advances knowledge of regional climate changes in the STP and even in the TP.

2. Data and methodology

The PDs is defined as daily precipitation of more than 0.1 mm. The monthly PDs data used in this paper are from the National Meteorological Information Center of China Meteorological Administration, which have been checked by primary quality control. Fourteen stations with more than 50-year continuous monthly PDs data in the periods 1961–2012 are selected, and annual and seasonal values are constructed based on monthly PDs. There are four seasons in a year including spring from March to May, summer from June to August, autumn from September to November and winter from December through February the following year. The study area and locations of meteorological stations are shown in Figure 1.
The Mann-Kendall (M-K) test is a rank-based nonparametric method for trend identification (Mann, 1945; Kendall, 1975), which has been widely used in trend testing of hydrologic and climatic time series (Zhang and Du, 2008; Wang and Zhang, 2012; Manish, 2014; Harriet et al., 2015; Ding et al., 2016; Zeng et al., 2016; Wang, 2018). There are many advantages of the M-K test method for time series analysis, which mainly includes that (1) it can handle non-normality, censoring or data reported as values “less than”, missing values, or seasonally and (2) it has a high asymptotic efficiency (Gan, 1998; Fu et al., 2009). Based above discussion, the M-K test method is used to identify the PDs trend on the STP in this study. The trend estimator $Z$ and trend magnitude $\beta$ are the two test statistics in M-K test method (Sen, 1968; Hirsch et al., 1982; Gan, 1998). If the value of $Z$ is positive, the tested time series shows an increasing trend, and vice versa. If $|Z| \geq Z_{1-\alpha/2}$, that tested time series shows a statistically significant trend at the given significance level $\alpha$, and $Z_{1-\alpha/2}$ could be queried in the standard normal cumulative distribution table (Gan, 1998; Fu et al., 2009). $Z = 1.96$ when $\alpha = 0.05$.

### 3. Results

#### 3.1 General characteristics of PDs

The area-averaged PDs is the average PDs of the 14 stations over the STP. Table 1 shows the main statistics for the area-averaged PDs time series in the STP at annual and seasonal scales during the study period. There are eight statistics that of mean, maxima, minima, range (the difference between maxima and minima), variance, standard deviation, coefficient of kurtosis and coefficient of skew.

According to Table 1 and Figure 2, the annual area-averaged PDs in the STP is 148.78 days. The seasonal PDs are from 12.38 days to 63.30 days. There were obvious seasonal changes, and the maximum PDs and minimum PDs happened in summer and winter. 42.25% of the annual PDs occurred in summer, but only 8.32% of the annual PDs occurred in winter. The monthly...
variation of PDs in the STP also were obvious, and 55.30% of the annual PDs concentrated in the June to September in a year. The peak and the bottom appeared in July and December, respectively.

Figure 3 shows the plots of the annual and seasonal area-averaged PDs in the STP during 1961–2012, and the 5-year moving averages time curves also are shown in Figure 3.

The PDs had a non-uniform spatial distribution over the STP and had some relationship with altitude. For example, Gongshan station (altitude 1583.3 m), with maximum seasonal and annual PDs, is the lowest station (refer to Figure 4). Though the minimum seasonal and annual PDs did not occur in Jiali station being the highest station (altitude 4488.8 m), these were mainly found in high altitude area such as Longzi station (altitude 3860.0 m), Zuogong station (altitude 3780.0 m) and Batang station (altitude 2589.2 m) in this research.

According to Figure 4, the Nujiang River is a dividing line for the magnitude of PDs in the STP. Stations with relatively large PDs are almost all located on the west bank of that river, except for Longzi station and Linzhi station in winter. However, stations with relatively small PDs are almost all located on the east bank of the river.

3.2 Trends of PDs

According to the results of the M-K test shown in Figure 5, the annual area-averaged PDs showed a non-significant increasing trend, in agreement with Groisman et al. (1999) for China. On seasonal scales, the spring area-averaged PDs was the only season being significant increasing trend at 95% confidence level. The winter area-averaged PDs was non-significant increase, whereas the summer and autumn area-averaged PDs were non-significant decreases. The area-averaged trend magnitudes for annual, spring, summer, autumn and winter were 6.85, 7.13, −1.01, −1.24 and 0.60 days per 100 years, respectively.

For annual station PDs, there were nine of 14 stations with increasing trends but only one of them (Zuogong station) with significant increase at 95% confidence level (Refer to Figure 6 E). Five of 14 stations had decreasing trends but only one of them (Chayu station) was significant at the significance level 0.05. On seasonal scales, nine of the stations had increasing trends in winter and five in autumn, but none of them passed the significance test (Refer to Figure 6 C and D). There were 11 and two stations with decreasing trends in summer and
In the four seasons, only two stations (Suoxian station and Dege station) were significant increase at 95% confidence level in spring, while only two stations (Gongshan station and Deqin station) were significant decrease at 95% confidence level in summer. Trend changes of stations in autumn and winter did not pass the significance test. Therefore, the observation stations mainly showed decreasing trends in summer and increasing trends in spring.

The station PDs trend variation shows notable spatial distributions, but not related to altitude. According to Figure 6, the 30° N can be seen as a dividing line for PDs trend changes of the STP. Stations with increases are mainly north of that latitude.
and those with decreases are mainly to the south, except for summer. Decreasing trends were generally in summer, and the two stations with significant decreasing trends were also south of 30° N.

The spatial distributions of annual and seasonal PDs trend magnitudes at the stations are shown in Figure 7. The spatial distribution of station PDs trend magnitude is similar to that of the station PDs trend. Latitude 30° N is also a dividing line of station PDs trend magnitude. For example, the top five relatively large increasing annual trend magnitude stations except Zuogong (the other four stations are Suoxian, Changdu, Jiali and Nangqian) are north of that latitude, but the latitude of Zuogong station is 29° 40’ N which is almost near that latitude. The relatively large decreasing annual trend magnitude stations, such as Chayu, Deqin and Gongshan, are to the south. Among all stations, the annual maximum increasing magnitude (0.4063 days per year) is at Zuogong, and the annual maximum decreasing magnitude (−0.3575 days per year) is at Chayu. On the seasonal scale, the seasonal maximum decreasing magnitudes all are in Chayu (−0.0381 days per year in spring, −0.1342 days per year in summer, −0.0931 days per year in autumn and −0.1482 days per year in winter), while the maximum increasing magnitude station changes with seasonal change, namely, Dege (0.1465 days per year) in spring, Zuogong (0.1739 days per year) in summer, Dingqing (0.0625 days per year) in autumn and Suoxian (0.0440 days per year) in winter. In general, the stations near or in the main body of the TP are more obvious.
variation of magnitude in spring than those of the other seasons. Stations in the Hengduan Mountains area, namely south of the STP with decreasing magnitude are observation fact almost in four seasons.

4. Discussion

The PDs have a non-uniform spatial distribution over the STP and there is no significant relationship between PDs and altitude. The maximum seasonal and annual PDs are in the lowest station, but the minimum seasonal and annual PDs do not occur in the highest station. The PDs shows distinct regional features, and the Nujiang River is a dividing line for the magnitude of PDs in the STP. The annual and seasonal area-averaged PDs trends for the STP are generally insignificant except for that of spring. The tendencies of the PDs are differences between the northern and the southern STP, and latitude 30° N can be seen as a dividing line for the PDs trend changes.

In general, the rate of PDs is not significantly changed. Maybe the impact of the water vapor transports from the Bay of Bengal or South China Sea on the spatial distribution variations of PDs trend magnitude. The relatively large increasing annual trend magnitude of PDs are north of latitude 30° N, the relatively large decreasing annual trend magnitude of PDs are to the south. In general, the stations near or in the main body of the TP are more obvious variation of magnitude in spring than those of the other seasons. Stations in the Hengduan Mountains area, namely

![Fig. 7. Spatial distributions of station PDs trend magnitudes (days per year). A-spring; B-summer; C-autumn; D-winter; E-annual.](image_url)
south of the STP with decreasing magnitude are observation fact almost in four seasons.

The present study shows differences of trend change for the PDs between the southern and northern STP, which may be related to the unique topography structure and water vapor transports of the STP. Water vapor comes into the STP mainly through two moisture channels, which are Indian Ocean via the Bay of Bengal channel and South China Sea via the Bay of Bengal channel (Wang et al., 2009). The precipitation spatial distribution over the STP are influenced by the water vapor transports (Miao et al., 2007; Lin et al., 2016). The water vapor transports in the STP are mainly along the Yarlung Zangbo River to Yarlung Zangbo Grand Canyon (Zhang et al., 2016), so the impact area of water vapor from the Bay of Bengal on PDs is mainly in the southern STP rather than the northern STP. However, it is necessary to further study combined atmospheric circulations to find causative mechanisms and to determine whether some results in this research could be applied to the TP.

From the discussion as aforesaid, it showed that the climate characteristics in the STP is very complex because of complex topography and particular location. Under the background of global warming, it is necessary to study the regional local climate change features for the key climate factors, such as temperature, precipitation, PDs in this paper, etc.

5. Conclusions

According to the observation station data from 1961 to 2012, this research revealed the PDs trends and their spatial distribution over the STP for the first time. The work aids understanding of the regional climate characteristic of the STP under global warming. It is beneficial to reveal the precipitation change rules in complex terrain of the TP.

The annual and seasonal area-averaged PDs trends for the STP were generally non-significant except for that of spring during the study period. The spring area-averaged PDs exhibited significant increasing trend at 95% confidence level. Winter and annual area-averaged PDs time series showed non-significant increasing trends, while non-significant decreasing trends in autumn and summer. The trends except in spring were not significant in the STP, but area-averaged PDs generally changed, as evident from values of trend magnitude, and the largest trend magnitude also occurred in spring. Overall, the observation stations mainly showed decreasing trends in summer and increasing trends in spring.

The PDs and their tendencies had notable spatial distribution variations over the STP. The PDs had some relationship with altitude, but the tendencies of the PDs were unrelated to altitude on the STP. The Nuijiang River is a dividing line for the PDs, and latitude 30° N can be seen as a dividing line for the PDs trend changes.

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