

Variation in Rainy Season Precipitation and Its Contribution in the Northeastern Tibetan Plateau from 1961 to 2017 (Postprint)

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Abstract

Using daily precipitation data from 53 meteorological observation stations during May–September of 1961–2017, this study analyzes the variation characteristics of rainy-season precipitation in the northeastern Tibetan Plateau and the relative contributions of different precipitation-grade changes to precipitation increments. The results show that during 1961–2017, rainy-season precipitation in the arid regions of the northeastern Tibetan Plateau exhibits an increasing trend, while precipitation extremes intensify in semi-arid and semi-humid regions. Precipitation intensity shows a general increase across most regions. Further analysis reveals that changes in rainy-season precipitation in the northeastern Tibetan Plateau are primarily attributed to variations in precipitation intensity, and the contribution from increases in moderate-rain-grade precipitation is greater than that from other grades. The trend toward precipitation extremization is significantly intensified in the eastern parts of semi-humid and semi-arid regions. These results contribute to a deeper understanding of the climatic effects on ecological environment changes in the northeastern Tibetan Plateau.

Full Text

Analysis of Precipitation Variation and Its Contribution in the Rainy Season over the Northeastern Qinghai-Tibet Plateau from 1961 to 2017

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Abstract

Based on daily precipitation data from May to September during 1961-2017 at 53 meteorological stations, this study analyzes the characteristics of rainy season precipitation in the northeastern Qinghai-Tibet Plateau and the relative contributions of different precipitation grade changes to precipitation increments. The results show that from 1961 to 2017, rainy season precipitation in the arid region of the northeastern Qinghai-Tibet Plateau exhibited an increasing trend, while precipitation extremes intensified in semi-arid and semi-humid regions. Precipitation intensity increased generally across most areas. Further analysis reveals that changes in rainy season precipitation over the northeastern Qinghai-Tibet Plateau were primarily caused by variations in precipitation intensity, with moderate rainfall grade increases contributing more than other grades. The trend toward precipitation extremization was notably enhanced in the eastern parts of semi-humid and semi-arid zones. These findings enhance understanding of the climatic effects of ecological environmental changes in the northeastern Qinghai-Tibet Plateau.

Keywords: Northeastern Qinghai-Tibet Plateau; precipitation grades; precipitation; contribution

1. Data and Methods

1.1 Research Data

Daily precipitation data for May-September were obtained from the meteorological information centers of Qinghai Province and Gansu Province, covering 53 stations in the northeastern Qinghai-Tibet Plateau. The data underwent homogeneity quality control. To ensure representativeness and temporal consistency, stations with continuous missing data exceeding 5 days were excluded. For stations with missing data of ≤ 5 days, interpolation was performed using adjacent station data. The final dataset comprised 53 stations. Based on the eco-geographical regionalization provided by the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, the study area was divided into three climate zones: semi-humid, semi-arid, and arid (Fig. 1). A precipitation day was defined as a day with daily precipitation ≥ 0.1 mm. The total precipitation during rainy season precipitation days was recorded as the rainy season total precipitation. The ratio of rainy season total precipitation to precipitation days was defined as precipitation intensity. Climatological normal values refer to the 1961-2017 average.

1.2 Methodology for Contribution Analysis

Previous research [23] indicates that precipitation variation is jointly caused by changes in precipitation days and intensity. The contribution from precipitation days (be) can be calculated by multiplying the trend in precipitation days (bf) by the average precipitation during the study period (Pe). This method has

been successfully applied in precipitation characteristic studies across various regions of China. The specific process is as follows:

The trend component of precipitation variation caused by precipitation intensity change (b_i) can be obtained by subtracting the precipitation days-induced component from the total precipitation trend (b):

$$b_i = b - b_e$$

To compare the relative contributions of precipitation intensity and precipitation days trends to precipitation increments, we use the absolute difference between b_i and b_e relative to the multi-year mean of a specific precipitation grade:

$$r = \frac{|b_i - b_e|}{P_e} \times 100\%$$

where r is the percentage difference. Positive values indicate that precipitation intensity changes contributed more to precipitation increase than precipitation days changes, while negative values indicate the opposite.

Significance of precipitation trends was estimated using the least squares method. According to the confidence level α , if the correlation coefficient $|R| > R\alpha$, the temporal trend is considered significant [24].

2. Results Analysis

2.1 Spatiotemporal Characteristics of Precipitation Variation

2.1.1 Statistical Characteristics Fig. 2 shows the precipitation trend and spatial distribution over the northeastern Qinghai-Tibet Plateau. Rainy season precipitation was above normal primarily in the 21st century, especially after 2000. Average precipitation ranged from 15-600 mm, with the maximum in Jiuzhi (605.2 mm) and the minimum in the arid region (15.4 mm). The spatial difference in annual average precipitation was significant, with scarce precipitation in arid zones (<200 mm). This demonstrates that north-south precipitation differences exceed east-west differences in the northeastern Qinghai-Tibet Plateau.

Due to large spatial variations in precipitation, the China Meteorological Administration precipitation grade standard [25] was referenced: 0.1-10 mm for light rain, 10-25 mm for moderate rain, 25-50 mm for heavy rain, and ≥ 50 mm for torrential rain.

2.1.2 Precipitation Trends in Different Climate Zones Table 1 presents trends in rainy season precipitation amount, days, and intensity for different climate zones from 1961-2017. Precipitation resources showed significant regional differences: the arid region exhibited a more pronounced increasing trend than

the semi-arid region, while the semi-humid region showed a decreasing trend. Both precipitation days and intensity increased in the arid region, though not significantly. In the semi-arid region, precipitation intensity contributed more to precipitation increase than precipitation days, whereas in the semi-humid region, precipitation days contributed more to precipitation decrease than intensity. This suggests that under climate warming, precipitation characteristics vary across climate zones. Warming enhances local water vapor recycling in arid and semi-arid regions, increasing its contribution to precipitation and causing above-normal precipitation—consistent with studies by Li Lin et al. [26] and Yao Tandong et al. [27] on climate change composition across different timescales on the Plateau.

2.2 Relative Contributions of Precipitation Days and Intensity

As previously analyzed, increased precipitation intensity (or decreased precipitation days) leads to increased (or decreased) precipitation, with regional variations. To further understand their relative contributions, we quantitatively compared their contributions to precipitation variation using relative trend changes. Fig. 4 shows that increased precipitation intensity caused above-normal rainy season precipitation across most of the northeastern Qinghai-Tibet Plateau, consistent with Zeng Yingting et al. [28], who found that precipitation intensity contributes more than frequency to summer precipitation variation in the Plateau's northeastern region.

To comprehensively understand precipitation resource changes, we combined precipitation amount, days, and intensity trends (TP, Td, and Ti), which can be categorized into six scenarios (Table 2). Rainy season precipitation variation is determined jointly by precipitation days and intensity. The most common scenarios were: (1) simultaneous increase in both intensity and days, and (2) increased intensity with decreased days leading to increased precipitation, followed by simultaneous decrease in both causing decreased precipitation. Fig. 3 shows the spatial distribution of these six scenarios.

2.3 Comparison of Contributions from Different Precipitation Grades

Different precipitation grades have varying impacts on flood season precipitation increases. Therefore, we further examined contributions of different grades to precipitation increments (Fig. 5). Light rain characteristics differed significantly from other grades. Light rain days increased in the northwestern arid region, southeastern semi-humid region, and southern humid region, positively contributing to precipitation increases. In other areas, intensity dominated. For moderate rain and above, intensity contributed more across most regions, particularly for torrential rain, where positive intensity contributions concentrated in eastern arid, eastern semi-arid, and parts of semi-humid zones. Overall, moderate rain contributed most across the study area, followed by heavy rain, with light rain contributing least (Fig. 6). This distribution may be influenced by moisture sources: areas north of 35°N are primarily controlled by westerlies,

while those south of 30°N are influenced by the Indian monsoon, and the 30°-35°N zone is affected by both [29].

The positive contribution pattern of precipitation intensity indicates enhanced precipitation extremization across the northeastern Plateau. Li Wanzhi et al. [30] identified eastern semi-humid and semi-arid regions as high-risk areas for torrential rain floods and secondary disasters. Combined with our analysis, these disasters are caused by short-duration heavy precipitation.

3. Discussion and Conclusion

Using meteorological station observations from 1961-2017, this study analyzed rainy season precipitation characteristics in the northeastern Qinghai-Tibet Plateau under global warming and quantitatively assessed contributions of precipitation intensity and days to precipitation increments through contribution analysis. The main conclusions are:

From 1961-2017, precipitation increased in the arid region of the northeastern Qinghai-Tibet Plateau, while precipitation extremes intensified in semi-arid and semi-humid regions. Precipitation intensity enhancement was widespread across all regions. Different climate zones exhibited varying precipitation characteristic changes, possibly because climate warming accelerated water vapor cycling in arid and semi-arid regions, leading to above-normal precipitation [31]. The response to climate warming was more sensitive in the study area. Moderate rain contributed most across most regions, with precipitation extremization intensifying in eastern semi-arid and semi-humid zones.

Unlike the significant increasing trend across the entire Plateau, rainy season precipitation did not increase significantly in most of the northeastern region. According to Li Lin et al. [32], this area is a climate transition zone influenced synergistically by multiple factors including the Plateau monsoon, westerlies, and Indian monsoon, with different factors dominating in different months and producing offsetting effects. Additionally, different factors have different interdecadal oscillation periods, and their combined effects result in lower warming-wetting significance than in other regions.

The pattern of decreased light rain and increased moderate rain aligns with Gao Jiqing et al. [33], who found that arid regions show decreased light rain frequency and increased moderate rain frequency compared to other areas. The correlation between light rain and vegetation is negative in areas with annual precipitation >600 mm, indicating light precipitation events are not critical for vegetation growth in precipitation-abundant regions, but positive in areas <600 mm, where light rain is crucial for plant growth. Compared with precipitation intensity, the effect of precipitation days cannot be ignored. These findings provide new insights for vegetation restoration and protection in the Qinghai-Tibet Plateau region and demonstrate the importance of incorporating precipitation pattern effects into land-atmosphere coupling models.

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